

Research Article



Unveiling Population Density and Distribution of Sun Bear using Unmarked Spatial Capture-Recapture and Occupancy Modeling in Bukit Barisan National Park, Indonesia

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ARTICLE INFO

Article history:

Received September 4, 2025

Received in revised form February 28, 2026

Accepted May 18, 2026

Available Online May 20, 2026

KEYWORDS:

Helarctos malayanus,
occupancy modeling,
population size,
protected areas,
species conservation,
wildlife management



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ABSTRACT

Sun bear (*Helarctos malayanus*), the smallest bear species, is increasingly threatened in their Southeast Asian range. Despite their globally vulnerable status, studies on their density remain limited, particularly in Indonesia. This study aims to estimate sun bear density and occupancy in the Intensive Protection Zone of Bukit Barisan Selatan National Park using camera-trap data collected between 2015 and 2022. Due to the inability to reliably identify individual bears from their markings, we employed an unmarked Spatial Capture-Recapture (SCR) approach within a Bayesian framework to estimate density. We found that sun bear density was estimated to be 9.0 individuals/100 km² (95% CI = 4.5–16.7) in 2015, 5.5 individuals/100 km² (95% CI = 2.3–10.8) in 2019, and 9.0 individuals/100 km² (95% CI = 3.8–16.7) in 2022. The occupancy of sun bears was estimated to be 0.62 in 2015, 0.82 in 2019, and 0.66 in 2022. These results highlight the effectiveness of the unmarked SCR approach for unmarked species and provide essential baseline data for long-term monitoring. The findings emphasize the importance of continued protection and habitat management within the remaining protected area in southern Sumatra to safeguard this vulnerable species.

1. Introduction

Estimating the population density of terrestrial mammal species is fundamental to ecological research and conservation, providing critical insights into species status, guiding conservation priorities, and assessing the effectiveness of habitat management (O'Grady *et al.* 2004; Chandler & Royle 2013; Nazeri *et al.* 2014; Santini *et al.* 2024). Asian bear populations are at risk of extinction, making effective monitoring essential (Morin *et al.* 2022). Sun bear (*Helarctos malayanus*), the smallest bear species, inhabits the tropical forests of Southeast

Asia and, in Indonesia, is found on the islands of Borneo and Sumatra (Tumbelaka & Fredriksson 2006).

Categorized as Vulnerable on the IUCN Red List (Scotson *et al.* 2017) throughout their distribution, sun bears are threatened by habitat degradation and loss, conflict with humans, poaching for body parts, the pet trade, and accidental capture in traps meant for other animals (Crudge *et al.* 2019). Despite these challenges, Bukit Barisan Selatan National Park (BBSNP) in South Sumatra remains a crucial sanctuary for the species in Sumatra (Weiskopf *et al.* 2019).

Although numerous camera trap studies have been conducted on the sun bear (Te Wong *et al.* 2004; Linkie *et al.* 2007; Wong *et al.* 2013; Guharajan *et al.* 2018,

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2023; Tee *et al.* 2021), studies focused on estimating their density remain limited. Previous work in BBSNP has primarily utilized camera trap bycatch data to assess sun bear occupancy and activity patterns (Sibarani *et al.* 2024). To estimate sun bear density and update occupancy data within the park's Intensive Protection Zone (IPZ), this study uses a bycatch dataset from camera-trap surveys of Sumatran tigers (*Panthera tigris sumatrae*).

Camera-trap sampling designs differ depending on study objectives. Occupancy surveys typically position cameras to maximize detection probability (e.g., along trails or movement features), whereas density estimation using spatial capture–recapture (SCR) ideally requires trap placement that is spatially independent of expected animal activity. In this study, sun bears were recorded as bycatch from a camera-trap design originally implemented for tiger monitoring. We therefore acknowledge that the sampling framework was not explicitly optimized for sun bear density estimation, and we have taken this limitation into account when interpreting the results.

