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Letter to the editor
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Population size estimates based on GPS telemetry

DEAR EDITOR,

Accurate estimation of population size is a crucial issue in wildlife population ecology and conservation. While Global Positioning System (GPS) collars are well recognized as an effective method for monitoring wildlife behavior, their application in direct wildlife population size estimation remains underutilized. In this study, GPS telemetry was employed to survey a rhesus macaque (*Macaca mulatta*) population on Neilingding Island in Guangdong, China. From May 2021 to April 2022, 32 macaques across nine groups were fitted with GPS collars, producing a dataset of 109 739 location fixes. Analyzing data from all tracked individuals revealed the annual home ranges of the nine groups, which varied from 13.9 ha to 55.4 ha. Substantial home range overlap among groups was observed, with the highest level of exclusivity occurring in March. Based on the data, the study area was projected to support approximately 38.6 macaque groups within their respective home ranges, with a total population size of 957±193 macaques, derived from a mean group size of 24.8±5.0. Further analysis highlighted a consistent spatial utilization pattern between individual macaques and their corresponding groups, suggesting that data from a single individual may represent the home range and utilization patterns of the entire group. The presented methodology is time-effective, operates independently of surveyor expertise, demonstrates high repeatability, and yields extensive data suitable for further ecological studies.

Population monitoring is a core aspect of wildlife population ecology and conservation. Such monitoring provides crucial information regarding population status and its response to threats and conservation interventions, particularly in the context of rapid biodiversity decline driven by unsustainable anthropogenic activities. Traditionally, population monitoring has relied on the assessment of direct counts or indirect traces, such as distance and mark-recapture sampling approaches (Li, 2021). These conventional methods, while reliable, are labor- and time-intensive and necessitate substantial surveyor expertise. Technological advances, combined with field studies, have provided alternative tools for surveying wildlife populations, including infrared cameras and passive acoustic sensors (Piel et al., 2022). Notably, GPS tracking is a promising technology for population monitoring as it overcomes many sampling limitations and can automatically generate long-term and scientifically robust data (Nathan et al., 2022). While such technology has been used to estimate the population size of intra-sexually territorial species such as fishers (*Martes pennanti*) (Koen et al., 2007), its high cost and installation difficulties have limited its broader application in population censuses.

In the current study, we explored the feasibility of using GPS tracking technology to estimate the size of a rhesus macaque (*Macaca mulatta*) population located on Neilingding Island (N22°23′49″−22°25′35″, E113°46′18″−113°49′49″) in Guangdong, China (Figure 1A), a small enclosed island (total land area of 4.98 km^2) with minimal variation in elevation (highest elevation of 340.9 m a.s.l.). Historical surveys have regularly monitored this macaque population, with the most recent 2016 survey estimating a population size of approximately 1 000 individuals (Chu et al., 2019). These historical data provide a robust foundation to evaluate the viability of GPS tracking. During the study period, macaques were equipped with GPS collars to track their trajectories, ascertain their home ranges, and estimate population size by determining the number of groups that the study area could accommodate based on the specified home ranges. From May 2021 to April 2022, 32 individuals from nine groups were tracked, yielding a dataset of 109 739 location fixes. To ensure the accuracy of locations, we adopt a data screening method to filter fixes with locating deviation. After data screening, 26 667 fixes (24.3%) were excluded. Detailed information regarding GPS collar implementation, data validation and screening processes, group size assessment, and tracked individuals can be found in the Supplementary Materials and Methods.

Annual and monthly home range sizes were derived using kernel density estimates. Results indicated that macaques on Neilingding Island maintained constrained home ranges (mean: 31.2±11.8 ha, range: 13.9–55.4 ha) with a high degree of overlap (Figure 1B). The extent of monthly home ranges fluctuated (Figure 1C), with a maximum in August (coefficient of variation (CV) 0.40, mean: 35.26 ha, range: 14.2–57.3 ha) and a minimum in April (CV=0.30, mean: 18.27 ha, range: 11.5–26.1 ha). For each group, the exclusive home range (home range not overlapping with any other tracked group) and exclusive ratio (proportion of the exclusive area to total home range size) were calculated. As the exclusive home range may be overestimated due to potential undetected overlaps with neighboring groups not subject to tracking, and a lower exclusive ratio indicates a higher extent of this overlap, monthly home range with the highest exclusive ratio

