<div align="center">**Supplementary Materials**</div>

<div align="center">**From co-occurrence to management: a compact workflow for umbrella species — Baluran National Park**</div>

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 (deduplicated).	3: ≥ 10 | 2: 6–9 | 1: ≤ 5
C3	Home-range size	Largest reported home-range (km²) 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; $\geq$ 30-min separation).

Species	Total independent detections
Bos javanicus javanicus	59
Bubalus bubalis	19
Cuon alpinus sumatrensis	12
Macaca fascicularis fascicularis	33
Muntiacus muntjak muntjak	28
Panthera pardus melas	13
Rusa timorensis russa	97
Sus scrofa	35
Trachypithecus auratus	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 ($\leq$ 33rd = Low; 34th–66th = Moderate; $\geq$ 67th = High). (Ardiantiono et al., 2024; Caro, 2010; Fleishman et al., 2000; Seddon and Leech, 2008; Thompson et al., 2021; Wilson et al., 2010)

No	Species	Total Score	Co-Occurrence (%) (C1)	Score	Bio Ecological Knowledge (C2)	Score	Home Range (C3)	Score	Iucn Status (C4)	Score	Management Priority (C5)	Score	Sensitivity To Human Disturbance (C6)	Score	Ease Of Monitoring (C7)	Score
1	*B. b. javanicus*	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	*P. p. melas*	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	*C. a. sumatrensis*	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	*M. m. muntjak*	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	*R. t. russa*	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

#	Species															
6	*S. scrofa*	**15**	3.57%	2	Less studied species (2)	1	7 km² (Pinsky and McCauley, 2019)	Large (3)	LC	3	Management concern	2	Low	1	Easy	3
7	*B. bubalis*	**12**	3.57%	2	Less studied species (3)	1	2.83 km² (Napolitano et al., 2017)	Medium (2)	NE	1	Limited management concern	1	High	2	Easy	3
8	*M. f. fascicularis*	**12**	5.80%	3	Moderately studied species (7)	2	1.75 km² (Hansen et al., 2015)	Small (1)	EN	1	Limited management concern	1	Low	1	Easy	3
9	*T. auratus*	**12**	2.46%	1	Well studied species (10)	3	0.14 km² (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 ≤ 0.05). No negative pairs were detected at α = 0.05.

Species 1	Species 2	n_i	n_j	O (joint stations)	E (expected)	Δ (O−E)	p_lt	p_gt
B. bubalis	R. t. russa	6	12	6	1.29	4.71	1.000	0.0000285
B. bubalis	M. f. fascicularis	6	11	5	1.18	3.82	1.000	0.000655
M. f. fascicularis	R. t. russa	11	12	7	2.36	4.64	1.000	0.000767
B. j. javanicus	R. t. russa	13	12	6	2.79	3.21	0.997	0.022
M. f. fascicularis	M. m. muntjak	11	11	5	2.16	2.84	0.996	0.029
R. t. russa	S. scrofa	12	7	4	1.50	2.50	0.997	0.032
B. j. javanicus	S. scrofa	13	7	4	1.62	2.38	0.995	0.043
M. m. muntjak	R. t. russa	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).

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

Ardiantiono, Deere, N.J., Ramadiyanta, E., Sibarani, M.C., Hadi, A.N., Andayani, N., Ginting, Y., Bull, J.W., Struebig, M.J., 2024. Selecting umbrella species as mammal biodiversity indicators in tropical forest. Biol Conserv 292. https://doi.org/10.1016/j.biocon.2024.110511

Caro, T., 2010. Conservation by Proxy: Indicator, Umbrella, Keystone Flagship and other Surrogate Species. Island Press.

Fleishman, E., Murphy, D.D., Brussard, P.F., 2000. A new method for selection of umbrella species for conservation planning, Ecological Applications.

