Demographic status and activity patterns of the Endangered Togean Islands babirusa: a contribution towards evaluating its conservation status

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Research Article

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Abstract

The Togean Islands babirusa (*Babyrousa togeanensis*) is an Endangered wild pig species endemic to the Togean Archipelago, Indonesia. Despite its conservation status, our knowledge of the species is limited, which hampers conservation efforts. We here report the results of an island-wide camera trapping study, assessing the species' demographic status and activity patterns. We sampled 103 camera stations distributed throughout the entire range of the species from July-October 2022. Through N-mixture modeling, we estimated the babirusa's population size as 440 adult individuals (CI: 340–580), with a sex ratio of 1:2.3. The male babirusas were mostly solitary, but females were typically part of a group dominated by juveniles. Using multistate occupancy modeling, we also found the probability of reproductive babirusas being present in an occupied site was 0.74 ± SD 0.11, and the probability was higher with increasing distance to human settlement. Despite high human activities, the babirusa remained diurnal, with activities concentrated in the early morning and late afternoon. We suggest the IUCN Red List status of the Togean Islands babirusa should remain Endangered or shifted to Critically Endangered if the risk from potential African Swine Fever outbreak is considered.

Introduction

The Togean Islands babirusa (*Babyrousa togeanensis*; hereafter Togean babirusa) is an Endangered wild pig species endemic to the Togean Archipelago, Indonesia (Macdonald et al., 2016). This babirusa is nationally protected and one of the conservation priority species in Indonesia (Regulation of Ministry of Forestry Indonesia No: P.55/Menhut-II/2013). Being confined to small, isolated islands, the species is highly vulnerable to extinction due to demographic stochasticity, inbreeding depression, human-wildlife conflicts, habitat loss, and disease outbreaks (Luskin et al., 2021; Jati et al., 2024).

Knowledge on the basic demographic parameters of this species is lacking (Ito & Melletti, 2017). The previous study conducted >20 years ago estimated the population size of the Togean babirusa as 100-1000 individuals; nevertheless, this study was based on interview surveys and it did not cover the entire species range (Akbar et al., 2007). Consequently, an updated field-based assessment is warranted. We also lack detailed knowledge on the demographic structure of its populations, such as reproduction status, group structure, and sex ratio. Without these data, it will be challenging to predict the species chance of survival, such as by conducting a population viability analysis (Chaudhary & Oli, 2020).

Furthermore, our knowledge of the species' behaviour is limited only to the interview study and speculation from other babirusa species (Ito & Melletti, 2017), whereas animals' behaviour is important for understanding their adaptation strategies. For example, mammals worldwide have become more nocturnal to avoid humans (Gaynor et al., 2018). The Togean babirusa may adopt a similar strategy to compete with humans for space, but this speculation will require field investigations.

The goal of our study is to estimate key demographic parameters and behaviour of the Togean babirusa. Our study design allowed us to estimate population size, group structure, sex ratio, and probability of reproduction. We also report babirusa's activity patterns to evaluate the species' ability to adapt to the high human pressure in the Togean Archipelago. Lastly, we provide insights for the IUCN Red List assessment of the babirusa based on our study and other recent findings.

Study area

We conducted this study on four islands in the Togean Archipelago, Central Sulawesi, Indonesia, representing the entire range of the Togean babirusa (Fig. 1): Batudaka (244 km^2), Togean (177 km^2), Talatako (96 km^2), and Malenge (13 km^2). The entire archipelago is part of the Togean-Tojo Una-Una UNESCO's Biosphere Reserve, and some portions of the islands' interior, along with the marine area surrounding the archipelago, are included in the Togean Islands National Park (Purwanto & Nugroho, 2022). The archipelago is covered by tropical lowland forests, mangroves, pioneer vegetation, and agricultural areas. Coconut and clove plantations dominate the agricultural areas, but other short-term crops, such as corn and cassava, are also planted. As of 2022, there were 42 human settlements distributed throughout the study sites (Jati et al., 2024).

Methods

Camera trapping survey

To collect babirusa data, we deployed 103 sampling stations following a stratified random sampling (across four land cover types: forest, pioneer vegetation, mangrove, and agriculture) throughout the study area (Fig. 1) from July to October 2022. Each station was equipped with two camera traps spaced about 100 m and active for 24 hours for 15 to 21 days. We placed cameras in areas where the chance to record the babirusa was high, such as in front of animal tracks, fruiting trees, or wallowing ponds. All cameras were set to record a 20-second video each time the sensor was triggered with a one second interval between recordings. We counted the number of babirusas in each video and identified them as male, female, or juvenile. Males and females only refer to adults and subadults.

