

Supplementary Information

Meta-analytic evidence that sexual selection improves population fitness

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Supplementary Methods

Our aim was to investigate the effects of sexual selection on population fitness by conducting a meta-analysis on studies that measured fitness related outcomes after experimentally evolving a population under varying levels of opportunity for sexual selection. Here we describe the process of the literature search, data extraction, effect size calculation, formulation of multilevel models and assessing publication bias. We used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) as a guide during this meta-analysis. The repository used to formulate this document can be found here: <https://github.com/JustinCally/SexualSelection>. The more extensive HTML version of Supplementary Information is hosted through github pages here: <https://justincally.github.io/SexualSelection/>

Literature Search

The literature search was conducted under the following conditions:

1. We searched ISI Web of Science and Scopus on 9th June 2017. The two search engines produced a somewhat different set of papers (**see PRISMA Figure in manuscript**).
2. Studies were restricted to those from peer-reviewed and in the English language.
3. We devised a search strategy that sought to find studies which manipulated the presence or strength of sexual selection using experimental evolution, and then measured some proxy of population fitness. As such the search terms were as follows:

ISI Web of Science

We used the following search on ISI Web of Science:

Topic (TS) = “Sexual Selection” OR Promisc* OR Monogam* OR Polygam* OR Polyandr* OR Polygyn* OR “Mate choice”

AND

Topic (TS) = Fitness OR “Population Fitness” OR Deleterious OR “Male Strength” OR Fecund* OR Viability OR Productiv* OR “Reproductive Success” OR “Reproductive Rate” OR Surviv* OR | “Development Rate” OR Extinct* OR “Competitive Success” OR Mortality OR Mass OR “Body Size” OR “Wing Size” OR Emergence OR Mating Rate OR “Mating Propensity” OR Adapt* OR “Novel | Environment” OR “Sexual Conflict” OR “Sexual Antagonis*”

AND

Topic (TS) = Generations OR “Experimental evolution” OR “mutation load”

AND

Research Area (SU) = “Evolutionary Biology”

Scopus

We used the following search on Scopus:

TITLE-ABS-KEY = “Sexual Selection” OR Promisc* OR Monogam* OR Polygam* OR Polyandr* OR Polygyn* OR “Mate choice”

AND

TITLE-ABS-KEY = Fitness OR “Population Fitness” OR Deleterious OR “Male Strength” OR Fecund* OR Viability OR Productiv* OR “Reproductive Success” OR “Reproductive Rate” OR Surviv* OR | “Development Rate” OR Extinct* OR “Competitive Success” OR Mortality OR Mass OR “Body Size” OR “Wing Size” OR Emergence OR Mating Rate OR “Mating Propensity” OR Adapt* OR | “Novel Environment” OR “Sexual Conflict” OR “Sexual Antagonis*”

AND

TITLE-ABS-KEY = Generations OR “Experimental evolution” OR “mutation load”

Additions to the Literature Search

In addition to studies found from the literature search we also included three relevant studies that we found, which were not picked up in the subsequent formal searches^{1–3} see **PRISMA Figure in manuscript**.

Inclusion/Exclusion criteria

After removing duplicates papers recovered from both *Web of Science* and *Scopus*, we read the titles and abstracts of the remaining 1015 papers, and removed papers that were not relevant (typically because they were not an empirical study using experimental evolution). This left 130 papers, for which we read the full text and applied the following selection criteria:

- **(1: Study Design)** The study was an experimental evolution study lasting >1 generation
- **(2: Population)** a) The study was conducted using an animal species that was b) dioecious
- **(3: Intervention and Control)** The study experimentally manipulated the strength of sexual selection for at least one generation (e.g. via enforced monogamy or an altered sex ratio)
- **(4: Outcomes)** The study measured a trait that we judged to be a potential correlate of population fitness.

Criterion 4 is somewhat subjective, because there is rarely enough data justify the assumption that a particular trait is (or is not) correlated with population fitness. We therefore relied on our best judgement when deciding which studies to exclude (see **Supplementary Table 1**). The inclusion/exclusion criteria as applied to each study are detailed in **Supplementary Table 2**.

Data Extraction and Effect Size Calculation

The rules utilised during the data extraction and effect size calculation were as follows:

1. Arithmetic means, standard deviations/errors and sample sizes were extracted from a paper, supplementary material or a linked data repository (e.g. Data Dryad). This was possible when means and SD were reported in text or in a table. We would preferentially extract data for each experimental evolution line/replicat/family if possible and only extract data for the final reported generation (which was noted down).
2. If we could not find the means and SD in text format we used web-plot digitizer (v.3.12) to extract data from graphs.
3. If means were not reported then we extracted a summary statistic or proportion value, which we could later convert to Hedges g' using the *compute.es* package⁴. Summary statistics included F , z , t and χ^2 . These conversions still required providing sample sizes for each treatment so these needed to be extractable from the study. Some summary statistics were obtained from generalized linear model summary tables, others from straight forward ANOVAs and then some from more complex analysis such as proportional hazards statistical tests.
4. We also collected various covariates for some of the studies (**Supplementary Table 3**), which are discussed later.

Supplementary Table 1

We classified each of the twenty fitness outcomes into three broad groups – direct, indirect and ambiguous – based on the established link with population fitness, the directionality of the measure. Here we detailed how these outcomes were measured in the primary studies, which are cited in the “Citation” column.

Outcome	Classification	Explanation	Citation
Behavioural Plasticity	Ambiguous	Female kicking against male harassment in different sociosexual contexts for the beetle <i>Callosobruchus maculatus</i> .	5
Body Size	Ambiguous	Body size was often recorded to correct for other morphometric traits (e.g. body condition, strength or testes weight). It was measured as either length or dry mass.	6,7
Development Rate	Ambiguous	Egg-to adult development time was recorded in several studies and often alongside traits other life-history traits suspected to impact fitness.	8–10
Early Fecundity	Ambiguous	Early fecundity was measured (alongside lifetime fecundity) as a life-history trait that may impact lifetime reproductive success. It was defined as either the total or proportional reproductive output in earlier stages of maturity (e.g. within the first 7 days).	11,12
Immunity	Ambiguous	Phenoloxidase (PO) activity or parasite load.	10,13–15
Male Attractiveness	Ambiguous	Inferred from female preference tests in mice and male ornament size (coloration) in guppies.	16–18
Male Reproductive Success	Ambiguous	Measured as the total progeny sired in males.	9
Mating Duration	Ambiguous	Mating duration may have variable fitness impacts based on the sociosexual conditions and extent of sexual conflict. It may be beneficial to have longer mating bouts for a male in a competitive environment however it may be damaging for a female under benign conditions.	5,19–21
Pesticide Resistance	Ambiguous	Pesticide resistance was measured both in the presence and absence of pesticides for the insect <i>Tribolium castaneum</i> , it was a binary measure of resistance to knockdown that was incorporated into generalized linear mixed models.	22
Mutant Frequency	Indirect	Allele and mutant frequency measured at the population level.	23,24
Body Condition	Indirect	Mean body weight of <i>Onthophagus Taurus</i> adjusted for body size (thorax width).	6
Fitness Senescence	Indirect	Rate of decline in survival probability across lifespan.	9,25
Lifespan	Indirect	Longevity or survival across the entire lifespan or from a given point once under stressful conditions, such as starvation or after females mated in different operational sex ratios.	26,27
Mating Frequency	Indirect	Number of mounts by males on females in <i>Tribolium castaneum</i> and <i>Drosophila melanogaster</i> .	13,20
Mating Latency	Indirect	Time taken for a male to undertake their first copulatory mount from the time of being first put together with female/s.	5,9,19–21
Mating Success	Indirect	Male mating success measured males ability to successfully mate with females. Often in the presence of other males. Mating success of a male against a rival male can be determined via competing a focal male against an irradiated (infertile) competitor, the resulting proportion of eggs hatching are then determined to be a measure of the focal males success. Mating success also included measurements of mating capacity where males were continually presented with females until exhausted, the number of sequential matings were then recorded and mating offence and defence ability. The mating offence and defence capability was estimated via paternity share of a male when in the first mating position (P1) or the second (P2).	12,21,28–30
Strength	Indirect	Male pulling strength in the dung beetle, <i>Onthophagus Taurus</i> , measured by attaching weights and measuring the weight the beetle was able to pull.	7
Ejaculate Quality and Production	Indirect	Sperm quality and production grouped multiple measured outcomes together, both within a study (28) and during the meta-analysis. This includes sperm size, plug size, testes size, soporific effect, ejaculate weight, accessory gland size, motility, path velocity, sperm longevity.	5,31–34
Extinction Rate	Direct	Extinction rate was measured at the population level, either via recording the proportion of extinct lines after a given number of generations or via analysis of extinction rate over consecutive generations via the Weibull baseline hazard distribution.	35–37
Offspring Viability	Direct	Offspring viability, also recorded as egg-to-adult viability or embryonic viability, was measured as survival to a certain age (e.g. 1 year or life stage and hatching).	18,38
Female Reproductive Success	Direct	A measure of the number of offspring produced by an individual female. Reproductive success was also described as fecundity, number of offspring produced, fertility in females and proportion.	19,39,40
Both Reproductive Success	Direct	Similar to Female Reproductive Success, however measurements of offspring produced are sourced from a focal male-female pair, of which either male or female may limit the number of offspring produced.	37

