How to Measure Intersexual Dominance?

Supplementary Material

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Contents

1 DomWorld parameters

A list of standard parameter values for our simulations in DomWorld (Table S1)

Table S1: Default parameters for DomWorld simulations

Parameter	Females	Males
Number of mental battles	1	1
Field of View	120	120
PersSpace	2	2
NearView	24	24
MaxView	48	48
FleeDist	2	2
WithdrawDist	0	0
ChaseDist	1	1
MoveDist	1	1
WiggleTurn (WiggleTurnError)	0 (10)	0 (10)
SearchTurn (SearchTurnError)	90 (10)	90 (10)
WonTurn (WonTurnError)	0 (0)	0 (0)
FleeTurn (FleeTurnError)	180 (10)	180 (10)

2 FDI and dominance hierarchies

We performed Spearman correlations between observed and internal values of intersexual dominance. We did this on 40 runs of each parameter setting (n = 36) in DomWorld. We compare different ways of calculating the Female Dominance Index (FDI) based on the different ways of deriving a hierarchy. We use three popular methods in the literature, David's score (Gammell 2003; de Vries 2006), Average Dominance Index (Hemelrijk et al. 2005), the I&SI algorithm (de Vries 1998) and randomised Elo-rating (Farine and Sanchez 2021).

2.1 Methods of calculating a dominance hierachy

2.1.1 I&SI

The I&SI methods aims to order individuals in a maximally linear hierarchy. It does this by reducing the number of inconsistencies (a lower ranking individual winning against a higher ranking individual) and the strength (rank distance) of these inconsistencies in a dominance hierarchy (de Vries, 1998). It does this by first ordering individuals based on how many opponents they dominate. Then, it implements an iterative process, where each lower ranking individual in an inconsistency gets repositioned to a randomly higher rank; this process retains the rank order with the minimal number of inconsistencies (I) over all iterations. This process is repeated with a similar iterative process to minimize the strength of inconsistencies (SI); however, the number of inconsistencies (I) is prioritized over the strength of inconsistencies (SI), and a new order of ranks with weaker inconsistencies is retained only if the number of inconsistencies remains the same. In the end, there may be multiple possible hierarchies with the same number and strength of inconsistencies. In this case, individuals are provided with average ranks.

2.1.2 David's score

David's score is calculated based on the number of wins and losses per individual with other individuals using the calculation w + w2 - l - l2 where w refers to the summed proportion of conflicts an individual (i) wins with each of its partners (j) (Pij), w2 is the summed w of the individual i weighted by the w of the interacting individual j. l and l2 are similar but for losses, with l calculated as the summed proportion of conflicts lost (Pji) and l2 the summed l weighted by l values of the appropriate partner (de Vries, 1998). The David's score can either be un-modified (referred to as Pij) or corrected for chance, where the number of interactions in each dyad is taken into consideration and the proportions of wins and losses are modified accordingly (referred to as Dij: de Vries, 1998; de Vries et al., 2006). In the present study we use the Dij method (corrected for chance), since it performed significantly better than the Pij method (paired Wilcoxen test, V = 308, $p < 0.001$).

2.1.3 Randomised Elo-rating

Randomised Elo-rating is a form of Elo-rating where the order of interactions are randomised a number of times (in our case 1000) and then the Elo-scores per individual are averaged. Individuals are ordered from highest to lower in their Elo-scores to determine a dominance hierarchy. In the original Elo-rating, individuals are assigned initial Elo-scores of arbitrarily 1000 and these scores develop overtime as individuals interact. When two individuals have a conflict, they both have a probability to win against the other calculated. If the two partners have the same Elo-score then the probaiblty to win for each of them is equal (0.5) and this probability increases (decreases) the higher (lower) the Elo-score is of them compared to their partner. The probability of individual A winning against individual B is calculated as shown in equation S1. In the r package aniDom (Farine & Sanchez-Tojar, 2021) the value that controls the steepness of the sigmoid function ('0.01' in equation 1) can be changed, but we kept it as the default parameter.

