Supplementary Information

Oil palm cultivation critically affects sociality in an endangered Malaysian primate

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Supplementary Figure

Figure S1. Habitat types at the study site in Segari, Peninsular Malaysia. From left to right: tropical rainforest, plantation edge (i.e. oil palm plantation area within 50 metres from the forest border) and plantation (i.e. areas of oil palm plantation at a distance of more than 50 metres from the forest border).

Supplementary Tables

Table S1. Results of the GLMMs exploring the effect of the habitat on the rates of grooming (model 1), social play (model 2) and non-physical aggression (model 4) among Southern pig-tailed macaques. Shown are model estimates, standard errors (SE), lower and upper confidence intervals (CI) and test results of individual effects. Control variables are not interpreted. Significant p-values are shown in bold. As the full-null model comparison of model 3 (physical aggression) did not reveal significance (LRT habitat: χ^2 = 2.11, df = 2, p = 0.35), no details about individual effects are presented.

Predictor variable	Estimate	SE	lower CI	upper CI	X^2	P
Rate of grooming (model 1)						
Intercept	-0.06	0.24	-0.53	0.38		
Habitat (forest vs. plantation edge)[a]	-0.78	0.14	-1.05	-0.54	120.96	**< 0.001**
Habitat (forest vs. plantation)[a]	-3.80	0.36	-4.75	-3.25		
Control variables						
Age-sex class (adult ♂ vs. adult ♀)[b]	1.13	0.24	0.67	1.57		
Age-sex class (adult ♂ vs. immature ♂)[b]	0.67	0.31	0.07	1.24	20.36	**< 0.001**
Age-sex class (adult ♂ vs. immature ♀)[b]	1.01	0.28	0.43	1.56		
Rank[c]	0.04	0.10	-0.16	0.24	0.12	0.73
Group (*AMY*=0, *VOL*=1)	-0.66	0.25	-1.18	-0.17	6.72	**0.010**
Daytime (early morning vs. late morning)[d]	-0.04	0.13	-0.28	0.21		
Daytime (early morning vs. early afternoon)[d]	-0.26	0.17	-0.60	0.05	2.67	0.45
Daytime (early morning vs. late afternoon)[d]	-0.04	0.17	-0.33	0.27		
Rate of social play (model 2)						
Intercept	1.65	0.35	0.97	2.31		
Habitat (forest vs. plantation edge)[a]	-1.97	0.30	-2.67	-1.47	40.28	**< 0.001**
Habitat (forest vs. plantation)[a]	-1.76	0.33	-2.49	-1.23		
Control variables						
Age-sex class (♂ = 0, ♀ = 1)	-1.31	0.40	-2.05	-0.55	9.00	**0.003**
Rank[e]	-0.08	0.19	-0.48	0.34	0.18	0.67
Group (*AMY*=0, *VOL*=1)	-1.56	0.76	-3.62	-0.24	4.10	**0.043**
Daytime (early morning vs. late morning)[d]	-0.80	0.31	-1.39	-0.21		
Daytime (early morning vs. early afternoon)[d]	-0.81	0.30	-1.41	-0.23	12.32	**0.006**
Daytime (early morning vs. late afternoon)[d]	-0.54	0.27	-1.15	-0.03		
Rate of non-physical aggression (model 4)						
Intercept	-0.59	0.20	-1.02	-0.21		
Habitat (forest vs. plantation edge)[a]	0.07	0.19	-0.35	0.41	6.06	**0.048**
Habitat (forest vs. plantation)[a]	0.44	0.17	0.10	0.76		
Control variables						
Age-sex class (adult ♂ vs. adult ♀)[b]	-0.69	0.17	-1.00	-0.36		
Age-sex class (adult ♂ vs. immature ♂)[b]	-0.28	0.23	-0.74	0.14	23.39	**< 0.001**
Age-sex class (adult ♂ vs. immature ♀)[b]	-1.00	0.23	-1.48	-0.58		
Rank[c]	-0.16	0.07	-0.30	-0.03	4.64	**0.031**
Group (*AMY*=0, *VOL*=1)	0.35	0.18	0.002	0.67	3.80	**0.051**
Daytime (early morning vs. late morning)[d]	-0.25	0.19	-0.61	0.13		
Daytime (early morning vs. early afternoon)[d]	-0.23	0.17	-0.58	0.11	4.21	0.24
Daytime (early morning vs. late afternoon)[d]	0.06	0.19	-0.34	0.45		

[a] Reference level is forest.
[b] Reference level is adult male.
[c] z-transformed to mean = 0 and SD = 1 prior to model fitting; original mean (SD) was 0.51 (0.35).
[d] Reference level is early morning.
[e] z-transformed to mean = 0 and SD = 1 prior to model fitting; original mean (SD) was 0.51 (0.34).

