Received: 22 February 2019 | Revised: 11 November 2019 | Accepted: 30 November 2019
DOI: 10.1002/ajp.23083

RESEARCH ARTICLE

AMERICAN JOURNAL OF PRIMATOLOGY WILEY

Estimating the population size of the Sanje mangabey (*Cercocebus sanjei*) using acoustic distance sampling

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Funding information
Natural Environment Research Council, Grant/Award Number: NE/N007980/1; Bristol Zoological Society; Primate Conservation, Grant/Award Number: #1443

Abstract

The Sanje mangabey (*Cercocebus sanjei*) is endemic to the Udzungwa Mountains, Tanzania, and is classified as Endangered due to its putatively declining population size, habitat degradation and fragmentation. Previous population size estimates have ranged from 1,350 to 3,500 individuals, with the last direct survey being conducted 15 years before the present study. Previous estimates are now thought to have underestimated the population due to a limited knowledge of group and habitat size, nonsystematic approaches and the use of visual methods that are not suitable for surveying the Sanje mangabey with its semi-terrestrial and elusive behaviors. We used an acoustic survey method with observers recording the distinctive "whoop-gobble" vocalization produced by mangabeys and point transect distance sampling to model a detection function and estimate abundance. Twenty-eight surveys were conducted throughout the two forests where Sanje mangabeys are found: Mwanihana forest in the Udzungwa Mountains National Park ($n = 13$), and the Uzungwa Scarp Nature Reserve ($n = 15$). Group density was found to be significantly lower in the relatively unprotected Uzungwa Scarp forest (0.15 groups/km^2; 95% CI: 0.08–0.27) compared to the well-protected Mwanihana forest (0.29 groups/km^2; 95% CI: 0.19–0.43; $p = .03$). We estimate that there are 1,712 (95% CI: 1,141–2,567) individuals in Mwanihana and 1,455 (95% CI: 783–2,702) in the Uzungwa Scarp, resulting in a total population size of 3,167 (95% CI: 2,181–4,596) individuals. The difference in group density between sites is likely a result of the differing protection status and levels of enforcement between the forests, suggesting that protection of the Uzungwa Scarp should be increased to encourage recovery of the population, and reduce the threat of degradation and hunting. Our results contribute to the reassessment of the species' IUCN Red List status and informing management and conservation action planning.

KEYWORDS
acoustic, distance sampling, mangabey, point transect, population size

1 | INTRODUCTION

Nonhuman primates are key to the successful functioning of their ecosystems; however, primates are currently facing an extinction crisis with approximately 75% of species declining and 60% threatened with extinction, with the largest threats including habitat loss to agriculture, logging and livestock farming, and hunting (Estrada et al., 2017). Research efforts into monitoring wild primate populations have proven crucial in conservation management as recording data on population abundance and distribution can provide insights into the response of a species to changes in habitat and

[The copyright line for this article was changed on 20 January 2020 after original online publication] population trends over time (Campbell, Head, Junker, & Nekaris, 2016; Chapman et al., 2018; Jones, Hawes, Norton, & Hawkins, 2019; Lwanga, Struhsaker, Struhsaker, Butynski, & Mitani, 2011). By establishing an initial baseline and appropriate methodology, these data can be used to assess population trends in subsequent years and develop adaptive management plans that call for the implementation of improved methods to protect species (Lyons, Runge, Laskowski, & Kendall, 2008; Nichols & Williams, 2006).

The Sanje mangabey (*Cercocebus sanjei*) is endemic to the Udzungwa Mountains in south-central Tanzania (Ehardt, Butynski, & Struhsaker, 2008). Since its discovery in 1979 by Homewood and Rodgers (1981), it has been studied to elucidate its distribution and population size to determine its conservation status and required management (Ehardt et al., 2008; Ehardt, Jones, & Butynski, 2005; Rovero et al., 2006; Rovero, Mtui, Kitegile, & Nielsen, 2012), and an inferred declining population size has resulted in an IUCN Red List Endangered status (EN; McCabe, Rovero, Fernández, Butynski, & Struhsaker, 2019). The population is divided between two isolated forest blocks: Mwanihana forest in the well-protected Udzungwa Mountains National Park, and the Uzungwa Scarp Nature Reserve forest, which has a lower level of protection and regulations that are not strongly enforced (Ehardt et al., 2005). These forests are separated by 100 km of agricultural land and low elevation habitat unsuitable for mangabeys, preventing dispersal of individuals between forests, which could potentially limit the recovery of each population.

