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Baseline Diurnal Activity and Seasonal Patterns of the Critically Endangered Tamaraw (*Bubalus mindorensis* Heude 1888) and Co-occurring Mammals in a Strict Protection Zone

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ABSTRACT. – Mammal activities are influenced by temperature and foraging opportunities particularly in the tropics which highlights the importance of understanding diel patterns and seasonal variations for evidence-based conservation. However, in the Philippines, behavioral studies on mammals remain scarce particularly for the critically endangered tamaraw *Bubalus mindorensis* (Heude, 1888). Hence, a targeted camera trap survey was conducted in the Tamaraw Strict Protection Zone of Mts. Iglit-Baco Natural Park to provide baseline information for the species. From the survey, a total of five medium-large sized mammal species (*B. mindorensis, Sus oliveri* Groves, 1997*, Rusa marianna* [Desmarest, 1822]*, Macaca fascicularis* [Raffles, 1821], *Viverra tangalunga* (Gray, 1832) were captured across 3,556 camera trapping days from March 2016 to October 2018. Among the mammals, *B. mindorensis*, *R. marianna* and *M. fascicularis* were the most frequently detected species (>100). Among these, only *M. fascicularis* was observed to exhibit seasonal variations in detections ($p = 0.026$). Furthermore, observations reveal a predominantly diurnal pattern for the tamaraw, likely as foraging adaptations in a strictly protected habitat. These findings provide crucial baseline information for the conservation and monitoring of threatened Philippine mammals.

KEYWORDS: bovine, conservation, ethology, tropical ecosystem, protected area

INTRODUCTION

Mammals are known for their rapid response to varying environmental conditions, which ultimately determines their activity allocations throughout the day (Ohashi et al., 2013; Oberosler et al., 2017; Marques and Fabian, 2018; Ikeda et al., 2021). The activity patterns of tropical mammals, in particular, are shaped by body sizes and ecological processes such as thermos-regulation and foraging strategies (Vallejo-Vargas et al., 2022). As the species approach relatively bigger body size, they display higher thermal sensitivity, causing shifts of diel cycles in response to seasonal changes (Ogurtsov et al., 2018). Meanwhile, species-specific dynamics concerning habitat overlap force animals to adjust their temporal activity patterns to avoid niche overlap and enhance foraging opportunities while minimizing hunting pressure and predation risks (Gracanin et al., 2022; Yildiz and Uzun, 2024). These factors highlight the importance of the complex relationship between morphological traits, presence of threats, and ecological pressures in shaping mammalian diel activity. Understanding these dynamics is particularly relevant in the case of Philippine tamaraw (*Bubalus mindorensis*), an endemic bovid restricted to Mindoro Islands.

Historically, the tamaraw was widespread across the island, with an estimated population of 10,000 individuals (Harrison, 1969; Long et al., 2018). However, human-mediated deforestation and fragmentation of its natural habitats, exacerbated by anthropogenic hunting pressure and the rinderpest outbreak, led to a drastic population decrease (Long et al., 2018; Schütz et al., 2023) with an estimated global population of c. 150-200 individuals reported in 1971 (Kuehn, 1975a, 1975b, 1977; National Research Council, 1973). Subsequent protection and conservation efforts, principally the Tamaraw Conservation Program, a flagship initiative of the Department of Natural Resource (DENR), prevented this species' extinction. At present, its population is divided between three known sub-populations, one of which resides within a legally protected area (Schütz et al., 2023; Buebos-Esteve et al., 2024; Almadrones-Reyes et al., 2024) and is estimated at fewer than 500 individuals. The largest

sub-population is currently found within a strict protection zone of less than 3000 hectares in Mts. Iglit-Baco Natural Park (MIBNP), found at the south-central portion of Mindoro (Schütz et al., 2023). This small area also serves as the core zone of tamaraw monitoring, where annual censuses are conducted (Long et al., 2018; Schütz et al., 2023) alongside other studies that focus on the species' population (Bonenfant et al., 2023). However, despite the paramount importance of understanding diel patterns for wildlife conservation, current knowledge of tamaraw behaviour have focused on specific behavioral adaptations such as wallowing behavior and occurrence data (Bate et al., 2025; Tilker et al., 2026), while detailed daily behavioral observations were extrapolated only from captive individuals (Momongan and Walde, 1993).

Spatiotemporal activity patterns of mammals are important considerations for conservation. For the case of the known mammals in MIBNP, their spatial distribution and occurrence have been the focus in recent studies (Matsubayashi et al., 2010; Alviola et al., 2023; Schutz et al., 2023). Particularly, the less understood temporal scales must also be integrated in crafting conservation measures for ecologically important mammal species (Mariton et al., 2023). For example, the diel patterns of the endemic Cabrera vole (*Microtus cabrerae*) were investigated by Grácio et al., (2016), leading to important insights regarding habitat management and individual fitness of the species in its locality.