Individual identification of sun bear using camera traps has typically relied on the unique pale chest markings observed in some individuals, which have been used as natural marks in photographic capture–recapture and spatial capture–recapture studies (Ngoprasert *et al.* 2012). However, the applicability of this approach to sun bears is limited because chest markings are often faint, partially obscured, highly variable in visibility, or absent altogether, leading to a substantial proportion of unidentifiable individuals and increased misidentification risk (Ngoprasert *et al.* 2022; Proctor *et al.* 2022). These constraints reduce recapture certainty and can bias density estimates, making individual-based capture–recapture methods less reliable for sun bears than for species with more distinct and consistently visible natural markings. To address this, we apply an unmarked Spatial Capture–Recapture (SCR) approach, which estimates density by modeling spatial detection patterns across the camera trap array without needing individual recognition (Chandler & Royle 2013; Herliansyah *et al.* 2024). The SCR approach enables direct density estimation by assuming each individual has a spatially and randomly distributed activity center (Chandler & Royle 2013).

The aim of this study was to estimate the occupancy and density of sun bears within the Intensive Protection Zone (IPZ) of Bukit Barisan National Park (BBNSP). Specifically, this study sought to (1) determine the spatial distribution of sun bears across the IPZ using

occupancy modeling, and (2) generate density estimates using camera-trap data to support informed population monitoring and guide targeted conservation management within this protection area. To our knowledge, this is the first published study to apply spatial capture–recapture (SCR) modeling to estimate sun bear density. By incorporating the spatial configuration of detections and recaptures, SCR provides a more robust framework for density estimation than traditional non-spatial approaches, particularly for elusive and wide-ranging species.

2. Materials and Methods

2.1. Study Site

We conducted this study in the IPZ of BBSNP, southern Sumatra, approximately between 4°30'–5°45' S latitude and 103°30'–104°45' E longitude (Figure 1). BBSNP covers 355,511 ha, within which the IPZ covers 100,000 ha, and has an elevation range of 0–1,964 m. The IPZ was established as a priority area for the remaining populations of endangered species in BBSNP under Government Decree SK.152/IV-Set/2015. The Park comprises mangrove forests, coastal forests, tropical palm forests, and montane forests. Besides the sun bear, the area supports other endangered mammals, such as the Sumatran elephant (*Elephas maximus sumatranus*), the Sumatran rhinoceros (*Dicerorhinus sumatrensis*), the Malay tapir (*Tapirus indicus*), the Sumatran tiger, and the dhole (*Cuon alpinus*; Bukit Barisan National Park, 2019).

2.2. Data Collection

We used bycatch data from camera traps deployed in the IPZ in 2015, 2019, and 2022. A total of 130 cameras (Bushnell Trophy Cam (series 119876, 119875), Bushnell Core DS (119977C, 119977M), and Reconyx HC500) were installed in pairs within 65 3-by-3 grid cells, following tiger monitoring protocols (Surya *et al.* 2023). All grid cells were surveyed concurrently, and cameras remained active until 90 sampling days had been achieved at each station. Cameras were not rotated among subsets of grid cells during the survey period. Total grid coverage represented approximately ±59% of the IPZ area (100,000 ha or 1,000 km²). Cameras were positioned in pairs approximately 45 cm off the ground and 4–5 m apart perpendicular to the target path to maximize tiger identification (Surya *et al.* 2023). In this study, each grid-cell camera pair is considered a single sampling unit.