$$EquationS1 : P_A = \frac{1}{1 + exp(-0.01(Elo_A + Elo_B))}$$

Following a conflict, the winner's Elo-score is increased and the losers Elo-score is decreased according to equation S2. Unexpected results (e.g. .g. lower ranked individual wins) update Elo-scores more than expected results (higher ranked individual wins). The value of k is a constant (in our case 200) and scales the degree in which Elo-scores are updated for the winner and loser; the update to Elo-scores is larger if k is larger.

$$EquationS2 : Elo_A, new = Elo_A, old + (1 - P_A)k$$

2.1.4 Average Dominance Index

The Average Dominance Index (ADI) is the average proportion of conflicts an individual win against each opponent, excluding those opponents it did not interact with (Hemelrijk et al., 2005). Thus, an individual A that wins eight out of ten times with individual B, six out of ten times with individual C, and never interacts with individual D, has a score of 0.7, that is the average proportion of wins of the two known dyads.

2.2 Accuracy of different hierarchy methods

Regarding hierarchies built from all interactions, David's score performed best, followed by Average Dominance Index, I&SI algorithm and randomised Elo-rating (Table S2, S3, S4).

Table S2: Summary statistics for correlations between FDI and internal degree of intersexual dominance based on different methods of deriving a hierarchy

Measure	variable	n	min	max	median	iqr	mean	sd	se	ci
FDIADI	value	36	0.40	0.96	0.80	0.22	0.76	0.16	0.03	0.05
FDIDS	value	36	0.39	0.96	0.81	0.15	0.78	0.14	0.02	0.05
FDIISI	value	36	-0.01	0.93	0.48	0.30	0.51	0.23	0.04	0.08
FDI_EloRatingRand	value	36	-0.04	0.72	0.44	0.26	0.40	0.20	0.03	0.07

We compared the ordinal ranks of individuals in their intrasexual hierarchy with their ordinal ranks in relative to other members of their own sex in the internal hierarchy. We calculated intrasexual dominance hierarchies either using only outcomes from intersexual conflicts or using both intra- and intersexual conflicts.

Table S3: Friedman test comparing accuracy of different ways of deriving a hierarchy in order to calculate FDI (all interactions)

.y.	n	statistic	df	p	method
value	36	90.159	3	0	Friedman test

Table S4: Paired Wilcoxon tests between FDI based on different methods of deriving a hierarchy (all interactions) correlated with the internal degree of intersexual dominance

.y.	group1	group2	n1	n2	statistic	p	p.adj	p.adj.signif
value	FDI_EloRatingRand	FDIADI	36	36	0	0	0	****
value	FDI_EloRatingRand	FDIDS	36	36	0	0	0	****
value	FDI_EloRatingRand	FDIISI	36	36	146	0	0	**
value	FDIADI	FDIDS	36	36	100	0	0	***
value	FDIADI	FDIISI	36	36	666	0	0	****
value	FDIDS	FDIISI	36	36	666	0	0	****

We found that intrasexual hierarchies were more accurate when both intra- and intersexual were used in the analysis rather than just intrasexual conflicts (Table S5).

Table S5: Comparison of accuracy (correlation with internal hierarchy) of male and female intra-sexual hierarchies built from only intrasexual conflicts, or all conflicts)

Sex	.y.	group1	group2	n1	n2	statistic	p
Female	value	Intra- and intersexual conflicts	Intrasexual conflicts	36	36	879.0	0.009
Male	value	Intra- and intersexual conflicts	Intrasexual conflicts	36	36	916.5	0.003

3 Measures of intersexual dominance

We here report the summary statistics on the correlations between the observed values and internal values of intersexual dominance for the measures we studied FDI, the proportion of intersexual conflicts initiated (PISI), the proportion of intersexual conflicts won (PISW) and the proportion of female-dominant dyads (PFDD) (Table S6).