The study aims to describe the diel and seasonal patterns of the mammals that inhabit Mts. Iglit-Baco Natural Park using an exploratory camera trap survey. The findings of the study provide insights for understanding mammalian ecology in response to seasonal variations in a strictly protected habitat. Furthermore, this study aims to contribute to the baseline information for management and conservation of data deficient mammals in the Philippines, particularly the critically endangered Tamaraw.

MATERIALS AND METHODS

Study site

The study was conducted in Mts. Iglit-Baco Natural Park (MIBNP), a 105,655-hectare protected area situated in the south-central portion of Mindoro Island, Philippines (12°43' N 121°06' E) (Fig 1). The park is dominated by montane and bamboo forest, and grasslands where tamaraw censuses are annually conducted (Schütz et al., 2023; Redeña-Santos et al., 2024; Sobremonte-Maglipon et al., 2025). The MIBNP includes land within the ancestral domains of two ethnolinguistic tribes who co-inhabit with resident species such as the *B. mindorensis* and *Sus oliveri* Groves, 1997. In 2016, a 1,600-hectare agreed no-hunting zone, now referred to as the tamaraw strict protection zone (SPZ), was established upon the agreement of park managers and indigenous Taobuid people, within whose domain the area is situated. Yearly, the grasslands within the monitoring area are intentionally burned prior to the annual tamaraw counting to increase visibility, and to retain the tamaraws in a newly sprouted grassland, which they prefer to eat (Bonenfant et al., 2023)

The targeted camera trap survey was conducted at an activity-dense area within the SPZ (849 – 870 masl) of MIBNP (Fig 1A) where *B. mindorensis* sub-population is reported to occur (Bonenfant et al., 2023; Schütz et al., 2023). The cameras are spaced approximately 70-100 meters apart (Fig 1B), representing a gradient from open grassland (Fig 2C) to the forest-grassland ecotone (Fig 2B), a trail corridor (Fig 2D) and incorporating a known wallowing site (Fig 2A). The mountain experiences two prominent seasons: (1) Dry season which occurs from January – May, and (2) wet season, which occurs from June – December (De Alban, 2009).

Camera trap survey

The initial survey was conducted by the World Wide Fund for Nature Philippines (WWF-Phils) in collaboration with the Department of Environmental Resources of the Philippines - Tamaraw Conservation Program (DENR-TCP). Given the rarity of the species, the team opted to purposely survey the area with the largest known tamaraw subpopulation (Bonenfant et al., 2023; Schütz et al., 2023) that matches the prior records of park rangers and long-term monitoring data, in order to maximize the detections despite limited distribution. This aimed to provide preliminary behavioural descriptions of the tamaraw and gain insights to widen knowledge regarding its ecology for informed conservation measures of the species.

At each site, a single camera model was positioned to capture the activities of medium-large sized mammals. The Bushnell Trophy Cam HD Essential E2 operated from March 12, 2016 to July 30, 2017, recording the date and time. The Reconyx Ultrafire XR6, operated from August 1, 2017, to October 24, 2018, recording the date, time, and ambient temperature. Cameras were mounted on tree trunks, 1.5 meters above ground level and were maintained and retrieved monthly by the TCP and park rangers. Both cameras were set at high sensitivity, capturing three photographs at a 1-second interval per trigger. Each photograph was captured with an image size of 5 megapixels, and 640 x 480 image resolution.

