

Supplementary Materials

From co-occurrence to management: a compact workflow for umbrella species — Baluran National Park

Appendix S1 — Literature search protocol

Databases: Scopus; Google Scholar; GARUDA; Neliti. *Status and policy sources:* IUCN Red List; Baluran National Park management documents. *Timespan and language:* Up to 2024; English and Bahasa Indonesia. *Scope:* Medium- to large-bodied mammals detectable by camera traps in Baluran National Park.

Query structure (Boolean):

Base: [scientific OR common/vernacular synonyms] AND [topic terms] AND [Java OR Indonesia].

Examples:

Bos javanicus javanicus OR banteng AND (biology OR ecology OR home range OR wilayah jelajah OR range size OR movement) AND (Java OR Indonesia).

Panthera pardus melas OR "Javan leopard" OR "Macan tutul jawa" AND (biology OR ecology OR disturbance OR gangguan OR human activity OR aktivitas manusia) AND (Java OR Indonesia).

Synonyms used for other species included: dhole/ajag (*Cuon alpinus sumatrensis*), Javan rusa/rusa timor (*Rusa timorensis russa*), muntjac/kijang muncak (*Muntiacus muntjak muntjak*), wild boar/babi hutan (*Sus scrofa*), long-tailed macaque/monyet ekor panjang (*Macaca fascicularis fascicularis*), and Javan langur/ebony leaf monkey/lutung budeng (*Trachypithecus auratus*).

Inclusion/exclusion:

Include peer-reviewed empirical studies and reviews relevant to Java or, if unavailable, closely comparable Southeast Asian contexts.

Exclude captive, veterinary, or production studies unless they inform free-ranging ecology relevant to Baluran.

For C2 (natural history & ecology well-known), count unique peer-reviewed papers per species (deduplicate across databases).

For C3 (home-range), extract the largest reported home range (km²) and note estimator where stated.

For C6 (sensitivity), record direction and strength of responses to human pressure and classify as low, moderate, or high sensitivity (see Appendix S3).

For C5 (management needs that benefit co-occurring species), classify as Priority species, Management concern, or Limited management concern based on current park plans.

Screening and extraction:

Titles and abstracts were screened; full texts were checked. Extracted values and notes were logged in a spreadsheet. Final C2, C3, and C6 scores appear in Appendix S4.

Appendix S2 — Indicator definitions and scoring rules (C1–C7)

Seven indicators were used with equal weights and explicit mappings. C1 tertile thresholds for this dataset: Q1 = 3.1994 %, Q2 = 4.9107 % (tie-friendly: a value exactly equal to Q2 is assigned Score 2).

Code	Criterion	Operational Definition & Data Source	Scoring Rule (1–3)
C1	Species co-occurrence	Site-level co-occurrence across camera stations (park-wide, N = 56), summarized as mean O_{ij}/N across other mammals; companion hypergeometric check (R 'cooccur').	3: > 4.9107 % 2: > 3.1994 ≤ 4.9107 % 1: ≤ 3.1994 %
C2	Natural history & ecology well-known	Number of peer-reviewed papers for Java/analog systems.	3: ≥ 10 2: 6–9 1: ≤ 5
C3	Home-range size	Largest reported home-range (km ²) in Java/analog contexts.	3: > 5.56 2: > 2.44–≤ 5.56 1: ≤ 2.44
C4	Probability of persistence	Ordinal mapping from IUCN Red List status.	3: LC 2: NT 1: VU/EN/CR/NE
C5	Management needs that benefit co-occurring species	Alignment between species needs and park actions that confer broader benefits (e.g., savanna restoration, water provisioning, patrol focus).	3: Priority species 2: Management concern 1: Limited concern
C6	Sensitivity to human disturbance	Response to human pressures affecting habitat/activity/space use/foraging/reproduction.	3: Moderate 2: High 1: Low
C7	Sampling & monitoring feasibility	Ease of detection by camera traps / sign survey / direct observation.	3: Easy 2: Moderate 1: Difficult

Appendix S3 — Camera-trap detections and presence–absence

Table S2.1. Independent detection events by species (events; ≥ 30 -min separation).

