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Dynamic Occupancy, Temporal Activity and Distribution Pattern of The Sulawesi Palm Civet (*Macrogalidia musschenbroekii*) in Bogani Nani Wartabone National Park

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Abstract. The Sulawesi Palm Civet (*Macrogalidia musschenbroekii*) is the only endemic carnivore on Sulawesi and a key mesopredator within Wallacean forest ecosystems. Despite its conservation significance, empirical information on its population dynamics and habitat associations remains limited. This study analyzes four consecutive years of camera-trap monitoring (2021–2024) in Bogani Nani Wartabone National Park to evaluate occupancy patterns, environmental drivers, and temporal activity. Using a Bayesian dynamic occupancy framework, we estimated annual occupancy (ψ), detection probability (p), colonization (γ), and local extinction (ε), while examining the influence of elevation, slope, and additional landscape covariates. A consistent sampling effort of 49–50 cameras per year yielded 3,446–4,047 trap nights annually, with low but stable detection rates. Occupancy declined markedly from 0.86 in 2021 to 0.51 in 2024. Elevation and slope emerged as the strongest predictors of occupancy, indicating a preference for mid-elevation forest habitats. Colonization (0.364–0.654) and extinction probabilities (0.286–0.587) exhibited high interannual variability, suggesting a metapopulation-like dynamic influenced by habitat fragmentation and environmental instability. Temporal activity analysis revealed predominantly nocturnal and crepuscular behavior, consistent across years. These findings provide the most comprehensive ecological assessment of sulawesi palm civet to date and highlight the species' sensitivity to habitat degradation. Long-term monitoring, protection of montane forest corridors, and community-based conservation programs are recommended to ensure long-term persistence.

Keywords: *Dynamic occupancy; sulawesi palm civet; activity pattern; colonization; local extention*

INTRODUCTION

Indonesia is a tropical archipelagic country recognized as one of the world's centers of megabiodiversity. Its complex geography supports at least 22 ecosystem types ranging from terrestrial to marine environments, which collectively sustain a high proportion of global species richness. Indonesia is home to approximately 9% of the world's flowering plants, 15% of mammals, 9% of reptiles, 6% of amphibians, 17% of bird species, and 9% of global freshwater fish diversity (Bappenas RI, 2024). This exceptional biodiversity is strongly shaped by island isolation and historical biogeographic processes, resulting in high levels of endemism across several regions.

Sulawesi Island represents one of the most distinctive biogeographic units in Indonesia. Situated within Wallacea, a transitional zone between the Indo-Malayan and Australasian faunal regions, Sulawesi is separated from surrounding landmasses by deep-sea barriers that historically limited species dispersal (Wallace, 1876). This isolation has led to remarkable mammalian endemism, with approximately 62% of the island's 127 mammal species being endemic (Whitten et al., 1987). Endemic ungulates such as the babirusa (*Babyrousa celebensis*) and anoa (*Bubalus depressicornis* and *Bubalus quarlesi*) exemplify the evolutionary uniqueness of Sulawesi's terrestrial fauna.

Unlike many other large tropical islands, Sulawesi lacks large-bodied carnivores. The Sulawesi palm civet (*Macrogalidia musschenbroekii*) is the only endemic carnivorous mammal on the island and functions as a key mesopredator within forest ecosystems. This species plays an important ecological role through regulation of small prey populations and potentially contributes to seed dispersal processes. Sulawesi palm civet is primarily associated with intact natural forests and is therefore considered an important indicator of forest ecosystem health. Together with other civet species present on Sulawesi, such as the Malay civet (*Viverra tangalunga*) and the common palm civet (*Paradoxurus hermaphroditus*), which is suspected to be introduced, the Sulawesi palm civet is widely distributed in forested areas with relatively low levels of disturbance (Weber, 1899).

