Identifying habitat and understanding movement resistance for the Endangered Bornean banteng *Bos javanicus lowi* in Sabah, Malaysia

Hong Ye Lim, Penny C. Gardner, Nicola K. Abram
Kalsum M. Yusah and Benoit Goossens

Supplementary Material 1 Management differences between Protected Areas, Protection Forest Reserves and Production Forest Reserves in Sabah, Malaysia.

For the purpose of environmental protection neither forest harvesting nor crop plantations are permissible in Protection Forest Reserves, which include Class I (Protection Forest), Class IV (Amenity Forest), Class VI (Virgin Jungle Reserve) and Class VII (Wildlife Reserve) Forest Reserves, and Protected Areas, which consist of Sabah Parks and Wildlife Sanctuaries (Sabah Forestry Department, 2015). In Production Forest Reserves, natural forest harvesting, industrial tree plantations, mosaic forests and oil palm are permitted in Class II (Commercial Forest). Natural forest harvesting is permitted in Class III (Domestic Forest) and Class V (Mangrove Forest) Reserves for local consumption and trading, respectively (Forest Enactment, 1968).

1

SUPPLEMENTARY TABLE 1 Camera-trap survey locations, sampling method (grid or opportunistic) and distance between camera-trap stations for various studies in Sabah, Malaysia.
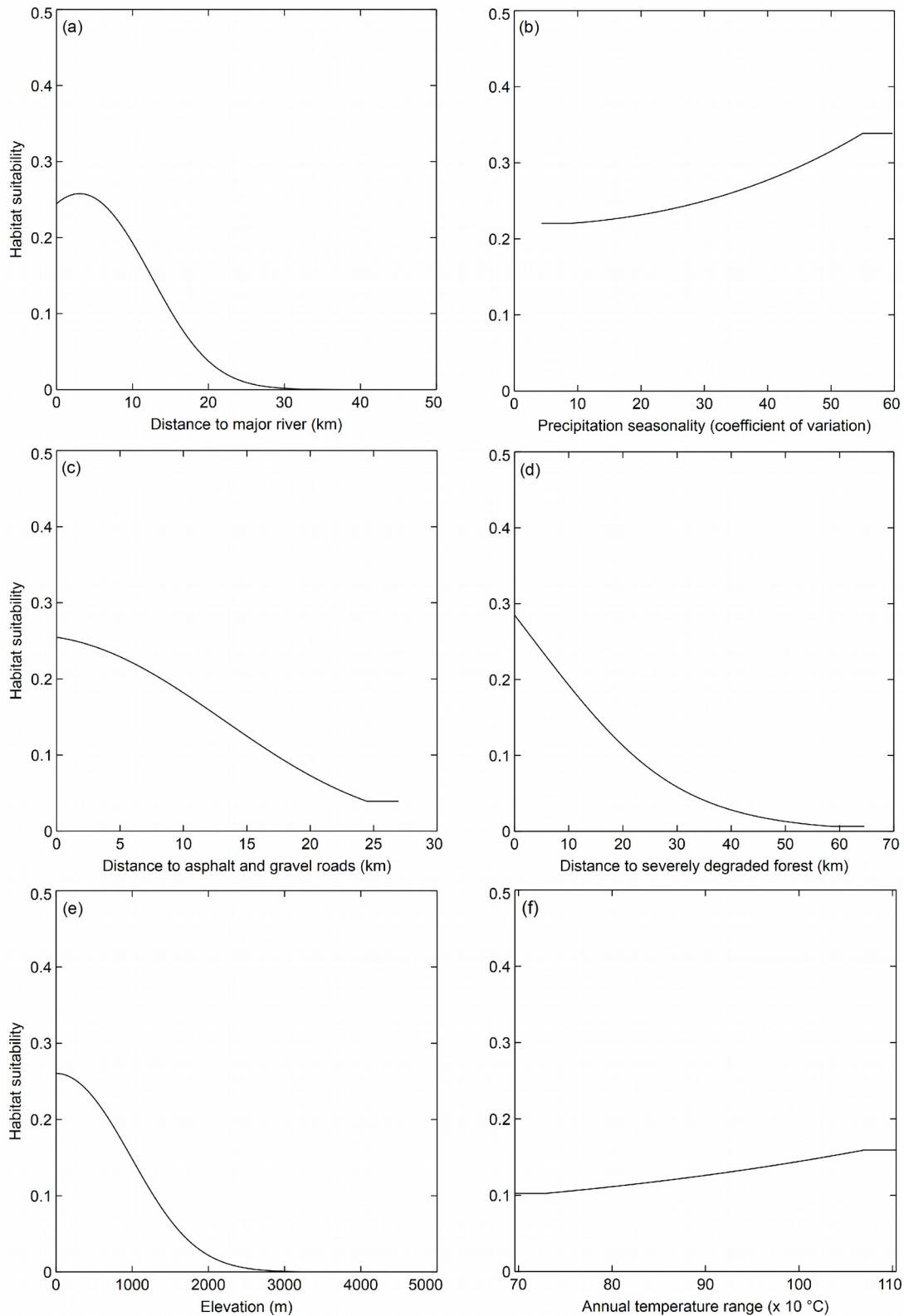
Location	Sampling method	Camera distances (km)	Source
Tabin Wildlife Reserve	Grid	0.5	Gardner (2015)
Malua Forest Reserve	Grid	0.5	Gardner (2015)
Maliau Basin Conservation Area Buffer Zones	Opportunistic	1	Gardner (2015)
Sipitang Forest Reserve	Opportunistic	1	P.C. Gardner (unpubl. data)
Sapulut Forest Reserve	Opportunistic	1	P.C. Gardner (unpubl. data)
Silabukan Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Madai-Baturong Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Kuamut Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Deramakot Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Tangkulap Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Segaliud-Lokan Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Sugut Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Paitan Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)
Ulu Tungud Forest Reserve	Opportunistic	1	P.C. Gardner & H.Y. Lim (unpubl. data)