Table S6: Summary statistics for all measures of intersexual dominance (values are correlations with internal intersexual dominance)

Measure	variable	n	min	max	median	iqr	mean	sd	se	ci
FDIDS	value	36	0.393	0.962	0.815	0.154	0.784	0.143	0.024	0.048
PropInterSexConflictsInit	value	36	0.305	0.938	0.839	0.110	0.779	0.160	0.027	0.054
PropInterSexConflictsInitGroup	value	36	0.259	0.925	0.841	0.148	0.774	0.170	0.028	0.058
PropInterSexConflictsWon	value	36	0.282	0.920	0.789	0.162	0.737	0.146	0.024	0.049
PropInterSexConflictsWonGroup	value	36	0.295	0.910	0.797	0.174	0.743	0.153	0.025	0.052
PropFemDomDyad0.5	value	36	0.351	0.908	0.671	0.180	0.668	0.158	0.026	0.053

3.1 Group versus individual level measures

Interestingly, we find that group measures of proportion of intersexual conflicts won and initiated were slightly higher median and correlation than at the individual level, but do not have a higher mean or smaller iqr (Table S6). Nevertheless, we strongly urge researchers to use individual levels measures which are less likely to be biased by a single individual or dyad, although this was not the case in our data (Fig S1).

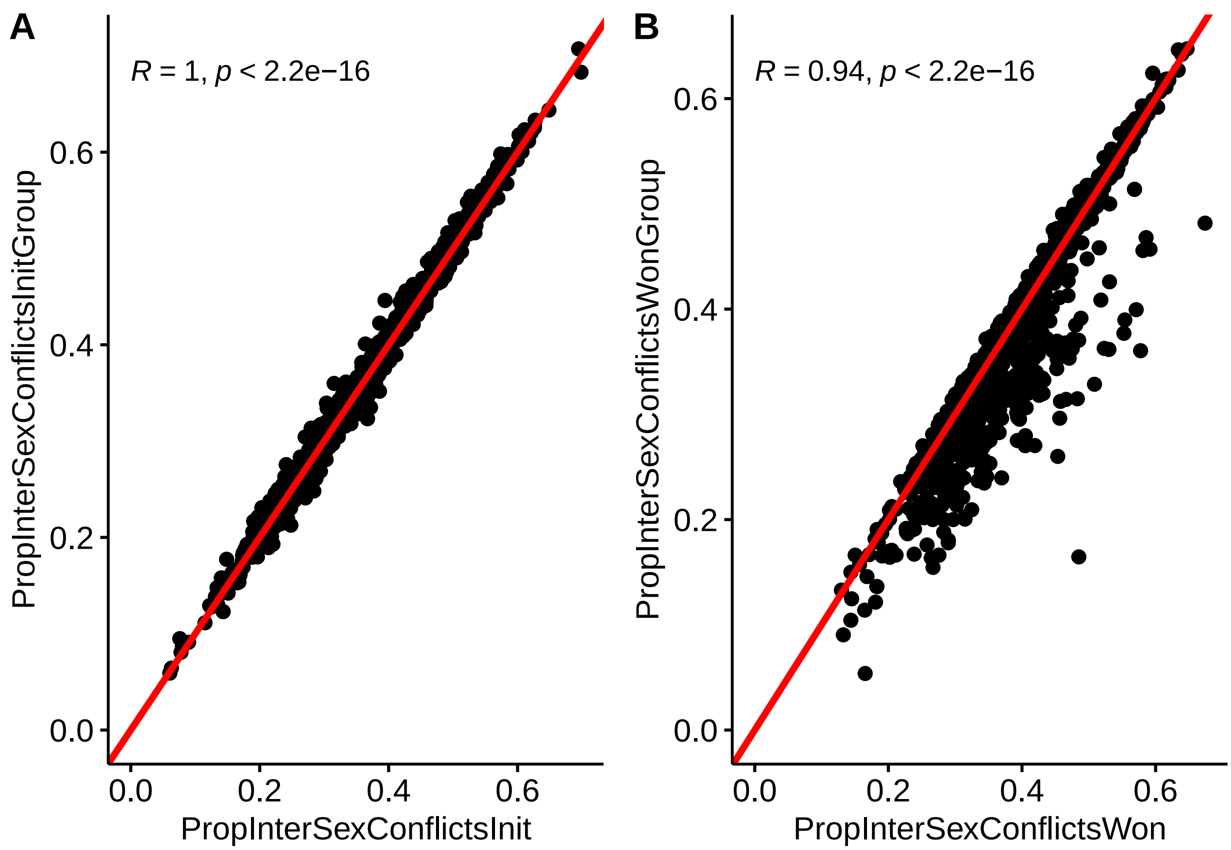

Figure S1: A) Relationship between the proportion of intersexual conflicts initiated on an individual and group level (n = 1440) B) Relationship between the proportion of intersexual conflicts won on an individual and group level (n = 1440)

3.2 Effects of the measure used, intensity of aggression, group size and sex ratio (GLM)

Excluding group-level measures, we tested whether the strength of the correlation between the observed and internal measure depended on the measure used, the intensity of aggression, sex ratio or group size using a GLM with beta family and logit link (Table S7). We found all variables significantly affected the accuracy (compared to the internal degree of intersexual dominance), apart from the sex-ratio (proportion of females in the group) (Table S8).