Environmental variables

We measured environmental variables at each station through a combination of remote sensing, GIS, and ground surveys. We first employed Google Earth Engine to generate a cloud free mosaic of Landsat 8 and Landsat 9 imagery in 2022, then developed a land cover map of the study area (Fig. 1) in ArcGIS Pro using supervised image classification. Based on this map, we estimated the following variables: land cover diversity (Shannon-Wiener index), proportion of forest, proportion of mangrove, proportion of pioneer vegetation, proportion of agricultural area (all previous variables are within 4 km of the site), distance to human settlement, and distance to road. We took fisheye photographs of the sky on all camera trap points and processed them in Gap Light Analyzer software (Frazer et al., 1999) to estimate canopy openness (percent of open sky) at each station.

Population size, sex ratio, and group structure estimation

We fitted single season N-mixture models to our data (Royle, 2004) to estimate the population size of the babirusa using the *unmarked* package in R 4.3.3 (Fiske & Chandler, 2011; R Core Team, 2022). For this analysis, we created a dataset containing the number of adult babirusas recorded within 24 hours at each station. To avoid double counting, we only selected one video containing the highest number of individuals per day per station. We used the Poisson distribution for this analysis because we believed our data contained true zeros, i.e., no babirusas in the area (Joseph et al., 2009; Jati et al., 2024).

We used combinations of environmental variables that were previously identified as affecting the babirusa's occupancy and detectability as predictors for the N-Mixture models (see Jati et al., 2024). We first compared univariate models through Delta Akaike Information Criterion (ΔAIC). If there was more than one model with ΔAIC lower than 2 below the null (model without a predictor), we created additive models with covariate combinations of those models and reevaluated the ΔAIC. This approach was first applied to establish the most supported detectability model, then the same procedure was applied to model abundance. Note that detectability here refers to the probability of detecting a single individual, unlike occupancy models where it refers to species detectability.

We used the selected model to estimate local abundance at each station and totalled the local abundance of all stations to obtain the babirusa's population size. This approach followed the assumption that our camera trap stations represented the entire study area and no individual babirusa was recorded at multiple stations. We also estimated the number of males and females separately, by fitting models to male and female only data, to calculate the sex ratio.

To estimate group size, we counted the number of individuals that appeared in a single video. If there was more than one video recorded within 60 minutes at one camera station, we only included one video with most babirusas, following the assumption that multiple recordings within an hour were individuals of the same group. For each video, we noted the presence of males and females, then created box plots to summarize the group size for each sex separately. Group size was counted regardless of sex and age class composition. We also calculated the proportion of juveniles in each group.

Reproduction probability

We estimated the probability of a reproductive individual being present in an occupied site (reproduction probability) by fitting single-season multistate occupancy models to our data using the *RPresence* package in R 4.3.3 (MacKenzie & Hines, 2018; R Core Team, 2022). We developed a babirusa daily detection history dataset containing three categories: no detection, detection of non-reproductive individuals (at least one adult without the presence of juvenile), and detection of reproductive individuals (at least one juvenile was confirmed).

Our models included four parameters: occupancy probability, species detectability, reproduction probability, and detectability of reproductive individuals. For all models, covariates for the occupancy and species detectability followed Jati et al. (2024). Because babirusa can reproduce throughout the year (Berger et al., 2006), we assumed the detectability of reproductive individuals was constant for the entire survey duration. Because reproduction model is nested within occupancy model, we used environmental variables that were not covariates of occupancy and species detectability model to develop reproduction models, which were: proportion of pioneer vegetation, proportion of agricultural area, land cover diversity, distance to human settlement, and distance to road. Model development and selection procedure for the reproduction models followed the same procedure as the N-mixture models.

Activity patterns

We created kernel-density curves to visualize the babirusa's activity patterns using the *overlap* and *circular* packages in R 4.3.3 (Meredith, Ridout, et al., 2018; Agostinelli & Lund, 2023). Following an assumption that videos recorded within 60 minutes were the same individuals performing the same activities, we only included the first observation within an hour from each camera station. In total, we used 792 observations to visualize the babirusa's activity pattern. We performed Watson-Wheeler test (Jammalamadaka & SenGupta, 2001) to compare the patterns observed in Batudaka, Togean, and Talatako Islands to test if the activity pattern is similar throughout the entire population. We did not include Malenge Island in this comparison due to a small number of observations (n=32). We also plotted the activity pattern for male (469 observations) and female (314 observations) separately and performed a Watson-Wheeler test to compare differences in activity patterns between sexes.

Results

The top-ranked N-Mixture model (Table 1) shows that factors affecting individual detection were island, canopy openness (β = -0.05 ± SE 0.02), and proportion of pioneer vegetation (β = -1.47 ± SE 1.73). The babirusa local abundance was positively affected by the proportion of forest (β = 2.92 ± SE 0.67; Fig. 2). The population size of the Togean babirusa was estimated as 440 adult individuals (CI 340 – 580).

