

**Supporting Information for:**

Human influences on the strength of phenotypic selection

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Supplementary Methods & Results

Tables S1 to S4

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Data sources

**Supplementary Methods & Results***Properties of studies included in the database*

All data sources are referenced at the end of this document. We classified systems based on major taxa (vertebrate, invertebrate, or plant), type of disturbance, experimental design, and fitness component(s), to explore whether these moderator variables could influence human impacts on selection strength. Types of human disturbances included in the database were: (1) climate change, defined as an increase in ambient temperature and/or CO<sub>2</sub> concentration (in controlled experiments, as noted in the main text); (2) habitat degradation/modification, including anthropogenic fire, pollution, eutrophication, land conversion, habitat fragmentation, and pollinator loss; (3) harvest, including fishing, hunting, and gathering of wild organisms; (4) invasion, whereby selection is measured in a native population experiencing the presence of a newly-introduced species; and (5) introduction, whereby selection is measured in a population that was moved by humans to a new location.

Types of experimental designs included: (1) temporal comparison of selection before and after disturbance within a single population; (2) spatial comparison of selection at any given time between disturbed and natural populations; (3) experimental simulation of the disturbance, e.g., warming chambers; (4) selection partitioning, whereby anthropogenic and natural selection can be distinguished within a single population, for example exploited fish stocks in which both natural and fishing mortality can be recorded. For two systems, we compared selection between two or more congeneric species (native vs. invasive, respectively corresponding to natural vs. disturbed conditions) for the same set of traits and in the same locality; we termed this design 'species comparison'. For experimental studies, we further split systems into three categories based on the expected level of maladaptation in control ('natural') conditions. We noted if selection in natural conditions was measured *in situ* in the field on a native population ('field, native'), *in situ* in the field on an exotic population relatively naive to local conditions ('field,

exotic'), or in a laboratory environment to which all populations are naive regardless of whether they are native or exotic ('laboratory'). One might expect stronger selection in control conditions in the latter two contexts if the population is maladapted to the control environment, which could then mask any effect of disturbance. Finally, we also classified systems based on the fitness components used to calculate selection, namely: (1) biomass, growth, or condition; (2) fecundity (e.g., number of eggs or seeds); (3) mating success; (4) survival; and (5) 'composite', when more than one fitness component was used to measure fitness.

We also classified all traits into four different categories, following previous studies that reported differences in selection strength among trait types (1, 2). Note that trait category is a property of individual selection coefficients, not of systems (as several systems included multiple traits). Trait categories included 'size' (a length or mass measurement of overall organism size, or a body part measurement used by the authors as a proxy for organism size), 'morphology' (morphological traits other than body size, e.g. coloration or the relative length of a given body part which does not obviously correlate with body size), 'life history' (e.g., migration date or growth rate), and 'physiology' (e.g., concentration of a given chemical compounds). The latter category also included the few behavioral traits in the database. Five traits did not fit any category (e.g., a feature of a superorganism's nest) and were thus excluded from analyses.

Table S1 reports the number of systems and selection coefficients available for each class of each moderator variable. Most studies included in the final database focused on plants or vertebrates rather than invertebrates, and most used experimental approaches or spatial comparisons to contrast selection in natural and disturbed conditions. Authors calculated relative fitness based on a variety of fitness components, with survival being the most common metric. Body size was by far the most common trait in the database, and selection coefficients for physiological/behavioral traits were very rare (Table S1).

### *Maximum selection strength*

In addition to mean selection strength, we also modeled maximum selection strength using linear quantile mixed models (LQMMs) to estimate the 99<sup>th</sup> conditional quantile of  $|S|$  or  $|\beta|$ . Models were fitted with the R package 'lqmm' (3), using a Nelder-Mead optimization algorithm to find maximum likelihood parameter estimates. LQMMs included the same fixed effects as the LMMs of mean selection strength; however, the lqmm package does not allow for nested random effects. We therefore used 'system' as the only random intercept. To assess whether our results were affected by potential within-trait correlations, we fitted two LQMMs per coefficient type: one model used the full data set (ignoring non-independence among multiple estimates from the trait), and one model used a 'pooled' dataset where each trait has a single (mean) value in either disturbance conditions (thus eliminating within-trait correlations). Standard errors and statistical significance of model coefficients were determined using block bootstrapping (100 replications).

