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RESEARCH ARTICLE

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Occupancy and abundance of a West African mangabey species (*Cercocebus atys* Audebert, 1797) in forest patch habitat

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Abstract

Sooty mangabeys are Old World primates from the Upper Guinea Rainforests of West Africa. They suffer from habitat degradation due to deforestation and hunting for the bush-meat trade. Tiwai Island and adjacent small islands are a small protected area surrounded by the Moa River that is known for its high diversity of primate species. We evaluated the occupancy and abundance of sooty mangabeys on Tiwai Island and the surrounding islands using camera traps during 2008–2011. Over two seasons, we obtained a naïve occupancy rate of 0.77 for Tiwai Island but only 0.19 for surrounding smaller islands. We used Abundance-Induced Heterogeneity Model and Royle Repeated Count Model to estimate the abundance of 326 ± 92 (SE) and 530 ± 102 (SE) individuals of sooty mangabeys respectively. Based on these occurrences, sooty mangabeys usually appeared in riparian, mature and young secondary forests. Activity patterns of sooty mangabeys based on circadian patterns of detections confirmed that they were diurnal with several activity peaks during the daylight hours. The results of this study suggest that a viable population of sooty mangabeys still inhabits Tiwai Island and its vicinity, but that their core population is primarily limited to the Tiwai Island reserve. Thus, there is a need to protect the island and its adjacent habitats to ensure the conservation of sooty mangabeys in particular and other primate species in general.

KEYWORDS
abundance, *Cercocebus atys*, occupancy, sooty mangabeys, Tiwai Island

Résumé

Les mangabeys fuligineux sont des primates de l'Ancien Monde vivant dans les Forêts Pluviales de Haute-Guinée en Afrique de l'Ouest. Ils subissent la dégradation de leur habitat due à la déforestation et à la chasse pour le commerce de la viande de brousse. L'île Tiwai et les petites îles adjacentes constituent une petite zone protégée entourée par la Rivière Moa, connue pour sa grande diversité d'espèces de primates. Nous avons évalué l'occupation et l'abondance des mangabeys fuligineux sur l'île de Tiwai et des îles environnantes en utilisant des pièges à caméra pendant la période 2008-2011. Sur deux saisons, nous avons obtenu un taux d'occupation naïf de 0,77 pour l'île de Tiwai, mais seulement 0,19 pour les petites îles environnantes. Nous avons utilisé le modèle d'hétérogénéité induite par l'abondance et le modèle de Royle à comptage répété pour estimer l'abondance de 326 ± 92 (SE) et 530 ± 102 (SE) individus de mangabeys fuligineux respectivement. Sur la base de ces occurrences, les mangabeys fuligineux apparaissaient généralement dans les forêts riveraines, les forêts matures et les jeunes forêts secondaires. Les modèles d'activité des mangabeys fuligineux basés sur les modèles circadiens des détections ont confirmé qu'ils étaient diurnes avec plusieurs pics d'activité pendant les heures de la journée. Les résultats de cette étude suggèrent qu'une population viable de mangabeys fuligineux habite toujours l'île de Tiwai et ses environs, mais que leur population principale est principalement limitée à la réserve de l'île de Tiwai. Il est donc nécessaire de protéger l'île et ses habitats adjacents pour assurer la conservation des mangabeys fuligineux en particulier et des autres espèces de primates en général.

1 | INTRODUCTION

Accurate abundance estimates of wildlife populations are critical for conserving a species and for making management decisions (Williams et al., 2002). However, non-habituated populations of species may be difficult to estimate using direct observational methods. As a result, indirect methods that use detection probabilities are used in their place (Thompson, 2004). Direct observations are also flawed due to observers' error and the fact that the detection rate may be lower due to human avoidance behaviours. Camera traps are used to detect elusive species, particularly those missed with other survey methods (Karanth, 1995; Srbek-Araujo & Chiarello, 2005). Data collected from camera traps could be used to estimate occupancy (i.e. the fact or condition of a species occupying a place) and abundance (i.e. the relative representation of a species in a particular ecosystem) of a species (MacKenzie & Royle, 2005). These data can then be used to make inferences over greater habitats and ranges in cases where species inhabit areas that are too large to sample effectively (Royle & Nichols, 2003).