Supplementary Table 2

A study was deemed eligible for inclusion in the meta-analysis if it met all four criteria discussed above (referred to by their numbers, 1-4, in this table). We went through these four criteria in a step-wise fashion, for each of the 130 studies for which we read the full text, and noted the first criterion that was failed (if any). For pdf formatting this table has been resized and does not have the paper title and notes. Please refer to the html table on github for the extensive table: <https://justincally.github.io/SexualSelection>

AuthorYear	Study Design	Population	Intervention and Control	Outcomes	Included	Exclusion Reason
Aguirre (2012) ⁴¹	No				No	1
Ahuja (2008) ⁴²	No				No	1
Almbro (2014) ⁷	Yes	Yes	Yes	Yes	Yes	
Amitin (2007) ⁴³	Yes	Yes	No		No	3
Antolin (2003) ⁴⁴	No				No	1
Arbuthnott (2014) ⁴⁵	Yes	Yes	No		No	3
Arbuthnott (2012) ²³	Yes	Yes	Yes	Yes	Yes	
Arbuthnott (2014) ⁴⁶	Yes	Yes	No		No	3
Archer (2015) ²⁵	Yes		Yes	Yes	Yes	
Artieri (2008) ⁴⁷	No				No	1
Bacigalupe (2007) ⁴⁸	Yes	Yes	Yes	No	No	4
Bacigalupe (2008) ⁴⁹	Yes	Yes	Yes	Yes	No	Data not suitable
Barbosa (2012) ⁵⁰	No				No	1
Bernasconi (2001) ⁴⁰	Yes	Yes	Yes	Yes	Yes	
Bielak (2014) ⁵¹	No				No	1
Blows (2002) ⁵²	Yes	Yes	Yes	No	No	4
Brommer (2012) ⁵³	Yes	Yes	Yes	Yes	Yes	
Castillo (2015) ⁵⁴	Yes	Yes	No		No	3
Cayetano (2011) ⁵⁵	Yes	Yes	Yes	No	No	4
Chandler (2013) ⁵⁶	Yes	No			No	2a
Chenoweth (2015) ⁵⁷	Yes	Yes	Yes	No	No	4
Chenoweth (2007) ⁵⁸	No				No	1
Chenoweth (2008) ⁵⁹	Yes	Yes	Yes	No	No	4
Chenoweth (2010) ⁶⁰	Yes	Yes	Yes	No	No	4
Crudgington (2005) ⁶¹	Yes	Yes	Yes	Yes	Yes	
Crudgington (2009) ³⁰	Yes	Yes	Yes	Yes	Yes	
Crudgington (2010) ¹¹	Yes	Yes	Yes	Yes	Yes	
Debelle (2016) ²⁸	Yes	Yes	Yes	Yes	Yes	
Demont (2014) ⁶²	Yes	Yes	Yes	Yes	Yes	
Edward (2010) ¹⁹	Yes	Yes	Yes	Yes	Yes	
Fava (1975) ⁶³	Yes	Yes	No		No	3
Firman (2011) ³⁹	Yes	Yes	Yes	Yes	Yes	
Firman (2014) ¹⁶	Yes	Yes	Yes	Yes	Yes	
Firman (2011) ⁶⁴	Yes	Yes	Yes	Yes	Yes	
Firman (2015) ⁶⁵	Yes	Yes	Yes	Yes	Yes	
Firman (2014) ⁶⁶	Yes	Yes	Yes	Yes	Yes	
Firman (2010) ³¹	Yes	Yes	Yes	Yes	Yes	
Firman (2011) ⁶⁷	Yes	Yes	Yes	Yes	Yes	
Firman (2012) ⁶⁸	Yes	Yes	Yes	Yes	Yes	
Fricke (2010) ⁶⁹	Yes	Yes	Yes	No	No	4
Fricke (2007) ⁸	Yes	Yes	Yes	Yes	Yes	
Fritzsche (2016) ⁷⁰	Yes	Yes	Yes	Yes	Yes	
Fritzsche (2014) ³²	Yes	Yes	Yes	Yes	Yes	
Garcia (2015) ⁷¹	Yes	Yes	Yes	Yes	No	Data not suitable
Gay (2009) ⁷²	Yes	Yes	No		No	3
Gay (2011) ⁷³	Yes	Yes	No		No	3
Gay (2009) ³³	Yes	Yes	Yes	Yes	Yes	
Grazer (2014) ⁷⁴	Yes	Yes	Yes	Yes	Yes	
Grieshop (2016) ⁷⁵	Yes	Yes	No		No	3
Hall (2009) ⁷⁶	Yes	Yes	No		No	3
Hangartner (2015) ¹³	Yes	Yes	Yes	Yes	Yes	
Hangartner (2013) ¹⁴	Yes	Yes	Yes	Yes	Yes	
Hicks (2004) ⁷⁷	Yes	Yes	No		No	3
Holland (2002) ⁷⁸	Yes	Yes	Yes	Yes	Yes	
Holland (1999) ⁷⁹	Yes	Yes	Yes	Yes	Yes	
Hollis (2009) ²⁴	Yes	Yes	Yes	Yes	Yes	
Hollis (2011) ⁸⁰	Yes	Yes	Yes	Yes	Yes	
Hollis (2016) ⁸¹	Yes	Yes	Yes	No	No	4
Hollis (2014) ⁸²	Yes	Yes	Yes	No	No	4
Hollis (2014) ⁹	Yes	Yes	Yes	Yes	Yes	