The results for maximum selection strength followed the same general pattern than the results for mean selection strength (i.e., an overall negative effect of disturbance on selection

strength except for some harvested systems showing strong positive effects of disturbance; Fig. S2). However, the effect of disturbance type or conditions were weaker and not statistically significant in QLMMs (Table S3).

#### *Effect of disturbance on selection strength across various moderator variables*

We explored how our results could be influenced by variation among studies in focal taxa, types of disturbance, study designs, and fitness components. The limited number of systems with standard errors available (18 for  $|S|$  and 20 for  $|\beta|$ ) precludes a formal meta-analysis of these potential influences. We instead used all data available and ignored observation-level uncertainty, calculating for each trait from each system an effect size of human disturbance. These effect sizes were log response ratios computed as the natural logarithm of mean selection strength in disturbed conditions over mean selection strength in natural conditions, yielding one data point per trait. We then modelled variation in effect sizes as a function of grouping classes (listed in Table S1), fitting for each grouping a separate Bayesian mixed model. These models had the equation:  $\hat{y}_{ijk} \sim class_i + system_j + e_{ijk}$ , where  $\hat{y}_{ijk}$  is the effect size measured on the  $k$ -th trait in the  $j$ -th system belonging to the  $i$ -th grouping class (although note that for ‘trait type’ groupings, class is a property of individual effect sizes rather than systems). Class is a fixed effect with a coefficient estimated for each grouping class, system is a random effect (following a normal distribution with a mean of zero and a variance estimated by the model), and  $e_{ijk}$  are residuals. We estimated a single variance term for residuals in each model because many grouping classes had two or few systems. Grouping classes with a single system were excluded from models. We recorded the mean and 95% credible intervals of the posterior distribution of estimated fixed effects, namely the mean effect of human disturbance on selection strength for each grouping class. We also fitted similar models to test for an effect of ‘types of control population’ in experiments (‘field native’, ‘field exotic’, or ‘laboratory’, as described above), using the subset of data originating from experimental studies.

Disturbance had a small negative effect on selection strength across most grouping factors that we examined, although these effects were generally not significant due to the low number of systems per grouping class (Fig. S3). The only noticeable exception to this general trend were harvested systems in which human impacts on selection were measured by partitioning natural from artificial selection (i.e., two of four harvested systems for  $S$  and both harvested systems for  $\beta$ ; Fig. S3). For experimental studies, the type of control population used to estimate selection in ‘natural’ conditions possibly had an effect on estimated human impacts (Fig. S4). This effect, however, was opposite to what we initially hypothesized, with laboratory studies showing a significantly-stronger *negative* effect of disturbance on selection strength than in the other two contexts. Therefore, we conclude that the statistically-significant trend reported in the main text of weaker selection in disturbed conditions (when pooling all non-harvested systems) was also the dominant trend when grouping systems based on a variety of system properties, with no study designs, trait types, fitness components, taxa, or disturbance types (other than harvest) obviously departing from this trend.

### Supplementary references

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**Table S1.** Number of systems (taxon-disturbance combinations) for which a given coefficient type is available, grouped by either taxonomic group, type of human disturbance, study design, fitness component measured, or the type of trait on which selection was quantified. The numbers in parentheses indicate the total number of coefficients of a given type gathered from those systems. Note that many systems included multiple traits and trait types, such that system number for grouping ‘trait type’ indicates the number of systems with a least one coefficient of a given trait type. Grouping classes are described above.