One of the key habitats for this species is Bogani Nani Wartabone National Park (BNWNP) in northern Sulawesi. However, in recent decades, Sulawesi has experienced increasing pressures from deforestation, habitat fragmentation, agricultural expansion, and infrastructure development. These landscape changes have altered forest structure and connectivity, which are critical for forest-dependent species. Species with strong reliance on primary forests typically exhibit low tolerance to habitat modification and are therefore particularly vulnerable to population decline under conditions of landscape degradation. Given that Sulawesi palm civets are more frequently detected in densely forested areas with minimal human disturbance, ongoing land-use change poses a significant threat to their persistence.

Despite its ecological importance, scientific information on sulawesi palm civet remains extremely limited. Existing studies are largely restricted to presence records and basic morphological descriptions, while quantitative data on spatial distribution, temporal activity, and population dynamics are almost absent. This lack of systematic ecological data constrains accurate assessment of conservation status and limits the development of evidence-based conservation strategies. In recognition of these knowledge gaps, the Ministry of Environment and Forestry in 2021 designated the Sulawesi palm civet as a priority species and mandated population assessments within BNWNP.

Against this background, this study aims to quantify occupancy trends and spatial distribution of the Sulawesi palm civet as indicators of conservation area management effectiveness, map its distribution patterns within BNWNP, and analyze its temporal activity patterns. By integrating occupancy modeling, spatial analysis, and activity pattern assessment, this research provides essential baseline information to support adaptive and sustainable conservation planning for this endemic carnivore and Sulawesi's forest ecosystems more broadly

METHODS

This study was conducted in Bogani Nani Wartabone National Park (BNWNP), North Sulawesi Province, Indonesia, using a long-term camera-trap monitoring approach to assess the occupancy dynamics, spatial distribution, and temporal activity patterns of the Sulawesi palm civet (*Macrogalidia musschenbroekii*). The monitoring area comprised 50 permanent sampling grids, each measuring 2 × 2 km, distributed across Dumoga Barat and Dumoga Utara resorts (SPTN II), as well as Pinogaluman and Lolanan–Boroko resorts (SPTN III). The total study area covered approximately 44,964 ha, representing about 16% of the total area of BNWNP. The selected monitoring sites were designed to represent spatial variability in habitat suitability for key mammal species. Camera-trap deployment was conducted annually during comparable periods (June–October) from 2021 to 2024, while data analysis was carried out between August and November 2025.

The primary data sources included camera-trap records and environmental covariates. Environmental covariates consisted of both geographic and anthropogenic variables that potentially influence species occurrence. These included elevation and slope derived from DEMNAS, distances to forest edge, roads, settlements, and rivers obtained from national spatial datasets (RBI), precipitation data from CHIRPS (NASA), camera effort records, and distances to threat locations based on SMART Patrol data collected between 2021 and 2024. All covariates were extracted spatially using GIS tools and converted into raster format for further analysis. Camera-trap data comprised detection history and camera operation datasets stored in CSV format.

Camera trapping followed a systematic grid-based design arranged in a checkerboard pattern, with cameras placed alternately among grid cells. The grid size was selected based on estimates of home-range sizes of ecologically comparable species, such as wild boar (*Sus scrofa*, 2–4 km²) and Malay civet (*Viverra tangalunga*, 1–2 km²), to ensure adequate spatial independence among sampling units (Gaston et al., 2008; Jennings et al., 2010; Jetz et al., 2004; Tucker et al., 2014). Camera placement within each grid was optimized by targeting animal trails and areas showing frequent signs of use, such as footprints or feces. For *M. musschenbroekii*, cameras were installed at heights of approximately 50–60 cm above ground level. Each camera station followed a standardized operational sequence consisting of installation, routine checks for battery and data retrieval, and final removal. Cameras operated continuously for 90–100 days per year, with the total deployment period not exceeding six months to meet the assumption of population closure within each survey season (Williams et al., 2002).