For adult males, the individual detection was affected only by island and canopy openness (β = -0.07 ± SE 0.03), while for females, the proportion of pioneer vegetation also negatively affected individual detection (β = -4.03 ± SE 2.15), besides island and canopy openness (β = -0.04 ± SE 0.02). Proportion of forest positively affected local abundance of males (β = 2.50 ± SE 1.0) and females (β = 2.16 ± SE 0.87). The sex ratio of the Togean babirusa was 1:2.3.

Most adult males (82%) were solitary, but some individuals were observed as part of groups of up to 8 individuals. Most females were observed in a group (mean group size = 3.13 ± SD 1.86), where about half of the groups consisted of 3-7 individuals, and the other half 1-3 individuals, with some outliers of up to 11 individuals (Fig. 2). The proportion of juveniles in a group was 0.47 ± SD 0.26.

The top-ranked multistate occupancy model included distance to human settlement as the most supported predictor of reproduction probability (Table 2) with positive relationship: the greater the distance, the higher the probability (β = 0.48 ± SE 0.25; Fig. 4). The estimated reproduction probability was 0.74 ± SD 0.11.

We collate information generated through this study to evaluate the conservation status of this species based on the IUCN Red List Categories and Criteria Version 16 (Supplementary Table 1).

Discussion

Population size, sex ratio, and group structure

We estimated the population size of the Togean babirusa as 440 (CI 340–580) adult individuals (approximately one individual/ km^2). Our estimate was lower than 1000 individuals, the current estimate adopted by the IUCN Red List (Macdonald et al., 2016). It is possible that the population is declining, nevertheless we emphasize that two very different approaches were used to estimate abundance, as the previous one was estimated through interview surveys (Akbar et al., 2007). However, locals reported the disappearance of the Togean babirusa in some areas during the past decade (pers.obs.), supporting that the babirusa is indeed declining.

Our population estimate was derived from an extensive field survey, covering the entire distribution range of the species. Overall, we elected to be conservative in our analytical approach, specifically the number of babirusa individuals was counted from a single video rather than from multiple videos per day, which could potentially underestimate the total abundance if multiple groups visited a station at different time within a day. We followed this approach as in most cases it was not possible to identify individuals. Also, our camera stations were randomly distributed throughout the study area, rather than being deployed systematically. While this ensured a representative sample in terms of habitat types, some individual babirusas might be under-sampled due to irregular area coverage of the stations.

Female Togean babirusas were about twice as abundant as males, which is in line with other Suidae species (D’Huart, 1993; Macdonald, 1993; Rademaker et al., 2016). A higher number of females compared to males is expected in polygyny species since a male can mate with multiple females in a single breeding cycle (Espinoza & Weckerly, 2021). Togean babirusa’s matting system is still largely unknown, but this female-biased sex ratio indicates that this babirusa could be polygyny. A different survival rates between males and females could also shape sex ratio (Espinoza & Weckerly, 2021). A study on captive Sulawesi babirusa (*B. celebensis*) indicates a territorial behaviour of male individuals (Leus et al., 1996), suggesting that competition among males could push less-dominant individuals to suboptimal habitats and increase male’s mortality. Hunting can also influence sex ratio by targeting a specific sex (Loveridge et al., 2007). Local farmers kill the Togean babirusa for pest control (Jati et al., 2024), but establishing whether males are more affected requires further investigations.

Almost all adult males were solitary, while most females were part of groups dominated by juveniles. This was similar to the group size and composition described by locals (Akbar et al., 2007) and to the group size observed in Sulawesi babirusa (Patry et al., 1995; Clayton & MacDonald, 1999). The difference in group size between males and females may also explain why the proportion of pioneer vegetation negatively affected detectability of females, but not males, since moving in a group is more difficult in areas with dense pioneer vegetation.

Reproduction probability

The reproduction probability of the Togean babirusa was about 70% and positively affected by distance to human settlement. Selecting rearing habitat with less predation risk, or in this case, lower human activities, is common in ungulates to increase offspring survival (Viejou et al., 2018; Heffelfinger et al., 2020; Blum et al., 2023). At the same time, reproductive individuals also require high quality habitat to raise their young (Heffelfinger et al., 2020). Therefore, to successfully reproduce, the Togean babirusa also need high-quality habitats, besides being away from humans. This is represented in our reproduction model where reproduction probability is conditional upon occupancy; hence, reproduction will not happen if factors contributing to the species occupancy (i.e., high proportion of forests and mangroves; Jati et al., 2024) are not available.