AuthorYear	Study Design	Population	Intervention and Control	Outcomes	Included	Exclusion Reason
Hollis (2017) ⁸³	Yes	Yes	Yes	Yes	Yes	
Hosken (2009) ⁸⁴	Yes	Yes	Yes	No	No	4
House (2013) ⁸⁵	Yes	Yes	Yes	No	No	4
Hunt (2012) ⁸⁶	Yes	Yes	Yes	No	No	4
Immonen (2014) ⁸⁷	Yes	Yes	Yes	Yes	Yes	
Innocenti (2014) ⁸⁸	Yes	Yes	Yes	Yes	Yes	
Jacomb (2016) ²²	Yes	Yes	Yes	Yes	Yes	
Janicke (2016) ⁸⁹	Yes	No			No	2b
Jarzebowska (2010) ³⁵	Yes	Yes	Yes	Yes	Yes	
Klemme (2013) ⁹⁰	Yes	Yes	Yes	Yes	Yes	
Long (2012) ⁹¹	Yes	Yes	No		No	3
Lumley (2015) ³⁷	Yes	Yes	Yes	Yes	Yes	
MacLellan (2012) ⁹²	No				No	1
MacLellan (2009) ⁹³	No				No	1
Maklakov (2009) ⁹⁴	Yes	Yes	Yes	Yes	Yes	
Maklakov (2009) ⁹⁵	Yes	Yes	Yes	No	No	4
Maklakov (2007) ⁹⁶	Yes	Yes	Yes	No	No	4
Mallet (2011) ⁹⁷	Yes	Yes	No		No	3
Mallet (2011) ⁹⁸	No				No	1
Martin (2003) ²⁷	Yes	Yes	Yes	Yes	Yes	
Martin (2004) ⁹⁹	Yes	Yes	Yes	Yes	Yes	
Matsuyama (2009) ¹⁰⁰	Yes	Yes	No		No	3
McGuigan (2011) ²⁹	Yes	Yes	Yes	Yes	Yes	
McKean (2008) ¹⁰	Yes	Yes	Yes	Yes	Yes	
McLain (1992) ¹⁰¹	No				No	1
McNamara (2016) ³⁴	Yes	Yes	Yes	Yes	Yes	
McNamara (2014) ¹⁵	Yes	Yes	Yes	Yes	Yes	
Meffert (2006) ¹⁰²	Yes	Yes	No		No	3
Michalczyk (2011) ¹⁰³	Yes	Yes	No		No	3
Michalczyk (2011) ²⁰	Yes	Yes	Yes	Yes	Yes	
Morrow (2008) ¹⁰⁴	Yes	Yes	No		No	3
Nandy (2013) ²¹	Yes	Yes	Yes	Yes	Yes	
Nandy (2014) ¹⁰⁵	Yes	Yes	No	Yes	Yes	
Nelson (2013) ¹⁷	Yes	Yes	Yes	Yes	Yes	
Nie (2016) ¹⁰⁶	No				No	1
Palopoli (2015) ¹⁰⁷	Yes	No			No	2b
Partridge (1980) ¹⁰⁸	Yes	Yes	Yes	Yes	Yes	
Pelabon (2014) ¹⁸	Yes	Yes	Yes	Yes	Yes	
Perry (2016) ¹⁰⁹	Yes	Yes	No		No	3
Pischedda (2005) ¹¹⁰	No				No	1
Pischedda (2006) ¹¹¹	No				No	1
Pitnick (2001) ¹¹²	Yes	Yes	Yes	Yes	Yes	
Pitnick (2001) ¹¹³	Yes	Yes	Yes	Yes	Yes	
Plesnar (2011) ³⁸	Yes	Yes	Yes	Yes	Yes	
Plesnar (2013) ¹¹⁴	Yes	Yes	Yes	No	No	4
Plesnar (2012) ³⁶	Yes	Yes	Yes	Yes	Yes	
Power (2014) ¹¹⁵	Yes	Yes	Yes	Yes	Yes	
Power (2015) ¹¹⁶	Yes	Yes	Yes	Yes	Yes	
Price (2010) ¹¹⁷	Yes	Yes	No		No	3
Prokop (2017) ¹¹⁸	No				No	1
Promislow (1998) ¹¹⁹	Yes	Yes	Yes	Yes	Yes	
Radwan (2004) ¹²⁰	Yes	Yes	Yes	Yes	Yes	
Radwan (2004) ¹²¹	Yes	Yes	Yes	Yes	Yes	
Rundle (2006) ¹²²	Yes	Yes	Yes	Yes	Yes	
Rundle (2009) ¹²³	Yes	Yes	Yes	No	No	4
Rundle (2007) ¹²⁴	Yes	Yes	No		No	3
Savic (2013) ¹²⁵	Yes	Yes	Yes	Yes	No	Data not suitable
Seslija (2008) ¹²⁶	Yes	Yes	No		No	3
Sharma (2012) ¹²⁷	Yes	Yes	Yes	No	No	4
Sharp (2008) ¹²⁸	No				No	1
Sharp (2009) ¹²⁹	No				No	1
Simmons (2014) ¹³⁰	Yes	Yes	Yes	No	No	4
Simmons (2008) ⁶	Yes	Yes	Yes	Yes	Yes	
Simmons (2011) ¹³¹	Yes	Yes	Yes	No	No	4
Simmons (2009) ¹³²	Yes	Yes	Yes	No	No	4
Snook (2013) ¹³³	Yes	Yes	Yes	No	No	4
Tilszer (2006) ¹²	Yes	Yes	Yes	Yes	Yes	
van (2014) ⁵	Yes	Yes	Yes	Yes	Yes	
Whitlock (2000) ¹³⁴	Yes	Yes	No		No	3
Wigby (2004) ²⁶	Yes	Yes	Yes	Yes	Yes	

Supplementary Table 3

Table of effect sizes included in our meta-analysis.

	n
Effect sizes (Total)	459
Publications	65
Blind experiments	54
Effect sizes (Enforced monogamy)	241
Effect sizes (Ambiguous)	144
Effect sizes (Indirect)	141
Effect sizes (Direct)	174
Effect sizes (Stressful)	92
Effect sizes (Benign)	337
Effect sizes (Male)	189
Effect sizes (Female)	219
Effect sizes (Both sexes)	51
Different species	15
Effect sizes (Beetle)	116
Effect sizes (Fly)	254
Effect sizes (Mouse)	40
Effect sizes (Nematode)	9
Effect sizes (Mite)	25
Effect sizes (Cricket)	6
Effect sizes (Guppy)	9

Supplementary Table 4

Table of fitness outcomes included in our meta-analysis by sex.

Parameters	Both	Female	Male	Total
Behavioural Plasticity	0	2	0	2
Body Condition	0	0	1	1
Body Size	2	13	11	26
Both Reproductive Success	12	0	0	12
Development Rate	5	1	1	7
Early Fecundity	0	14	0	14
Ejaculate Quality and Production	0	0	23	23
Extinction Rate	4	0	0	4
Female Reproductive Success	0	102	0	102
Fitness Senescence	0	3	3	6
Immunity	5	15	15	35
Lifespan	0	35	3	38
Male Attractiveness	0	0	6	6
Male Reproductive Success	0	0	42	42
Mating Duration	0	1	9	10
Mating Frequency	0	6	5	11
Mating Latency	0	1	12	13
Mating Success	0	0	39	39
Mutant Frequency	6	0	2	8
Offspring Viability	15	26	15	56
Pesticide Resistance	2	0	0	2
Strength	0	0	2	2

Supplementary Table 5

These estimates are presented in the text of the Results section. The test statistic is either the p-value (REML) or Bayes factor (BF) comparing the effect size to zero (Bayesian).

Method	Grand_mean_effect_size_g	Lower_95_CI	Upper_95_CI	Test_statistic
REML	0.24	0.055	0.43	0.011
Bayesian	0.25	-0.0074	0.51	35

Supplementary Table 6

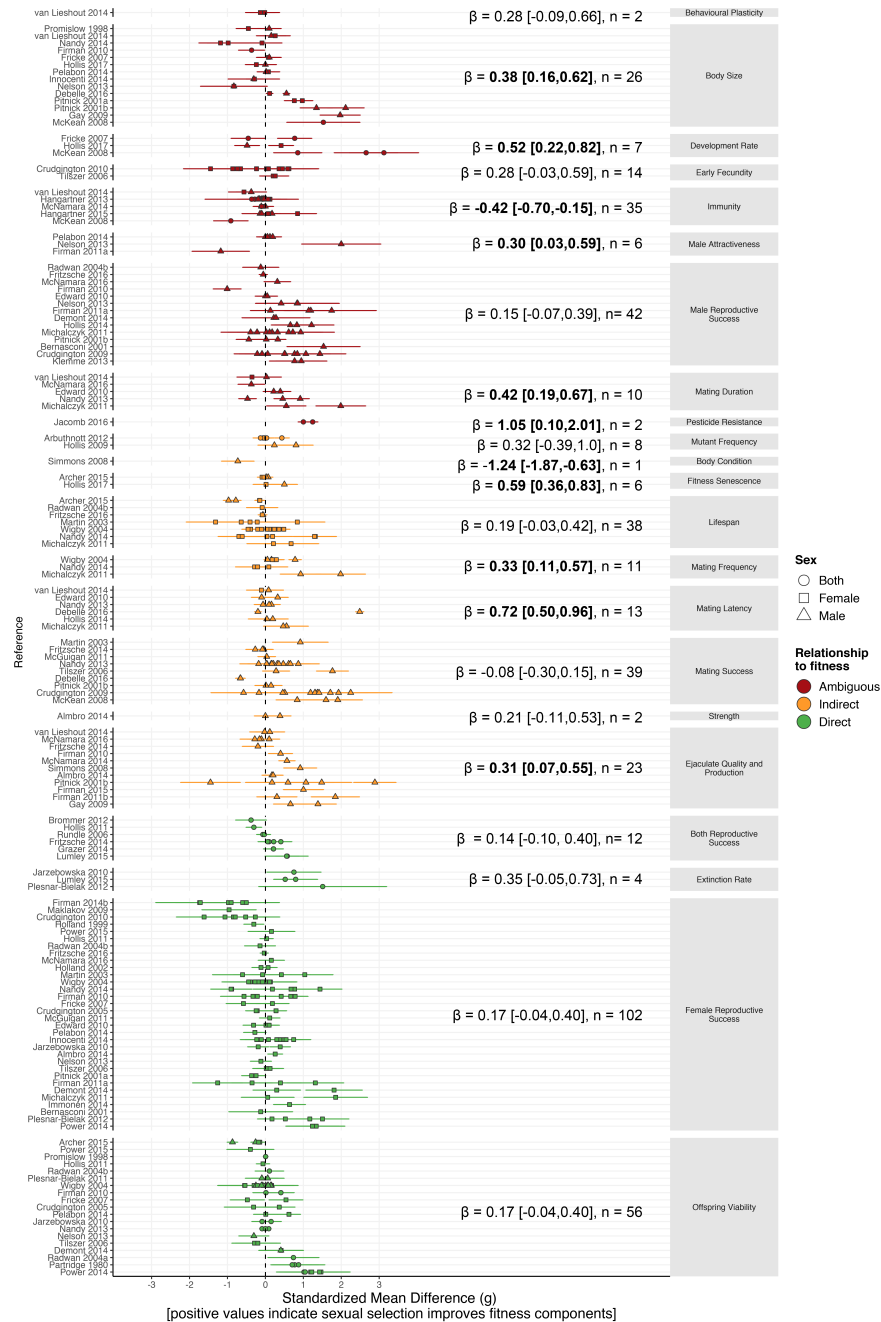
The predicted effect size for each of the three fitness trait classes (Ambiguous, Indirect and Direct) that are presented in Figure 1 in the manuscript. This table presents both Bayesian and REML predictions with some discrepancies in the estimated error margins. Figure 1 within the manuscript uses REML predictions.