Primates are highly diverse in their habitats and they are unevenly distributed within their geographical ranges (Fashing, 2007). Species with restricted distribution range are more likely to go extinct than those with wide-range of distribution as the latter consists of different sub-species that vary from place to place across their range (Johnson, 1998). Thus, data about primate distribution and abundance provide important information for management decisions (Campbell et al., 2016).

Primates adapt to live in the challenging environment (Groves, 2005). The majority of primates live in tropical habitats and Africa is a continent of special concern in terms of primate conservation. The loss of tropical forest mainly due to logging and farming contributes to the decline of primate population in Africa. Protected areas serve as final refuges for wildlife species across their distribution range (Mena et al., 2020). Sooty mangabeys (*Cercocebus atys* Audebert, 1797) are a primate species that live in the Upper Guinea Rainforests of West Africa in areas of high rainfall and warm temperatures (McGraw, 1996). The population sizes of sooty mangabeys decrease due to habitat loss and overhunting for their meat. The species is highly hunted for its meat in Ivory Coast (Refisch & Koné, 2005).

Sooty mangabeys are a diurnal species that travel on the ground and climb on trees and they inhabit both mixed old and mid-aged forest habitats (Fimbel, 1994; McGraw, 1996). They provide a variety of ecosystem services such as seed dispersers since their diet consists of fruits, fungi and invertebrates. They are also used as a prey for crowned hawk eagles (*Stephanoaetus coronatus*), chimpanzees (*Pan troglodytes*) and leopards (*Panthera pardus*) (Boesch, 1994; Jenny, 2009). Conversely, sooty mangabeys act as sentinels to warn other primate species of predator presence. For example, McGraw and Bshary (2002) found red colobus (*Procolobus badius badius*) and Diana monkeys (*Cercopithecus diana*) altered their use of habitat when sooty mangabeys were present because predation risk was lower.

Research on sooty mangabeys has focused on diets and movement in Côte d'Ivoire using a group of habituated individuals (Janmaat et al., 2006; McGraw et al., 2011). One case in Côte d'Ivoire used line-transect sampling and determined a density of 25 individuals/km^2 (Refisch & Koné, 2005), in Tiwai 38.5 individuals/km^2, in Ivory Coast 11.9 individuals/km^2 (McGraw & Zuberbühler, 2007).

In the present study, we used camera traps to collect data on occupancy and abundance of sooty mangabeys in Sierra Leone with the hypothesis that the study species is uniformly distributed on and around a protected river island, Tiwai Island. Understanding the conservation status, limited in situ knowledge, distribution and abundance of sooty mangabeys within an ecosystem can help ecological research and conservation efforts across the species range. Therefore, the main objective of this research is to determine occupancy, abundance and activity patterns of sooty mangabeys in Tiwai

Island and its surrounding islands, Sierra Leone, so as to design appropriate strategies for its sustainable conservation.

2 | MATERIALS AND METHODS

2.1 | Study area

We conducted our research during 2008–2011 on Tiwai Island Wildlife Sanctuary and surrounding small islands (hereafter Tiwai), Sierra Leone (ca. 07°33′N Latitude, and 11°21′W Longitude) with a total area of 15 km^2. Tiwai Island is located on the Moa River with elevation between 80 and 110 m above sea level. Tiwai is a mosaic of raphia swamp, young secondary forest, mature forest, riparian and bush fallow habitat types (McCollum et al., 2018). Average precipitation of the study area ranges from 200 mm per month in the rainy season (May to September) to 8 mm per month in the dry season (October to April), with temperatures averaging 27°C (McCollum et al., 2018). The island was designated as a Wildlife Sanctuary in 1987, which included a management plan for the island, and a research station to promote research and conservation of species on the island (Oates, 1999).