Activity patterns

The Togean babirusa showed a bimodal activity pattern, with peaks in the early morning and late afternoon, confirming the description reported by locals (Akbar et al., 2007). Activity patterns on Batudaka, Togean, and Talatako Islands did not show significant differences, indicating that this bimodal pattern is general across the population. A similar pattern was observed in other Suidae species, such as *Sus barbatus* (Davison et al., 2019)d *blouchi* (Rode-Margono et al., 2020). However, activity patterns between males and females were significantly different, with females being more active during the day (Fig. 5B & C). This was likely caused by the larger group size of females which required them to spend more time foraging (Markham et al., 2015).

Although our camera traps recorded babirusa at nighttime, the activity density was low. Unlike many mammals that became more nocturnal in response to high human disturbances (Gaynor et al., 2018; Davison et al., 2019), the Togean babirusa seems to remain diurnal despite high human presence in the islands. The following factors may contribute to this pattern. First, the babirusa is relatively hairless which may affect their thermoregulatory ability (Romanovsky, 2014), specifically to stay warm at night. Second, coconut and clove plantations are the dominant agricultural products on the archipelago. These plantations do not require intensive management, i.e., farmers do not visit plantations every day, so babirusas can forage during the daytime when farmers are absent. Still, being mostly diurnal increases the chance of meeting humans who would try to kill them.

Conservation implications

Our study provides new insights into the demographic status and behaviour of the babirusa, a species previously known only from limited field observations. The total abundance of the Togean babirusa was relatively low, but the high reproduction probability might contribute to the species' persistence. Still, the small population size makes this species highly vulnerable to disease outbreaks, particularly the African

Swine Fever (ASF) that is already island-hopping in Southeast Asia and decimating other Suidae species on neighbouring islands (Ewers et al., 2021). Should the virus reach the Togean Archipelago, it could eradicate the entire Togean babirusa. Establishing a captive population, which is currently unavailable for this species, could be considered as a backup strategy if reintroduction is needed. Promoting human-babirusa coexistence should also be seriously considered to reduce the impact of presumably severed human-wildlife conflict. The species is currently listed as Endangered, and our assessment, as well as a recent occupancy study (Jati et al., 2024), emphasize that Togean babirusa should remain Endangered under the IUCN Red List Category and Criteria Version 16 (Supplementary Table 1). However, weighing the risk of potential ASF outbreak in the islands, raising its status to Critically Endangered should be considered.

Declarations

Author contributions Study design: ASJ, AM; fieldwork: ASJ, BWB; analysis: ASJ; writing: ASJ, AM, JRW, MM

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Conflicts of interest None.

Ethical standards This study was conducted under SIMAKSI permit issued by the Togean Islands National Park Agency No: SI.02/T.23/TU/KSA/06/2022 and University of Maine IACUC (Institutional Animal Care and Use Committee) protocol A2021-12-04.

Data availability The datasets and R script generated and analysed in this study are available from the corresponding author on reasonable request.