Relationship to Fitness	Bayes Prediction	Bayes SE	Bayes LCI	Bayes UCI	n	BF	REML Prediction	REML SE	REML LCI	REML UCI
Indirect	0.24	0.098	0.0326	0.43	141	59	0.24	0.057	0.132	0.36
Ambiguous	0.20	0.098	-0.0016	0.39	144	38	0.21	0.058	0.093	0.32
Direct	0.13	0.097	-0.0790	0.31	174	11	0.13	0.057	0.019	0.24

Supplementary Table 7

Summary of model predictions for 22 fitness components. In Supplementary Figure 1 these values are presented as a text overlay using the Bayesian values. Additionally, Bayes Factors (BF) are presented as the likelihood ratio that the effect size is greater than 0. Where values greater than 1 correspond to higher likelihood of the effect size being positive and values less than 1 suggest that the effect size is more likely to be negative. The right side of the table provides the REML estimates with SE and 95

Fitness Component	Bayes Prediction	Bayes SE	Bayes LCI	Bayes UCI	n	BF	REML Prediction	REML SE	REML LCI	REML UCI
Behavioural Plasticity	0.282	0.19	-0.090	0.66	2	1.5e+01	0.279	0.172	-0.057	0.616
Body Size	0.380	0.11	0.159	0.62	26	2.2e+02	0.378	0.078	0.225	0.532
Development Rate	0.517	0.15	0.223	0.82	7	6.7e+02	0.515	0.125	0.270	0.761
Early Fecundity	0.281	0.16	-0.027	0.59	14	2.7e+01	0.280	0.134	0.017	0.543
Immunity	-0.422	0.14	-0.702	-0.15	35	2.6e-03	-0.419	0.111	-0.636	-0.201
Male Attractiveness	0.302	0.14	0.031	0.59	6	5.8e+01	0.298	0.111	0.081	0.515
Male Reproductive Success	0.155	0.12	-0.072	0.39	42	1.4e+01	0.152	0.080	-0.005	0.310
Mating Duration	0.422	0.12	0.186	0.67	10	3.1e+02	0.420	0.089	0.247	0.594
Pesticide Resistance	1.051	0.49	0.095	2.01	2	6.4e+01	1.076	0.457	0.180	1.973
Mutant Frequency	0.319	0.36	-0.387	1.02	8	4.5e+00	0.294	0.334	-0.361	0.949
Body Condition	-1.235	0.32	-1.871	-0.63	1	0.0e+00	-1.227	0.305	-1.825	-0.629
Fitness Senescence	0.587	0.12	0.363	0.83	6	1.1e+03	0.585	0.083	0.423	0.748
Lifespan	0.190	0.11	-0.025	0.42	38	2.5e+01	0.188	0.076	0.038	0.337
Mating Frequency	0.333	0.12	0.113	0.57	11	1.4e+02	0.330	0.080	0.173	0.487
Mating Latency	0.722	0.12	0.499	0.96	13	8.0e+03	0.720	0.080	0.563	0.877
Mating Success	-0.083	0.11	-0.303	0.15	39	2.4e-01	-0.085	0.078	-0.238	0.068
Strength	0.212	0.17	-0.111	0.53	2	1.0e+01	0.211	0.145	-0.074	0.496
Ejaculate Quality and Production	0.308	0.12	0.066	0.55	23	9.4e+01	0.308	0.088	0.137	0.480
Both Reproductive Success	0.141	0.13	-0.101	0.40	12	8.0e+00	0.140	0.095	-0.046	0.327
Extinction Rate	0.348	0.20	-0.053	0.73	4	2.3e+01	0.350	0.185	-0.012	0.712
Female Reproductive Success	0.170	0.11	-0.044	0.40	102	1.8e+01	0.168	0.074	0.022	0.314
Offspring Viability	0.173	0.11	-0.041	0.40	56	1.9e+01	0.171	0.075	0.024	0.318



Supplementary Figure 1

Forest plot of raw effect sizes and their 95% confidence intervals, grouped according to measured fitness components and the sex of the individuals whose fitness trait was measured (male, female, or both sexes mixed together). Rows with multiple data points denote studies that provided multiple effect sizes. Positive values indicate fitness benefits of sexual selection.

Supplementary Table 8

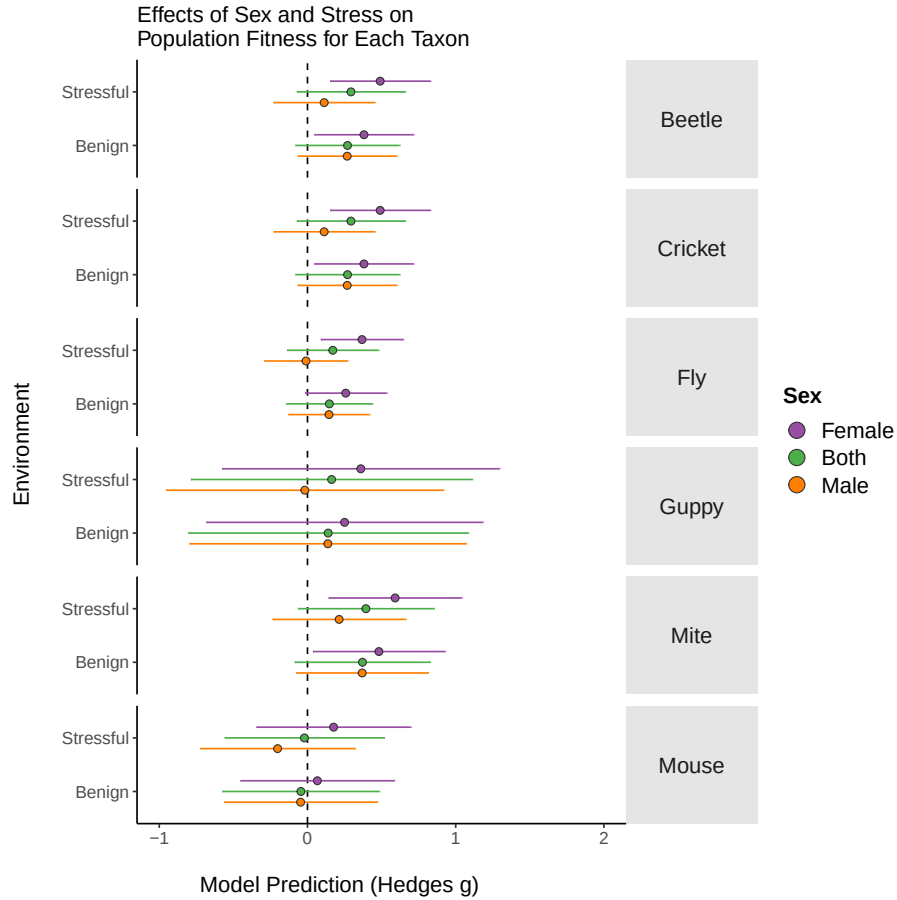
In some instances it may be beneficial to the reader to obtain average effect sizes of each fitness trait **entirely independently** of other traits. For this reason we present a summary of independent model estimates for 16 fitness components with a sample size greater than 3 effect sizes ($n > 3$). Unlike above where estimates were generated based on predictions from a single model, here we run individual meta-analyses for each fitness related trait. Independent models generally reduce the power and significance of some of the estimates with ‘Extinction rate’ and ‘Ejaculate quality and production’ the only two traits with p-values < 0.05 .