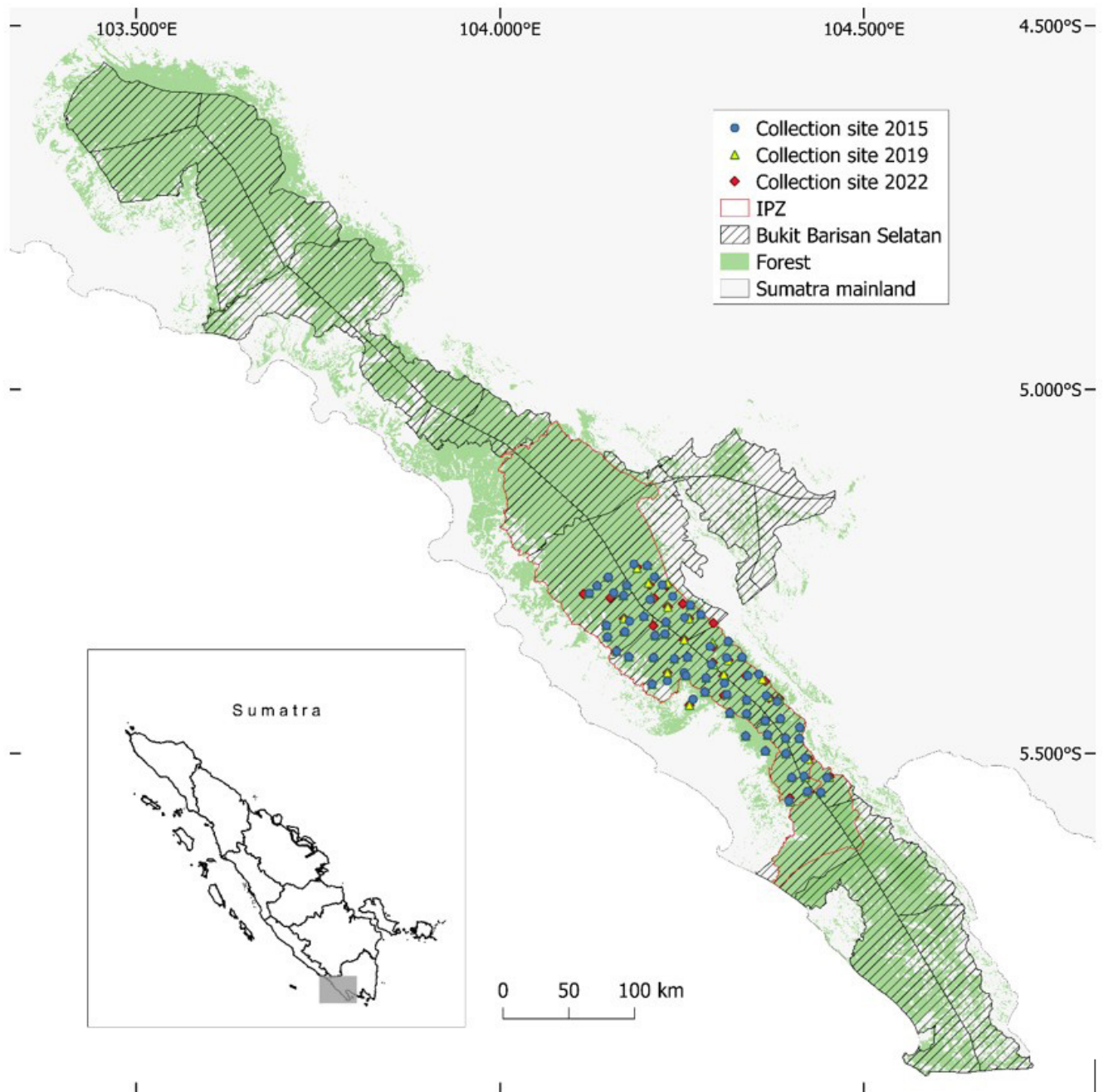


Figure 1. Camera trap locations in the Intensive Protection Zone of BBSNP. Sun bear data were obtained from three Sumatran tiger camera-trap surveys conducted in 2015, 2019, and 2022

Since camera trap placement followed a protocol designed to maximize the detection of large carnivores along movement features. Such placement may influence encounter rates relative to designs optimized for density estimation. We therefore acknowledge that some bias associated with trap placement cannot be entirely excluded. However, density was estimated using spatial

capture-recapture models that explicitly incorporate trap configuration and spatial recapture patterns, rather than relying solely on detection frequency. While these data were not collected under a design explicitly optimized for sun bears, applying SCR methods provides valuable baseline density information for a poorly studied population in Sumatra.