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Tables

Tables 1 to 2 are available in the Supplementary Files section

Figures

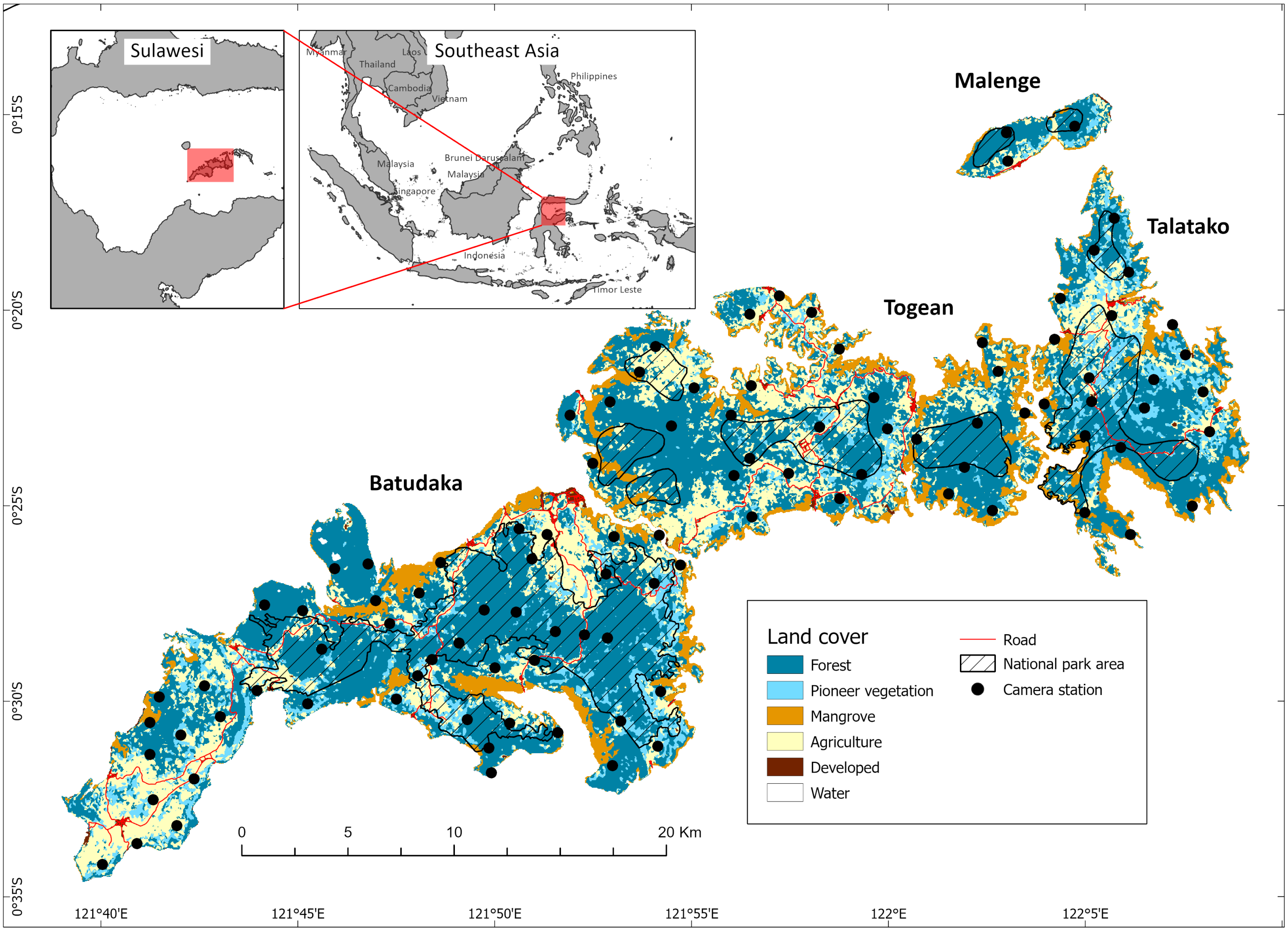

Figure 1

Representation of the study area in the Togean Archipelago, showing the position of 103 camera trap stations. The insetmaps show the study site's relative position to the Sulawesi mainland and Southeast Asia. Figure adapted from Jati et al. (2024).