Prior to modeling, all environmental covariates were standardized using the *scale()* function in R to ensure comparability across variables with different units. Multicollinearity among covariates was assessed using correlation analysis, with a threshold of $|r| \geq 0.7$ used to identify strongly correlated variables (Schober et al., 2018). This step was critical because multicollinearity can inflate parameter variance, reduce model stability, and bias ecological inference, particularly in occupancy modeling (MacKenzie, 2006b; Socolar et al., 2022). Correlation analysis and feature reduction were conducted using the *correlation* package in R (Makowski et al., 2020), while ecological relevance was also considered to ensure biologically meaningful covariate selection.

Camera-trap data management was performed using the *camtrapR* package in R (Niedballa et al., 2015). Photographs were organized following a standardized directory structure, and metadata tables including station, camera operation, and species reference tables were compiled. Independent detection events were defined using a minimum time interval of 30 minutes to avoid repeated counts of the same individual (O’Brien et al., 2003). Detection histories were generated using predefined sampling occasions, accounting for camera downtime to prevent false absences. This structured workflow ensured data integrity and reproducibility (Burton et al., 2015; O'Connell et al., 2011; Rovero et al., 2014).

Dynamic occupancy analysis was conducted using Bayesian hierarchical multi-season occupancy models implemented in JAGS via the *jagsUI* package in R. This approach explicitly separates ecological processes (true occupancy) from observation processes (imperfect detection), which is particularly important for cryptic and arboreal carnivores such as the Sulawesi palm civet. The model estimated initial occupancy (ψ), colonization (γ), local extinction (ε), and detection probability (p), all assigned non-informative uniform priors. Temporal changes in these parameters and the effects of selected covariates were evaluated with 95% credible intervals. This framework aligns with metapopulation theory and matrix population models, allowing inference on site turnover and persistence dynamics (Caswell, 2001; MacKenzie, 2006b).

Finally, temporal activity patterns were analyzed using the *activity* package in R, applying kernel density estimation to camera-trap timestamps converted into circular (radian) data (Marcus Rowcliffe, 2014). This analysis produced activity density curves that describe daily activity rhythms of sulawesi palm civet, providing insights into behavioral adaptations relevant for conservation planning.

RESULTS

Camera Trap Survey

Camera trap surveys conducted continuously over four years (2021–2024) in Bogani Nani Wartabone National Park (BNWNP) provide a comprehensive overview of the presence and activity of the sulawesi palm civet (**Figure 1**). Survey effort remained highly consistent across years, with 49–50 active camera stations annually and total camera-trap days ranging from 3,446 to 4,047 (**Table 1**). Such consistency is essential to ensure that interannual variation in detections reflects ecological dynamics rather than differences in sampling intensity (O'Connell et al., 2011; Rovero et al., 2014).

Figure 1. Photos of Sulawesi palm civet from camera traps

The number of photographs capturing sulawesi palm civet showed a gradual decline over the study period, decreasing from 46 records in 2021 to 33 records in 2024. Despite this decline, the species was detected in every survey year, indicating continued occupancy within the study landscape. This pattern aligns with known characteristics of small tropical carnivores, which typically exhibit low detection rates due to cryptic behavior, low population densities, and predominantly nocturnal activity (Burton et al., 2015; Steenweg et al., 2017).

Table 1. Camera trap survey summary

Year	Total Number of Active Days	Active Camera	Number of Photos	Number of Photos of Sulawesi Palm Civet
2021	3769	49	1284	46
2022	3523	50	1072	38
2023	4047	49	1158	37
2024	3446	50	830	33

The proportion of Sulawesi Civet photographs relative to total wildlife images remained consistently low (<5% annually), reinforcing the importance of analytical approaches that explicitly account for imperfect detection. Raw camera trap detections alone may underestimate true presence, particularly for arboreal or semi-arboreal carnivores such as sulawesi palm civet (Guillera-Arroita, 2017; MacKenzie, 2006b). Consequently, these survey results provide a necessary empirical foundation for occupancy modeling rather than serving as direct indicators of abundance or population size.

Overall, the four-year camera trap dataset demonstrates stable survey effort, persistent species presence, and a gradual decline in detections that warrants further investigation through dynamic occupancy analyses to distinguish between true population change and variation in detectability.