2.3. Unmarked SCR

We estimated sun bear density using the unmarked Spatial Capture-Recapture (SCR) approach, which enables direct density estimation by assuming each individual has a spatially and randomly distributed activity center (Chandler & Royle 2013). Although our 3×3 km is larger than the 1.5–2 km spacing used by Ngoprasert *et al.* (2012), it remains within the average of the reported annual home range of the sun bear in Borneo (14.8 ± 6.1 km²; Te Wong *et al.* 2004). Home range estimates were primarily derived from daytime telemetry data from other regions (e.g., Borneo) and may not fully represent space use in our study area. Camera trap spacing is a key determinant of detection probability and spatial dependence in density analyses (Morin *et al.* 2022). Based on the reported average home range diameter (~4.3 km), the 3 km spacing represents approximately 0.69 of the diameter and falls within recommended thresholds (>0.67 and <1.0 of the home range diameter; Fuller *et al.* 2022), ensuring that bear home ranges were unlikely to overlap no more than two camera trap locations. While uncertainty remains regarding local movement ecology, this spacing likely reduced excessive spatial overlap among neighboring stations while maintaining the potential for spatial recaptures.

The unmarked SCR model addresses two key sources of heterogeneity: differences in detection probability and spatial heterogeneity in individual distribution (Rahman *et al.* 2024). It assumes that the count of camera-trap detections over a given period follows a Poisson distribution, in which the average detection rate declines as the distance between the animal's activity center and the camera position increases (Herliansyah *et al.* 2024). Unlike traditional capture-recapture methods, this model enables density estimation using spatially structured count data without requiring individual identification. Parameter estimation is performed using the Markov Chain Monte Carlo (MCMC) algorithm in a Bayesian framework. The primary parameters estimated include δ (the spatial scale of individual movement), λ_0 (baseline detection probability), and N (population size), thereby enabling robust inference of density and spatial distribution.

The parameter σ reflects the scale of individual movement and is closely linked to home range size. Based on Te Wong *et al.* (2004), sun bear home ranges span 6–21 km², covering an estimated 95% of individual movements. Assuming a circular home range, the

movement radius of the sun bear is estimated between 1,381 and 2,585 m. Following Chandler & Royle (2013), we derived the σ range by dividing the radius by the square root of the 95% critical value of the chi-square distribution with 2 degrees of freedom (i.e., 5.99), yielding a σ range of 0.565–1.056 km (1 unit = 1,000 m). To incorporate this prior knowledge within the Bayesian framework, we used a Gamma (40, 44) distribution for σ , which aligns well with this range.

The prior distributions were chosen to reflect limited prior knowledge while ensuring model stability and interpretability. The baseline detection rate parameter (λ_0) was assigned a Uniform (0, 10) prior to allow a broad range of plausible values without imposing strong assumptions about detection intensity. This range is sufficiently broad to encompass detection rates ranging from low to relatively high under varying field conditions, while remaining bounded to avoid unrealistic parameter values and computational instability.

For the population size parameter (N), a non-informative Uniform prior was used to minimize the influence of prior beliefs on posterior estimates. This choice allows the data to primarily drive inference about population size, which is particularly important when prior information is scarce or when avoiding subjective bias in abundance estimation. Using a flat prior for N ensures that all plausible population sizes within the defined range are treated as equally likely a priori, supporting objective and data-driven estimation.

The unmarked SCR model requires three key components: trap location, detection data, and survey periods. Of 65 locations (each paired camera treated as a single sampling unit), 59 remained functional and provided usable data, while 6 units were lost/failed during the survey. The survey spanned 90 days, following the assumption of demographic closure as stated by Sibarani *et al.* (2024), given that the period is relatively short compared to the species' lifespan (the lifespan of sun bear is 10 years; Pacifici *et al.* 2013). This survey period was divided into 13 occasions, each representing one week of observation, resulting in 59 trap stations ($J = 59$) and 13 observation periods ($T = 13$). The analysis was performed using R version 4.4.1, utilizing a custom Bayesian algorithm available in the scripts "C template.R" (<https://bit.ly/C-template-R>) and "RJMCMC.R" (<https://bit.ly/RJMCMC-R>). The study area was defined as a spatial window using the `as.owin()` function. Model parameters (δ , λ , and N) were estimated using the `rjmcMIR()` function.