Grouping	Class	<i>S</i>		$\beta$	
		<i>all</i>	<i>with SE</i>	<i>all</i>	<i>with SE</i>
Taxa	Invertebrate	1 (10)	0 (0)	2 (18)	1 (10)
	Plant	16 (238)	9 (132)	14 (271)	11 (193)
	Vertebrate	10 (462)	9 (410)	9 (367)	8 (336)
Type of disturbance	Climate change	6 (94)	1 (8)	3 (69)	2 (21)
	Habitat degradation	7 (108)	5 (44)	9 (307)	6 (246)
	Harvest	4 (251)	4 (251)	2 (16)	2 (16)
	Invasion	4 (48)	3 (38)	5 (50)	4 (42)
	Introduction	6 (209)	5 (201)	6 (214)	6 (214)
Study design	Before vs. after	2 (100)	1 (48)	1 (31)	0 (0)
	Experimental	15 (179)	10 (93)	11 (161)	9 (105)
	Selection partitioning	2 (188)	2 (188)	2 (16)	2 (16)
	Spatial comparison	6 (103)	3 (73)	9 (328)	7 (298)
	Species comparison	2 (140)	2 (140)	2 (120)	2 (120)
Fitness component	Biomass/growth/condition	5 (28)	2 (8)	3 (28)	2 (20)
	Fecundity	6 (161)	4 (89)	11 (234)	8 (156)
	Mating success	2 (22)	1 (16)	1 (20)	1 (20)
	Survival	10 (468)	8 (408)	8 (188)	7 (157)
	Composite	4 (31)	3 (21)	2 (186)	2 (186)
Trait type	Size	18 (403)	13 (319)	19 (197)	16 (146)
	Morphology	14 (181)	7 (145)	19 (320)	15 (278)
	Life history	14 (94)	7 (54)	14 (111)	11 (87)
	Physiology / behavior	2 (20)	2 (20)	4 (20)	4 (20)
<b>Total</b>		<b>37 (1366)</b>	<b>18 (542)</b>	<b>25 (656)</b>	<b>20 (539)</b>

**Table S2.** Results of general(ized) linear mixed models fitted in a maximum likelihood framework, using the R package “lme4” (formula = response ~ 1 + fixed effects + (1|system/trait)). Results indicate the maximum likelihood estimates of fixed effects along with 95% confidence intervals; effects are ‘statistically-significant’ if their confidence interval does not include zero. Separate analyses were conducted on the full dataset (ignoring observation-level uncertainty) and on the subset of selection coefficients with standard errors. For the latter, the inverse of squared standard errors was used as weights in the model, which can then be considered a formal meta-analysis. We used three types of models: a gamma GLMM with a log link function (because the distribution of data points is right-skewed), a linear mixed model on log-transformed absolute coefficients, and a linear mixed model on untransformed absolute coefficients. Fixed effect ‘disturbance:harvest’ is a two-way interaction effect; the sum of this interaction plus the fixed effect ‘disturbance’ indicates the effect of disturbance on selection strength in harvested systems. Large positive interactions indicate that the sign of the disturbance effect reverses in harvested systems, leading to significantly stronger selection in disturbed than natural conditions. Effects of disturbance type on  $|\beta|$  could not be assessed due to data limitations; we thus fit separate models including (H+) or excluding (H-) harvested systems.

<i>response</i>	<i>analysis</i>	<i>Type of model</i>	<i>fixed effect</i>	<i>estimate</i>	<i>lower bound</i>	<i>upper bound</i>
S	Full dataset (no weight)	Gamma GLMM	disturbance	-0.361	-0.5373	-0.1847
			harvest	0.1804	-0.702	1.0627
			disturbance:harvest	0.5066	0.1402	0.873
S	Full dataset (no weight)	LMM (untransformed)	disturbance	-0.0819	-0.1646	0.0007
			harvest	-0.1076	-0.3776	0.1624
			disturbance:harvest	0.479	0.3318	0.6261
S	Full dataset (no weight)	LMM (log transformed)	disturbance	-0.4991	-0.716	-0.2823
			harvest	-0.0936	-1.0915	0.9044
			disturbance:harvest	0.6282	0.2424	1.0139
S	Weighted regression	Gamma GLMM	disturbance	-0.3916	-0.636	-0.1472
			harvest	0.2317	-0.7288	1.1922
			disturbance:harvest	0.5014	0.0825	0.9204