Tiwai island harbours different species of primates including sooty mangabey, red colobus (*Procolobus badius*) [EN], olive colobus (*Procolobus verus*) [VU], western black and white colobus (*Colobus polykomos*) [EN], Diana monkey (*Cercopithecus diana*) [EN] and chimpanzee (*Pan troglodytes*) [EN].

2.2 | Methods

2.2.1 | Data collection

Tiwai and the surrounding islands were divided into a grid system of 1 km^2 blocks across the entire study area, resulting in a total of 15 blocks. Edge blocks include areas of the island and therefore it encompasses the whole island and adjacent buffers. Although mangabeys have the potential to be individually identified based on physical markings, we were unable to identify them in most cases. Hence, in each block, a single camera (Moultrie Game Spy) was placed within 50 m distance of a random location generated by a Geographic Information System (ArcGIS 9). Open areas with tree trunk availability were used to create as large a viewing cone as possible. Locations were reached using a series of permanent man-made transects wherever possible to minimise forest and vegetation disturbance.

Camera placement on the smaller islands and the mainland followed the same protocol as on Tiwai. Data were collected over two field seasons using cameras that operated for 24 h a day. During the first field season (2008–2009), 20 cameras were deployed for 14 days, then collected and moved to another random location for the next period. This process was repeated two additional times, for a total of three sampling periods. During the second field season (2010–2011), the cameras were out for 21 days, collected, and redeployed for a total of six sampling periods. Due to low detectability, the days were grouped into three periods for all field seasons, each consisting of 7 days.

During each trapping period, we placed 15 cameras on Tiwai, and five cameras on the surrounding mainland and the smaller islands for a total of 160 camera locations and 2812 camera-days. Camera-days were divided into two field seasons, with three 14-day periods in the first season (886 camera-days), and six periods in the second season (1926 camera-days). The data were then combined into 7-day intervals, resulting in three detection periods per camera per monitoring timeframe.

2.2.2 | Data analysis

We used data collected from camera traps to construct a detection/non-detection matrix (i.e. 1 if detected, 0 if not detected). A new photo capture was considered to be a new detection event when taken >0.5 h from the last photograph, similar to Kelly (2008). The data were analysed using the program *presence*, which used occupancy modelling methodologies to estimate species-specific occupancy while accounting for detection rates (MacKenzie et al., 2005). Typically, there is a trade-off in sampling intensity (i.e. amount of time a camera is in the field per detection period) and detection rates (the number of detections of an animal divide by the total amount of time the camera operated). Lower detection rates usually require larger numbers of detection periods (MacKenzie et al., 2005). We combined sampling days into week detection periods to increase detection rates. We incorporated five main covariates into the *presence* framework, specifically canopy type, understory type, vegetation density and the location of the camera (i.e. Tiwai, smaller surrounding islands, or mainland). We further divided forest canopy type including raphia swamp forest (a forest flooded with freshwater), young secondary forest (a forest which has re-grown after harvesting of the primary forest), mature forest (a primary forest with climax community), riparian forest (a forest adjacent to a river) and bush fallow (a habitat with natural vegetation that grows on land left uncultivated) following Conway (2013), and Oates et al. (1990). We also assessed occupancy and detection probabilities based on the location of transects or animal trails. Finally, we estimated abundance using models by Royle (2004) and Royle and Nichols (2003).

For activity pattern analyses, we used time and date stamped on each photograph by the camera. Days were classified into five categories based on sunrise and sunset: dawn (06:00–06:59), morning (07:00–11:59), afternoon (12:00–17:59), dusk (18:00–18:59) and night (19:00–05:59). Data for activity pattern of sooty mangabeys were synthesised in a database relative to total captures during a category and the total hours per category. Monthly activity patterns were compiled the photographs collected in a 1-month time period and weighting the total photographs to the number of trap days within each month.