Multicollinearity Assessment of Environmental Covariates

Prior to occupancy modeling, multicollinearity among environmental covariates was assessed to ensure robust parameter estimation. High correlation among predictors can inflate standard errors, obscure ecological interpretation, and reduce model stability (Dormann et al., 2013). Covariates evaluated included elevation, slope, distance to forest, distance to roads, distance to rivers, and distance to settlements.

Correlation analysis revealed strong collinearity between distance to roads and distance to settlements ($r = 0.97$) (**Figure 2**), as well as between distance to roads and distance to forest ($r = 0.83$). Such high correlations indicate redundant information and pose a risk of unstable parameter estimates if retained simultaneously in the model (Zuur et al., 2010). In contrast, slope, elevation, and distance to rivers exhibited weak correlations with other variables ($r < 0.2$), suggesting that these covariates provide independent ecological information (Kutner, 2005).

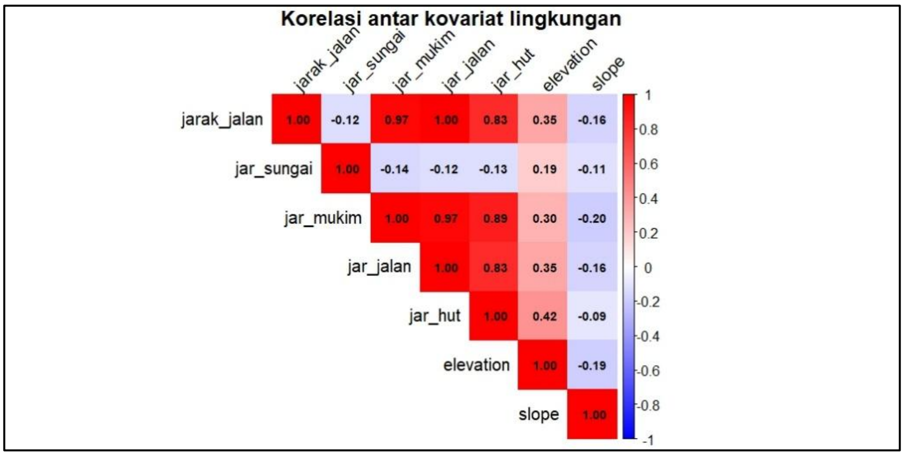

Figure 2. Results of covariate multicollinearity analysis

Given the sensitivity of dynamic occupancy parameters occupancy (ψ), colonization (γ), and local extinction (ε) to covariate structure, only ecologically meaningful and statistically independent predictors were retained. This approach follows best practices in occupancy modeling, emphasizing both statistical rigor and ecological relevance (Legendre & Legendre, 2012).

Dynamic Occupancy Modeling and Model Selection

Dynamic occupancy of the Sulawesi Civet was estimated using a Bayesian hierarchical multi-season occupancy framework implemented in JAGS via the jagsUI package (Kellner & Meredith, 2015). This approach explicitly separates the ecological process (true presence or absence) from the observation process (imperfect detection), making it particularly suitable for rare and cryptic carnivores (Dorazio & Royle, 2005).

Three parsimonious models were evaluated. Model 1 (null model) assumed constant occupancy and detection without covariates. Model 2 incorporated elevation and slope as site-level covariates influencing occupancy, with detection modeled as a function of year and camera effort. Model 3 represented a fully parameterized model including multiple environmental and anthropogenic covariates across all parameters (**Table 2**).

Table 2. Selection of dynamics occupancy models

Nama Model	Parameter	DIC	pD
Model 1 (Null)	ps1~1, p~1, col~1, eps~1	663.588	224.417
Model 2 (Site Cov)	psi~elevation+slope, p~year+effort, col~1, eps~1	602.44	149.012
Model 3 (Full)	psi~elevation+slope+jar_sungai, p~year+effort, col~ancaman+curah hujan, eps~ ancaman+curah	1127.2	625.81

Model comparison using Deviance Information Criterion (DIC) identified Model 2 as the most parsimonious and informative (DIC = 602.44), substantially outperforming both the null model and the fully parameterized model. Model 3 exhibited a very large effective number of parameters (pD = 625.81), indicating overfitting and poor identifiability (Spiegelhalter et al., 2002). These results highlight the importance of parsimony in ecological modeling, particularly when data are limited and detection probabilities are low (Burnham et al., 2010).