<i>Species</i>	<i>Total independent detections</i>
<i>Bos javanicus javanicus</i>	59
<i>Bubalus bubalis</i>	19
<i>Cuon alpinus sumatrensis</i>	12
<i>Macaca fascicularis fascicularis</i>	33
<i>Muntiacus muntjak muntjak</i>	28
<i>Panthera pardus melas</i>	13
<i>Rusa timorensis russa</i>	97
<i>Sus scrofa</i>	35
<i>Trachypithecus auratus</i>	13

Note:

- Counts are events, not number of stations.
- Presence–absence by station is provided as a CSV (co_occur_bnp_56.csv), available in the data repository: <https://github.com/drajat313/baluran-umbrella-spp-data>

Appendix S4 — Composite seven-indicator scores and tiers (C1–C7) for nine mammal candidates in Baluran National Park

Table S6.1. Per-species scores (1–3) for seven indicators, unweighted totals, and priority tier (≤ 33 rd = Low; 34th–66th = Moderate; ≥ 67 th = High). (Ardiantiono et al., 2024; Caro, 2010; Fleishman et al., 2000; Seddon and Leech, 2008; Thompson et al., 2021; Wilson et al., 2010)

<i>N</i> <i>o</i>	<i>Species</i>	<i>Total</i> <i>Score</i> <i>e</i>	<i>Co-</i> <i>Occurrence</i> <i>(%)</i> <i>(C1)</i>	<i>Score</i> <i>e</i>	<i>Bio</i> <i>Ecologic</i> <i>al</i> <i>Knowledge</i> <i>(C2)</i>	<i>Score</i> <i>e</i>	<i>Home</i> <i>Range</i> <i>(C3)</i>	<i>Score</i> <i>e</i>	<i>IUCN</i> <i>Status</i> <i>(C4)</i>	<i>Score</i> <i>e</i>	<i>Management</i> <i>Priority</i> <i>(C5)</i>	<i>Score</i> <i>e</i>	<i>Sensitivity</i> <i>to</i> <i>Human</i> <i>Disturbance</i> <i>(C6)</i>	<i>Score</i> <i>e</i>	<i>Ease of</i> <i>Monitoring</i> <i>(C7)</i>	<i>Score</i> <i>e</i>
1	<i>B. b. javanicus</i>	16	4.91%	2	Well studied species (10)	3	3.37 km ² (Santosa and Delfiandi, 2007)	Medium (2)	CR	1	Priority species	3	High	2	Easy	3
2	<i>P. p. melas</i>	16	0.45%	1	Well studied species (15)	3	13.6 km ² (Wibisono et al., 2018)	Large (3)	EN	1	Priority species	3	High	2	Easy	3
3	<i>C. a. sumatrensis</i>	15	2.01%	1	Moderately studied species (9)	2	14.18 km ² (Nurvianto et al., 2015)	Large (3)	EN	1	Management concern	2	Moderate	3	Easy	3
4	<i>M. m. muntjak</i>	15	4.92%	3	Moderately studied species (6)	2	1.68 km ² (McCullough et al., 2000)	Small (1)	LC	3	Management concern	2	High	2	Moderate	2
5	<i>R. t. russa</i>	15	7.14%	3	Less studied species (5)	1	5 km ² (Rahman et al., 2020)	Medium (2)	VU	1	Management concern	2	Moderate	3	Easy	3

