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SUPPLEMENTARY MATERIALS

Predicting Prosociality in Primates: Socio-Ecological Influences and a Framework of Inter-Brain Neural Synchronization

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Supplementary File 1

Table S1. Variable re-codes from raw data for analysis in R-Studio

Variable Name	Meaning & Code
Inter/Intra Aggression	High = 1, Low = 2
Physical or Threatening aggression	Threatening = 1, Physical = 2
Affiliative behavior out-group	None = 1. Rare = 2, Common = 3
Affiliative behavior within-group	Yes = 1, None = 2
Pair bond	Absent = 1, Present = 2
Coalition presence	Absent = 1, Present = 2
Group hunting	Absent = 1, Present = 2
Consolation	Absent =1, Present = 2
Allo-parenting	Absent =1, Present = 2
Food-sharing	Absent = 1, Present = 2
Group-foraging	Absent = 1 Present = 2
Infanticide Present	Absent = 1, Rare = 2, Common = 3, High = 4
Predator number	Low = 1, Moderate = 2. High = 3
Remain in natural habitat	None =1, Male = 2, Female = 3, Both = 4
Diurnal or nocturnal	Nocturnal = 1, Diurnal = 2
Location	Madagascar = 1, Africa = 2, Asia = 3, Neotropics = 4
Habitat	Arboreal =1, Semi-terrestrial = 2, Terrestrial = 3
Predation pressure	Very low = 1, Low = 2. Moderate =3, High = 4 (see Hart, D., 2007)
Solitary	No = 1, Yes = 2
Resource Density	Low = 1, Seasonal = 2, High = 3
Feeding comp	BGC = 1, WGS/BGC = 2, WGC/S = 3, WGC = 4, WGS/BGC/WGC= 5, WGS = 6 (see van Schaik, C. P. 1989).
Feeding Competition Intensity	None = 1, Low = 2, Seasonal = 3, High = 4
Social Tolerance	Low =1, Mod =2, High =3
Intrasexual Competition	None = 1, Low = 2, Common = 3, High = 4
Primary Diet	Omnivorous =1, Folivorous = 2, Frugivorous = 3, Exudativore = 4, Graminivore = 5, Carnivore= 6
Altricial/Precocial	Altricial = 1, Precocial = 2
Sex. Dimorphism	None = 1, Low = 2, Moderate = 3, High = 4
Co-operative Breeding	Absent =1, Present = 2
Singular vs Plural Breeding	Singular = 1, Plural = 2

Variable Name	Meaning & Code
Mating System	Polyandrous = 1, Monogamous, = 2, Polygynous = 3, Polygamy = 4
Dominance Hierarchy	Fdominance = 1, M/Fdominance = 2, Mdominance = 3, None = 4
Hierarchy type	Ambiguous =1, Despotic = 2, Egalitarian = 3
Sexual segregation	Absent =1, Present = 2
Empathy Presence	Absent = 1, Present = 2
Recorded Empathy Type	Affective = 1, Cognitive = 2, Both = 3
Tool use	Present (true use) =1, Present (proto use) = 2, Present (both) = 3

Table S2.

	Estimate	Std. Error	Z-Value	Pr(>|Z|)
Intercept	0.29	0.34	0.84	0.40
Cooperative Breeding Presence	18.28	2662.86	0.01	1.00

Pr(>|Z|) = P-value associated with Z-score.
Std.Error = standard error value.