The current population size of the Sanje mangabey remains debated and with previous habitat loss and degradation and the current impact of hunting in the forests likely to impact the species, especially in the Uzungwa Scarp (Hegerl et al., 2017), current estimates and subsequent monitoring are essential to assess the conservation status and needs of the species. Previous population size estimates range from as little as 1,350 individuals to 3,500 (Dinesen, Lehmberg, Rahner, & Fjeldså, 2001; Rovero, Marshall, Jones, & Perkin, 2009, respectively; Table 1) with the last dedicated survey conducted by Ehardt et al. (2005) between 1997 and 2002. However, previous studies used methods that were not suitable for the elusive behavior of the Sanje mangabey, and the group size and habitat area calculations used to extrapolate group density were underestimations, resulting in an underestimated population size.

All previous surveys of the mangabeys have been nonsystematic or have used line transect methods to estimate population size. These methods are now recognized to be inefficient for this species as unhabituated groups flee rapidly from humans and are difficult to detect in dense vegetation (Rovero & Struhsaker, 2007; Rovero et al., 2006, 2012). This was supported by line transect observations when individuals were heard calling but were not seen by observers (Rovero et al., 2006).

The study by Ehardt et al. (2005) used a group size of 10.2–13.6 individuals to empirically estimate population size. This value is now thought to be a large underestimate for the Sanje mangabey which has been observed to have groups of up to 70 individuals (G. McCabe, personal observation). Rovero et al. (2009) estimated the population size using the values from Ehardt et al. (2005) but adjusted for a larger group size of 35 individuals, which may be more accurate as it is similar to the closely related Tana River mangabey group size (*C. galeritus*: 27 individuals/group; Wieczkowski & Butynski, 2013).

The total suitable habitat size used by Ehardt et al. (2005) is also thought to be an underestimate having used only the closed forest area (Mwanihana: 100 km^2; Uzungwa Scarp: 131 km^2). However, long-term studies of a habituated group in Mwanihana have confirmed that Sanje mangabeys routinely use a variety of habitats; including secondary growth and elephant disturbed shrubland (McCabe, Fernández, & Ehardt, 2013). Thus, more recent primate surveys have predicted a much larger total forest size with potentially suitable habitat throughout the full extent for Sanje mangabeys (Mwanihana: 150.59 km^2; Uzungwa Scarp: 314.48 km^2; Marshall et al., 2010).

Low detection efficiency has been found in other primate species that live in dense rainforests or mountainous regions or are elusive and live at low densities (Lee, Powell, & Lindsell, 2015; Marques et al., 2013; Plumptre, Sterling, & Buckland, 2013). In such species, acoustic methods have been successfully applied, including the black howler (*Alouatta pigra*) and spider monkey (*Ateles geoffroyi*; Estrada, Luecke, Van Belle, Barrueta, & Meda, 2004), indri (*Indri indri*; Glessner & Britt, 2005), and wild cotton-top tamarin (*Saguinus oedipus*; Savage, Thomas, Leighty, Soto, & Medina, 2010). Here, we employ an acoustic distance sampling method to estimate group density for the mangabeys, from which population size can be more accurately extrapolated.

This study aimed to conduct the first systematic survey of the Sanje mangabey population and provide the first inferential

TABLE 1 Previous population size estimates for the Sanje mangabey in the Udzungwa Mountains, Tanzania, and the survey methodology and average group size estimate used to calculate population size

Previous studies	Survey method	Estimated average group size	Estimated population size
Homewood and Rodgers (1981)	Random census walks in one region	15–20/25	1,800–3,000
Dinesen et al. (2001)	Recce walks around campsites	15	1,350
Ehardt (2001)	Recce walks along cleared pathways/animal trails	15	<1,300
Ehardt et al. (2005)	Refined data from 2001 study using results from the completed 1997–2002 study	10.2/13.6	<1,500
Rovero et al. (2009)	No survey; updated estimates from Ehardt et al. (2005) with larger group size estimate	35	2,800–3,500

estimates of population size for the species. This was the first survey of the Sanje mangabey for 15 years and therefore aimed to establish a more recent and accurate estimate of population size. We used acoustic surveys and a more recent estimate of available habitat size to estimate population size and hypothesized that greater habitat degradation and levels of hunting in the Uzungwa Scarp would put the population in this forest at a high risk of decline.

2 | METHODS

2.1 | Study site

Fieldwork was conducted in the Udzungwa Mountains, Tanzania, in the only two forest blocks in which the Sanje mangabey is found: Mwanihana forest (7°40′–7°57′S, 36°46′–36°56′E), situated in the Udzungwa Mountains National Park, and the Uzungwa Scarp Nature Reserve (8°14′–8°32′S, 35°51′–36°02′E; Ehardt et al., 2005; Figure 1). Data were collected during the dry season between June and November 2017, to minimize the chance of seasonal variation in climatic conditions and species behavior that may influence detection probability.

2.2 | Acoustic survey

A total of 28 survey locations were used to collect vocalization data for the Sanje mangabey: 13 in Mwanihana and 15 in Uzungwa Scarp (Figure 1). Quantum GIS (QGIS; QGIS Development Team, 2018) was used to design a systematic grid of points and randomly place this grid on each forest area to select survey locations in regions known to be accessible. Sanje mangabeys have home ranges of 2 km^2 (Ehardt et al., 2005); therefore, we aimed to position locations a minimum of 2 km apart to reduce the chance of groups being detected at more than one location.