Outcome	beta	zval	ci.lb	ci.ub	n	pval	I2	Class
Body Size	0.28	1.2	-0.16	0.72	26	0.22	97	Ambiguous
Development Rate	0.66	1.1	-0.53	1.80	7	0.28	95	Ambiguous
Early Fecundity	0.00	-0.0095	-0.45	0.44	14	0.99	49	Ambiguous
Immunity	-0.29	-1.3	-0.73	0.15	35	0.19	90	Ambiguous
Male Attractiveness	0.27	0.3	-1.50	2.00	6	0.76	99	Ambiguous
Male Reproductive Success	0.30	2.1	0.02	0.58	42	0.037	84	Ambiguous
Mating Duration	0.23	0.94	-0.25	0.70	10	0.35	91	Ambiguous
Mutant Frequency	0.25	1.1	-0.21	0.71	8	0.29	88	Indirect
Fitness Senescence	0.10	0.75	-0.15	0.35	6	0.45	81	Indirect
Lifespan	-0.08	-0.71	-0.29	0.13	38	0.48	89	Indirect
Mating Frequency	0.69	1.1	-0.57	1.90	11	0.29	99	Indirect
Mating Latency	0.28	1.9	-0.01	0.58	13	0.057	90	Indirect
Mating Success	0.39	1.8	-0.04	0.82	39	0.073	93	Indirect
Ejaculate Quality and Production	0.50	3.6	0.23	0.77	23	0.00031	83	Indirect
Both Reproductive Success	0.10	0.6	-0.24	0.45	12	0.55	87	Direct
Extinction Rate	0.62	4.9	0.37	0.87	4	9.4e-07	0	Direct
Female Reproductive Success	0.07	0.9	-0.08	0.23	102	0.37	82	Direct
Offspring Viability	0.13	1.5	-0.04	0.31	56	0.14	94	Direct

Supplementary Table 9

Bayesian model results for a preliminary model that explores many covariates collected in the dataset.

Model Parameter	Estimate	Est.Error	Q2.5	Q97.5	
b__Intercept	0.395	0.251	-0.095	0.899	
b__SexF	0.122	0.046	0.031	0.211	*
b__SexM	0.112	0.044	0.025	0.198	*
b__EnvironmentNotStated	0.028	0.146	-0.262	0.315	
b__EnvironmentStressed	0.03	0.06	-0.088	0.146	
b__logGenerations	-0.034	0.048	-0.127	0.061	
b__BlindingNotBlind	-0.065	0.201	-0.463	0.327	
b__Enforced.MonogamyYES	-0.133	0.086	-0.301	0.034	
b__SexF:EnvironmentNotStated	0.122	0.127	-0.13	0.374	
b__SexM:EnvironmentNotStated	0.076	0.119	-0.16	0.316	
b__SexF:EnvironmentStressed	0.09	0.067	-0.039	0.223	
b__SexM:EnvironmentStressed	-0.132	0.068	-0.264	0.002	
sd__Outcome__Intercept	0.327	0.074	0.214	0.499	*
sd__Study.ID__Intercept	0.485	0.053	0.393	0.6	*
sd__Taxon__Intercept	0.134	0.121	0.005	0.439	*



Supplementary Figure 2

The predictions from this model indicate some heterogeneity between taxon. However, the most apparent difference between taxa is that confidence bands increase for taxa with low sample size. As previously shown, the beetle and fly taxa are the most heavily sampled and in the above figure have the narrowest confidence bands. Importantly, the overall direction of effect does not change between taxon, although guppies and mice show near zero effect sizes. Here we see that under stressed environments, females from all taxa appear to have greater fitness increase than males or ‘both’.

Supplementary Table 10

The predictions for the above figure looking at the effect of sexual selection amongst taxa uses the following dataframe.

Sex	Environment	Taxon	Prediction	SE	CI.lb	CI.ub	n
M	Unstressed	Beetle	0.2680	0.17	-0.066	0.60	18
B	Unstressed	Beetle	0.2702	0.18	-0.081	0.62	2
F	Unstressed	Beetle	0.3810	0.17	0.047	0.71	15
M	Stressed	Beetle	0.1128	0.17	-0.228	0.45	2
B	Stressed	Beetle	0.2934	0.19	-0.072	0.66	6
F	Stressed	Beetle	0.4905	0.17	0.153	0.83	9
M	Unstressed	Cricket	0.2680	0.17	-0.066	0.60	1
B	Unstressed	Cricket	0.2702	0.18	-0.081	0.62	NA
F	Unstressed	Cricket	0.3810	0.17	0.047	0.71	NA
M	Stressed	Cricket	0.1128	0.17	-0.228	0.45	NA
B	Stressed	Cricket	0.2934	0.19	-0.072	0.66	NA
F	Stressed	Cricket	0.4905	0.17	0.153	0.83	NA
M	Unstressed	Fly	0.1453	0.14	-0.128	0.42	60
B	Unstressed	Fly	0.1475	0.15	-0.142	0.44	9
F	Unstressed	Fly	0.2583	0.14	-0.017	0.53	93
M	Stressed	Fly	-0.0099	0.14	-0.290	0.27	9
B	Stressed	Fly	0.1707	0.16	-0.138	0.48	8
F	Stressed	Fly	0.3678	0.14	0.090	0.65	19
M	Unstressed	Guppy	0.1374	0.48	-0.796	1.07	NA
B	Unstressed	Guppy	0.1395	0.48	-0.806	1.08	NA
F	Unstressed	Guppy	0.2503	0.48	-0.682	1.18	3
M	Stressed	Guppy	-0.0178	0.48	-0.953	0.92	NA
B	Stressed	Guppy	0.1627	0.48	-0.786	1.11	NA
F	Stressed	Guppy	0.3599	0.48	-0.575	1.30	NA
M	Unstressed	Mite	0.3690	0.23	-0.075	0.81	3
B	Unstressed	Mite	0.3711	0.23	-0.085	0.83	2
F	Unstressed	Mite	0.4820	0.23	0.037	0.93	9
M	Stressed	Mite	0.2138	0.23	-0.235	0.66	1
B	Stressed	Mite	0.3943	0.23	-0.064	0.85	4
F	Stressed	Mite	0.5915	0.23	0.143	1.04	3
M	Unstressed	Mouse	-0.0463	0.26	-0.564	0.47	1
B	Unstressed	Mouse	-0.0442	0.27	-0.574	0.49	2
F	Unstressed	Mouse	0.0666	0.26	-0.452	0.58	5
M	Stressed	Mouse	-0.2016	0.27	-0.723	0.32	NA
B	Stressed	Mouse	-0.0210	0.27	-0.558	0.52	NA
F	Stressed	Mouse	0.1761	0.27	-0.344	0.70	5

Supplementary Table 11

Using the `anova.rma` function we can conduct hypothesis tests between two categorical groups in the model. Here we conduct 5 tests comparing the relative effect of sexual selection between the sexes, and in different environments.

	Estimate	Est.Error	CI.Lower	CI.Upper	
M vs F, Benign	-0.113	0.030	-0.173	-0.054	
M vs F, Stressful	-0.377	0.046	-0.468	-0.287	*
Benign vs Stressful, Female	-0.108	0.037	-0.181	-0.036	*
Benign vs Stressful, Male	0.156	0.043	0.072	0.240	*
Benign vs Stressful, Both	-0.028	0.080	-0.184	0.128	

Supplementary Table 12

Model estimate summary table for the Bayesian model investigating the effect of environment and sex (alongside sexual selection) on fitness.