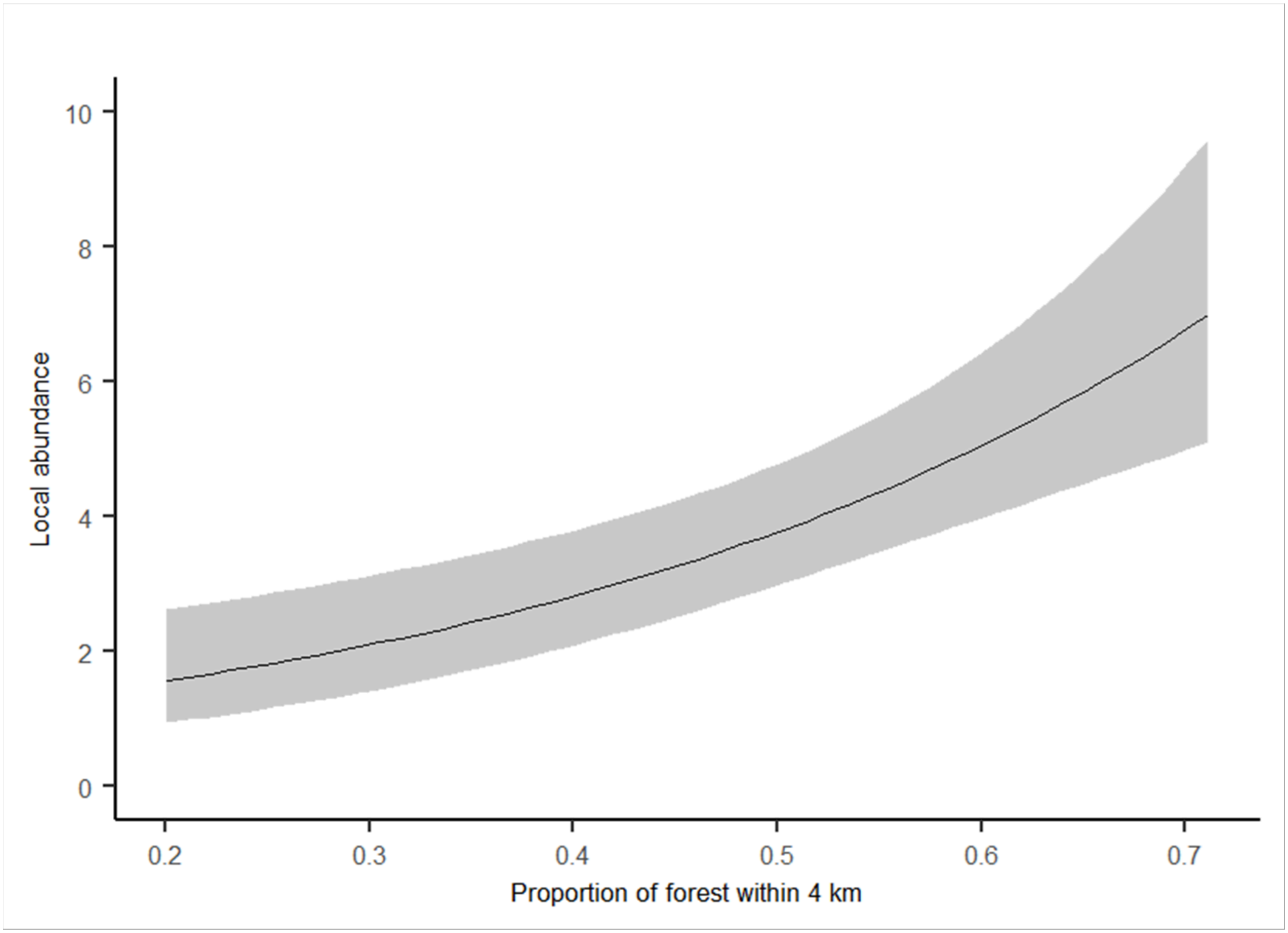

Figure 2

Relationship between Togean babirusa's local abundance (y-axis) and proportion of forest within 4 km (x-axis), predicted from the top-ranked N-mixture model. Local abundance increased with the proportion of forest. The grey ribbon indicates the 95% confidence interval.