Table S2. Results of the GLMM exploring the effect of habitat and its interaction with dominance rank and age-sex class on the macaques' individual scores of eigenvector centrality (model 6). Shown are model estimates, standard errors (SE), lower and upper confidence intervals (CI) as well as original and permuted p-values of the three-way interaction. Permuted p-values were obtained by comparing the observed regression coefficients with a distribution of 1,000 coefficients generated by randomly swapping the nodes of the social network prior to extracting centrality scores. Significance is indicated in bold.

Predictor variable	Estimate	SE	lower CI	upper CI	P	$P_{permuted}$
Intercept	0.34	0.07	0.20	0.48		
Predictors included in interaction						
Habitat (forest = 0, plantation edge = 1)	-0.26	0.10	-0.46	-0.07	[d]	[d]
Rank[a]	0.04	0.07	-0.11	0.19	[d]	[d]
Age-sex class (adult ♂ vs. adult ♀))[b]	0.21	0.09	0.03	0.40	[d]	[d]
Age-sex class (adult ♂ vs. immature ♀)[b]	0.14	0.10	-0.05	0.35	[d]	[d]
Age-sex class (adult ♂ vs. immature ♂)[b]	0.10	0.11	-0.12	0.30	[d]	[d]
Two-way interaction						
Habitat[c] * rank	-0.02	0.10	-0.22	0.19	[d]	[d]
Habitat[c] * age-sex class (adult ♂ vs. adult ♀)[b]	-0.08	0.12	-0.32	0.19	[d]	[d]
Habitat[c] * age-sex class (adult ♂ vs. immature ♀)[b]	0.05	0.14	-0.20	0.33	[d]	[d]
Habitat[c] * age-sex class (adult ♂ vs. immature ♂)[b]	0.21	0.15	-0.08	0.51	[d]	[d]
Rank * age-sex class (adult ♂ vs. adult ♀)[b]	-0.17	0.09	-0.36	0.01	[d]	[d]
Rank * age-sex class (adult ♂ vs. immature ♀)[b]	-0.19	0.10	-0.38	0.009	[d]	[d]
Rank * age-sex class (adult ♂ vs. immature ♂)[b]	-0.11	0.10	-0.31	0.09	[d]	[d]
Three-way interaction[e]						
Habitat[c] * rank * age-sex class (adult ♂ vs. adult ♀)[b]	0.27	0.13	0.02	0.53	0.038	**0.050**
Habitat[c] * rank * age-sex class (adult ♂ vs. immature ♀)[b]	0.43	0.14	0.16	0.72	0.002	**0.007**
Habitat[c] * rank * age-sex class (adult ♂ vs. immature ♂)[b]	0.26	0.14	-0.04	0.57	0.073	0.108

[a] z-transformed to mean = 0 and SD = 1 prior to model fitting; original mean (SD) was 0.50 (0.33).
[b] Reference level is adult male
[c] Reference level is forest.
[d] Values are not shown because of having a very limited interpretation as they are part of the interaction.
[e] The global testing (LRT habitat * rank * age-sex class) revealed X^2 = 11.50, df = 3, P = 0.009.

Table S3. Results of the GLMMs exploring the effect of the habitat on three measures describing the mother-infant relationship in Southern pig-tailed macaques, i.e. the proportion of contact time (model 7), the rate of mothers breaking contact (model 8) and the rate of mothers increasing distance (model 9). For all predictor variables except non-significant interactions, model estimates, standard errors (SE), lower and upper confidence intervals (CI) and test results of individual fixed effects are shown after removal of the non-significant interaction terms. Control variables are not interpreted. Significant p-values are shown in bold.