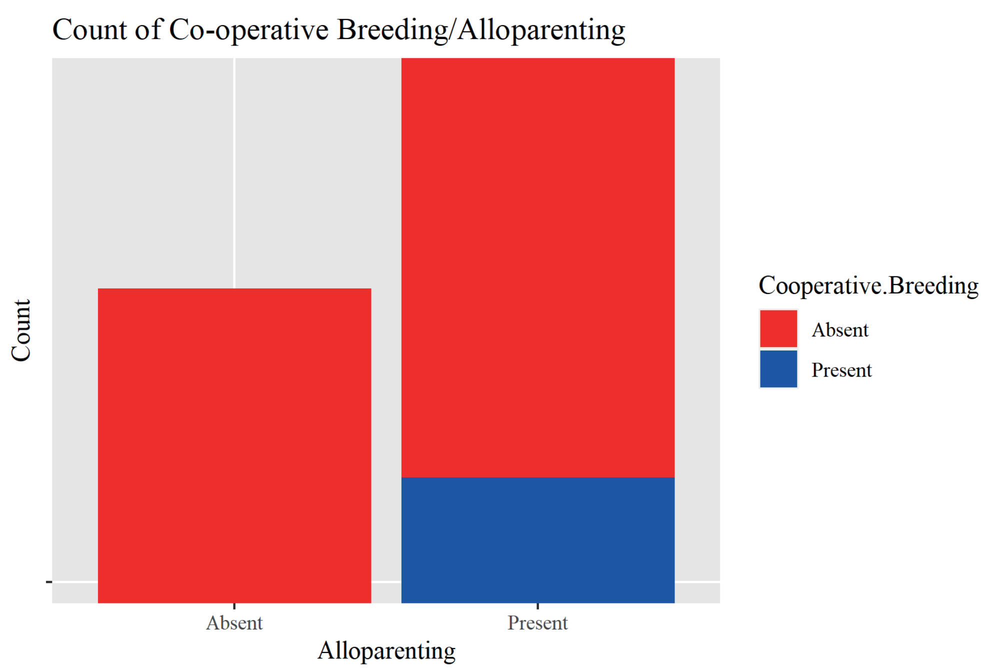

Figure S1. Bar graph representing perfect separation between co-operative breeding and allo-parenting

Table S3. McFadden's value for each full binary logit model

	Consolation	Group Foraging	Presence of Coalitions	Group Hunting	Food Sharing	Allo-Parenting
McFadden's ρ^2	0.26	0.48	0.51	0.25	0.15	0.11

Table S4. Empathy presence in a logit model with the consolation prosocial variable

	Estimate	Std. Error	Z-Value	Pr(>|Z|)
Intercept	-3.26	1.02	-3.20	0.00
Empathy Presence	2.97	1.15	2.58	0.01

Pr(>|Z|) = P-value associated with Z-score.

Std.Error = standard error value.

Table S5. Converted odds ratios to probability presence. Probability of consolation is represented as a percentage where 0.037 = 3.7%

Empathy Presence	Fit	Se.fit	Residual Scale	UB	LB	Predicted Probability
Absent	-3.26	1.02	1.00	0.22	0.01	0.04
Present	-0.29	0.54	1.00	0.68	0.21	0.43

Se.fit = Standard Error of Fit

UB = Upper boundary of 95% confidence interval

LB = Lower boundary of 95% confident

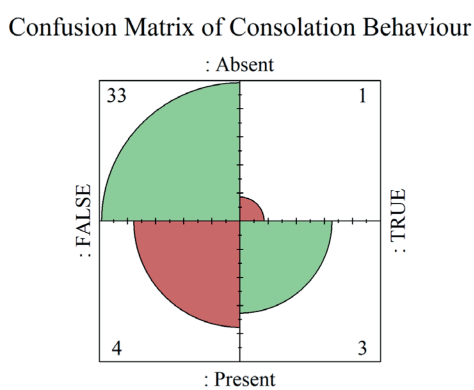

Figure S2. Four-fold plot displaying results of confusion matrix for consolation (DV) and empathy presence (IV) logit model

Table S6. 95% Confidence estimates for full binary logit modes compared to their respective LOOCV models

	AUC Consolation	LOOCV	AUC Food Sharing	LOOCV	AUC Group Foraging	LOOCV	AUC Presence of Coalitions	LOOCV
LB	0.80	0.41	0.58	0.29	0.81	0.75	0.89	0.80
PE	0.91	0.66	0.72	0.50	0.91	0.86	0.96	0.91
UB	1.00	0.90	0.87	0.70	1.00	0.98	1.00	1.00

LB = Lower boundary of 95% confidence interval
PE = Point estimate of 95% confidence interval
UB = Upper boundary of 95% confidence interval
LOOCV = Leave one out cross validation

Table S7. Logit model results of home range and daily socialization predicting group-foraging

	Estimate	Std.Error	Z-value	Pr(>|Z|)
Intercept	-2.40	0.97	-2.48	0.01
Home Range	0.37	0.17	4.14	0.03
Daily Social	0.37	0.16	2.33	0.02

Pr(>|Z|) = P-value associated with Z-score.
Std.Error = standard error value.

Table S8. Model summary of SEMB variables predicting the presence of coalitionary behavior in the primate sample

	Estimate	Std.Error	Z-value	Pr(>|Z|)
Intercept	-4.10	1.68	-2.44	0.02
Daily Social	0.60	0.29	2.05	0.04
Food Sharing	-4.75	2.26	-2.10	0.04
Hierarchy(Despotic)	4.13	1.60	2.58	0.01
Hierarchy(Egalitarian)	2.23	1.83	1.22	0.22

Pr(>|Z|) = P-value associated with Z-score.
Std.Error = standard error value.