Model Parameter	Estimate	Est.Error	Q2.5	Q97.5	
b_Intercept	0.188	0.175	-0.167	0.522	
b_SexB	0.003	0.073	-0.143	0.144	
b_SexF	0.113	0.03	0.053	0.171	*
b_EnvironmentStressed	-0.156	0.043	-0.241	-0.073	*
b_SexB:EnvironmentStressed	0.182	0.089	0.006	0.354	*
b_SexF:EnvironmentStressed	0.264	0.052	0.163	0.369	*
sd_Outcome__Intercept	0.413	0.119	0.241	0.703	*
sd_Study.ID__Intercept	0.452	0.053	0.36	0.57	*
sd_Taxon__Intercept	0.147	0.152	0.004	0.545	*

Supplementary Table 13

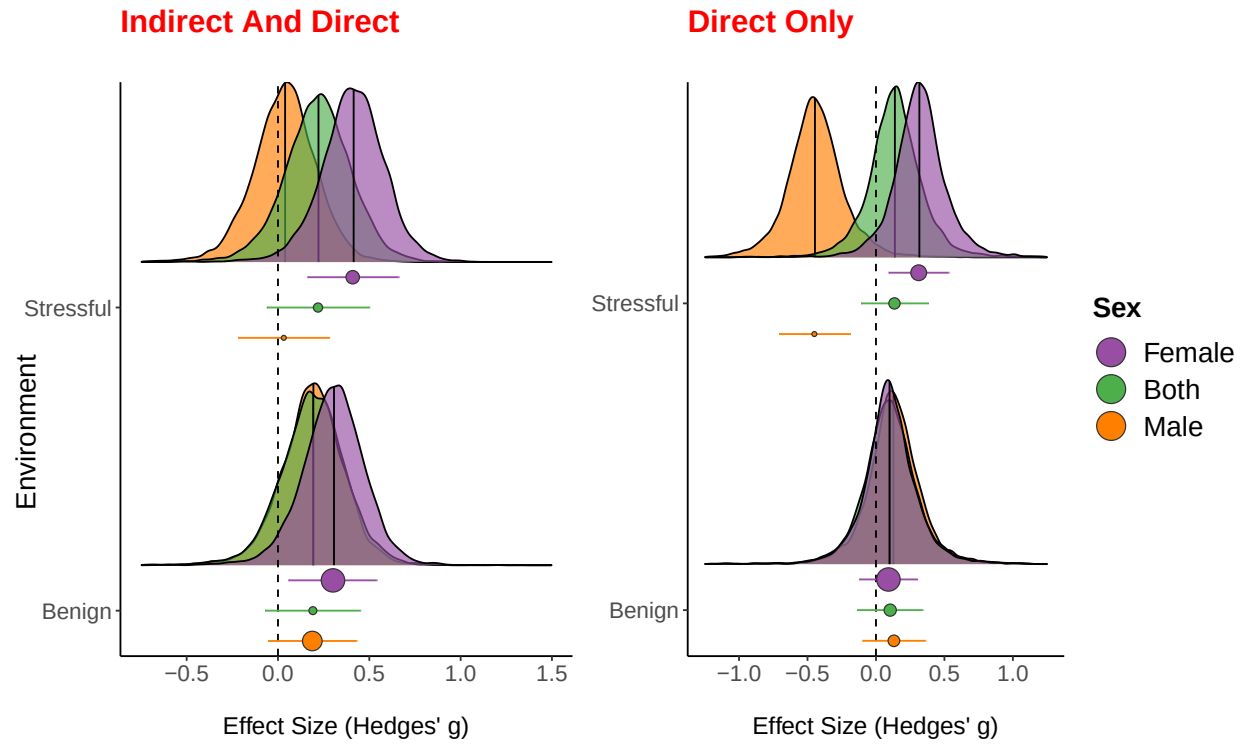
Hypothesis tests for the Bayesian model are similar to the REML model, with slight differences to CIs.

	Estimate	Est.Error	CI.Lower	CI.Upper	
M vs F, Benign	-0.113	0.030	-0.171	-0.053	*
M vs F, Stressful	-0.377	0.047	-0.471	-0.286	*
Benign vs Stressful, Female	-0.109	0.037	-0.182	-0.035	*
Benign vs Stressful, Male	0.156	0.043	0.073	0.241	*
Benign vs Stressful, Both	-0.026	0.080	-0.182	0.133	

Supplementary Table 14

The REML predictions in Figure 2a within the manuscript use the following dataframe

Sex	Environment	Prediction	SE	CI.lb	CI.ub	n
Male	Benign	0.188	0.12	-0.053	0.43	83
Both	Benign	0.191	0.13	-0.071	0.45	15
Female	Benign	0.301	0.12	0.058	0.54	125
Male	Stressful	0.032	0.13	-0.218	0.28	12
Both	Stressful	0.219	0.14	-0.061	0.5	18
Female	Stressful	0.409	0.13	0.162	0.66	36



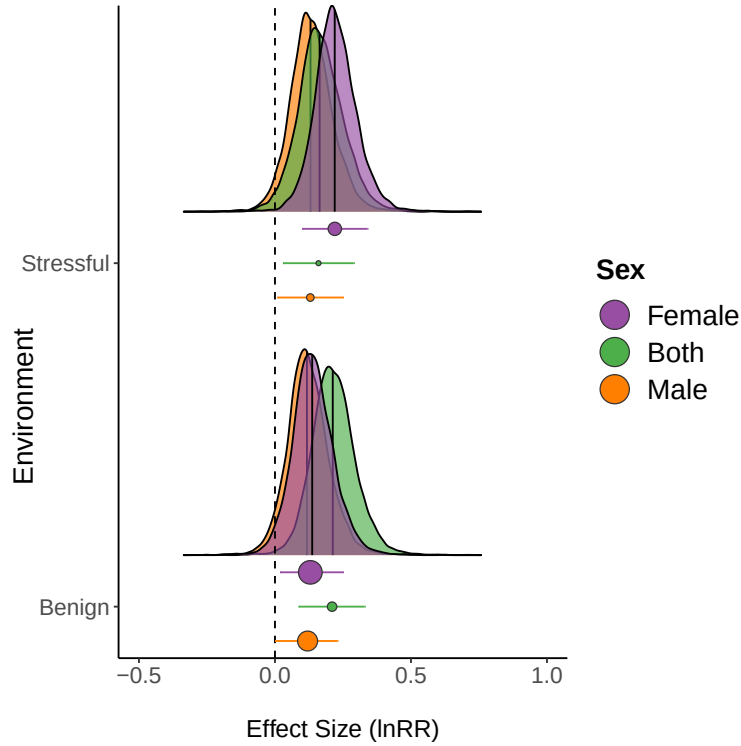
Supplementary Figure 3

The comparison of model predictions between models that use a dataset compiled from direct **and** indirect fitness components against a model that only uses direct fitness components. Notably, in both cases there is a significant positive effect of sexual selection on fitness for females evolving in stressful conditions. Bayesian predictions are depicted by a density curve while REML predictions are depicted with a circle (size corresponds to n) and 95 % CIs.

Supplementary Table 15

The REML predictions for the 'direct model' in the plot above use the following dataframe.

Sex	Environment	Prediction	SE	CI.lb	CI.ub	n
Male	Benign	0.131	0.12	-0.098	0.36	13
Both	Benign	0.104	0.12	-0.137	0.34	15
Female	Benign	0.091	0.11	-0.121	0.3	86
Male	Stressful	-0.45	0.13	-0.707	-0.19	2
Both	Stressful	0.135	0.12	-0.108	0.38	12
Female	Stressful	0.312	0.11	0.093	0.53	31



Supplementary Figure 4

Using an alternative effect size (lnRR) sexual selection also increases population fitness. Circle size is proportional to sample size (shown below). The REML predictions are shown as circles with error bars and the Bayesian predictions as density ridges. Note that the magnitude of the effect sizes presented here should not be directly compared with those using Hedges' g as lnRR is a log-transformed value.

Supplementary Table 16

The REML predictions for the meta-analysis using lnRR (plotted above) are formulated from the following model predictions.