3 | RESULTS

3.1 | Single season occupancy estimation with habitat covariates

The best-fit models for sooty mangabeys' occupancy included location, canopy type and trails as covariates (Table 1). The probability of occurrence was highest in riparian, mature and young secondary forests [$\psi_{riparian} = 0.92$ (0.20), $\psi_{mature} = 0.85$ (0.09), $\psi_{secondary} = 0.80$ (0.08)] respectively. Raphia swamp had with the probability of occurrence $\psi_{raphia} = 0.73$ (0.17) and bush fallow had the lowest occupancy rate at 0.20 (0.13).

We also evaluated occupancy based on the location of human or animal trails. Hence, sooty mangabeys had a naïve occupancy rate of 0.87 (0.10) for animal trails and 0.72 (0.07) for human trails. Other areas had occupancy of 0.58 (0.09). Tiwai had the greatest occupancy rate at 0.77 (0.06), whereas smaller islands were less likely to be occupied given occupancy rates of 0.19 (0.12). We recorded only one sooty detection on the mainland, and therefore the occupancy rate was very low (Table 2).

TABLE 1 Estimation of detection probability (*p*) using Akaike's Information Criterion (AIC) and weights field season 1 (2008–2009) and field season 2 (2010–2011) combined in for sooty mangabeys on and around Tiwai Island Wildlife Sanctuary, Sierra Leone.

Models	AIC	ΔAIC	AIC wgt	*K*	*p* (± SE)
ψ(location)p(.)	514.21	0.00	0.74	4	0.50 (±0.04)
ψ(canopy)p(.)	516.98	2.77	0.18	6	0.50 (±0.04)
ψ(trails)p(.)	524.26	10.05	0.01	4	0.50 (±0.04)

TABLE 2 Occupancy rates estimated by top models for sooty mangabeys (*Cercocebus atys*) on and around Tiwai Island Wildlife Sanctuary, Sierra Leone, during 2008–2011.

Covariates	ψ	SE
ψ(.)p(.)	0.75	0.06
Canopy type		
Swamp	0.71	0.17
Young secondary	0.78	0.077
Mature	0.78	0.08
Riparian	0.64	0.2
Bush fallow	0.08	0.08
Location		
Tiwai	0.77	0.06
Small islands	0.19	0.12
Mainland	0	0
Trail		
Animal	0.87	0.10
Human	0.72	0.07
No trail	0.58	0.09

3.2 | Abundance estimation

We obtained 233 detection events over all observation periods that revealed captures of 1–2 individuals (82.4% of observations) but as many as 12 individuals were captured in a single event. Abundances estimates with Royle Repeated Count Model yielding the highest (530 ± 102) estimate, while Abundance-Induced Heterogeneity Model yielding the lowest (326 ± 92) estimate of sooty mangabeys on Tiwai and the surrounding areas. Among all sites on Tiwai Island, the small islands and mainland the naïve occupancy rate using Abundance-Induced Heterogeneity Model was 0.62 with an estimated occupancy of 0.79 [detection probability of 0.28 (0.06)]. We calculated separate detection probabilities for the two field seasons at 0.39 (0.13) and 0.25 (0.07), and occupancy was estimated to be 0.60 (0.19) and 0.86 (0.08) respectively.

With the Royle Repeated Count Model, we estimated number of individuals at 530 ± 102. The estimated occupancy was 0.96 (0.02) and the detection probability was 0.22 (0.04) (Table 3).

3.3 | Activity patterns

Sooty mangabeys' detection rate demonstrated a diurnal activity pattern with most detections during daylight hours and none at night. Few observations were made around sunrise with 1.3% of daily activity between 06:00 h and 06:59 h. Detections on cameras demonstrated peak activity in the mornings between 07:00 h and 07:59 h and gradually declined throughout the day with 38% of detections were between 07:00 h and 11:59 h. Afternoon had a slight decline (32%), with activity dropping off after the sunset (activity during the night = 0.30%). When we calculated events per hour, we found the highest levels of activity at 07:00 h (11%) and 15:00 h (10%), displaying a slight bimodal distribution of activity patterns with small peaks at 10:00 h and 11:59 h, and another small peak between 17:00 h and 17:59 h (Figure 1).