S	Weighted regression	LMM (untransformed)	disturbance	-0.0809	-0.2029	0.0410
			harvest	-0.0992	-0.4178	0.2194
			disturbance:harvest	0.4717	0.2879	0.6554
S	Weighted regression	LMM (log transformed)	disturbance	-0.532	-0.8446	-0.2195
			harvest	0.0335	-1.1112	1.1783
			disturbance:harvest	0.6408	0.1708	1.1108
$\beta$   H+	Full dataset (no weight)	Gamma GLMM	disturbance	-0.1881	-0.191	-0.1852
$\beta$   H-	Full dataset (no weight)	Gamma GLMM	disturbance	<i>Failed to converge</i>		
$\beta$   H+	Full dataset (no weight)	LMM (untransformed)	disturbance	-0.0415	-0.0718	-0.0112
			disturbance	-0.0465	-0.0775	-0.0156
$\beta$   H-	Full dataset (no weight)	LMM (untransformed)	disturbance	-0.0465	-0.0775	-0.0156
			disturbance	-0.0465	-0.0775	-0.0156
$\beta$   H+	Full dataset (no weight)	LMM (log transformed)	disturbance	-0.217	-0.4001	-0.034
$\beta$   H-	Full dataset (no weight)	LMM (log transformed)	disturbance	-0.2499	-0.4368	-0.063
$\beta$   H+	Weighted regression	Gamma GLMM	disturbance	<i>Failed to converge</i>		
$\beta$   H-	Weighted regression	Gamma GLMM	disturbance	<i>Failed to converge</i>		
$\beta$   H+	Weighted regression	LMM (untransformed)	disturbance	-0.049	-0.0861	-0.0119
			disturbance	-0.0554	-0.0936	-0.0173
$\beta$   H-	Weighted regression	LMM (untransformed)	disturbance	-0.0554	-0.0936	-0.0173
			disturbance	-0.0554	-0.0936	-0.0173
$\beta$   H+	Weighted regression	LMM (log transformed)	disturbance	-0.2592	-0.4757	-0.0426
$\beta$   H-	Weighted regression	LMM (log transformed)	disturbance	-0.3003	-0.5226	-0.078

**Table S3.** Results of linear quantile mixed models predicting the effects of disturbance conditions ('natural' vs. 'disturbed'), disturbance type ('other' vs. 'harvest'), and their interaction on maximum selection strength, measured as  $|S|$  or  $|\beta|$ . Results indicate the maximum likelihood estimate of the 99<sup>th</sup> conditional quantile  $\pm$  95% confidence intervals. Models could only include a single random effect (system); thus, separate analyses were conducted on the full dataset (ignoring non-independence among multiple estimates from the same trait), and on a 'pooled' dataset where each trait has a single (mean) value in either disturbance conditions (thus eliminating within-trait correlations but reducing the size of the dataset considerably). Effects of disturbance type on  $|\beta|$  could not be assessed due to data limitations; we thus fit separate models including (H+) or excluding (H-) harvested systems.

<i>response</i>	Analysis: <i>fixed effect</i>	<b>Full dataset</b>			<b>Pooled dataset</b>		
		<i>estimate</i>	<i>lower bound</i>	<i>upper bound</i>	<i>estimate</i>	<i>lower bound</i>	<i>upper bound</i>
$ S $	disturbance	-0.1033	-0.5795	0.3728	-0.0829	-0.5398	0.374
	harvest	-0.2543	-0.8857	0.3772	-0.1513	-0.7809	0.4783
	disturbance:harvest	1.2656	-0.0681	2.5994	-0.0807	-0.9784	0.817
$ \beta $ H+	disturbance	-0.016	-0.1634	0.1314	-0.1121	-0.4837	0.2594
$ \beta $ H-	disturbance	-0.016	-0.2396	0.1113	-0.1091	-0.5408	0.3226