Predictor variable	Estimate	SE	lower CI	upper CI	X²	P
Contact time (model 7)						
Intercept	0.70	0.32	0.09	1.30		
Habitat (forest vs. plantation edge)[a]	1.99	0.29	1.45	2.54	44.91	**< 0.001**
Habitat (forest vs. plantation)[a]	3.96	0.28	3.42	4.50		
Control variables						
Infant age[b]	-2.13	0.15	-2.42	-1.87	31.04	**< 0.001**
Infant sex (♂ = 0, ♀ = 1)	0.51	0.45	-0.38	1.44	1.32	0.25
Parity (multiparous = 0, primiparous = 1)	-1.37	0.45	-2.19	-0.54	5.94	**0.015**
Mother's rank[c]	0.27	0.20	-0.11	0.68	1.54	0.21
Daytime (early morning vs. late morning)[d]	-0.74	0.44	-1.62	0.14		
Daytime (early morning vs. early afternoon)[d]	0.09	0.40	-0.67	0.90	3.53	0.32
Daytime (early morning vs. late afternoon)[d]	0.19	0.28	-0.35	0.81		
Interaction excluded due to non-significance						
Habitat (forest vs. plantation edge)[a] * infant.age	0.17	0.36	-0.60	0.84	0.25	0.88
Habitat (forest vs. plantation)[a] * infant.age	-0.05	0.35	-0.81	0.69		
Mother breaks contact (model 8)						
Intercept	0.04	0.23	-0.45	0.46		
Control variables						
Infant age^2	-0.36	0.09	-0.54	-0.18	15.33	**< 0.001**
Infant sex (♂ = 0, ♀= 1)	-0.05	0.19	-0.42	0.37	0.06	0.81
Parity (multiparous = 0, primiparous = 1)	0.73	0.18	0.35	1.08	14.31	**< 0.001**
Mother's rank[c]	-0.26	0.09	-0.44	-0.08	8.06	**0.005**
Daytime (early morning vs. late morning)[d]	0.36	0.29	-0.23	0.93		
Daytime (early morning vs. early afternoon)[d]	0.46	0.31	-0.17	1.07	6.31	0.10
Daytime (early morning vs. late afternoon)[d]	0.49	0.20	0.05	0.88		
Predictors included in interaction						
Habitat (forest vs. plantation edge)[a]	-0.64	0.23	-1.14	-0.23	[e]	[e]
Habitat (forest vs. plantation)[a]	-0.98	0.29	-1.58	-0.47	[e]	[e]
Infant age[b]	0.01	0.14	-0.27	0.32	[e]	[e]
Two-way interaction						
Habitat (forest vs. plantation edge)[a] * infant.age	0.82	0.25	0.37	1.37	16.82	**< 0.001**
Habitat (forest vs. plantation)[a] * infant.age	0.74	0.21	0.33	1.18		
Interaction excluded due to non-significance						
Habitat (forest vs. plantation edge)[a] * Infant.age^2	-0.07	0.21	-0.56	0.32	0.11	0.95
Habitat (forest vs. plantation)[a] * infant.age^2	-0.04	0.25	-0.63	0.38		
Mother increases distance (model 9)						
Intercept	1.41	0.26	0.87	1.91		
Control variables						
Infant age^2	-0.50	0.10	-0.70	-0.33	15.89	**< 0.001**
Infant sex (♂ = 0, ♀ = 1)	-0.45	0.42	-1.32	0.38	1.24	0.27
Parity (multiparous = 0, primiparous = 1)	0.72	0.40	-0.09	1.49	2.62	0.11
Mother's rank[c]	-0.17	0.19	-0.56	0.18	0.75	0.39
Daytime (early morning vs. late morning)[d]	-0.09	0.21	-0.54	0.32		
Daytime (early morning vs. early afternoon)[d]	-0.19	0.19	-0.55	0.22	2.82	0.42
Daytime (early morning vs. late afternoon)[d]	0.13	0.16	-0.19	0.46		
Predictors included in interaction						
Habitat (forest vs. plantation edge)[a]	-1.75	0.34	-2.54	-1.09	[e]	[e]
Habitat (forest vs. plantation)[a]	-2.26	0.48	-3.22	-1.45	[e]	[e]
Infant age[b]	0.79	0.17	0.48	1.10	[e]	[e]
Two-way interaction						
Habitat (forest vs. plantation edge)[a] * infant.age	1.04	0.20	0.66	1.50	25.56	**< 0.001**
Habitat (forest vs. plantation)[a] * infant.age	1.20	0.21	0.72	1.76		
Interaction excluded due to non-significance						
Habitat (forest vs. plantation edge)[a] * Infant.age^2	0.08	0.21	-0.47	0.46	0.19	0.91
Habitat (forest vs. plantation)[a] * infant.age^2	-0.05	0.27	-0.77	0.47		

[a] Reference level is forest.
[b] z-transformed to mean = 0 and SD = 1 prior to model fitting; original mean (SD) was 80.98 (49.42).
[c] z-transformed to mean = 0 and SD = 1 prior to model fitting; original mean (SD) was 0.45 (0.32).
[d] Reference level is early morning
[e] Values are not shown because of having a very limited interpretation as they are part of the interaction.