Griffith, D.M., Veech, J.A., Marsh, C.J., 2016. cooccur: Probabilistic Species Co-Occurrence Analysis in R. J Stat Softw 69. https://doi.org/10.18637/jss.v069.c02

Hansen, M.F., Wahyudi, H.A., Supriyanto, S., Damanik, A.R., 2015. The interactions between long-tailed macaques (*Macaca fascicularis*) and tourists in Baluran National Park, Indonesia.

Leca, J.-B., Gunst, N., Rompis, A., Soma, G., Putra, I.G.A.A., Wandia, I.N., 2013. Population Density and Abundance of Ebony Leaf Monkeys (*Trachypithecus auratus*) in West Bali National Park, Indonesia. Primate Conservation 26, 133–144. https://doi.org/10.1896/052.026.0106

McCullough, D.R., Pei, K.C.J., Wang, Y., 2000. Home Range, Activity Patterns, and Habitat Relations of Reeves' Muntjacs in Taiwan. J Wildl Manage 64, 430. https://doi.org/10.2307/3803241

Napolitano, F., Pacelli, C., Braghieri, A., Grasso, F., De Rosa, G., 2017. Animal - Environment Interaction: Buffalo Behavior and Welfare, in: Napolitano, F., Pacelli, Corrado, Braghieri, Ada, Grasso, Fernando, De Rosa, G. (Eds.), The Buffalo (*Bubalus Bubalis*) - Production and Research. BENTHAM SCIENCE PUBLISHERS, pp. 69–104. https://doi.org/10.2174/9781681084176117010007

Nurvianto, S., Imron, M.A., Herzog, S., 2015. Activity Patterns and Behaviour of Denning Dholes (*Cuon alpinus*) in a Dry Deciduous Forest of East Java, Indonesia, Bull. Env. Pharmacol. Life Sci.

Pinsky, M., McCauley, D., 2019. Home range and body size data compiled from the literature for marine and terrestrial vertebrates. Biological and Chemical Oceanography Data Management Office. https://doi.org/10.1575/1912/bco-dmo.752795.1

Rahman, D.A., Condro, A.A., Rianti, P., Masy'ud, B., Aulagnier, S., Semiadi, G., 2020. Geographical analysis of the Javan deer distribution in Indonesia and priorities for landscape conservation. J Nat Conserv 54. https://doi.org/10.1016/j.jnc.2020.125795

Santosa, Y., Delfiandi, 2007. Analisis Pola Penggunaan Ruang dan Wilayah Banteng (*Bos javanicus* d'Alton, 1832) di Taman Nasional Alas Purwo Jawa Timur.

Seddon, P.J., Leech, T., 2008. Conservation short cut, or long and winding road? A critique of umbrella species criteria. ORYX. https://doi.org/10.1017/S003060530806119X

Thompson, L.J., Krüger, S.C., Coverdale, B.M., Shaffer, L.J., Ottinger, M.A., Davies, J.P., Daboné, C., Kibuule, M., Cherkaoui, S.I., Garbett, R.A., Phipps, W.L., Buechley, E.R., Godino Ruiz, A., Lecoq, M., Carneiro, C., Harrell, R.M., Gore, M.L., Bowerman, W.W.,

2021. Assessing African Vultures as Biomonitors and Umbrella Species. Frontiers in Conservation Science 2. https://doi.org/10.3389/fcosc.2021.729025

Wibisono, H.T., Wahyudi, H.A., Wilianto, E., Romaria Pinondang, I.M., Primajati, M., Liswanto, D., Linkie, M., 2018. Identifying priority conservation landscapes and actions for the Critically Endangered Javan leopard in Indonesia: Conserving the last large carnivore in Java Island. PLoS One 13. https://doi.org/10.1371/journal.pone.0198369

Wilson, K.A., Meijaard, E., Drummond, S., Grantham, H.S., Boitani, L., Catullo, G., Christie, L., Dennis, R., Dutton, I., Falcucci, A., Maiorano, L., Possingham, H.P., Rondinini, C., Turner, W.R., Venter, O., Watts, M., 2010. Conserving biodiversity in production landscapes. Ecological Applications 20, 1721–1732. https://doi.org/10.1890/09-1051.1