Temporal Dynamics of Occupancy, Colonization, and Extinction

Estimates from the best-supported model (Model 2) revealed a declining trend in occupancy probability over the four-year period. Occupancy was highest in 2021 ($\psi = 0.86$; CI: 0.76–0.96) and declined in 2022 ($\psi = 0.57$; CI: 0.42–0.78), followed by a more gradual decrease through 2024 ($\psi = 0.51$; CI: 0.36–0.70) (**Figure 3**). Such declines may reflect changes in habitat quality, increased anthropogenic pressure, or reduced population size, patterns commonly observed in small carnivores inhabiting fragmented tropical landscapes (Ngoprasert et al., 2012; Rovero & Zimmermann, 2016).

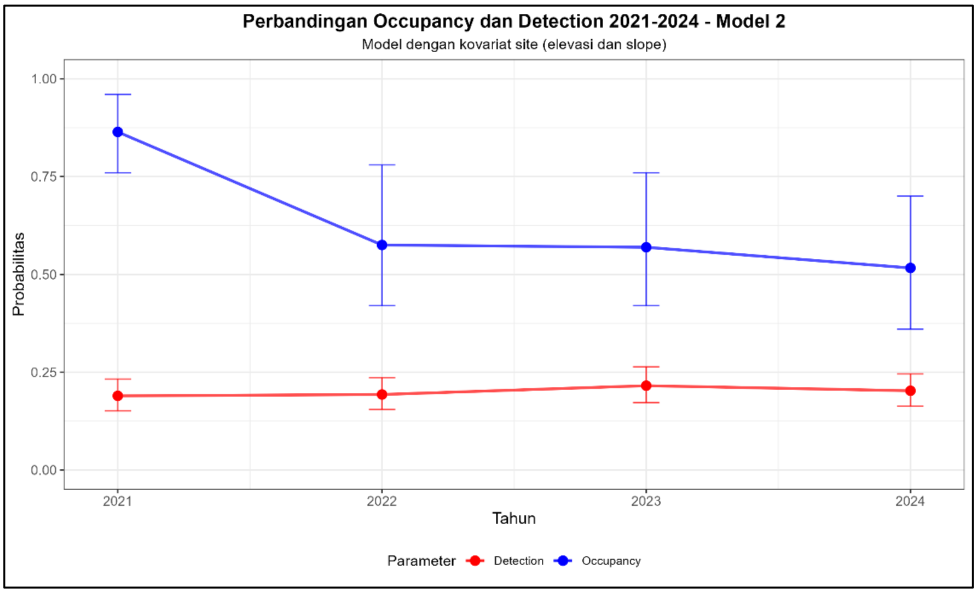

Figure 3. Occupancy trends and detection 2021-2024

Detection probability remained low to moderate throughout the study period, consistent with the species' nocturnal and semi-arboreal behavior. Low detection does not necessarily indicate rarity but underscores the importance of repeated surveys and explicit modeling of detection processes to avoid false absences (Guillera-Arroita, 2017; MacKenzie et al., 2002).

Colonization probabilities varied substantially among years. Moderate colonization was observed between 2021–2022 ($\gamma = 0.49$), followed by a decline in 2022–2023 ($\gamma = 0.36$) and a marked increase in 2023–2024 ($\gamma = 0.65$) (**Figure 4**). These fluctuations suggest dynamic habitat use, potentially driven by local habitat recovery, shifting resource availability, or changes in connectivity (Kennedy et al., 2011; Cusack et al., 2015).