Sex	Environment	Prediction	SE	CI.lb	CI.ub	n
Male	Benign	0.12	0.059	7e-05	0.23	73
Both	Benign	0.21	0.063	0.08705	0.33	12
Female	Benign	0.13	0.059	0.0193	0.25	110
Male	Stressful	0.13	0.061	0.00907	0.25	8
Both	Stressful	0.16	0.068	0.02938	0.29	6
Female	Stressful	0.22	0.060	0.1002	0.34	27

Supplementary Table 17

Model estimates, including random effect sigma value for the model of phenotypic variance (lnCVR)

Model Parameter	Estimate	Est.Error	Q2.5	Q97.5	
b_Intercept	0.067	0.304	-0.537	0.671	
b_SexB	-0.257	0.039	-0.333	-0.181	*
b_SexF	-0.031	0.015	-0.06	-0.002	*
b_EnvironmentStressed	0.156	0.022	0.115	0.199	*
b_SexB:EnvironmentStressed	-0.733	0.044	-0.82	-0.645	*
b_SexF:EnvironmentStressed	-0.975	0.026	-1.027	-0.925	*
sd_Outcome__Intercept	0.557	0.16	0.342	0.963	*
sd_Study.ID__Intercept	0.267	0.038	0.203	0.352	*
sd_Taxon__Intercept	0.521	0.32	0.137	1.319	*

Supplementary Table 18

The REML predictions in figure 2b within the manuscript uses the following dataframe (model predictions).

Sex	Environment	Prediction	SE	CI.lb	CI.ub	n
Male	Benign	0.068	0.23	-0.38	0.51	73
Both	Benign	-0.187	0.23	-0.64	0.26	12
Female	Benign	0.037	0.23	-0.41	0.48	110
Male	Stressful	0.225	0.23	-0.22	0.67	8
Both	Stressful	-0.764	0.23	-1.22	-0.31	6
Female	Stressful	-0.781	0.23	-1.23	-0.34	27

Supplementary Table 19

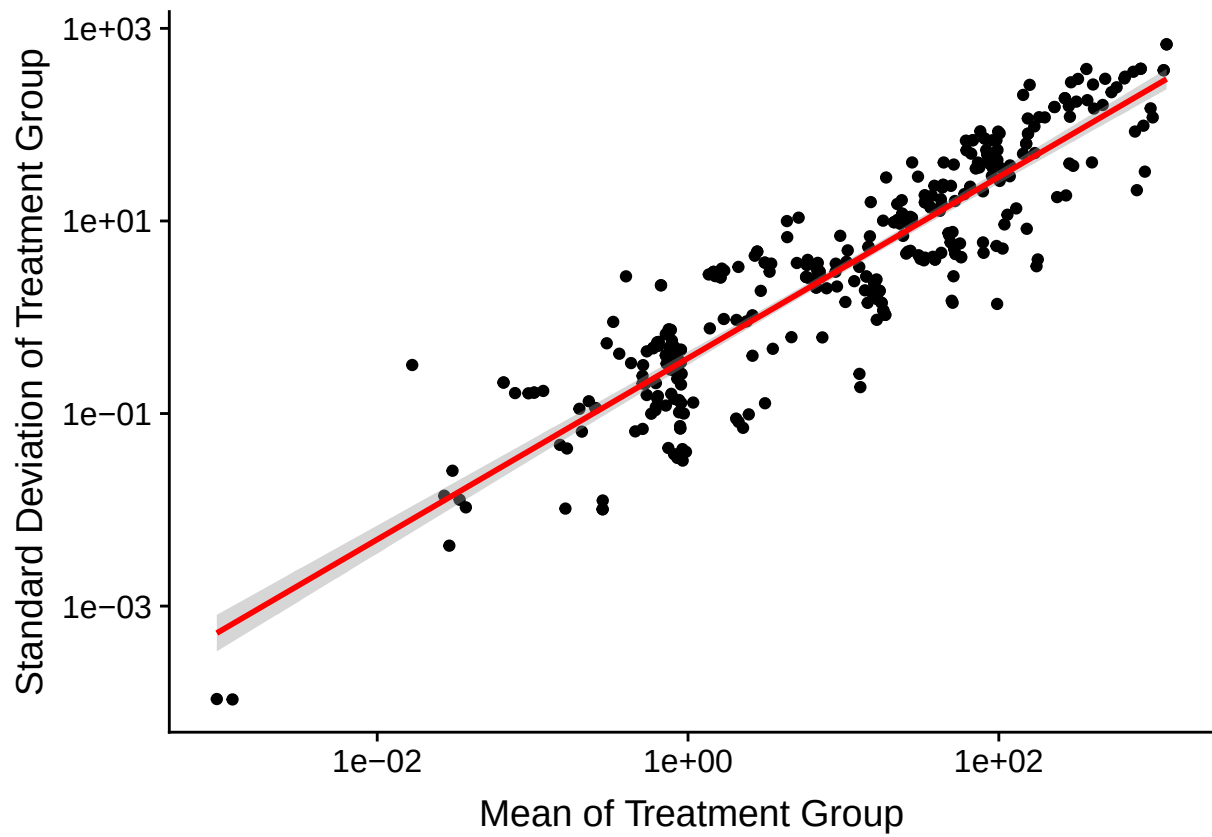
Bayesian hypothesis tests between categorical groups for phenotypic variation (lnCVR).

	Estimate	Est.Error	CI.Lower	CI.Upper	
M vs F, Benign	0.031	0.015	0.0016	0.06	*
M vs F, Stressful	1.006	0.024	0.9600	1.05	*
Benign vs Stressful, Female	0.819	0.018	0.7828	0.85	*
Benign vs Stressful, Male	-0.156	0.022	-0.1990	-0.11	*
Benign vs Stressful, Both	0.577	0.040	0.4978	0.65	*

Supplementary Table 20

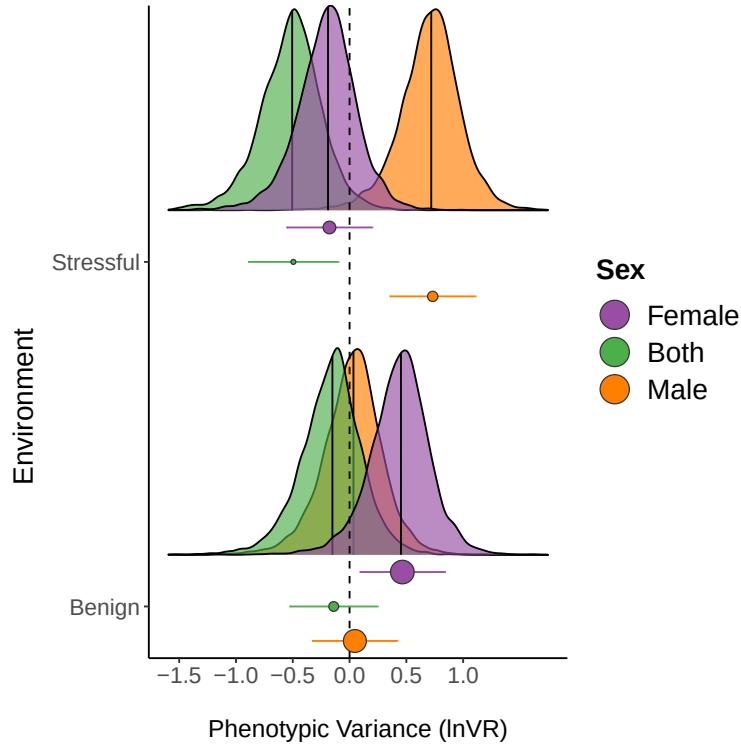
REML hypothesis tests between categorical groups for phenotypic variation (lnCVR).

	Estimate	Est.Error	CI.Lower	CI.Upper	
M vs F, Benign	0.031	0.015	0.0025	0.06	*
M vs F, Stressful	1.006	0.024	0.9598	1.05	*
Benign vs Stressful, Female	0.818	0.018	0.7831	0.85	*
Benign vs Stressful, Male	-0.157	0.022	-0.1990	-0.11	*
Benign vs Stressful, Both	0.577	0.040	0.4995	0.65	*



Supplementary Figure 5

The use of $\ln\text{CVR}$ (as opposed to $\ln\text{VR}$) is justified in this meta-analysis due to the strong mean-variance relationship. In this case the standard deviation from the treatment group is compared to the means of the treatment group on a log-scale.