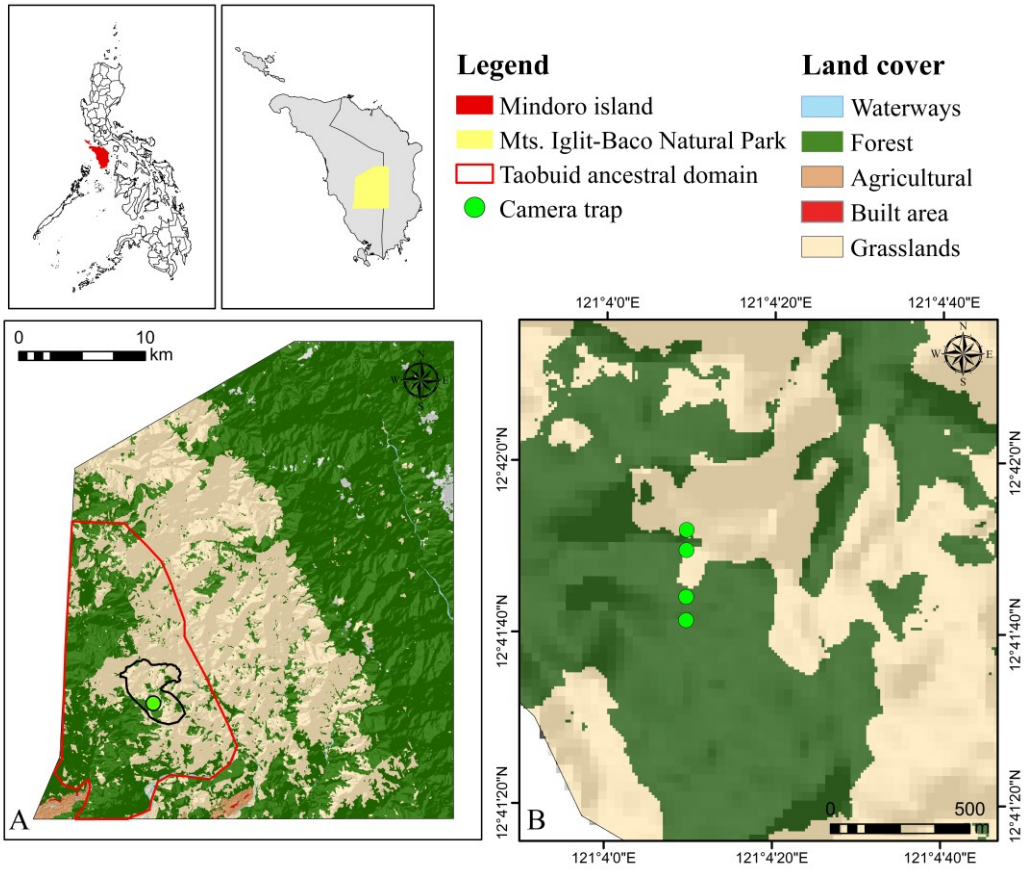


FIGURE 1. Study site map showing the land cover map of **A.** Mts. Iglit-Baco Natural Park, and **B.** the camera trap sites within the SPZ.

Photo organization and tagging

For this study, only the photograph capture feature of the camera traps was utilized; Hence, limiting behavioral observations to images but ensures consistency in detection data. Photographs captured were organized based on months using DigiKam ver. 8.4.0. Species identification was cross-checked with published biodiversity records of the mountain (Hernaez et al., 1999; Cebrian et al., 2014; Villegas et al., 2025) and diagnostic morphological descriptions to ensure accuracy while photographs were tagged with the corresponding species' name. The detection of the images was defined at a 30-minute interval, which serves as the effective image interval for most camera trapping studies involving medium-large sized mammals (Kelly and Holub, 2008; Peral et al., 2022; Leorna and Brinkman, 2024). This interval is estimated based on the time spent for each mammal activity before moving away from the detection radius of the camera, ensuring independent events are captured and also minimizes potential duplicate counts of individuals and behavior recorded. The function "*recordTable*" in the R package *camtrapR* (Niedballa et al., 2016) was used to extract the metadata including the timestamp, species, the average time for each event and the camera location.

Diel pattern categorization

To account for seasonal variation in day length, diel pattern categories were analyzed by anchoring observation times relative to solar events using local sunrise and sunset data using *suncalc* package (Thieurmel and Elmarhraoui, 2019). Crepuscular activity was classified as ± 1 hour window from sunrise and sunset respectively. Diurnal classification was defined as any detection occurring between the end of the morning crepuscular period and the start of the evening crepuscular period. Conversely, nocturnal activity was defined as all detections between the end of the evening crepuscular period and the start of the morning crepuscular period.

The diel activity of species where then categorized if majority of their activities fall within the time range of the classified diel pattern. Species that spend >50% of their activities during the day were classified as diurnal species, nocturnal if >50% of the detections were detected at night (González et al., 2025) and cathemeral if there is no clear distinction between diurnal or nocturnal activities.