Sanje mangabey territorial "whoop-gobble" vocalizations have been recorded at distances of up to 1 km (Ehardt et al., 2005); therefore, surveys used three listening posts arranged in a 3 × 1 array, positioned approximately 200 m apart, to allow calls to be detected at more than one post (Figure 2a). Distances and bearings between posts were measured using a GPS device (Garmin GPSMAP 54s Handheld Navigator). Posts were not always equally spaced due to the terrain constraints in some locations. When positioning posts, preferential use of ridges was made to reduce the possible obstructions to sound transmission across uneven terrain. This was the most effective use of the total survey effort available and

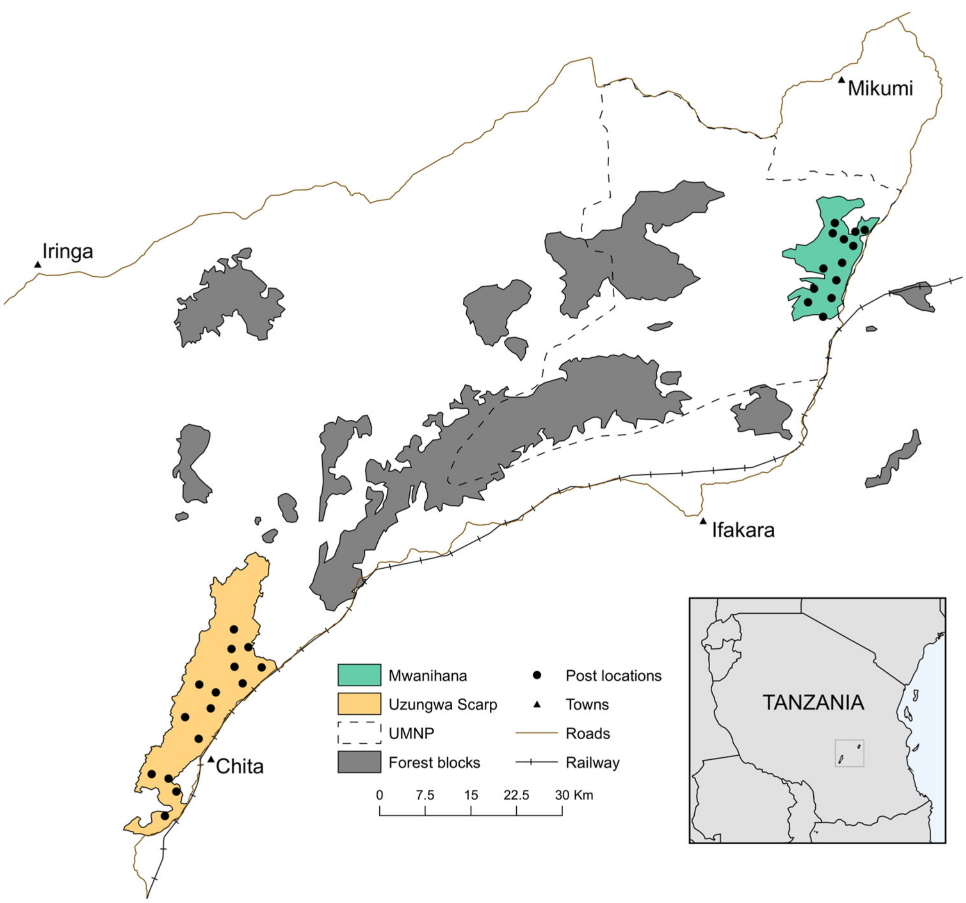

FIGURE 1 Map of the forest blocks in the Udzungwa Mountains and the forest blocks in which Sanje mangabey are found; Mwanihana within the Udzungwa Mountains National Park (UMNP) in the north-east (green), and the Uzungwa Scarp Nature Reserve in the south-west (orange). Listening post locations (circles) are shown at the position of the central listening post