6	<i>S. scrofa</i>	15	3.57%	2	Less studied species (2)	1	7 km ² (Pinsky and McCauley, 2019)	Large (3)	LC	3	Management concern	2	Low	1	Easy	3
7	<i>B. bubalis</i>	12	3.57%	2	Less studied species (3)	1	2.83 km ² (Napolitano et al., 2017)	Medium (2)	NE	1	Limited management concern	1	High	2	Easy	3
8	<i>M. f. fascicularis</i>	12	5.80%	3	Moderately studied species (7)	2	1.75 km ² (Hansen et al., 2015)	Small (1)	EN	1	Limited management concern	1	Low	1	Easy	3
9	<i>T. auratus</i>	12	2.46%	1	Well studied species (10)	3	0.14 km ² (Leca et al., 2013)	Small (1)	VU	1	Management concern	2	High	2	Moderate	2

Notes: *Bubalus bubalis* in Baluran NP is domestic/feral and Not Evaluated by the IUCN Red List; C4 was set to 1 to reflect limited umbrella value for native biodiversity rather than global extinction risk.

In C5, “Priority species” denotes species currently prioritized in park management plans; it does not imply the focal-species concept in the theoretical sense.

Appendix S5 — Pairwise site-level co-occurrence (hypergeometric 'cooccur', R)

Table S5.1. Significant pairs only (positive, $p_{gt} \leq 0.05$). No negative pairs were detected at $\alpha = 0.05$.

<i>Species 1</i>	<i>Species 2</i>	n_i	n_j	O (joint stations)	E (expected)	$\Delta (O-E)$	p_{lt}	p_{gt}
<i>B. bubalis</i>	<i>R. t. russa</i>	6	12	6	1.29	4.71	1.000	0.0000285
<i>B. bubalis</i>	<i>M. f. fascicularis</i>	6	11	5	1.18	3.82	1.000	0.000655
<i>M. f. fascicularis</i>	<i>R. t. russa</i>	11	12	7	2.36	4.64	1.000	0.000767
<i>B. j. javanicus</i>	<i>R. t. russa</i>	13	12	6	2.79	3.21	0.997	0.022
<i>M. f. fascicularis</i>	<i>M. m. muntjak</i>	11	11	5	2.16	2.84	0.996	0.029
<i>R. t. russa</i>	<i>S. scrofa</i>	12	7	4	1.50	2.50	0.997	0.032
<i>B. j. javanicus</i>	<i>S. scrofa</i>	13	7	4	1.62	2.38	0.995	0.043
<i>M. m. muntjak</i>	<i>R. t. russa</i>	11	12	5	2.36	2.64	0.992	0.045

Table S5.2. For each candidate: C1 (% park-wide) = mean of O_{ij}/N across other mammals (diagonal excluded; $N = 56$), and Score 1–3 (tertiles; tie-friendly). Thresholds for this dataset: Q1 = 3.1994 %, Q2 = 4.9107 % (a value exactly equal to Q2 is assigned Score 2).

<i>Species</i>	<i>C1 (% park-wide)</i>	<i>Score (1–3; tertiles, tie-friendly)</i>	<i>#Stations detected (n_i)</i>	<i>Mean (%)</i>	<i>SD (%)</i>	<i>Range (%)</i>
<i>R. t. russa</i>	7.14	3	12	46.8	27.2	0–100
<i>M. f. fascicularis</i>	5.80	3	11	37.3	24.4	0–83
<i>M. m. muntjak</i>	4.92	3	11	29.1	15.6	0–45
<i>B. j. javanicus</i>	4.91	2	13	30.5	18.4	0–57
<i>B. bubalis</i>	3.57	2	6	17.9	18.6	0–50
<i>S. scrofa</i>	3.57	2	7	19.6	13	0–33
<i>T. auratus</i>	2.46	1	7	17.7	8.1	8–33
<i>C. a. sumatrensis</i>	2.01	1	6	14.8	10.4	0–33
<i>P. p. melas</i>	0.45	1	3	3.9	6.7	0–17

Notes: Co-occurrence analysis script ('cooccur', R) (Griffith et al., 2016) available in the data repository: <https://github.com/drajat313/baluran-umbrella-spp-data>

Supplementary Materials References

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