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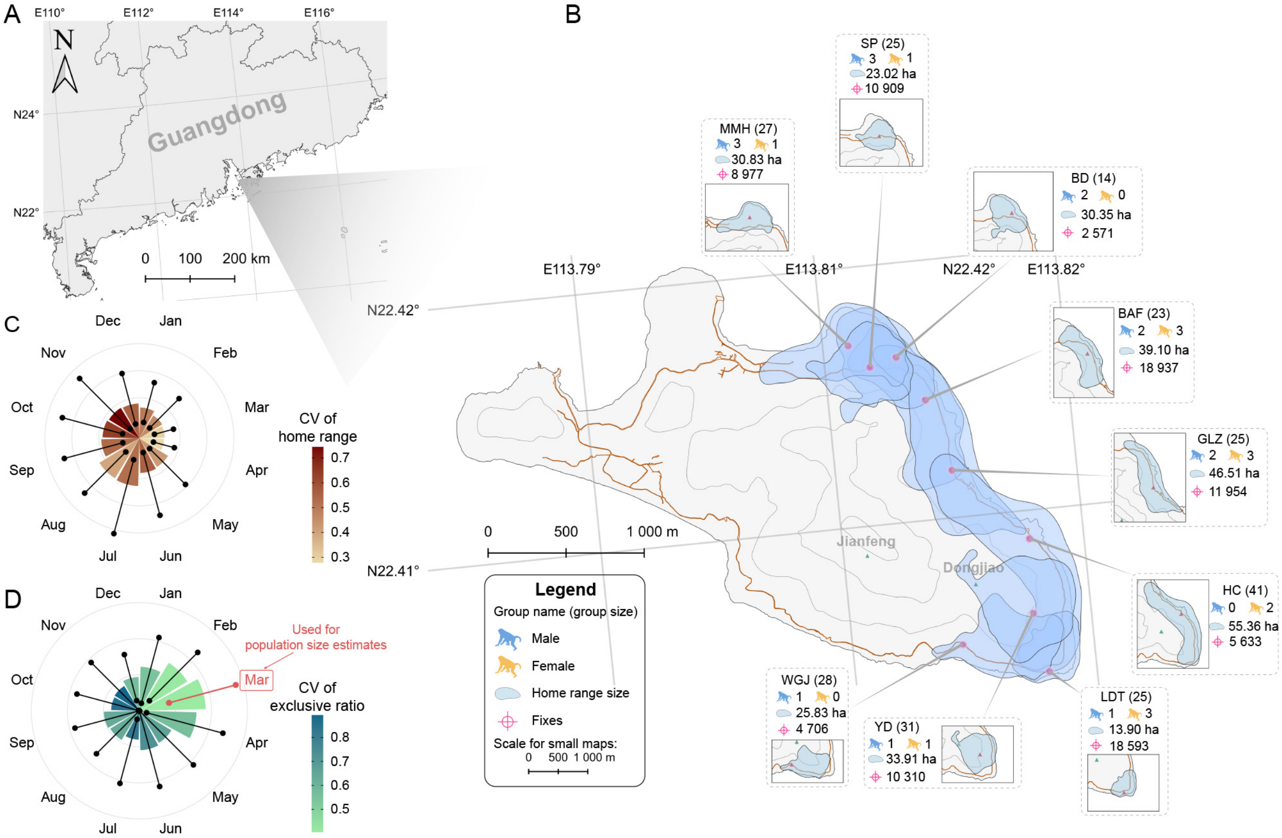

Figure 1 Locations and home range features of nine macaque groups with tracked individuals on Neilingding Island, Guangdong, China

A: Geographical location of Neilingding Island. B: Basic information of each tracked group. Group name, group size, number of collared males and females in each group, annual home range size, and number of fixes acquired are listed from top to bottom. C: Monthly variation in home range of nine macaque groups. Mean (brown bar) and range (black solid line) of monthly home range size are shown for each month. D: Monthly variation in exclusive ratio of nine macaque groups. Mean (green bar) and range (black solid line) of exclusive ratio of monthly home range are shown. March shows the highest exclusive ratio (red), which was used to estimate population size. For abbreviations see text.

was used to minimize the impact of undetected overlap. The highest exclusive home range ratio (55.2%) occurred in March (Figure 1D). To determine the potential capacity of the island, the aggregate exclusive home range ratio (derived from the proportion between the exclusive ranges of the nine groups and total home range) was multiplied by island area. The number of groups was estimated by dividing the island capacity by the average exclusive home range size. Thus, we estimated that the island could support 38.6 groups based on the mean exclusive area value (12.79 ha) in March.

To estimate the population size of rhesus macaques on Neilingding Island, field surveys were conducted to evaluate the size of the nine tracked groups. Group size was variable, ranging from 14 individuals in group BD (including two adult males and five adult females) to 41 individuals in group HC (including four adult males and thirteen adult females), with a mean of 26.4 (SE=7.1; Figure 1B). Considering that the largest group HC is a semi-provisioned group, which has been feeding regularly by reserve managers on the island, thus this group was omitted from population size calculation. And the adjusted mean group size decreased to 24.8 (SE=5.0).

By multiplying mean group size by the number of groups, the macaque population size was estimated at 957 (SE=193.0) individuals. This is comparable to the most recent estimation of 989 individuals (24 groups) using direct counting (Chu et al., 2019), although group number and mean group size differed. Due to significant home range overlap among adjacent groups, differentiating between groups and achieving accurate individual counts was challenging. This may have led to the previous study overestimating group size and underestimating group number. Alternatively, certain larger groups may have split into smaller groups between 2016 and 2021. Notably, after the conclusion of this study, several macaques from the HC group separated and established a new smaller group comprising 21 members.