2.4. Occupancy Modeling

We employed multi-season occupancy modeling to assess the occupancy of sun bears during three surveys (2015, 2019, and 2022) in the Intensive Protection Zone. Data from the entire survey period (135–141 nights) were used (Table 1). One sampling occasion was two weeks of trap nights (Sibarani *et al.* 2024), as this duration is intended to increase the detection probability of the species.

In the multi-season occupancy modeling, we estimated four parameters: detection probability (p), occupancy probability (Ψ), colonization probability (γ), and extinction probability (ϵ). We modeled detection probability using canopy and understory vegetation as predictors, based on field measurements taken directly at grid cells by WCS-IP and BBSNP (unpublished data). Canopy and understory openness were assessed at each grid cell using visual percentage estimates. Canopy openness was recorded above the camera point, while understory openness was estimated within a fixed radius area around the camera, focusing on vegetation below 2 meters height. As for other parameters, we consider eight predictors: elevation, slope, enhanced vegetation index (EVI), distance to non-forest, distance to river, and distance to road. The NASA Shuttle Radar Topographic Mission (SRTM) digital elevation model, featuring a 90-meter resolution, was used to represent slope and elevation. We extracted EVI value based on the blue (BLUE), near infrared (NIR), and red (RED) reflectance values at grid cells in a cloud-free Landsat image composite (Hansen *et al.* 2013) for 2015, 2019, and 2022. EVI was computed with the formula $2.5 \times (NIR - RED) / ((NIR + 6 \times RED - 7.5 \times BLUE) + 1)$. For assessing the distance to non-forest areas and rivers, we used the BBSNP land use map and a 5 km buffer in 2015 and 2019 (2022 is not available) created by WCS-

IP and BBSNP based on Landsat imagery (unpubl. data). Types of land use other than forest were classified in a non-forest category, and river classification was based on a water body category. The road shp map, a modification of the road structure map from the Indonesian Geospatial Portal and road data from the patrol team created by WCS-IP, was used to calculate distances to the roads. The Euclidean distance from each pixel to non-forest areas, rivers, and roads was determined using the distance() function in the raster package in R 4.4.1 (Hijmans 2025). Before occupancy modeling, we tested for multicollinearity between predictors and excluded distance to forest with a coefficient >0.7 (Dormann *et al.* 2013), leaving seven predictors used in the analysis. We conducted occupancy modeling in four stages. In the first stage, occupancy, colonization, and extinction parameters were held constant [$\Psi(1)$, $\gamma(1)$, $\epsilon(1)$] by comparing two models for the detection parameter: constant detection [$p(1)$] and time-varying detection [$p(\text{year})$]. The best model, chosen according to the smallest AIC value (Portet 2020), was compared with three alternatives: detection influenced by canopy density [$p(\text{can})$], by understory vegetation [$p(\text{und})$], and by both factors combined [$p(\text{can} + \text{und})$]. In the second stage, seven models with combinations of three predictors were used to estimate occupancy parameters [$\Psi(\text{ele, slo, ndv})$], while retaining the best detection from stage 1 [$p(\text{year})$]. In the third stage, using the best model from stages 1 and 2, five additional model sets were used to estimate colonization parameters [$\gamma(\text{drd, drv})$]. In the final stage, the same five models were used to estimate the extinction parameters [$\epsilon(\text{drd, drv})$], while retaining the best model from the earlier stage. The best model, $\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$ (Table 2), was used to estimate sun bear occupancy in the IPZ of BBSNP across the three survey periods.