SUPPLEMENTARY TABLE 2 Description and source(s) of the 11 environmental predictors that were extracted at 90 m resolution to describe the environmental conditions in Sabah, Malaysia.

Categories	Environmental predictor	Description
Climate	Annual temperature range (Bio7)	The layer measures temperature variation by subtracting the minimum temperature of the coldest month from the maximum temperature of the warmest month of the year. Downloaded from http://www.worldclim.org/ and reclassified to 90 m resolution.
	Precipitation of driest quarter (Bio17)	The layer sums up precipitation of the driest 3 months of the year. Downloaded from http://www.worldclim.org/ and reclassified to 90 m resolution.
	Seasonality of precipitation (Bio15)	The layer measures the variation in total monthly precipitation per year, which is known as the coefficient of variation, which represents the precipitation variability. Downloaded from http://www.worldclim.org/ and reclassified to 90 m resolution.
Infrastructure	Distance to asphalt & gravel roads (Landsat 2013)	The layer quantifies the distance to asphalt & gravel roads (digitized from 2013 Landsat images), using Euclidean distance.
Land cover/land use	Distance to agro-forest & re-growing forest (2010)	The layer quantifies the distance to regenerating forests & traditional rubber & fruit gardens, using Euclidean distance. The original data were from Gaveau et al. (2014).
	Distance to intact & logged forest (2010)	The layer quantifies the distance to both intact and logged natural forests, using Euclidean distance. The original data was developed by Gaveau et al. (2014).
	Distance to oil palm plantations	The layer quantifies the distance to planted or cleared oil palm plantations in 2010, using Euclidean distance. The original data were from Gaveau et al. (2014).
	Distance to severely degraded forest (2010)	The layer quantifies the distance to severely degraded forest that shows little sign of regeneration, using Euclidean distance. The original data were from Gaveau et al. (2014).
Soil	Soil association of 53 classes	The layer categorizes soils in Sabah into 53 classes and is based on digitized soil maps for Sabah produced in the 1970s (Acres et al., 1975).
Topography	Elevation	The layer quantifies the elevation (in m above sea level) of each cell, based on 10 m interval data digitized from a topographic map of Sabah.
	Distance to major river	The layer measures the distance to major rivers, calculated using Euclidean distance of nearest major rivers.

SUPPLEMENTARY TABLE 3 Matrix of Pearson's correlation coefficients between the 11 environmental predictor variables (Supplementary Table 2).