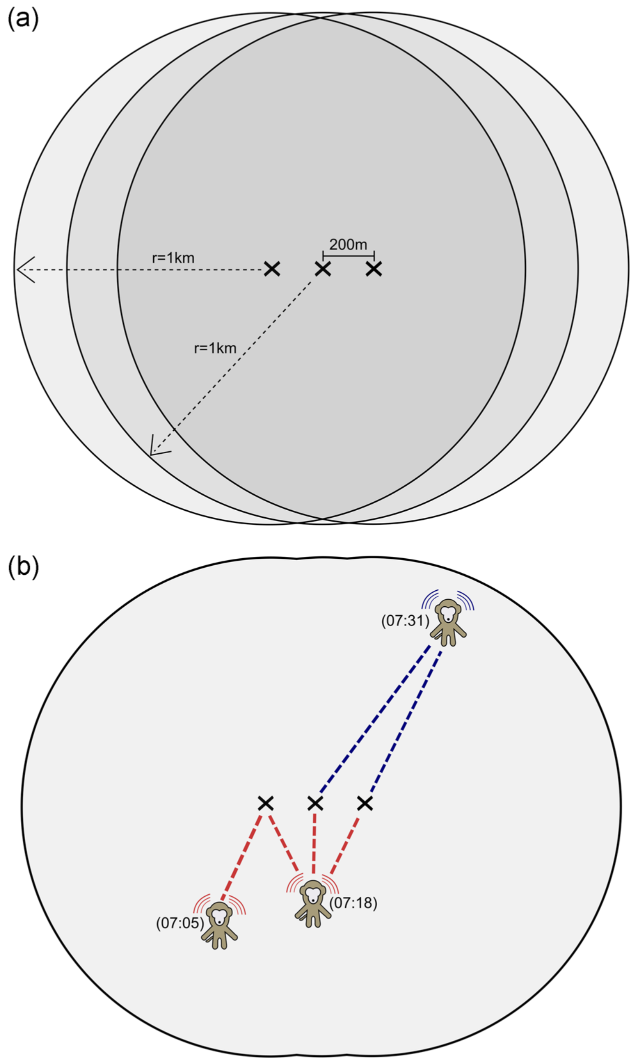

FIGURE 2 Diagrams of the acoustic distance sampling method used in this study: (a) The 3 × 1 array positioning of listening posts with observers (crosses) positioned 200 m apart, with the area of detection for each post (*r* = 1 km; shaded region), and (b) an illustration of an example of the call clustering method analysis and attribution of group identification to vocalizations. The time of the call is shown in brackets, dashed lines from posts show the posts that detected the call and the assumed group identification is shown by the color of lines. The two calls below the posts (red group) are assumed to be the same group as they are close in time and space; less than 30 min apart and less than 300 m apart. The call above the posts (blue group) is assumed to be a different group as it is over 300 m away and less than 30 min apart from the other calls

increased the likelihood that the maximum distance individuals could be heard would be similar in all locations. On days of heavy rain, surveys were suspended as the ability to detect calls decreased.

Each survey was conducted once and only early in the morning when the mangabeys are known to call at the highest frequency during the day (approximately 70% of calls before 1200 hr; Ehardt et al., 2005). The surveys started when light levels were safe enough for observers to move through the forest such that survey times were variable. Observations were recorded from the time the observers arrived at the post (mean start time: 0642 hr ± 11.6 min) until 0900 hr; all surveys covered a core time of 0700 hr to 0900 hr. The full survey time for each post was used so that the earliest calls (<0700 hr: 10.2% of calls) were not lost, which would have led to an underestimation of group density.

With each vocalization detected, observers recorded the time of the start of the call, a bearing from the post and estimated the distance to the origin of the call. Observers would estimate the number of groups heard whilst in the field, attributing individual vocalizations to an assumed group, to support later data analysis. All assistants had been a member of the Sanje Mangabey Project team before this study and therefore were well trained and reliable in identifying mangabey calls.

The method followed the assumptions of a point transect survey (Buckland et al., 2001). Individuals were detected with certainty at the posts and at the initial location of the call as observers were stationary which ensured groups would not be disturbed and therefore measured at their initial location. The assumption that measurements were exact was not met as distance to calls were estimates by the observers and the variation in terrain and loudness of calls may have affected the perceived distance by observers of each call. Groups could not be located by observers during the survey to validate distances as groups flee quickly if disturbed, making it difficult to locate groups at the original location and risked disturbing other groups. Before the study, observers underwent training whilst studying a habituated group to estimate distances and bearings of calls to minimize possible interobserver differences. The assumption that surveys were positioned at random was violated as listening posts were positioned on nearby ridges and vantage points which may have deviated from randomly assigned points.

2.3 | Estimating average group size

A mean average group size for the Sanje mangabey was calculated for each forest from focal follows of five groups (Mwanihana: *n* = 2; Uzungwa Scarp: *n* = 3) found opportunistically when in the field outside survey times, and from known average group sizes of an additional three habituated groups in Mwanihana.

2.4 | Estimating group density and population size

Vocalizations were plotted on a map in QGIS using the bearing and distance estimates recorded during the surveys. Call clusters were used to identify groups in a similar way to previous studies using indri vocalizations to identify distinct groups (*Indri indri*; Glessner & Britt, 2005; Pollock, 1986). Vocalizations that were within a 300 m distance of another call were assumed to be from the same group. If vocalizations were less than 30 min apart and more than 300 m apart, these were assumed to be separate groups (Figure 2b). If group definition was unclear (*n* = 13 out of 370 vocalizations) from the plotted vocalizations, notes from the field of assumed number of groups heard were used to attribute the individual calls to a group cluster.