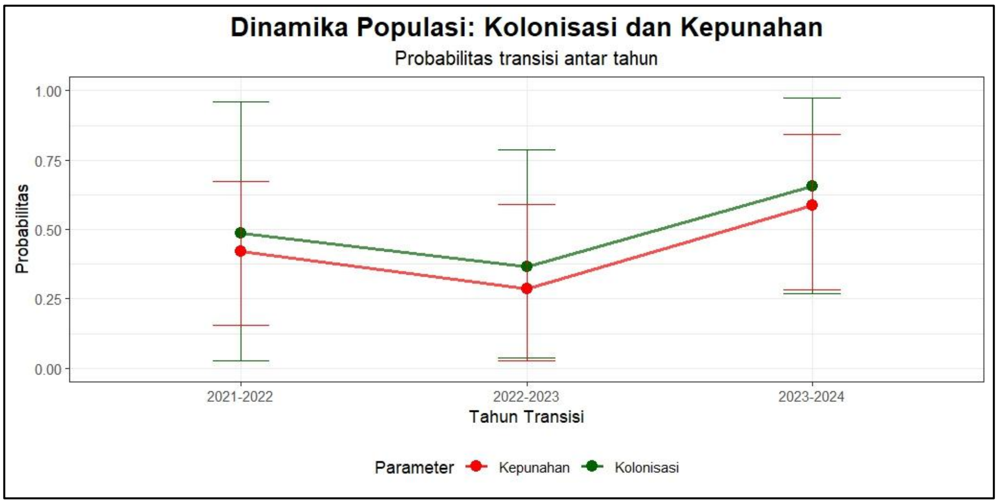

Figure 4. Colonization trends and epsilon 3 years of transition

Local extinction probabilities were also variable, with relatively high values in 2021–2022 (ε = 0.42), declining in 2022–2023 (ε = 0.29), and increasing sharply in 2023–2024 (ε = 0.59). The concurrent increase in both colonization and extinction during the final interval indicates high site turnover, a characteristic of species occupying heterogeneous and moderately disturbed landscapes (Bailey et al., 2014; Hanski, 1994).

Effects of Topography on Occupancy

Topographic variables emerged as key drivers of Sulawesi Civet occupancy. Elevation showed a strong positive effect, with an 88.6% posterior probability of a positive coefficient (**Figure 5**), indicating higher occupancy at mid-elevations. These zones in BNWNP are dominated by lower montane forests with dense canopy cover and reduced human disturbance, conditions favorable for small carnivores.

In contrast, slope exerted a strong negative influence on occupancy, with a 90.4% probability of a negative effect. Steep terrain likely limits movement and foraging efficiency for semi-arboreal civets and may be associated with less stable substrates and lower prey availability. Similar patterns have been reported for small carnivores in mountainous tropical systems (Kalle et al., 2013; Singh et al., 2022).

Collectively, these results indicate that optimal habitat for the Sulawesi Civet in BNWNP consists of mid-elevation areas with gentle to moderate slopes, emphasizing the importance of topographic heterogeneity in shaping species distributions.