	Bio7	Distance to major river	Distance to asphalt & gravel roads	Distance to agro-forest & re-growing forest	Distance to intact & logged forest	Distance to oil palm plantations	Distance to severely degraded forest	Elevation	Bio17	Bio15	Soil association
Bio7	1										
Distance to major river	0.15	1									
Distance to asphalt & gravel roads	0	0.03	1								
Distance to agro-forest & re-growing forest	0	0	0.04	1							
Distance to intact & logged forest	0.2	0.07	0	0	1						
Distance to oil palm plantations	0	0.01	0.1	0.06	0	1					
Distance to severely degraded forest	0.16	0.22	0.01	0	0.05	0.33	1				
Elevation	0	0	0.11	0.12	0	0.63	0.08	1			
Bio17	0	0	0	0.15	0	0	0	0	1		
Bio15	0.63	0.21	0	0	0.07	0	0.04	0	0	1	
Soil association	0.23	0.16	0.16	0	0.06	0	0.17	0	0.05	0.17	1

SUPPLEMENTARY FIG. 1Relationship between banteng *Bos javanicus lowi* habitat suitability and the remaining six spatial predictors in the MaxEnt model: (a) distance to major river (3.5%); (b) precipitation seasonality (3.2%); (c) distance to asphalt and gravel road (2.3%); (d) distance to severely degraded forest (2.2%); (e) elevation (1.8%); (f) annual temperature range (1.2%).

5
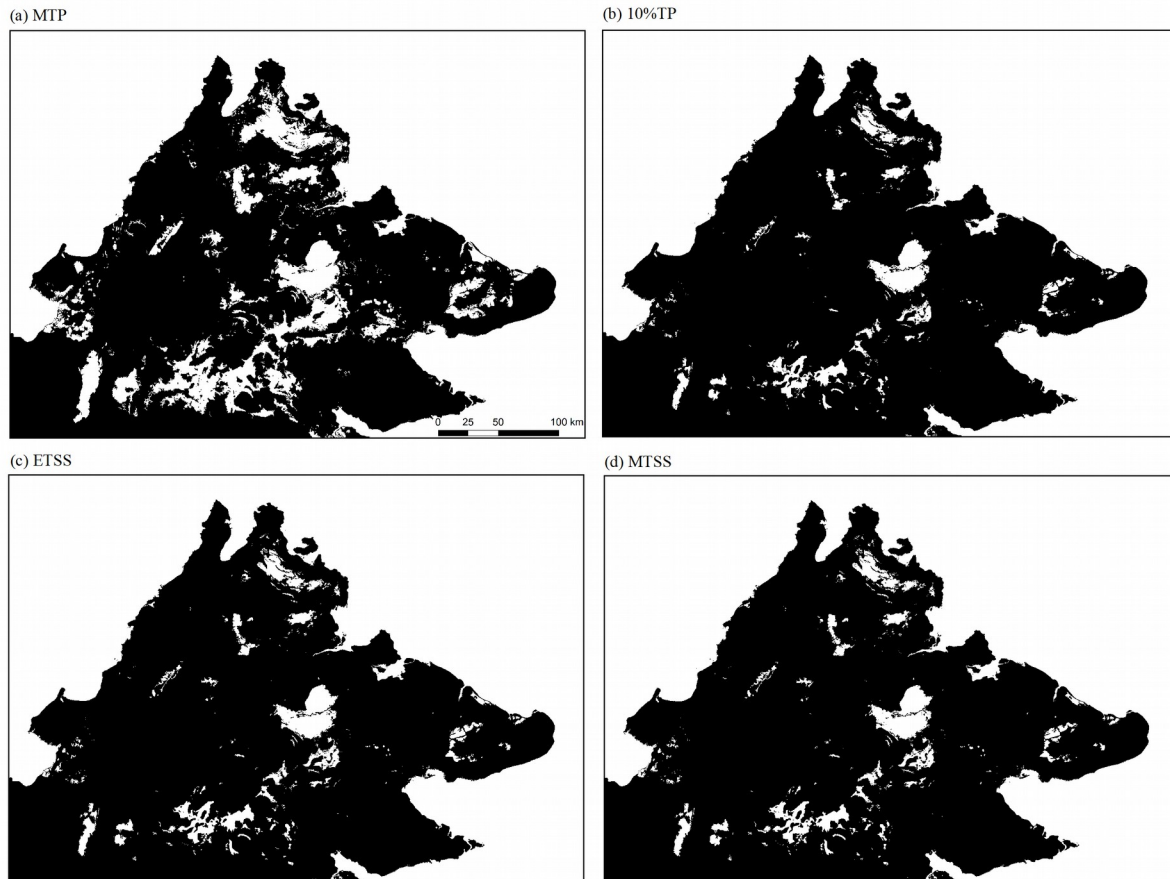
SUPPLEMENTARY FIG. 2 A visual comparison between four commonly applied thresholds to the habitat suitability model for the Bornean banteng in Sabah, Malaysia. The four thresholds were (a) minimum training presence (MTP, at a logistic threshold of 0.038), (b) ten percentile training presence (10%TP, 0.163), (c) equal training sensitivity and specificity (ETSS, 0.140), and (d) maximum training sensitivity plus specificity (MTSS, 0.139).