4 | DISCUSSION

When comparing the two seasons sampled, the first field season (2008–2009) had lower detection probabilities and occupancy rates, likely due to fewer capture periods (14 capture periods in the first field season and 21 capture periods in the second field season). Our data suggested a positive correlation between the number of capture periods and capture successes, which is supported by Tobler et al. (2008). Combining both field seasons into one dataset gave us the best fit for occupancy and detection rates. Our results suggest that while sooty mangabeys are abundant on Tiwai Island, they may be in lower densities in unprotected areas especially on the smaller islands in the surrounding areas and the mainland. This showed that sooty mangabeys are unevenly distributed on the entire study area and majority of individuals occupied the main island.

TABLE 3 Naïve occupancy, detection rates (*p*), estimated occupancy (ψ) and total abundance (N) for sooty mangabeys determined using abundance-induced heterogeneity, single season constant P occupancy and Royle repeated count models for field season one (2008–2009), field season two (2010–2011) and combined seasons on and around Tiwai Island Wildlife Sanctuary, Sierra Leone.

Model	Naïve occupancy	ψ	SE	*p*	SE	N	SE
Field season combined							
Abundance-induced heterogeneity	0.62	0.79	0.08	0.28	0.06	326.4	92.2
psi(.)p(.)		0.71	0.08	0.59	0.06		
Royle repeated count data	0.62	0.96	0.02	0.22	0.04	530.0	102.9
Field season 1							
Abundance-induced heterogeneity	0.52	0.60	0.19	0.39	0.13	94.6	44.2
psi(.)p(.)		0.68	0.11	0.53	0.09		
Royle repeated count data	0.52	0.95	0.06	0.22	0.10	200.8	88.9
Field season 2							
Abundance-induced heterogeneity	0.69	0.86	0.08	0.25	0.07	217.9	74.4
Single season occupancy, constant P		0.82	0.07	0.50	0.05		
Repeated count data	0.69	0.97	0.02	0.22	0.05	324.1	69.8

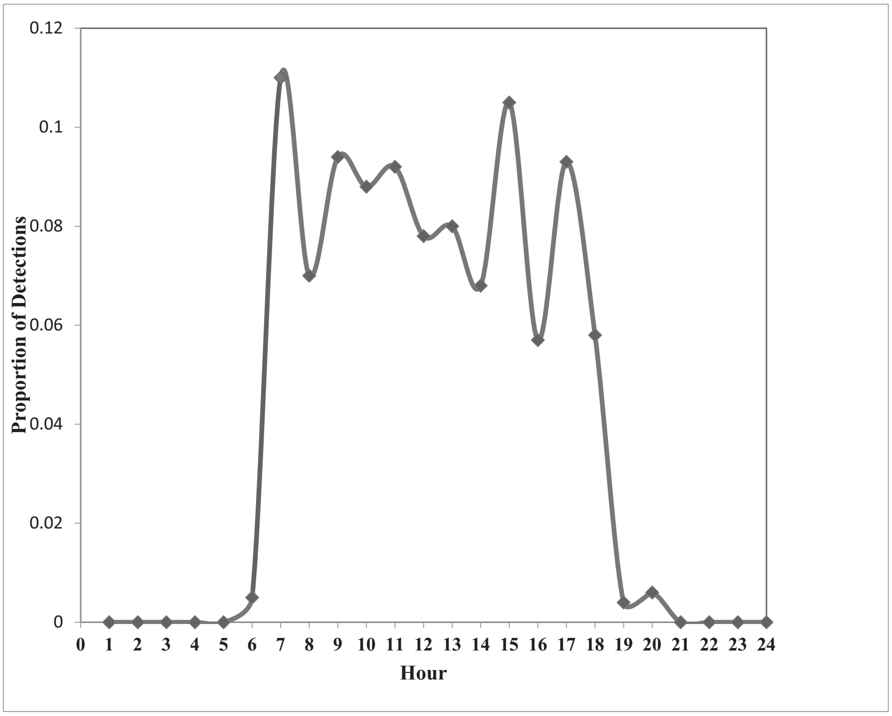

FIGURE 1 Diurnal activity patterns of sooty mangabeys as an index of activity using camera traps on and around Tiwai Island Wildlife Sanctuary, Sierra Leone, during 2008–2011 as recorded within 24-h period starting during midnight.