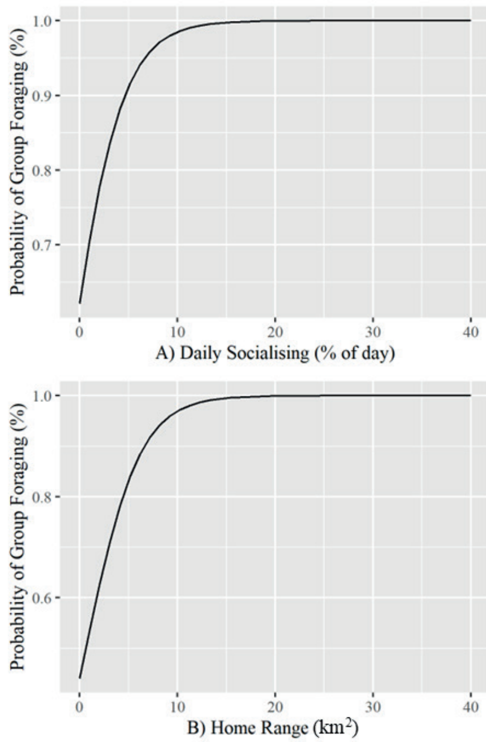

Figure S3. A) Daily Social Predicting Probability of Group Foraging – Predictions of group foraging based on the varying amounts of daily socialization in primates are more unstable at lower ranges. B) Home Range Predicts Probability of Group Foraging – Predictions of group foraging based on varying home ranges of primates reveal that smaller home ranges (below 2 km^2) poorly predict group foraging behaviors in primates. Home ranges above 5 km^2 predict the presence of group foraging in primates much more successfully

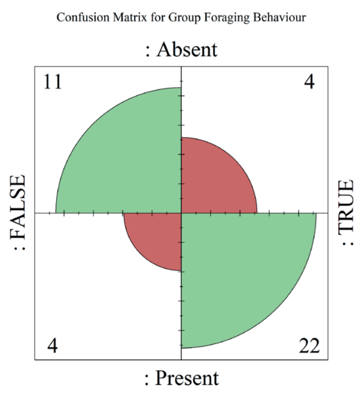

Figure S4. Four-fold plot displaying results of confusion matrix for group foraging (DV) and daily social & home range (IV) logit model

Table S9. Imputed results of GLM between group-hunting and adult-sex ratio and testosterone baseline

Term	Estimate	Std.Error	Fit	Df	P.Value
Intercept	-2.86	1.33	-2.15	30.74	0.04
Adult Sex Ratio	0.02	0.01	1.24	25.13	0.23
Baseline Testosterone	-0.04	0.08	-0.52	24.76	0.61

Df = Degrees of Freedom
Std.Error = Standard Error

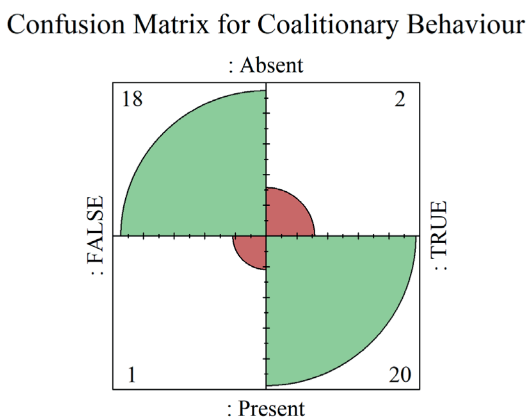

Figure S5. Four-fold plot displaying results of confusion matrix for Presence of Coalitions (DV) and daily social, food-sharing and hierarchy type (IV's) logit model

Table S10. Logit model results dispalying the predictive ability of the presence of coalitions on food-sharing in primates

	Estimate	Std.Error	Z-value	Pr(>|Z|)
Intercept	0.11	0.46	0.23	0.82
Presence of Coalitions	-1.95	0.77	-2.53	0.01

Pr(>|Z|) = P-value associated with Z-score.
Std.Error = standard error value.

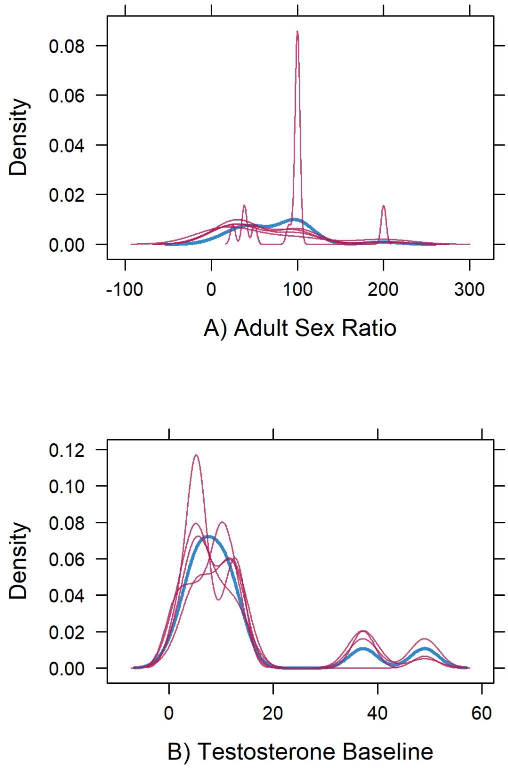

Figure S6. A) Imputed adult-sex ratio results in 5 iterations visualized on a density plot. Red lines show imputed values, while the blue line shows the original values. In this scenario adherence is accuracy. B) Imputed testosterone baseline results in 5 iterations visualized on a density plot. Red lines show imputed values, while the blue line shows the original values. In this scenario adherence = accuracy