SUPPLEMENTARY TABLE 4 Euclidean distance (km), cost-weighted distance (weighted km), least-cost path distance (km), and associated ratio of 21 least-cost paths (Fig. 4) between 17 core habitats of the Bornean banteng *Bos javanicus lowi* in Sabah, Malaysia.

Least-cost path ID	Core area	Core area	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, weighted km)	Least-cost path (LCP, km)	CWD : EucD	CWD : LCP
1	1	2	0.2	24.7	0.3	134.7	89.6
2	1	4	29.1	2657.2	30.8	91.3	86.2
3	2	3	13.5	1384.2	14.1	102.6	97.9
4	3	4	11.6	1221	11.9	105.6	102.4
5	3	13	52.2	5560.4	55.5	106.6	100.1
6	4	17	163.9	16797.7	164.6	102.5	102.1
7	5	7	11.2	1188.6	11.9	106	99.9
8	5	12	106.1	11527.9	112.1	108.7	102.8
9	6	7	0.1	9	0.1	99.2	99.2
10	6	8	41.6	4507.6	44.9	108.4	100.4
11	8	9	11.3	1144.1	11.4	101.5	100.7
12	8	10	14.6	1555.3	15.3	106.4	101.6
13	9	10	3	315.5	3.1	106.3	101.2
14	10	11	0.8	91.6	0.9	117.9	101
15	10	15	2.5	256	2.6	103.4	99.8
16	10	16	42.4	4597.9	45.6	108.4	100.8
17	11	12	0.1	3.5	0.1	38.5	38.5
18	12	13	0.1	4.4	0.1	47.8	47.8
19	14	15	6.7	692.1	6.8	103.4	102
20	14	17	12	1321.9	12.9	110.3	102.3
21	15	16	0.1	6.1	0.1	66.6	66.6
Total			522.8	54866.6	545.2	2076.2	1942.8
Mean			24.9	2612.7	26	98.9	92.5
SD			40.7	4254.9	41.7	22.1	18.4
Range			0	0	0	0	0

References

ACRES, B.D., BOWERS, R.P., BURROUGH, P.A., FOLLAND, C.J., KALSI, M.S., THOMAS, P. & WRIGHT, P.S. (1975) *The Soils of Sabah, Volume 1–5*. Land Resource Study No. 20. Land Resources Division, Ministry of Overseas Development, Surrey, UK.

FOREST ENACTMENT (1968) *Sabah No. 2 1968*. State of Sabah, Malaysia.

GARDNER, P.C. (2015) *The natural history, non-invasive sampling, activity patterns and population genetic structure of the Bornean banteng (*Bos javanicus lowi*) in Sabah, Malaysia*. PhD thesis. Cardiff University, Cardiff, UK.

GAVEAU, D.L.A., SLOAN, S., MOLIDENA, E., YAEN, H., SHEIL, D., ABRAM, N.K. et al. (2014) Four decades of forest persistence, clearance and logging on Borneo. *PLoS ONE*, 9(7), e101654.

SABAH FOREST DEPARTMENT (2015) *Fact Sheets of Forest Reserves in Sabah (2015)*. Sabah Forestry Department, Sandakan, Malaysia.