Table S7: Summary results of beta GLM of the effect of GroupSize, Intensity of aggression, sex ratio and measure used on how well values of intersexual dominance correlated with internal values

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.99	0.15	20.12	0.00
GroupSize	-0.05	0.00	-13.29	0.00
IntensityLow	-1.42	0.09	-16.41	0.00
IntensityMed(Mono)	-0.24	0.09	-2.54	0.01
IntensityMed(Sexdi)	-0.21	0.09	-2.21	0.03
SexRatio2	-0.18	0.16	-1.09	0.28
variablePISW	-0.29	0.09	-3.34	0.00
variablePISI	-0.04	0.09	-0.43	0.67
variablePFDD	-0.65	0.09	-7.54	0.00

Table S8: Likelihood ratio tests between full model and model without that variable

Variable	X2	df	p_LRT
Measure	58.78	3	0.00
GroupSize	117.93	1	0.00
SexRatio	1.19	1	0.28
Intensity of aggression	178.14	2	0.00

We performed post-hoc pairwise analyses (emmeans contrasts) on significant factors and found that high and moderate intensities of aggression resulted in more accurate results (Table S9), and that FDI and PISI were significantly better than other measures (Table S10, Fig S2)

Table S9: Post-hoc comparisons of different intensities of aggression in relation to how well measures reflected the internal intersexual dominance

contrast	estimate	SE	df	t.ratio	p.value
High - Low	1.42	0.09	134	16.41	0.00
High - Med(Mono)	0.24	0.09	134	2.54	0.06
High - Med(Sexdi)	0.21	0.09	134	2.21	0.13
Low - Med(Mono)	-1.18	0.08	134	-14.15	0.00
Low - Med(Sexdi)	-1.21	0.08	134	-14.58	0.00
Med(Mono) - Med(Sexdi)	-0.03	0.09	134	-0.35	0.99

Table S10: Post-hoc comparisons of different measures in relation to how well they reflected the internal intersexual dominance

contrast	estimate	SE	df	t.ratio	p.value
FDI - PISW	0.295	0.088	134	3.338	0.006
FDI - PISI	0.038	0.090	134	0.428	0.974
FDI - PFDD	0.649	0.086	134	7.537	0.000
PISW - PISI	-0.256	0.088	134	-2.924	0.021
PISW - PFDD	0.354	0.084	134	4.214	0.000
PISI - PFDD	0.610	0.086	134	7.130	0.000