Our estimates from the two estimation methods of about 326 and 530 sooty mangabeys suggest an average of 22 and 35 individuals/km^2. These densities are similar to the estimate of 25 individuals/km^2 found in Tai National Park using line transects in Côte d'Ivoire (Refisch & Koné, 2005) and 38.5 in Tiwai Island (Oates, 1990).

On Tiwai, habitat type appeared to influence occupancy rates of sooty mangabeys. The study species usually occurred in forest habitats compared to raphia swampy habitats, and they avoided bush fallow areas. The low detection rates and occupancy in bush fallow areas may be due to fewer nut and fruit producing trees, which sooty mangabeys need for their diet (McGraw et al., 2011). The density of understory vegetation did not seem to have much effect on their habitat use as much as the habitat type because sooty mangabeys can move through most vegetation on the ground.

The difference in occupancy between Tiwai Island, the small islands and mainland could also be attributed to the hunting ban on

Tiwai Island in 1987 (McCollum et al., 2018). Anecdotal evidence suggests that hunting is not strictly regulated on the smaller islands or on the mainland. The smaller islands are hunted for bush meat and to preemptively protect crops from damage. Because the mainland is a mosaic of farms, bush fallow and secondary forests are highly human-modified, sooty mangabeys may be less likely to inhabit these areas due to both human presence and habitat degradation. While hunting rates are unknown in this area, future studies should focus on determining the level of threat to the sooty mangabeys near Tiwai Island.

Our data showed little indication of increased sooty mangabeys' activity during crepuscular periods. This pattern differs from a group of sooty mangabeys studied in captivity that had relatively bimodal activity patterns of movement during the day (Bernstein, 1976). Captive animals showed peaks of activity in the early morning and in the late afternoon (Bernstein, 1976). Activity patterns in captivity might be more influenced due to food provisioning by keepers than other factors found in wild populations.

Future studies of sooty mangabeys across the region should extend the scope to focus on abundance between the mainland and corridors between Tiwai Island, Gola Forest and Kambui Hills.

5 | CONCLUSION

Our study suggests that a core population has been maintained in a small conservation reserve despite much of the region undergoing significant impacts from a long civil war, agriculture, deforestation and bush meat trade. The results of this study suggest that a viable population of sooty mangabeys still inhabits Tiwai Island and its vicinity, but that their core population is primarily limited to the Tiwai Island Reserve. Since isolated small populations might gradually lack heterozygosity and will suffer from inbreeding depression, further research is required to see the gene flow and/or vulnerability of isolated populations in these fragmented reserves. Moreover, sooty mangabeys are important for ecological studies and for better understanding modes of transmission for HIV (Wertheim & Worobey, 2009) and as such it should be protected.

Tiwai Island Reserve is known with a high diversity of primates; therefore, sustainable development and management strategies of such protected area are crucial for the conservation of the species. Awareness creation of local communities could also promote conservation efforts of these primate species in the area.

AUTHOR CONTRIBUTIONS

Kellie Laity and April Conway participated in field data collection and data analysis. Kellie Laity prepared the first draft of the manuscript. Sonia M. Hernandez helped in data analysis and editing the manuscript. John P. Carroll supervised the project work, participated in field data collection and data analysis. Dessalegn Ejigu contributed in manuscript completion, edition and its submission as a corresponding author to the journal for possible publication. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

All the authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

All data generated and analysed during this manuscript preparation are available on the hands of the corresponding author.

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