To calculate a detection function and estimated abundance in each forest using distance sampling, the package Distance (Miller, Rexstad, Thomas, Marshall, & Laake, 2019) was used in R (R Core Team, 2018). Survey area was estimated using a fixed radius of 1 km around each post (the furthest distance a mangabey call can be heard; Ehardt et al., 2005) and using QGIS to measure this combined area covered by the three posts. As posts were not always equally spaced, this area varied between locations. An average co-ordinate was calculated for each group from all assigned vocalizations and the central point of each survey area was calculated by averaging the co-ordinates of the three listening posts. The distance between this center point for the survey area and average group position was measured in QGIS to provide a single distance to each group. Group density was calculated for each survey and extrapolated to the total area of suitable habitat from Marshall et al. (2010; Mwanihana: 150.59 km^2, Uzungwa Scarp: 314.48 km^2). These estimates were considered the most accurate available as they reflected those found for the predicted suitable habitat area for each forest when using QGIS in this study. The average group size found in this study for each forest was used to inform cluster size in the Distance model to estimate number of individuals.

Observation distances were truncated at 1 km as it is unlikely mangabey calls were accurately detectable past this distance. This removed the detection of 2 groups from a total of 49 detected (4.1% of data) which resembles the removal of the furthest 5% of data suggested by Buckland et al. (2001) for point transect surveys. Four models were tested following combinations suggested by Thomas et al. (2010): half-normal key with cosine adjustments, half-normal key with Hermite polynomial adjustments, hazard-rate key with polynomial adjustments and uniform key with cosine adjustments, and the best model was selected using Akaike's information criteria (AIC).

The difference between the group density estimates for each forest was measured using a Student's *t* test, and the difference in group size between forests was measured using a Mann-Whitney *U* test. All summary statistics were calculated in R (R Core Team, 2018).

2.5 | Ethics statement

This study did not capture or handle animals and was in adherence to the American Society of Primatologists' Principles for the Ethical Treatment of Nonhuman Primates. All work was carried out under the approval and required permits from Tanzania National Parks (TANAPA), Tanzania Forest Service Agency (TFS), Commission for Science and Technology (COSTECH: 2017-205-NA-2017-115) and the Tanzanian Wildlife and Research Institute (TAWIRI).

3 | RESULTS

A total of 252 vocalizations were detected in Mwanihana and 118 in Uzungwa Scarp. Using the call clustering method, 32 calling groups were detected in Mwanihana and 17 groups recorded in the Uzungwa Scarp. The surveys covered a total area of 100 km^2 in Mwanihana and 113 km^2 in Uzungwa Scarp, which is approximately 66.4% and 35.9% of each forest area, respectively, at an average of 7.70 km^2 per survey in Mwanihana ($n = 13$; ±*SD* 0.40) and 7.51 km^2 per survey in Uzungwa Scarp ($n = 15$; ±*SD* 0.04). The mean number of individuals per group for Uzungwa Scarp (31.7 ± *SD* 2.9 individuals; $n = 3$) was lower than Mwanihana (39.2 ± *SD* 19.4 individuals; $n = 5$), however, the difference was not significant (Table 2).

TABLE 2 Average group size estimates for the Sanje mangabey in the two forests they occupy: Mwanihana and Uzungwa Scarp in the Udzungwa Mountains, Tanzania, and overall for all groups

Forest	Number of groups	Group size range	Average group size	±SD
Mwanihana	5	17–65	39.2	19.4
Uzungwa Scarp	3	30–35	31.7	2.9
Total	8	17–65	36.4	15.3

All detection function models fitted well with the data (ΔAIC < 2) and did not differ significantly in abundance estimations. The model using a uniform key with cosine adjustment was selected as the best fitting detection function model (ΔAIC = 0; goodness of fit: $p = .46$; Figure 3). Group density was estimated to be significantly higher in Mwanihana (0.29 groups/km^2; 95% CI: 0.19–0.43) than in Uzungwa Scarp (0.15 groups/km^2; 95% CI: 0.08–0.27; Student's *t* test: $t = 2.25$; $df = 26$; $p = .03$; Figure 4). An estimated 43.7 (95% CI: 29.1–65.5) groups and 1,712 (95% CI: 1,141–2,567) individuals were present in Mwanihana. In the Uzungwa Scarp, an estimated 45.9 (95% CI: 24.7–85.2) groups and 1,455 (95% CI: 783–2,702) individuals were