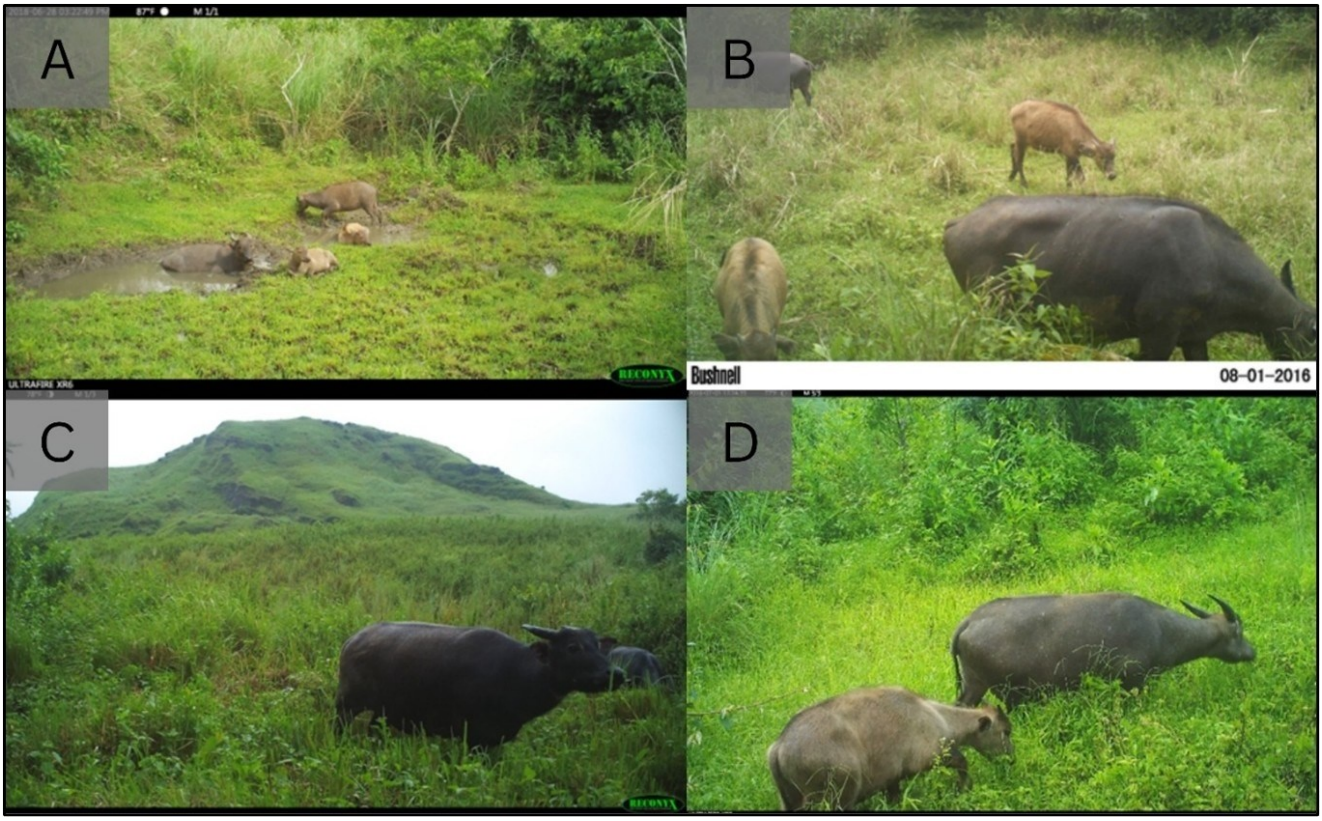


FIGURE 2. Camera trap placements at the SPZ of MIBNP showing **A.** wallowing site, **B.** forest-grassland boundary, **C.** open grassland, and **D.** the trail corridor. © WWF-Philippines

Data analysis

To test whether independent events (capture incidents) differ across seasons of species with sufficient seasonal detections, a Generalized Linear Model (GLM) with a log-link function using *MASS* package (Smith and Warren, 2019) was used because capture events represent discrete, non-negative count data that do not meet the assumptions of normal linear regression. To avoid spatial pseudo replication brought by the proximity of the camera trap placement, seasonal detections were pooled. The number of independent events per species were set as response variable.

Seasonal effects were set as the explanatory variable by pooling the detections from the dry season (Jan – May) and wet season (Jun – Dec). The dry season was specified as the reference category (coded as 0), while the wet season was coded as 1. The log transformed camera trap days was set as the offset term.

Model selection was based on the Akaike Information Criterion (AIC) (Popescu et al., 2014) by comparing candidate (including seasonal variable) and null models (intercept-only). A model was considered to have strong support if $\Delta AIC > 2$ (Burnham and Anderson, 2002). Furthermore, the most appropriate error distribution model was evaluated by comparing Poisson and Negative Binomial (NB) frameworks to account for overdispersion. Since all species displayed significant overdispersion, NB models were utilized to ensure robust parameter estimation.

For each independent detection, the time of day was converted into a fraction of the 24-hour day and then into radians ($0–2\pi$) to account for the circular nature of time and avoid discontinuities. Detections from the four cameras were pooled per species to avoid spatial pseudo-replication, habitat-induced bias, and ensures that the diel patterns reflected species-specific behaviours, instead of site-specific variations. Circular kernel density estimation was then performed using *ggplot2* (Wickham, 2016) with smoothing parameters adjusted (bandwidth = 1.5) to visualize the activity patterns across seasons Following the guidelines of Lashley et al. (2018) regarding minimum sample sizes for kernel density estimation, only the species with $n \geq 100$ were subsequently analysed.. The following R packages*: lubridate* (Grolemund and Wickham, 2011), *readr* (Wickham and Hester, 2023) *dplyr* and *tidyr* (Wickham et al., 2023a, 2023b) were utilized for data transformation. All analyses were carried out using R software version 4.4.1 (R Core Team, 2024).

TABLE 1. Summary of total photographic data and seasonal independent events of the species recorded.

	IUCN status	Endemicity	Total photos	Percentage of records (%)	# of independent events		
					Season		Total
					Dry	Wet	
Large size							
B. mindorensis	CR	ME	48,514	87.6	1125	1141	2,266
R. marianna	VU	PE	5,723	10.3	161	118	279
S. oliveri	VU	ME	397	0.7	32	24	56
Medium size							
M. fascicularis	EN	N	775	1.4	54	49	103
V. tangalunga	LC	N	6	0.01	0	2	2

CR – Critically Endangered; VU – Vulnerable; EN – Endangered; LC – Least Concern, ME – Mindoro endemic, PE – Philippine endemic, N- Native.