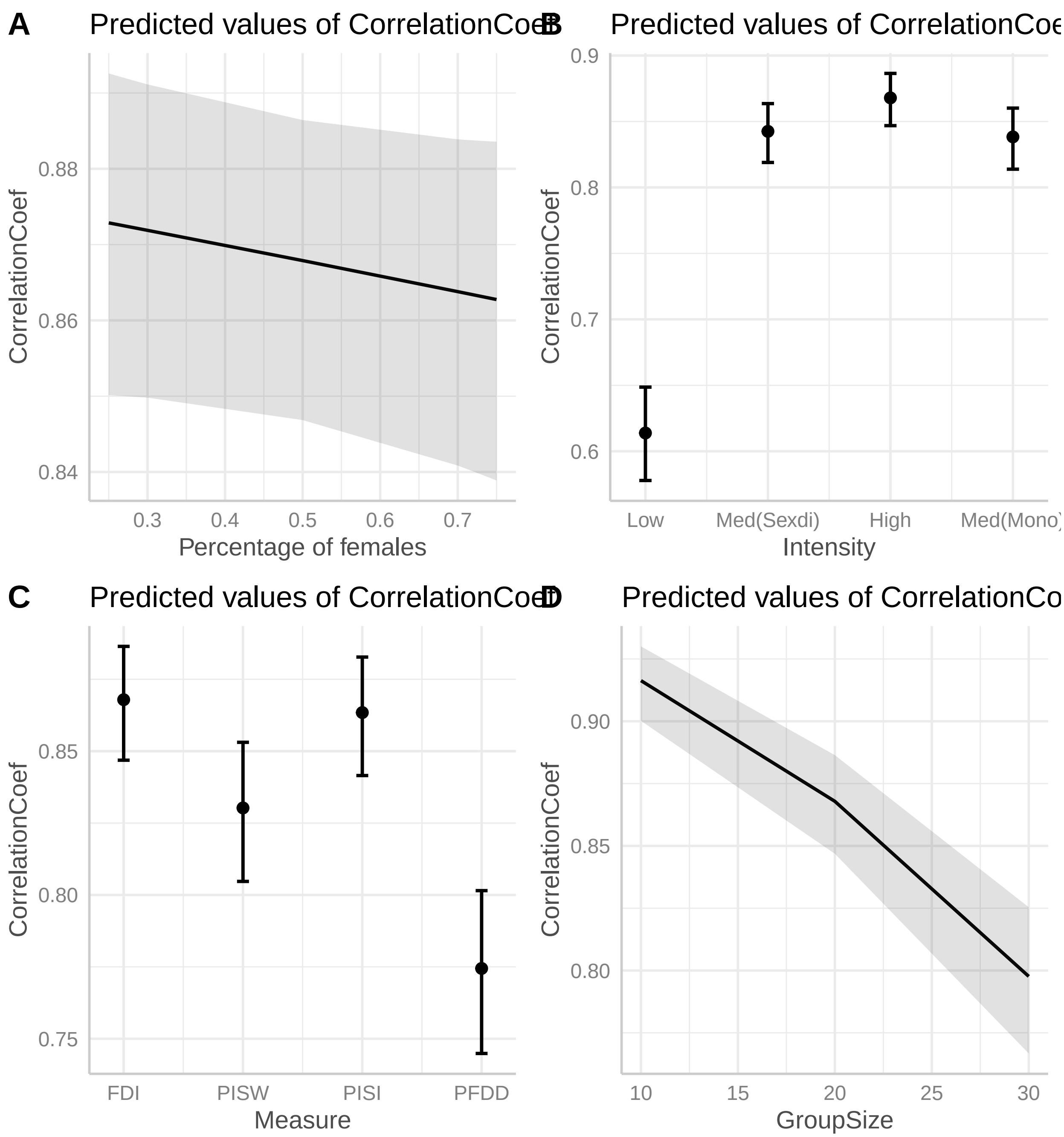

Figure S2: Partial residual plots of GLM examining differences in the correlation coefficicent between observed and internal values for differences in A) Sex Ratio B) Intensity of aggression C) Measure used D) GroupSize

We tested the goodness of fit of the model by simulating residuals and comparing them to the output of the model (Fig S3). There seemed to be no significant deviation from normality, over dispersion or outliers.