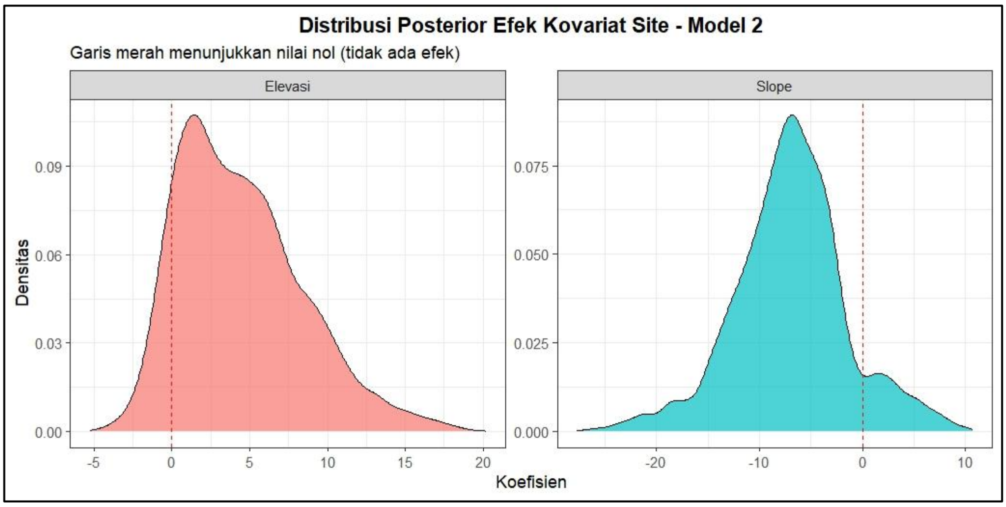

Figure 5. Effect of elevation and slope covariates on occupancy

Spatial Distribution Patterns

Spatial projections of occupancy revealed a persistent core area of high occupancy in the central portion of BNWNP across all years. This area likely functions as an ecological refugium, supporting stable populations and serving as a source for surrounding habitats (Laurance et al., 2011). In contrast, areas with moderate occupancy along the park periphery showed progressive contraction from 2021 to 2024, indicating declining habitat suitability or increased edge effects (**Figure 6**).

Temporary expansion of moderate-occupancy areas in 2023 suggests short-term colonization, potentially driven by localized habitat regeneration. However, the subsequent contraction in 2024 indicates that such gains were not sustained, consistent with the species' narrow ecological niche and sensitivity to microhabitat disturbance (MacKenzie, 2006).

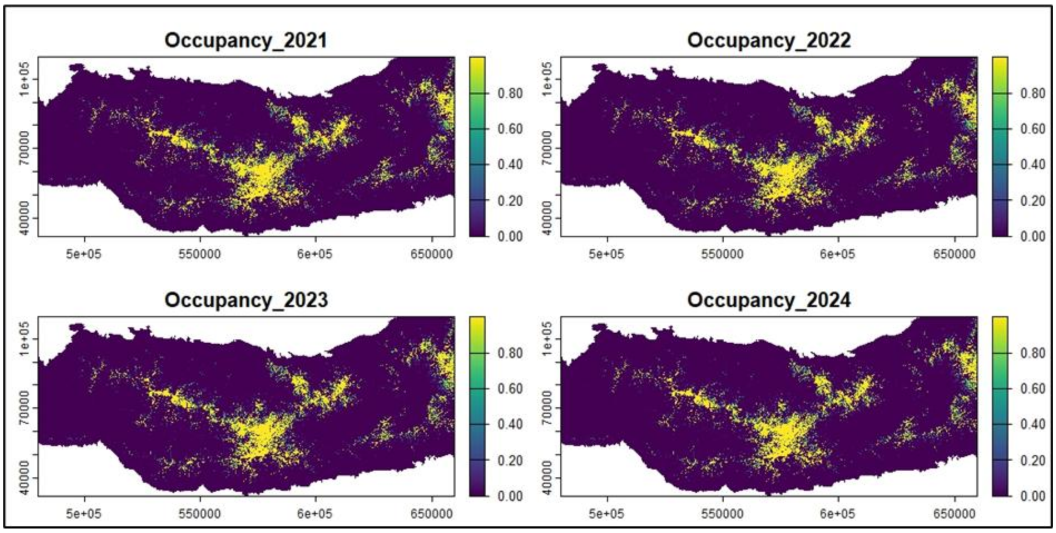

Figure 6. Sulawesi palm civet distribution pattern in 2021-2024

Temporal Activity Patterns

Activity pattern analysis demonstrated that the Sulawesi Civet maintains a consistently nocturnal and bimodal activity pattern, with peaks during early night

(19:00–22:00) and pre-dawn hours (02:00–04:00) (**Figure 7**). Kernel density curves were highly similar across all four years, and statistical testing (Kruskal–Wallis: p = 0.651) confirmed no significant interannual differences.