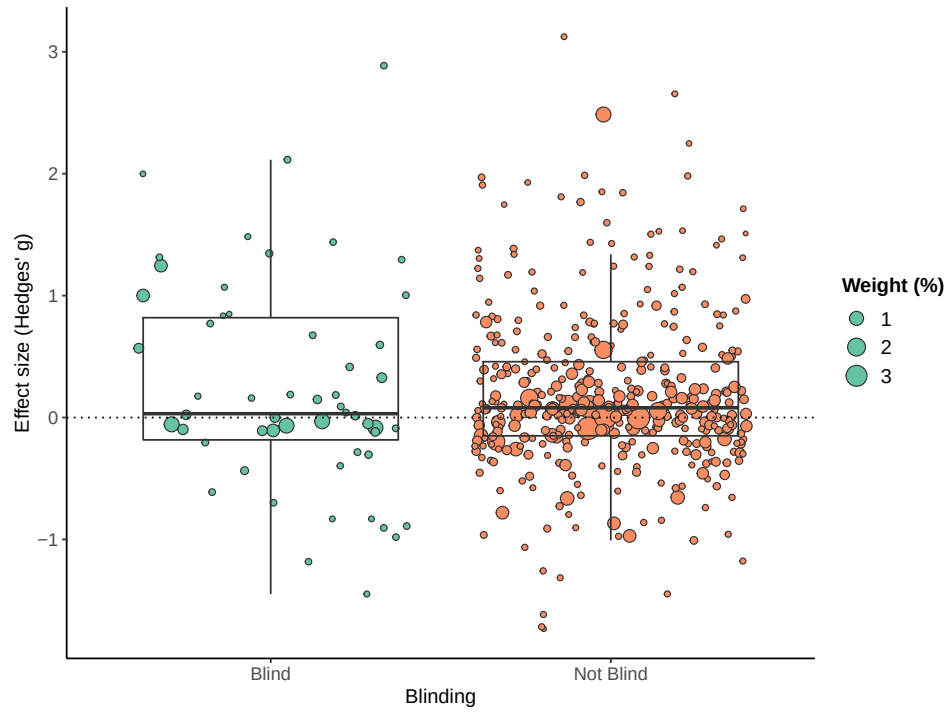
Supplementary Figure 6

The effects of sexual selection on the log-variance ratio (lnVR). Without accounting for the mean variance relationship (lnCVR) sexual selection has different effects on the variance measure.

Supplementary Table 21

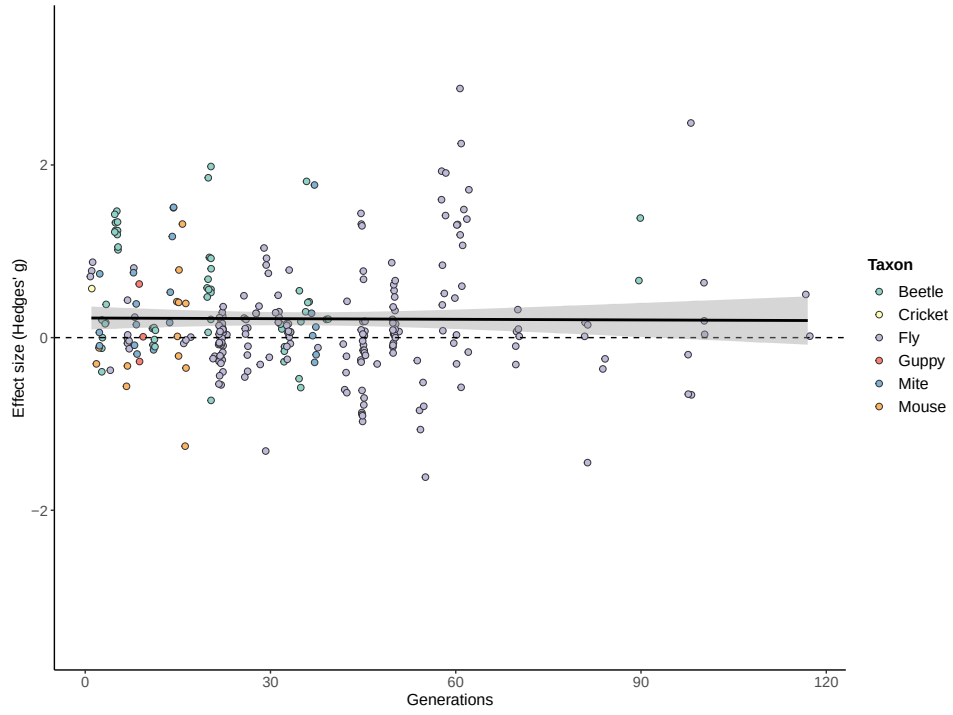
The points in the above plot are based on the following REML model and predictions. While the predicted effects of sexual selection on lnVR in stressful conditions is non-significantly negative, there is still a negative significant interaction between stressful environments and the female sex.

Sex	Environment	Prediction	SE	CI.lb	CI.ub	n
Male	Benign	0.047	0.19	-0.33	0.42	132
Both	Benign	-0.14	0.2	-0.53	0.25	17
Female	Benign	0.46	0.19	0.09	0.84	142
Male	Stressful	0.73	0.19	0.35	1.1	19
Both	Stressful	-0.49	0.2	-0.89	-0.098	8
Female	Stressful	-0.18	0.19	-0.55	0.2	31



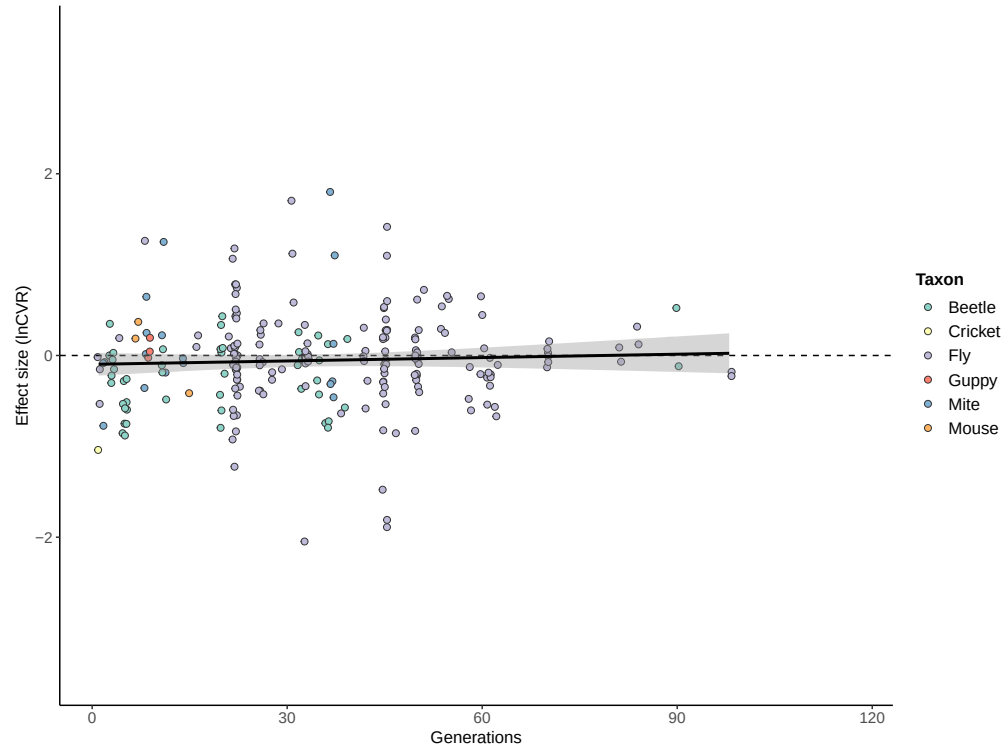
Supplementary Figure 7

Blinding does not appear to alter the magnitude or direction of effect sizes for the studies used in this meta-analysis. However, this should not be viewed as evidence against the validity of blinding as a research method.



Supplementary Figure 8

The number of generations an experimental evolution procedure is run for does not appear to affect the magnitude or direction of the effect size from the fitness related outcome measured at that point.



Supplementary Figure 9

Phenotypic variation (lnCVR) is not affected by the number of generations an experiment is ran for.

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