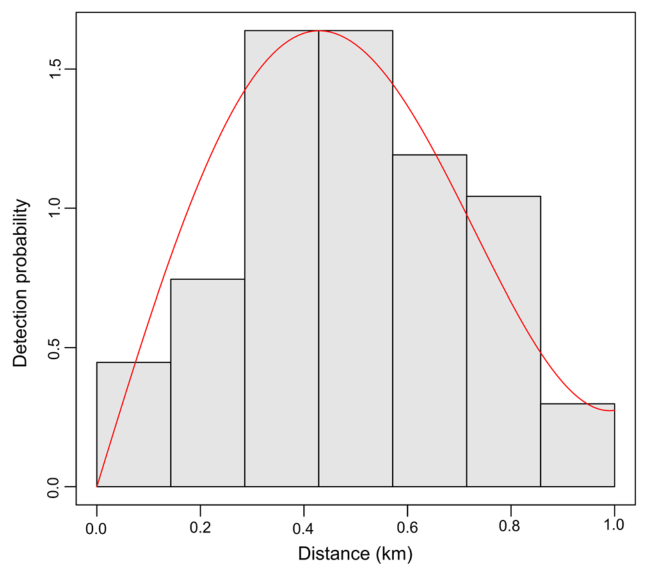

FIGURE 3 The detection function for a uniform model with cosine key for Sanje mangabey vocalizations detected during surveys of both Mwanihana and Uzungwa Scarp forests in the Udzungwa Mountains, Tanzania

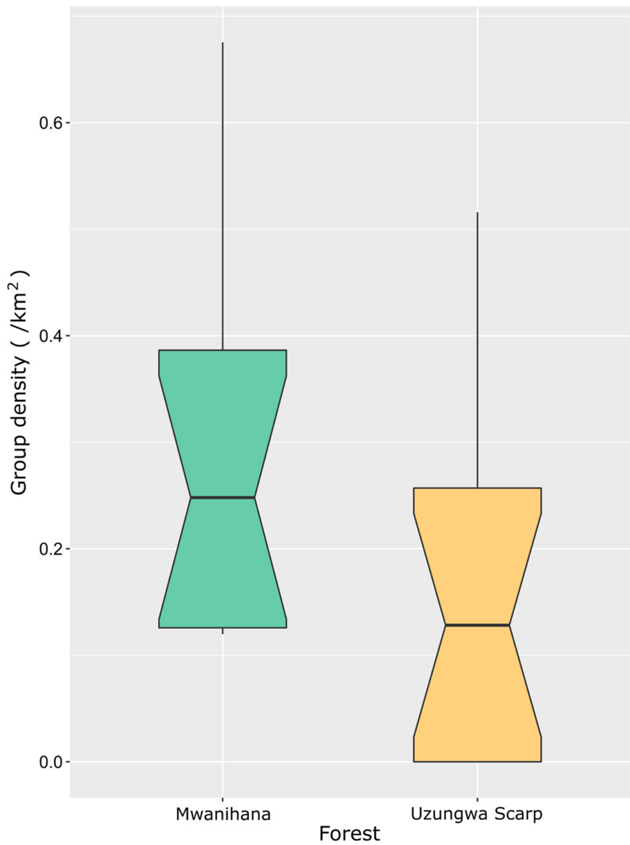

FIGURE 4 A boxplot showing the distribution of group density for the Sanje mangabey in the two forests in which they are found: Mwanihana and the Uzungwa Scarp forests in the Udzungwa Mountains, Tanzania. Group density was significantly higher in the well-protected Mwanihana forest than the lesser protected Uzungwa Scarp (Student's *t* test: $t = 2.25$; $df = 26$; $p = .03$)

found. Therefore, the estimated total number of groups for the Sanje mangabey was 89.6 (95% CI: 60.8–131.9) groups and estimated population size a total of 3,167 (95% CI: 2,181–4,596) individuals (Table 3).

4 | DISCUSSION

The population size estimates in this study are in concordance with previous predictions by Rovero et al. (2009), but larger than previous surveys of the Sanje mangabey due to the larger average group size and habitat size sampled in the current study (Dinesen et al., 2001; Ehardt, 2001; Ehardt et al., 2005; Table 3). Ehardt et al. (2008) predicted 40% of the population to be residing within Uzungwa Scarp and, here, we again found a very similar proportion, with 46% of the population in Uzungwa Scarp. Ehardt et al. (2005) empirically estimated that there were only <1,500 individuals across the two forests, however, when the original density estimates are used in conjunction with the values for habitat size and group size used in this study, now considered a more accurate estimate, total population estimate sizes would have ranged from 4,591 to 5,536 individuals (Table 3). This would suggest a possible decline; however, due to inaccuracies previously discussed of earlier population size estimates, it is not possible to definitively infer a temporal change. Therefore, this study provides the first inferential estimate to allow future surveys to detect and estimate population trends.