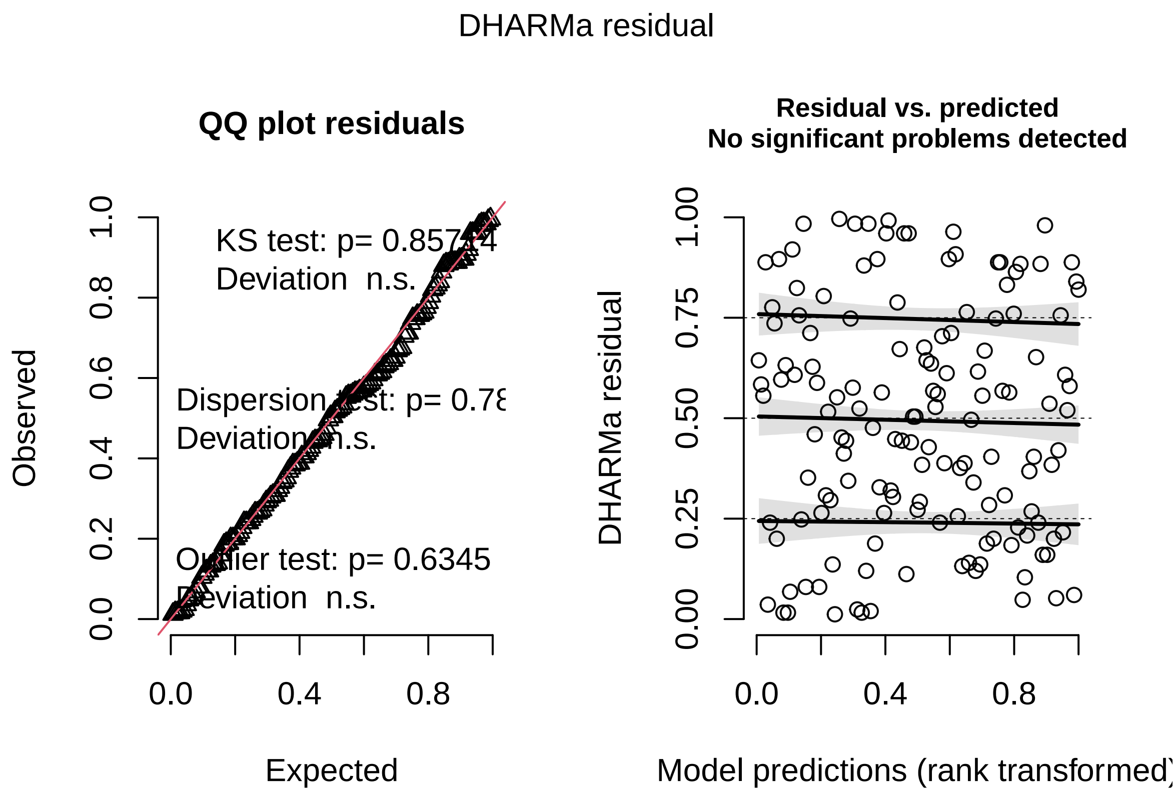

Figure S3: Simulated against fitted residuals of the beta GLM. Tests indictate non-significance for absense of normality, under/over-dispersion or outliers

4 Robustness of measures

To replicate shorter observation times, we omitted 5, 10, 15, 20 and 25 periods spread equally between periods 230-260 of 40 runs per parameter setting and calculated the different measures of intersexual dominance. We then correlated the values of intersexual dominance with the proportion of missing data to examine whether any measures are influenced by fewer data. We did this for a range of intensities of aggression and group size (Table S11).