RESULTS

A total of 3,556 camera trap days resulted in the acquisition of 55,415 photographs of native mammals (Table 1) comprising five species: the Mindoro endemics tamaraw (*B. mindorensis*) and Mindoro Warty Pig (*S. oliveri*); the widespread endemic Philippine Deer (*Rusa marianna*)*;* the native Long-tailed macaque (*Macaca fascicularis*) and the Malay Civet (*Viverra tangalunga* Gray, 1832) which are widespread across Southeast Asia (Fig 3).

The majority (n = 2,266; 84%) of independent events were of *B. mindorensis*, followed by *R. marianna* with 279 (10%), *M. fascicularis* with 103 (4%), and *S. oliveri* with 56 (2%). *V. tangalunga* was detected in only six photographs during the survey, which is insufficient to define the species' events, therefore, was excluded from subsequent analysis.

Diel activity categorization of the mammals

Species with predominantly diurnal tendencies (>50% of their activities done during the day) were *B. mindorensis* and *M. fascicularis*, while *R. marianna* was predominantly nocturnal. *S. oliveri* is classified as cathemeral with no distinct diel pattern (Table 2). *V. tangalunga* was only detected at night, however, three independent events are insufficient to categorize the species as nocturnal.

Activity patterns of the *Bubalus mindorensis, Rusa marianna* and *Macaca fascicularis*

Among the three mammals, both *B. mindorensis* and *M. fascicularis* display predominantly diurnal pattern for both seasons (Fig 4). The *B. mindorensis* showed distinct peaks at 16:00 for both seasons, and another peak at 8:00 during the wet season. The *M. fascicularis* showed similar patterns for both seasons, where activities increase right after the dawn at around 8:00. The *R. marianna* displays similar nocturnal patterns for both seasons, peaking at around 1:00.

Seasonal variation in detection frequency of *B. mindorensis, R. marianna,* and *M. fascicularis*

The GLM analysis revealed no significant difference between wet and dry season detections for *B. mindorensis* (p =0.535) and *R. marianna* (p= 0.051) (Table 3). While *M. fascicularis* detections during the wet season significantly decreased compared to the dry season (β = -0.839, z = –2.228, p = 0.026.)

DISCUSSIONS

By monitoring a small population from the tamaraw strict protection zone of MIBNP, this long-term camera trap survey provided a site-specific temporal activity pattern descriptions of *B. mindorensis, R. marianna, M. fascicularis*, *S. oliveri* and *V. tangalunga*. Although the CT survey was specifically conducted to detect the tamaraw, it was also able to capture other elusive mammals which lack occurrence and behavioural data such as the Mindoro warty pig, Philippine deer, and Malay civet that co-inhabit with the tamaraw. In fact, camera trapping has emerged as an important non-invasive tool globally for documenting understudied mammals in countries where its utilization is still growing (Chen et al., 2022; Cordier et al., 2022; Tilker et al., 2026)

Seasonal and diel patterns of *B. mindorensis, R. marianna,* and *M. fascicularis*

B. mindorensis exhibited consistent diurnal patterns at the site. This contrasts recent observations (Alvarez, 1969; Boyles et al., 2016) stating that they are