Table 1. Summary of unmarked SCR model parameter estimates

Survey period	Parameter	Estimates	CI (95%)
2015	δ	0.80	0.56–1.10
	λ_0	0.28	0.13–0.55
	N (ind)	90.97	46–167
	D (ind./100 km ²)	9.0	4.5–16.7
2019	δ	1.45	1.00–2.20
	λ_0	0.19	0.09–0.32
	N (ind)	55.77	24–109
	D (ind./100 km ²)	5.5	2.3–10.8
2022	δ	0.95	0.68–1.47
	λ_0	0.33	0.18–0.58
	N (ind)	89.80	38–167
	D (ind./100 km ²)	9.0	3.8–16.7

3. Results

3.1. Predicted Density of Sun Bear

Based on the results of unmarked SCR analysis using camera trap data, the estimated parameters of the sun bear population in the research area were acquired (Table 1): parameter estimates varied among survey periods, with density estimates of 9.0 ind./100 km² (95% CI: 4.5–16.7) in 2015, 5.5 ind./100 km² (95% CI: 2.3–10.8) in 2019, and 9.0 ind./100 km² (95% CI: 3.8–16.7) in 2022. Although the point estimate was lower in 2019, the 95% credible intervals overlapped across

Table 2. Sun bear detection based on camera trap survey IPZ of BBSNP

Variable	2015	2019	2022
Survey period	May–November 2015	May–November 2019	May–December 2022
Total number of trap nights (n)	8,808	9,184	7,970
Mean \pm SD trap nights per location	140 (26.0)	141 (16.3)	135 (26.4)
Elevation range (median)	164–962 m (525 m)	164–967 m (524 m)	164–985 m (527 m)
Camera trap type	Panthera	Bushnell and Reconyx	Bushnell and Reconyx
Number of sun bear photograph	261	1,882	2,145
Number of independent events	116	191	158
Number of grid cells	63	65	59
Number of locations with sun bear detections	36	52	38
Naïve occupancy	0.57	0.80	0.64

survey periods, indicating no firm evidence of temporal change in density.

3.2. Predicted Occupancy of Sun Bear

Across the three survey periods in the study area, there was a total of 25,962 trap nights, with 4,288 sun bear photos, that included 465 independent photos, defined as consecutive photographs within the same 3×3 km grid cells separated by a minimum interval of 30 minutes (Table 2). Naïve occupancy (occupancy without detection probability correction) was highest in the 2019 survey (0.80), followed by 2022 (0.64) and 2015 (0.57; Table 2). The best model, $\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$, consists of two covariates, survey period and understory openness for the detection parameter, while other parameters are held constant (Table 3). Based on this model, sun bear occupancy is estimated to be 0.62 (SE = 0.19) in 2015, increasing to 0.82 (SE = 0.06) in 2019, and diminishing to 0.66 (SE = 0.08) in 2022 (Figure 2).

4. Discussion

This study represents the first effort to assess the population density of sun bears in BBSNP, specifically within the Intensive Protection Zone, using camera trap data and a spatial capture–recapture framework. By contributing to the limited ecological knowledge of the species in this region, the study offers important insights for conservation management. SCR analyses conducted separately for each survey period showed that density estimates varied among years, with the lowest point estimate recorded in 2019; however, the 95% credible intervals overlapped across periods, indicating no firm evidence of temporal change in density. Such variation in point estimates was expected in spatial capture–recapture analyses. This difference was small relative to associated uncertainty and likely reflects variation in detection probability and spatial recapture

structure rather than actual demographic change (Efford 2004; Sollmann *et al.* 2012). Taken together, the results suggest relative stability in sun bear density within the study area over the seven years. Continued monitoring will nevertheless be essential to confirm long-term population trajectories (Lindenmayer & Likens 2010).