4.1 Table of all parameter settings

Table S11: Correlations and p values between proportion of missing time and values of intersexual dominance for 36 different parameter settings in DomWorld

X	SimName	FDI	p	PISW	p.1	PISI	p.2	PFDD	p.3
1	F3M7_0.05_0.5	0.12	0.06	-0.01	0.83	0.02	0.82	0.39	0.00
2	F3M7_0.1_1	0.04	0.58	0.01	0.90	-0.01	0.92	0.24	0.00
3	F3M7_0.8_1	0.00	0.95	0.01	0.82	-0.03	0.60	0.19	0.00
4	F3M7_0.5_0.5	-0.03	0.66	-0.02	0.79	-0.04	0.52	0.08	0.19
5	F5M5_0.05_0.5	0.25	0.00	0.03	0.61	0.02	0.74	0.47	0.00
6	F5M5_0.1_1	0.11	0.10	0.08	0.23	0.01	0.83	0.32	0.00
7	F5M5_0.8_1	0.03	0.64	0.12	0.07	0.01	0.91	0.24	0.00
8	F5M5_0.5_0.5	0.06	0.38	0.03	0.62	-0.08	0.20	0.12	0.07
9	F7M3_0.05_0.5	0.29	0.00	0.20	0.00	-0.01	0.88	0.53	0.00
10	F7M3_0.1_1	0.06	0.36	0.09	0.15	0.01	0.84	0.25	0.00
11	F7M3_0.8_1	0.06	0.37	0.15	0.02	0.03	0.65	0.18	0.00
12	F7M3_0.5_0.5	0.06	0.37	0.15	0.02	0.03	0.65	0.18	0.00
13	F5M15_0.05_0.5	0.39	0.00	0.06	0.39	-0.03	0.67	0.71	0.00
14	F5M15_0.1_1	0.10	0.12	0.06	0.35	-0.03	0.62	0.47	0.00
15	F5M15_0.8_1	0.11	0.08	0.04	0.55	-0.02	0.80	0.51	0.00
16	F5M15_0.5_0.5	-0.02	0.77	0.02	0.70	0.01	0.85	0.44	0.00
17	F10M10_0.05_0.5	0.40	0.00	0.13	0.05	-0.04	0.56	0.76	0.00
18	F10M10_0.1_1	0.16	0.01	0.16	0.01	0.06	0.34	0.68	0.00
19	F10M10_0.8_1	0.09	0.16	0.18	0.01	-0.02	0.71	0.51	0.00
20	F10M10_0.5_0.5	0.06	0.39	0.11	0.10	-0.02	0.81	0.50	0.00
21	F15M5_0.05_0.5	0.40	0.00	0.37	0.00	0.05	0.43	0.64	0.00
22	F15M5_0.1_1	0.23	0.00	0.39	0.00	0.00	0.98	0.64	0.00
23	F15M5_0.8_1	0.14	0.03	0.46	0.00	0.05	0.44	0.58	0.00
24	F15M5_0.5_0.5	-0.04	0.57	0.25	0.00	-0.03	0.68	0.43	0.00
25	F8M22_0.05_0.5	0.53	0.00	0.11	0.08	0.01	0.92	0.71	0.00
26	F8M22_0.1_1	0.29	0.00	0.19	0.00	-0.02	0.71	0.65	0.00
27	F8M22_0.8_1	0.19	0.00	0.16	0.01	0.04	0.54	0.53	0.00
28	F8M22_0.5_0.5	-0.08	0.23	0.05	0.48	-0.04	0.49	0.58	0.00
29	F15M15_0.05_0.5	0.57	0.00	0.29	0.00	-0.02	0.72	0.78	0.00
30	F15M15_0.1_1	0.36	0.00	0.34	0.00	0.11	0.09	0.70	0.00
31	F15M15_0.8_1	0.23	0.00	0.34	0.00	0.05	0.46	0.65	0.00
32	F15M15_0.5_0.5	0.00	0.97	0.20	0.00	0.08	0.20	0.64	0.00
33	F22M8_0.05_0.5	0.49	0.00	0.55	0.00	0.00	0.96	0.67	0.00
34	F22M8_0.1_1	0.30	0.00	0.51	0.00	0.03	0.68	0.58	0.00
35	F22M8_0.8_1	0.22	0.00	0.50	0.00	-0.02	0.81	0.62	0.00
36	F22M8_0.5_0.5	0.04	0.53	0.42	0.00	0.00	0.95	0.56	0.00

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