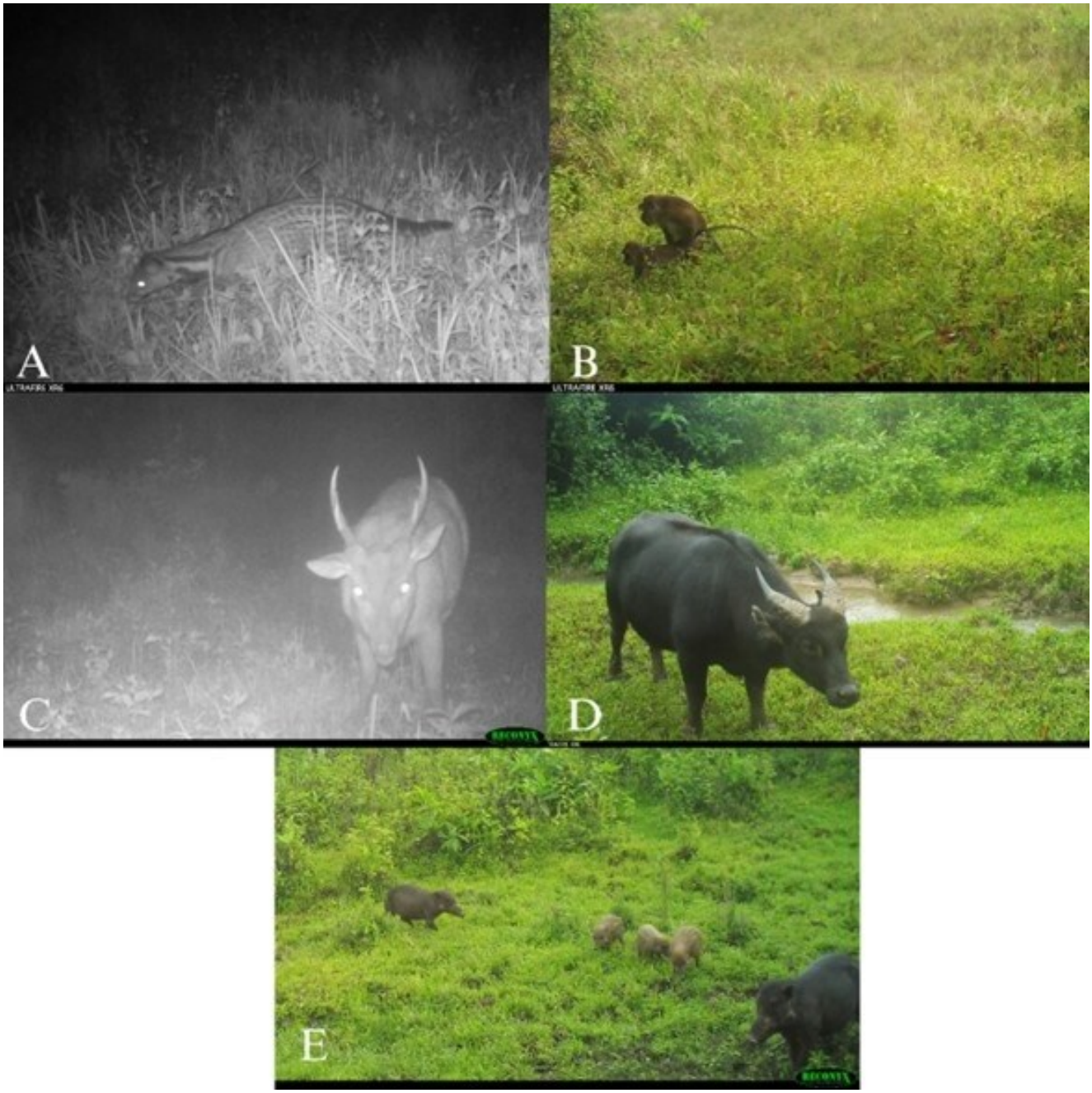


FIGURE 3. Captured photographs of **A.** a traversing *V. tangalunga*, **B.** mating *M. fascicularis*, **C.** foraging male *R. marianna,* **D.** a traversing male *B. mindorensis*, and **E.** a traversing family of *S. oliveri*, captured from different microhabitats within the study site. © WWF-Philippines

predominantly nocturnal circa 1990s due to the prevalence of human threats in the island. This observation likely reflects reduced daytime human interactions such as hunting and logging (Matsubayashi et al., 2010) due to the strict protection of the habitat. These findings are consistent with observations of captive tamaraw individuals (Momongan and Walde, 1993) and related species devoting most of the day actively feeding (Ryan and Jordaan, 2005; Megaze et al., 2018; Sahu et al., 2020). Furthermore, seasonal detections of the tamaraw did not differ significantly, which contrasts observations on related species such as the African buffalo *Syncerus caffer*, where seasonal differences across activity patterns are common (Ryan and Jordaan, 2005; Megaze et al., 2018; Roug et al., 2020). In the tamaraw's case, the seasonal stability of

TABLE 2. Diel activity of the recorded mammals counted from the independent events at the four habitat types.

Species	Percentage of records (%)			Predominant activity pattern
	Diurnal	Crepuscular	Nocturnal	
Large size				
Bubalus mindorensis	56.9	24.8	18.3	Diurnal
Rusa marianna	31.5	18.3	50.2	Nocturnal
Sus oliveri	41.1	32.1	26.8	Cathemeral
Medium size				
Macaca fascicularis	92.2	7.8	0	Diurnal

detections suggests that the SPZ provides high-quality and stable forage opportunities across seasons. This temporal consistency can also be attributed to the potential "source-sink dynamics" occurring at the SPZ (Bonenfant et al., 2023). As the camera traps were deployed at the "source" (high-quality core area), minimal behavioural variation were observed, suggesting that the optimal condition in this zone buffers seasonal stressors that might otherwise cause behavioural shifts in more marginal "sink" areas.

Both *R. marianna* and *M. fascicularis* followed well-documented temporal niches (Fig. 4). The deer showed expected strict nocturnal patterns (Villegas et al., 2022; 2025). While broader diel patterns are established, detailed activity pattern descriptions such as daily activity allocations and habitat utilization of the deer remain limited (Villegas et al., 2025), making direct comparisons with other populations difficult. Meanwhile, the macaque displayed expected strict diurnal patterns (Reyes et al., 2024). Related observations show varying seasonal activity patterns of *M. fascicularis* (Klegarth et al., 2016; Reinegger et al., 2023; Reyes et al., 2024). Studies report that that *M. fascicularis* tend to spend most of their day travelling/moving (Hansen et al., 2020; Reyes et al., 2024). Whereas wet-season observations has been associated with resting behavior, especially during heavy rains (Klegarth et al., 2016) reducing their overall daily movement. In our case, a significant seasonal variation is also shown by the *M. fascicularis* population. Lower independent event detections were observed during the wet season, which may have also been associated with decreased movement under cooler conditions brought by the rains (Hanya et al., 2018). In contrast, the increase in dry season independent event detections likely reflect increased foraging and movement at the grassland-ecotones in the SPZ. Perhaps, the decrease in forage quality under high temperatures likely prompts the macaques to seek resources on the ground, thereby increasing detectability.