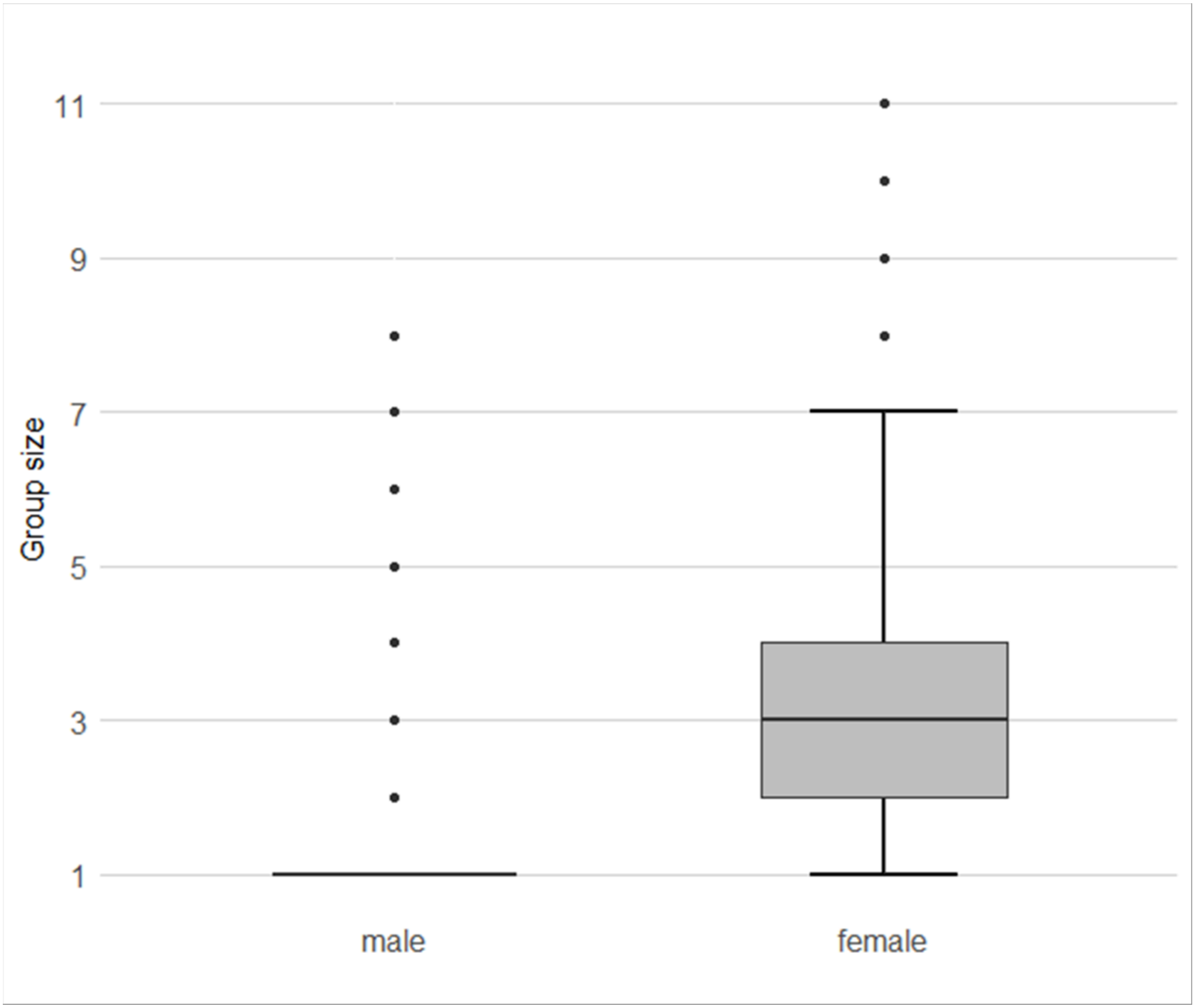

Figure 3

Box plots showing the group size of the Togean babirusa where adult males (left) and females (right) were present. Group size was counted regardless of sex and age class composition. Each box shows the range of the 25th - 75th percentile, with a horizontal line inside the box indicating the median. Vertical lines represent adjacent values within 1.5 interquartile range of the 25th and 75th percentiles. Dots represent outliers.

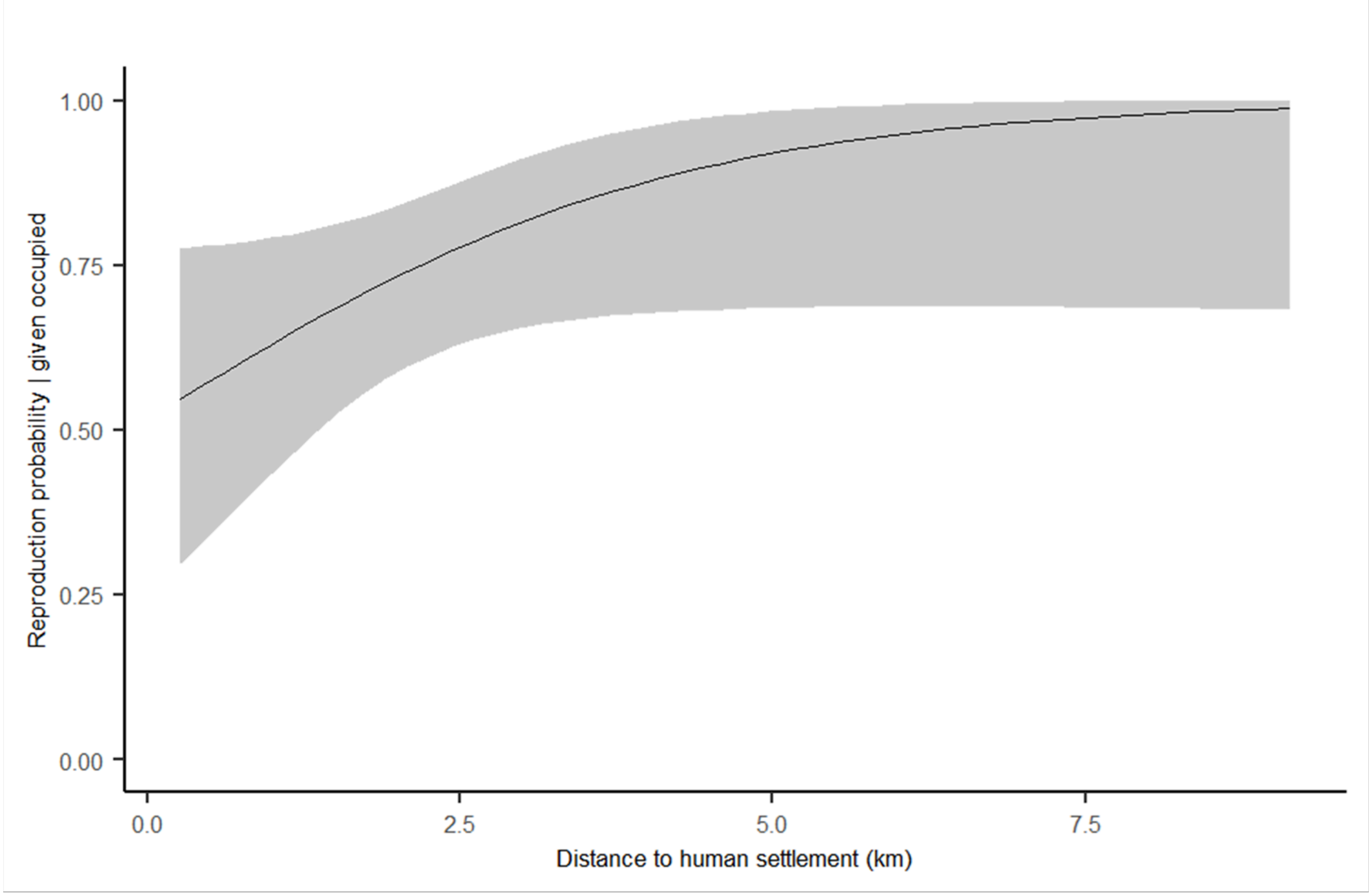

Figure 4

The probability of a reproductive Togean babirusa being present, given the area was occupied, predicted from the top-ranked single-season multistate occupancy model. The probability increased with the distance to human settlement. The grey ribbon indicates the 95% confidence interval.