Considering population trends from other primates in the same forests, it is likely that there may have been a decline and that the population in the Uzungwa Scarp continues to be at risk of further decline. Populations of primates in Mwanihana have shown to be stable in recent surveys and the active protection measures to be efficient (Beaudrot et al., 2016; Rovero et al., 2012, 2015), and although Rovero et al. (2012) detected a potential decline in mangabey abundance between surveys in 2004–2005 and 2007–2008 and a survey in 2009, the visual line transect method used was highlighted as inefficient for the mangabey and results to be taken with caution. For the Uzungwa Scarp however, studies report a decline for several primate species (Rovero et al., 2012, 2015). In surveys conducted between 2002 and 2012, Rovero et al. (2015) found that populations of the arboreal Udzungwa red colobus (*Procolobus gordonorum*) and Angolan colobus (*Colobus angolensis palliatus*) in Mwanihana were stable; however they showed a decline in the Uzungwa Scarp. This was attributed to increased human

TABLE 3 Habitat size, group density and group size estimates used to calculate population size for the Sanje mangabey in the Udzungwa Mountains, Tanzania, for the two forests they occupy: Mwanihana (MW) and the Uzungwa Scarp (US), in the current study compared to previous estimates

Population survey		Forest	Habitat size (km^2)	Group density (groups/km^2)	Group size	Population size	Estimated total population size
This study		MW	150.59	0.29 (95% CI: 0.19–0.43)	39.2	1,712 (95% CI: 1,141–2,567)	3,167 (95% CI: 2,181–4,596)
		US	314.48	0.15 (95% CI: 0.08–0.27)	31.7	1,455 (95% CI: 783–2,702)	
Rovero et al. (2009)		MW	–	–	35	1,750–2,100	2,800–3,500
		US	–	–		1,050–1,400	
Ehardt et al. (2005)	Original	MW	131	0.44–0.6	10.2–13.6	600–900	<1,500
		US	100	0.2		200–270	
	Adjusted	MW	*150.59*	0.44–0.6	*39.2*	2,597–3,542	4,591–5,536
		US	*314.48*	0.2	*31.7*	1,994	

Note: Results from Ehardt et al. (2005) are reported as the original data presented in the study and as adjusted estimates (new values italicized) where the group densities from the original calculations have been used to calculate population size with the higher group size and habitat size estimates found and used in this study.

disturbance in this time period through hunting and pole cutting, both likely to also impact the semi-terrestrial Sanje mangabey.

Group density in Mwanihana was significantly higher than that found in the Uzungwa Scarp, with the lower density found in the forest that presently and historically has had a considerably lower protection status and level of law enforcement. When using camera traps and occupancy modelling, which is likely an efficient method for the shy, semi-terrestrial mangabey, Hegerl et al. (2017) found Sanje mangabey occupancy in the Uzungwa Scarp was only a quarter of that found in Mwanihana. This difference, as with the difference in group density in this study, suggests that threats to other primates in the Uzungwa Scarp are likely also affecting the Sanje mangabey. Further, findings in this study reflect previous work examining group density for three arboreal primates in the Udzungwa Mountains: the Udzungwa red colobus, Angolan colobus and Sykes' monkey (*Cercopithecus mitis monoides/moloneyi*). Across Mwanihana, Uzungwa Scarp, and two other forests, group density of all three species was found to be lowest in the Uzungwa Scarp, which was attributed to the lack of active protection (Araldi, Barelli, Hodges, & Rovero, 2014). Lower densities have often been found for primates living in disturbed habitats compared to those in less disturbed regions due to factors such as reduced biomass, shelter, canopy cover and food availability (Phoonjampa et al., 2011). A study by Phoonjampa et al. (2011) of pileated gibbons (*Hylobates pileatus*) found group density was significantly associated with habitat disturbance, with higher densities found in forests that had been issued formal protection for longer than those that were more recently elevated.

While both the National Park and Nature Reserve were originally protected by Forest Reserve status, these regulations were weak and often poorly enforced. Mwanihana's protection was upgraded in 1992 when it was included within the Udzungwa Mountains National Park boundary; however, the Uzungwa Scarp was only upgraded to Nature Reserve protection in 2016, which strengthened regulations and management, but did not lead to active patrols or greater law enforcement on the ground. Human disturbance has increased in the Uzungwa Scarp since 2007 (Rovero, Mtui, Kitegile, Nielsen, & Jones, 2010) and the declining encounter rate for the mangabeys has previously been attributed to this escalation in encroachment (Rovero et al., 2012). A recent long-term study of the impact of protected areas in the Udzungwa Mountains found both species richness and encounter rates for the most commonly encountered medium to large-bodied mammals increased with level of protection status (Jones et al., 2019), which further supports the difference in density found in this study for the mangabey.