V. tangalunga is a large viverrid species native to the Sundaic and Wallacea regions including the Philippines (Jennings et al., 2010), was also captured traversing at the forest grassland boundary during the night, which is the common for the species (Jennings et al., 2010; Solina et al 2018; Nakabayashi et al 2021). However, it was only captured for a total of three independent events and was not enough to generate a kernel density estimate of their activity patterns. Studies on this civet has primarily focused on its distribution and occurrence; therefore, warranting further investigation on their ecology and behavior (Marler et al., 2019; Fernandez et al., 2020; Castañeda et al., 2022)

Because a substantial portion of detections for the three species occurred at a specific microhabitat *e.g.* wallow site for the tamaraw, open grassland for the macaque the observed activity peaks may partly reflect specific habitat use preferences rather than their general behavior. The limited spatial replication per microhabitat should be considered when interpreting the temporal activity patterns.

Implications for wildlife conservation in MIBNP

Our findings provide important conservation and management insights in MIBNP. Most notably, a shift to diurnal patterns was observed for the tamaraw which serves as a biological indicator of conservation success. The results suggest that the heavily protected population of tamaraw in MIBNP have shifted to diurnal pattern following 50 years of stringent protection and targeted conservation efforts of the Philippine government (DENR-TCP) and various non-government organizations for the tamaraw.

The robust temporal activity profiles of the tamaraw also provide evidence-based law enforcements within the strict protection zone of MIBNP. Synchronizing patrol schedule with the identified activity peaks of the threatened mammals could enhance anti-poaching efforts. More specifically, tamaraw protection may be most effective during the day (16:00 and 8:00).