Table S11.Odds ratios converted to probabilities where the presence of coalitions predicts food-sharing in primates

Presence of Coalitions	**Fit**	**Se.fit**	**Residual. Scale**	**UL**	**LL**	**Predicted Probability**
Absent	0.11	0.46	1.00	0.73	0.31	0.53
Present	-1.85	0.62	1.00	0.35	0.05	0.14

Se.fit = Standard Error of Fit

UB = Upper boundary of 95% confidence interval

LB = Lower boundary of 95% confident

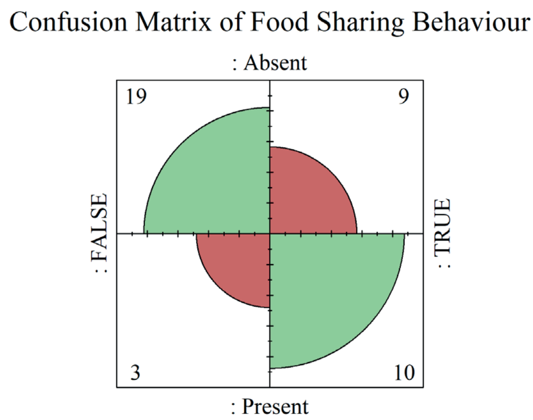

Figure S7. Four-fold plot displaying results of confusion matrix for Food-Sharing (DV) and presence of coalitions (IV) logit model

Supplementary File 2

Towards Better Predictors for IBNS and Group Hunting in Primates

There exist limited data on testosterone levels and adult sex ratios in many primates within our sample; limiting statistical analyses. Therefore, imputation was used to continue the analysis with these variables. While imputation is commonly used in machine learning analyses, it carries a significant risk of distorting ordinal data (Alam 2023). Adult sex ratio and testosterone were not significant predictors of group hunting in primates based on simulated data (Table S10). Reliability tests showed varied adherence to original data and so the pooled results of imputed logit models should be taken with caution (Figure S6a and S6b). Currently, we did not find any empirical evidence that supported a relationship between higher levels of testosterone and group-hunting. Group-hunting is a primarily co-operative behavior that likely uses neuroendocrine (dopamine) systems associated with reward and co-ordination (Samuni et al. 2018). However, this does not imply that testosterone is unrelated to hunting behavior (Trumble et al. 2014), nor that it is irrelevant to other displays of in-group co-operation (Reimers and Diekhof 2015). Ultimately, testosterone is an unlikely factor that could predict group-hunting. Dopamine presents a possible avenue for predicting group hunting in primates and would potentially show more association with IBNS (Previc 2009).

Group-hunting in primates is not strictly unisexual (Strum 1981; Gilby et al. 2015; Klein et al. 2021). This trend is also reflected in hominins, with recent research challenging the man-the-hunter hypothesis (Haas et al. 2020). However, this should not rule out adult sex ratio as a predictive variable of group-hunting in primates. Considering the effects of adult sex ratio on male-male mating competition (Darwin 1871) along with the fact that hunting ability influences mating access in *P. troglodytes* and hominins (Crick et al. 2013; Chaudhary et al. 2016), male adult sex ratio could be a plausible factor in predicting group-hunting in primates. However, looking at adult sex ratio and group hunting from the male perspective is one-dimensional and could limit predictions of group hunting in primates. In *P. troglodytes*, group-hunting probability increases with more females present; however, this statistic may be influenced by seasonal breeding and age-rank (Gilby et al. 2015). Therefore, it is likely a combination of mating competition, rank order, and adult sex ratio of both sexes which could potentially predict the likelihood of group hunting in primates. The dopaminergic system in apes facilitates communication and cooperation, underpinning motivation for exploration and problem-solving; enabling adaptation to a dynamic environment which is key in group-hunting efforts such as those seen in *P. troglodytes* (Previc 2009; Mine et al. 2022). Analysis of group-hunting probability using the SEMB variables listed above should be carried out in future research. Predictions of group-hunting using this combination of variables will likely reveal which primates should be investigated to observe IBNS evoked by group-hunting. Ultimately, this may reveal unique topographic IBNS patterns specific to cortical areas associated with group-hunting in primates.

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