The acoustic survey method used in this study addressed previous issues from line transect surveys as it did not rely on visual observations and did not disturb the mangabeys that are shy and quick to move away. Therefore, the estimates from this method are likely to be a more accurate representation of the current population size and future surveys of this species should include this approach. Anecdotal observations from the long-term study of the habituated group suggest that it is rare for the groups to not vocalize in the morning (G. McCabe pers. obs.); however, the method in this study could be adapted to bolster estimates by surveying the same location over multiple days to increase detection likelihood. Extrapolating average group density to the full extent of the forest assumed that groups were evenly distributed which may be unlikely given the wide elevation gradient and habitat heterogeneity of both forests. The survey posts were positioned at random and were successful in achieving a mostly full coverage of the forest extent, however, future studies should aim to cover the full extent of each forest and aim to determine whether a difference in group density is found in different habitat types, accounting for possible uneven distribution of groups across forests when estimating population size. Responses to food abundance, quality of forest, habitat structure and proximity to recent human disturbance have been found to influence group density in other studies of primates (Agetsuma, Koda, Tsujino, & Agetsuma-Yanagihara, 2015). The suitability of the habitat and presence of preferred dietary items were not measured in this study but may have had an influence on density within and between forests, and assessments of this should be included in future surveys.

No significant difference was found between the average group size for each forest; however, this is likely attributed to the small sample size for each forest and large range of group sizes known from Mwanihana due to two large habituated groups. Future studies would benefit from continuing to estimate group size of all groups encountered to increase the sample size for each forest. In the closely related Tana River mangabey (*Cercocebus galeritus*), a study of the impact of habitat degradation on life history traits found that the subpopulation in a forest of high degradation, due to anthropogenic activities, with lower food abundance had a reduced social group size compared to the subpopulation living with lower levels of habitat degradation (Mbora, Wieczkowski, & Munene, 2009). This was suggested to be attributable to increased parasite prevalence and/or increased competition for food in degraded forest resulting in lower fecundity and increased fitness costs, which may be also applicable in the Sanje mangabey subpopulation in the Uzungwa Scarp with further study.

The Sanje mangabey has shown behavioral and dietary flexibility in its ability to adapt to the use of both primary and secondary forest (Ehardt et al., 2005; McCabe et al., 2013), which suggests continued and improved protection of the forests to continue the recovery of currently unsuitable degraded habitat to usable secondary forest may encourage an increase in group density. This has been seen in conservation projects aimed at the San Martin titi monkey (*Plecturocebus oenanthe*), for example, where regeneration of forest by increased protection and active reforestation increased group density (Allgas et al., 2017). Similarly, increased tree density due to active forest protection led to increased group density for the gray-cheeked mangabey (*Lophocebus albigena*) in the Kibale Forest Reserve, Uganda (Olupot, Chapman, Brown, & Waser, 1994).

This study has provided the first inferential estimate of the Sanje mangabey population size which was essential due to previous estimates being considered inaccurate and the last direct survey being conducted over 15 years before this study (Ehardt et al., 2005). It is key to the survival and protection of species to monitor any changes in the population and the responses to changes in their environment, by natural disaster or anthropogenic disturbances. Populations can be slow to respond to such changes; therefore, long-term and regular monitoring can provide an insight into population trends. Recently, Newmark and McNeally (2018) described the predicted "sizable" extinction debt due to the fragmentation of forests within the Eastern Arc Mountains, including forests of the Udzungwa Mountains, and the threat to the survival of species within these biodiversity hotspots. Considering this for the Sanje mangabey, we recommend continuing regular population surveys with the acoustic method described here, adapted following recommendations, to regularly monitor the population and to use the results from this study as the baseline population size estimates. The isolation of the two forests preventing migration of individuals and recovery of a population, and the lower group density found in the Uzungwa Scarp, underlines the need for increased protection and active enforcement in this region. Continued active protection of the National Park is required for maintaining the population and potentially aiding an increased group density as highly degraded habitats recover. Active protection of the Uzungwa Scarp needs to be established to prevent the continued impact of hunting and habitat degradation and declining trend in primate populations in the region.

ACKNOWLEDGMENTS

Grateful acknowledgments go to Tanzania National Parks (TANAPA), Tanzania Forest Service Agency (TFS), Commission for Science and Technology (COSTECH) and the Tanzanian Wildlife and Research Institute (TAWIRI) for allowing the work to be conducted within the National Park and Nature Reserve. We would like to thank the Sanje Mangabey Project research team, Dr David Fernández, and the staff at the Udzungwa Ecological Monitoring Centre and Udzungwa Forest Project for their assistance with the research. We acknowledge the financial support provided by the UK Natural Environment Research Council (NERC; CASE Studentship NE/N007980/1), Bristol Zoological Society as the NERC CASE industry partner, and Primate Conservation Inc. (#1443) for the fieldwork to be completed.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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How to cite this article: Paddock CL, Bruford MW, McCabe GM. Estimating the population size of the Sanje mangabey (*Cercocebus sanjei*) using acoustic distance sampling. *Am J Primatol*. 2020;82:e23083. https://doi.org/10.1002/ajp.23083