This temporal stability suggests minimal behavioral disruption and aligns with known activity patterns of viverrids in tropical forests (Ramesh et al., 2012; Veron, 2001). Consistent activity rhythms further imply that, despite spatial and occupancy changes, core ecological conditions within BNWNP remain sufficient to support the species' natural behavior.

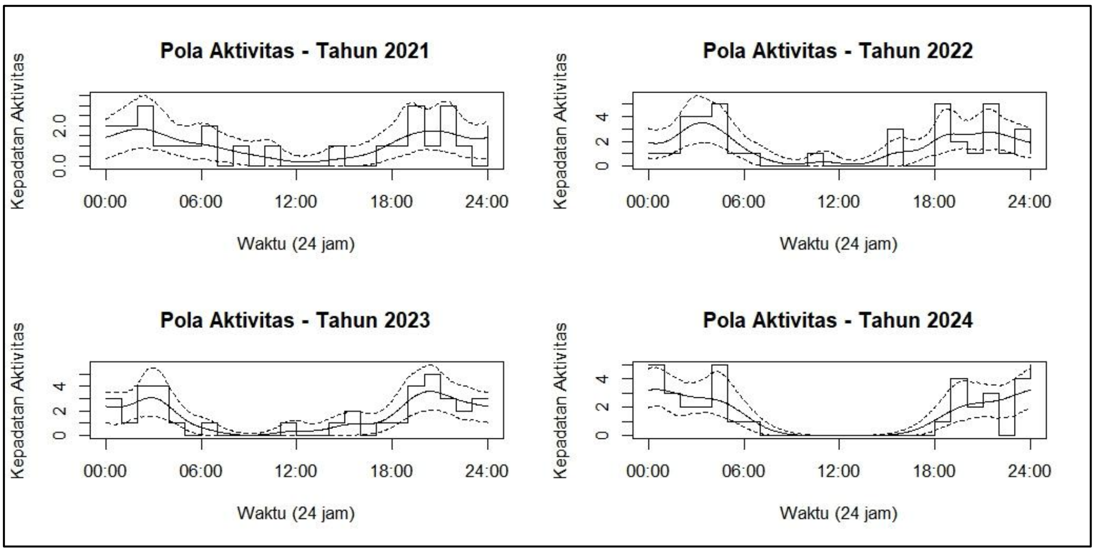

Figure 7. Temporal activity patterns of the Sulawesi palm civet 2021-2024

CONCLUSION

This study demonstrates that the Sulawesi Civet (*Macrogalidia musschenbroekii*) remains present within Bogani Nani Wartabone National Park (BNWNP), but has experienced a marked decline in occupancy between 2021 and 2024. Estimated occupancy probability decreased from 0.86 to 0.51, indicating increasing pressure on the species, potentially driven by habitat changes, anthropogenic disturbance, or other ecological factors. Occupancy was strongly influenced by environmental variables, with elevation and slope emerging as the most important determinants. The species showed a clear preference for mid-elevation areas and avoided steep slopes, reflecting dependence on lower montane forests with stable vegetation structure. Spatially, suitable habitat became increasingly concentrated in the central zone of TNBNW, while moderately suitable peripheral areas progressively contracted, suggesting habitat degradation and increasing isolation of habitat patches.

Dynamic occupancy analysis revealed substantial interannual variation in colonization and local extinction probabilities, indicating a high-turnover population dynamic typical of flexible space-use strategies in fragmented landscapes. Although colonization probability increased during the 2023–2024 period, this was accompanied by a simultaneous rise in local extinction, highlighting instability in newly occupied sites. In contrast, temporal activity patterns remained consistently nocturnal with a bimodal structure and showed no significant changes across years, suggesting behavioral stability despite declining occupancy. Detection probability was relatively low, consistent with the arboreal and nocturnal ecology of the species, underscoring the importance of hierarchical occupancy models to account for imperfect detection. Overall, these findings emphasize the need to maintain high-quality core habitats and enhance landscape connectivity within BNWNP to support the long-term persistence of this endemic carnivore.

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