The density of sun bear in this study was inferred using an unmarked SCR model, revealing patterns that were higher (approximately 9.0 individuals per 100 km² in 2015 and 2022, 95% CI = 4.5–16.7 and CI = 3.8–16.7) than previous research in Khao Yai National Park, Thailand (4.3 – 8.0 individuals per 100 km²; Ngoprasert *et al.* 2012). This Thai study employed a photographic capture–recapture method based on identification of chest marks. While effective under certain conditions, the photographic approach is inherently limited by its reliance on clear, distinctive morphological features that are not always visible, thereby introducing potential bias and reducing the accuracy of density estimates. In contrast, the unmarked SCR method applied here eliminates the need for individual recognition by modeling spatial detection patterns to infer activity centers and population density, making it particularly suitable for cryptic species lacking consistent natural markings. Moreover, unmarked SCR accounts for imperfect detection and leverages spatial autocorrelation as an additional source of ecological information, providing a robust and scalable framework for estimating population parameters. Integrating partially marked and unmarked data could further improve estimation accuracy and reliability (Jimenez *et al.* 2019).

The connection between density and occupancy often demonstrates a positive intraspecific correlation, where an increase in abundance is typically associated with a greater ratio of occupied area by the species (Gaston *et al.* 2000). Our result suggests that the occupancy of sun bears in the IPZ during 2015–2022 remains stable compared to that of Sibarani *et al.* (2024), even though we delivered a different model to estimate the occupancy.

Table 3. Model selection for occupancy modeling of sun bear in the IPZ of BBSNP

Models ¹	Number of parameters	AIC ²	Δ AIC ³	R ²
Step 1: Best models for detection (p)				
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	6	1231.89	0.00	0.43
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{can} + \text{und})$	7	1233.88	1.98	0.43
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year})$	5	1234.04	2.14	0.39
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{can})$	6	1235.93	4.03	0.39
Null model	4	1259.99	28.09	0.00
Step 2: Best models for initial occupancy (Ψ)				
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	6	1231.89	0.00	0.43
$\Psi(\text{ele} + \text{evi} + \text{slo}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	9	1233.37	1.47	0.47
$\Psi(\text{evi}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	7	1233.37	1.47	0.44
$\Psi(\text{ele}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	7	1233.85	1.96	0.43
$\Psi(\text{ele} + \text{evi}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	8	1235.28	3.39	0.44
$\Psi(\text{ele} + \text{slo}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	8	1235.34	3.44	0.44
$\Psi(\text{slo}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	7	1239.45	7.55	0.37
$\Psi(\text{evi} + \text{slo}) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	8	1240.70	8.80	0.38
Null model	4	1259.99	28.09	0.00
Step 3: Best models for colonization (γ)				
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	6	1231.89	0.00	0.43
$\Psi(1) \gamma(\text{drd}) \epsilon(1) p(\text{year} + \text{und})$	7	1233.32	1.43	0.44
$\Psi(1) \gamma(\text{drv}) \epsilon(1) p(\text{year} + \text{und})$	7	1234.76	2.87	0.42
$\Psi(1) \gamma(\text{drd} + \text{drv}) \epsilon(1) p(\text{year} + \text{und})$	8	1236.64	4.74	0.42
Null model	4	1259.99	28.09	0.00
Step 4: Best models for extinction (ϵ)				
$\Psi(1) \gamma(1) \epsilon(1) p(\text{year} + \text{und})$	6	1231.89	0.00	0.43
$\Psi(1) \gamma(1) \epsilon(\text{drd}) p(\text{year} + \text{und})$	7	1232.91	1.02	0.44
$\Psi(1) \gamma(1) \epsilon(\text{drv}) p(\text{year} + \text{und})$	7	1233.85	1.95	0.43
$\Psi(1) \gamma(1) \epsilon(\text{drd} + \text{drv}) p(\text{year} + \text{und})$	8	1234.81	2.91	0.44
Null model	4	1259.99	28.09	0.00

¹can: canopy openness; und: understory openness; evi: enhanced vegetation index; ele: elevation; slo: slope; drd: distance to road; drv: distance to river