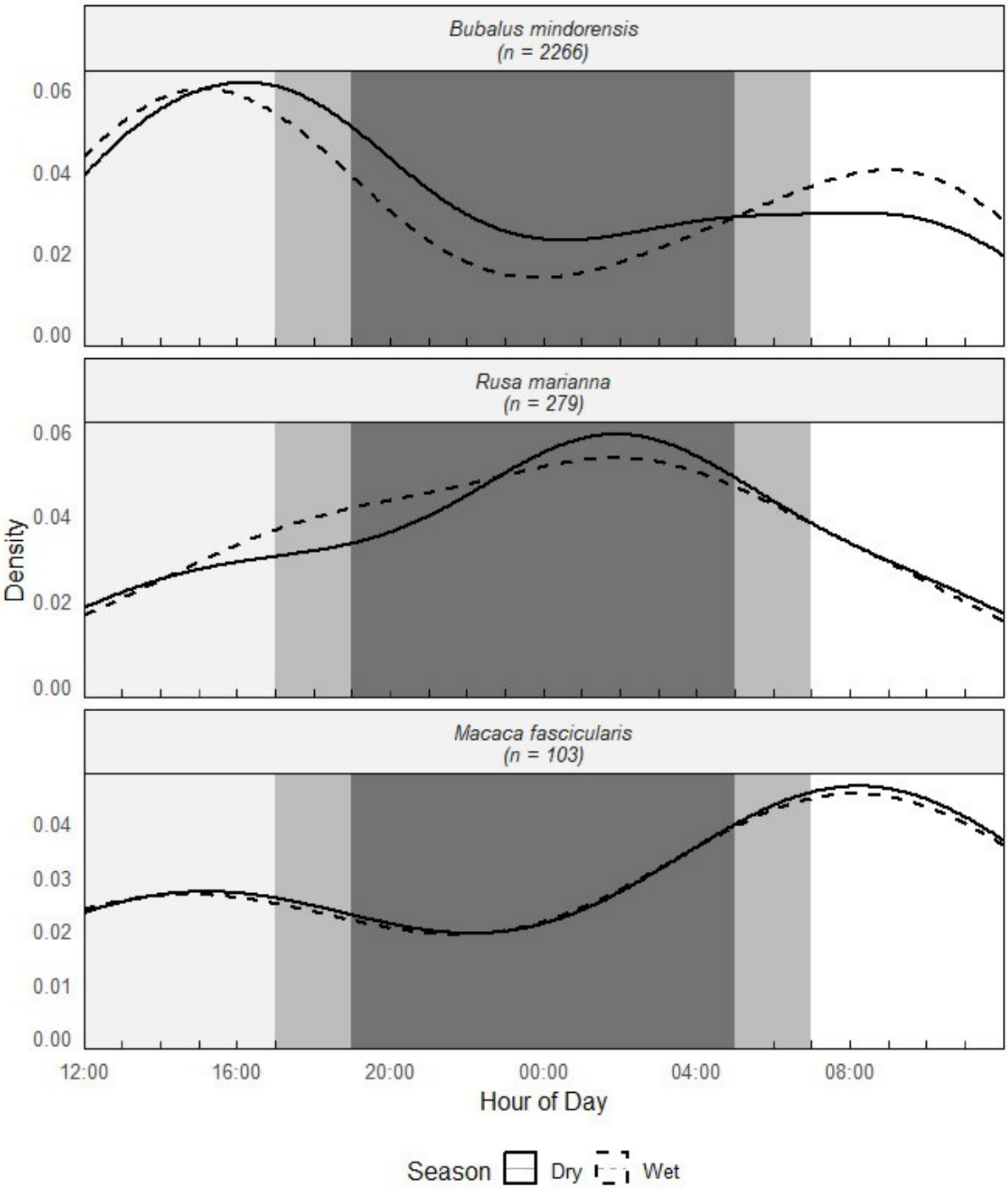


FIGURE 4. Kernel density estimation of activity patterns for *B. mindorensis, R. marianna,* and *M. fascicularis* using pooled independent events from wet and dry season across the three-year survey. Shaded regions represent the crepuscular (light grey) and nocturnal (dark grey) periods, calculated based on the average sunlight phases during the study period.

Finally, the potential reliance of some the ungulate species such as *B. mindorensis, S. oliveri,* and *R. marianna* on wallowing sites (Villegas et al., 2023; Bate et al., 2025) underscores climate change vulnerability. Given the region's susceptibility to drought (Perez et al., 2022) it is recommended to integrate microclimate tracking in the PA (Pettorelli et al., 2012; Rannow et al., 2014; Leclerc et al., 2020). Specifically, tracking the fluctuations in humidity and temperature because extreme heat events may

TABLE 3. Results of the Generalized Linear Models (GLM) using a Negative Binomial (NB) distribution with a log-link function to test the effect of season on the detection rates of *B. mindorensis, R. marianna,* and *M. fascicularis.*

Species	AIC (NB)	Δ AIC $_{null}$	Estimate (β)	z-value	P value
M. fascicularis	41.10	3.01	-0.839	-2.228	0.026*
R. marianna	57.56	2.32	-0.647	-1.947	0.051
B. mindorensis	87.04	0.38	-0.322	-0.620	0.535

β – estimate of the effect size. z – Wald z-statistic

detrimentally affect these ungulate species physiologically. Studies have shown that heat stress in related species reduces feeding efficiency as well as fertility issues, potentially hindering population growth in the site (Ross et al., 2015; Yadav et al., 2016; Napolitano et al., 2023; Felton et al., 2023).

Limitations, Recommendation, and Conclusion

Since the initial camera trap survey was targeted to observe *B. mindorensis* behavior, the size of the sampled area is limited to sites that are accessible from ranger stations. This constraint, combined with the vast region of uncharted areas, restricts the ability to assess and determine tamaraw populations on the island. Consequently, this study emphasizes the importance of comparison among populations in other sites for us to establish general temporal patterns of these mammals in Mindoro Island. Without such information, the findings of this study remain descriptive.

The limited sample size of the study underscores the need to conduct a comprehensive and intensive camera trap survey within the mountains of Mindoro Island where these animals are native to. The survey should integrate the study design with the objective to effectively capture animal behavior (Trolliet et al., 2014). These include increasing the number of sites observed, as well as the cameras deployed per site (Wong et al., 2019), and to utilize the video function of camera traps which also provide valuable behavioural insights (Scheibe et al., 2008). Furthermore, future monitoring efforts would greatly benefit from systematically integrating these camera trap surveys with direct observations and long-term monitoring data from park managers to cross-validate activity patterns. Importantly, maintaining the current conservation management of the SPZ to sustain ongoing monitoring efforts, as well as integrating temporal data from this study into the design and adaptive refinement of field protocols, will be vital for future conservation strategies for the inhabiting mammals. Moreover, the limited literature on certain endemic mammals such as *S. oliveri* and *R. Marianna,* reflects a broader gap for ecological research in the Philippines. This lack of baseline data, particularly regarding their behaviour, constrains comparative discussion but also highlights the contribution of this study by providing baseline diel and seasonal description of these species in the wild.

In conclusion, this study provides baseline data on temporal activity patterns of threatened mammals in Mts. Iglit-Baco Natural Park, captured from a targeted camera trap survey. While seasonal detections remained stable for the tamaraw, its daily activity pattern revealed a shift to diurnality, likely reflecting behavioural adaptation under stringent protection for several years. Despite constraints in spatial replication of our camera trap survey, our findings contribute behavioural insights regarding the seasonal and diel patterns of Philippines' rare endemic and native mammals.

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