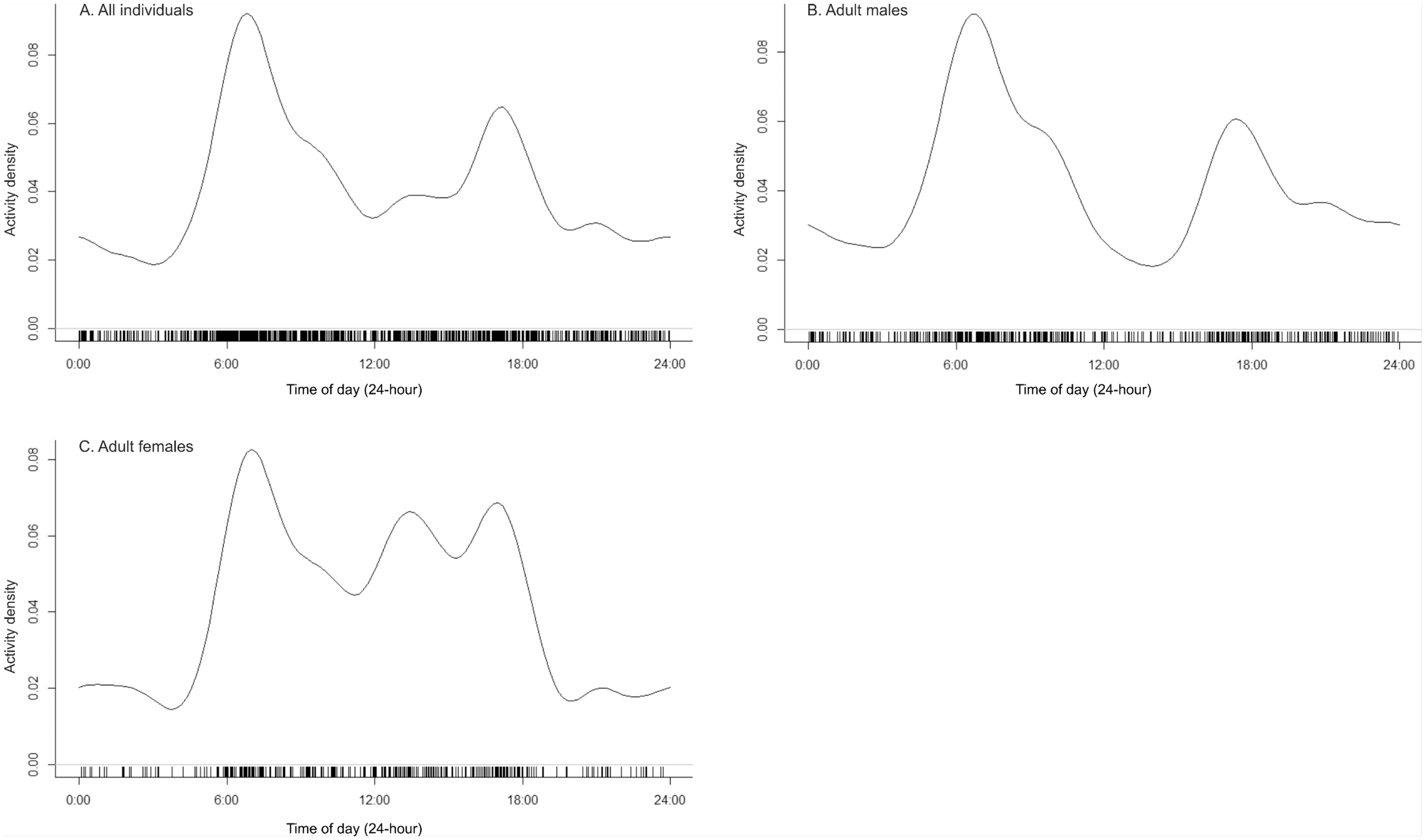

Figure 5

Kernel density curves of the Togean babirusa's activity patterns, showing all individuals (panel A; 792 observations), adult males (panel B; 469 observations), and adult females (panel C; 314 observations). X-axes show time of day in 24-hour format and Y-axes show activity density. Small tick marks along the X-axes indicate the data (observation time) used to estimate the activity patterns.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- OryxJatietalSupplementary.docx
- Tables.docx