²Akaike information criterion

³Difference in Akaike information criterion between the fit of the best model and the fit of each subsequent ('less good') model

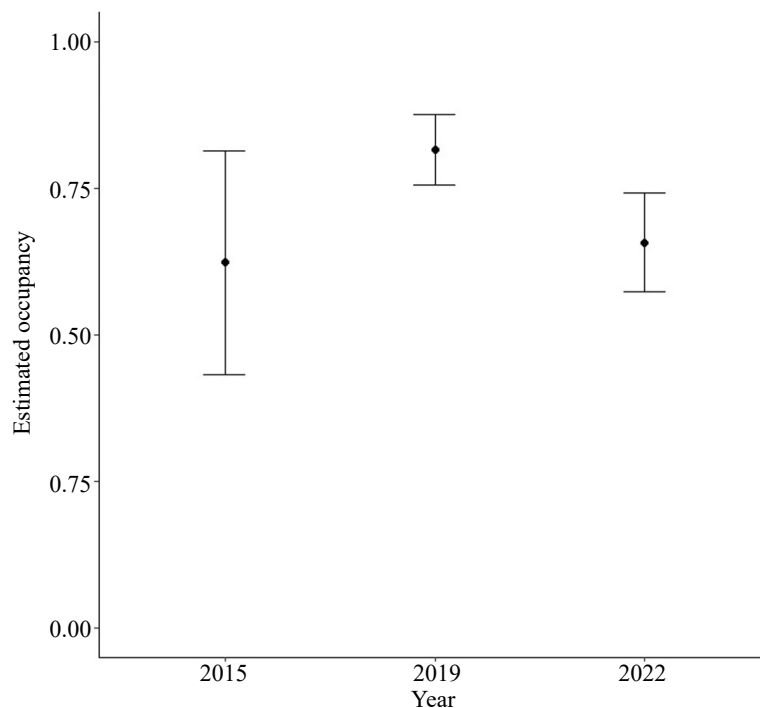


Figure 2. Estimated sun bear occupancy in the IPZ, BBSNP in 2015, 2019, and 2022 based on the best model (Table 2)

In our study, the best models were derived from data that included survey period and understorey openness as predictors of prediction probability.

Survey period (year) was included as a detection covariate to account for temporal variation in sampling conditions and effort. Differences among years likely reflect variation in environmental conditions, observer deployment, or changes in bear activity rather than true shifts in site use. The absence of strong year effects on occupancy suggests that spatial patterns of site use were relatively stable across survey periods, even where detection probability varied among years.

Sun bear are highly arboreal (Hwang *et al.* 2021). They regularly climb trees and select larger and denser canopies for feeding sites (Lee *et al.* 2019). In several studies across their range, Scotson *et al.* (2017) found that sun bear detection rates in camera-trap images (collected as bycatch) were positively correlated with the degree of canopy cover around the camera-trap sites. Canopy cover and understorey openness were partially collinear, in our study, understorey openness had a greater influence on detection probability. Cameras were placed along trails (approximately 45 cm above the ground) and relatively open areas to minimize obstruction, and detection was assumed to be driven primarily by sun bear movement rather than short-range limitations imposed by surrounding vegetation. However, some effect of the understorey on detection distance cannot be ruled out.

Despite the limitations, this study represents the first published application of spatial capture–recapture methods to estimate sun bear density. By incorporating the spatial structure of detections, SCR provides a rigorous framework for density estimation in elusive species and establishes a quantitative baseline for future monitoring efforts in Sumatra. These findings provide important guidance for conservation planning and long-term population monitoring within the protection area.

Acknowledgements

We thank the Balai Besar Taman Nasional Bukit Barisan Selatan for granting permission to conduct this study (SI.5/T.7/BIDTEK/KSA.1/2025). We express our sincere gratitude to the Wildlife Conservation Society–Indonesia Program (WCS-IP), especially Firdaus Rahman Affandi, for supporting our research, and to Fahrudin Surahmat for coordinating and maintaining the camera trap survey since 2015.

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