To compare the utilization distribution (UD) similarity between each individual and their group, the Bhattacharyya's affinity (BA) overlap index was applied. The mean BA value among all groups was 0.98 (SE=0.06, range: 0.40–1.00). Of note, 93% of the BA values exceeded 0.95, with only 20 values falling below this threshold (Supplementary Figure S1), 19 of which were calculated from a small sample size of less than 100 fixes, indicating that increasing sample size may improve similarity between individuals and groups. These results suggest that for species in cohesive groups, like the macaques in this study, a single GPS collar may adequately represent both the home range size and utilization patterns of the entire group, thereby offering a cost-effective approach for such research.

For animal species residing in dense forests that vocalize infrequently, options for population assessment remain limited. This research presents an approach that uses GPS collars to estimate animal population sizes. In contrast to conventional survey methods, the presented approach confers multiple distinct benefits. First, utilizing GPS technology to track wild animals overcomes challenges associated with long-term sampling in inaccessible or remote terrain, thereby reducing the need for human resource requirements. Large field teams often face significant logistic challenges. In our study, however, only three team members were required for all fieldwork, including macaque anesthetization, GPS collar attachment, and group size determination. Second, this approach is independent of the experience and observational ability of surveyors, thus ensuring high repeatability and reliability. Sustained and scientifically rigorous monitoring is important for delineating population dynamics (Chapman et al., 2010). Unlike the application of GPS devices, it is difficult for a single researcher to engage in continuous population monitoring to ensure comparability between surveys. Third, GPS collars can generate extensive datasets capturing the movements of multiple individuals simultaneously. Such data can play an important role in addressing ecological questions, such as those related to habitat selection, inter- and intra-group spatial interactions, and ecological constraints.

Our study was conducted on a small island with limited heterogeneity in terrain, elevation, and forest type, with the macaque groups exhibiting a relatively uniform distribution (Chu et al., 2019). Consequently, we did not consider habitat heterogeneity in our study. However, in environments with pronounced heterogeneity, including groups from different habitats in the sampling process is necessary to ensure comprehensive representation of the area (Kühl et al., 2008). The macaque population density is notably high on the island, and neighboring groups exhibit considerable overlap in home range. Consequently, we introduced an exclusive utilization ratio into the estimation function for quantifying groups. It should be noted that this function may not be applicable for areas with low population density, where the home ranges of neighboring individuals or groups do not overlap. In such instances, alternative methods exist to estimate population density, such as the Thiessen polygon approach (Bermejo et al., 2006), which employs home range centroids to construct polygons regardless of home range area or overlap. Lastly, when confronted with obvious variation in monthly home range, populations should be monitored for at least one year.

In conclusion, our study demonstrates the viability of integrating GPS telemetry and group censuses as a promising approach for wildlife population surveys. This method is particularly effective for assessing medium- to large-sized animals that occupy stable home ranges and live in dense forests with low visibility. The advantages of low labor costs, high repeatability, and inherent accuracy make it a promising approach for broad utilization across different taxa. We anticipate that the future incorporation of novel technologies will further facilitate wildlife monitoring in the fight against biodiversity loss.

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Permission for field surveys in Neilingding Island was granted by the Neilingding-Futian National Reserve. Permission for GPS collar implementation was granted by the Forestry Administration of Guangdong Province.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

P.F.F. and Y.X.F. contributed to the conception and design of the study. P.F.F., C.M., Y.X.F., P.Z.X., T.C., X.Y., H.L.X., and Q.Y. conducted the field study. Y.X.F. and P.F.F. wrote the manuscript. All authors read and approved the final version of the manuscript.

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REFERENCES

Bermejo M, Rodríguez-Teijeiro JD, Illera G, et al. 2006. Ebola outbreak killed 5000 gorillas. *Science*, **314**(5805): 1564.

Chapman CA, Struhsaker TT, Skorupa JP, et al. 2010. Understanding long-term primate community dynamics: implications of forest change. *Ecological Applications*, **20**(1): 179−191.

Chu YMR, Zan QJ, Yang Q, et al. 2019. Population dynamic and viability analysis of rhesus macaque (*Macaca mulatta*) in Neilingding Nature Reserve, Guangdong Province. *Chinese Journal of Wildlife*, **40**(2): 259−266. (in Chinese)

Koen EL, Bowman J, Findlay CS, et al. 2007. Home range and population density of fishers in eastern ontario. *Journal of Wildlife Management*, **71**(5): 1484−1493.

Kühl H, Maisels F, Ancrenaz M, et al. 2008. Best Practice Guidelines for Surveys and Monitoring of Great Ape Populations. Gland, Switzerland: IUCN SSC Primate Specialist Group (PSG).

Li YH. 2021. A review on estimating population size of large and medium-sized mammals. *Biodiversity Science*, **29**(12): 1700−1717. (in Chinese)

Nathan R, Monk CT, Arlinghaus R, et al. 2022. Big-data approaches lead to an increased understanding of the ecology of animal movement. *Science*, **375**(6582): eabg1780.

Piel AK, Crunchant A, Knot IE, et al. 2022. Noninvasive technologies for primate conservation in the 21st century. *International Journal of Primatology*, **43**(1): 133−167.