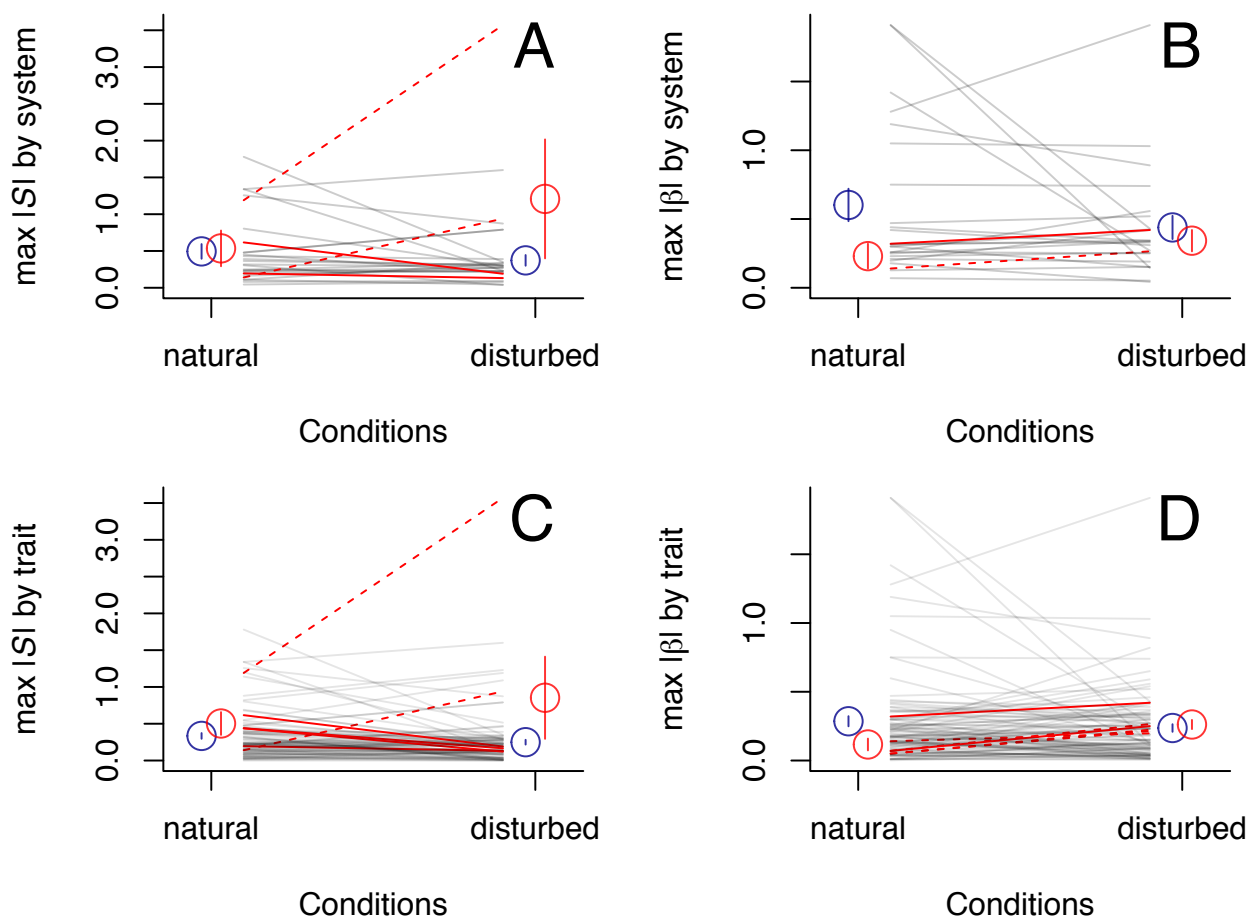
**Table S4.** Results of linear regressions between effect sizes (log response ratios) of disturbance on mean absolute fitness or on the opportunity for selection (using one of the two as the predictor variable) and effects sizes of disturbance on selection strength (the response variable). Each system contributed a single data point (effect size) for each variable such that a LMM was not necessary. Separate regression models were fitted for effect sizes calculated based on  $|S|$  and  $|\beta|$ . Harvested systems were excluded from the analysis. D: disturbed conditions.  $I$ : opportunity for selection. N: natural conditions. SE: standard error.  $w$ : mean individual (absolute) fitness.

<i>response</i>	<i>predictor</i>	<i>slope</i>	<i>SE</i>	<i>p</i>
$\ln(\overline{ S }_D/\overline{ S }_N)$	$\ln(\overline{w}_D/\overline{w}_N)$	-0.3909	0.4337	0.382
	$\ln(\overline{I}_D/\overline{I}_N)$	0.8492	0.2637	0.0057
$\ln(\overline{ \beta }_D/\overline{ \beta }_N)$	$\ln(\overline{w}_D/\overline{w}_N)$	-0.6272	0.2709	0.0363
	$\ln(\overline{I}_D/\overline{I}_N)$	0.4523	0.1980	0.0398

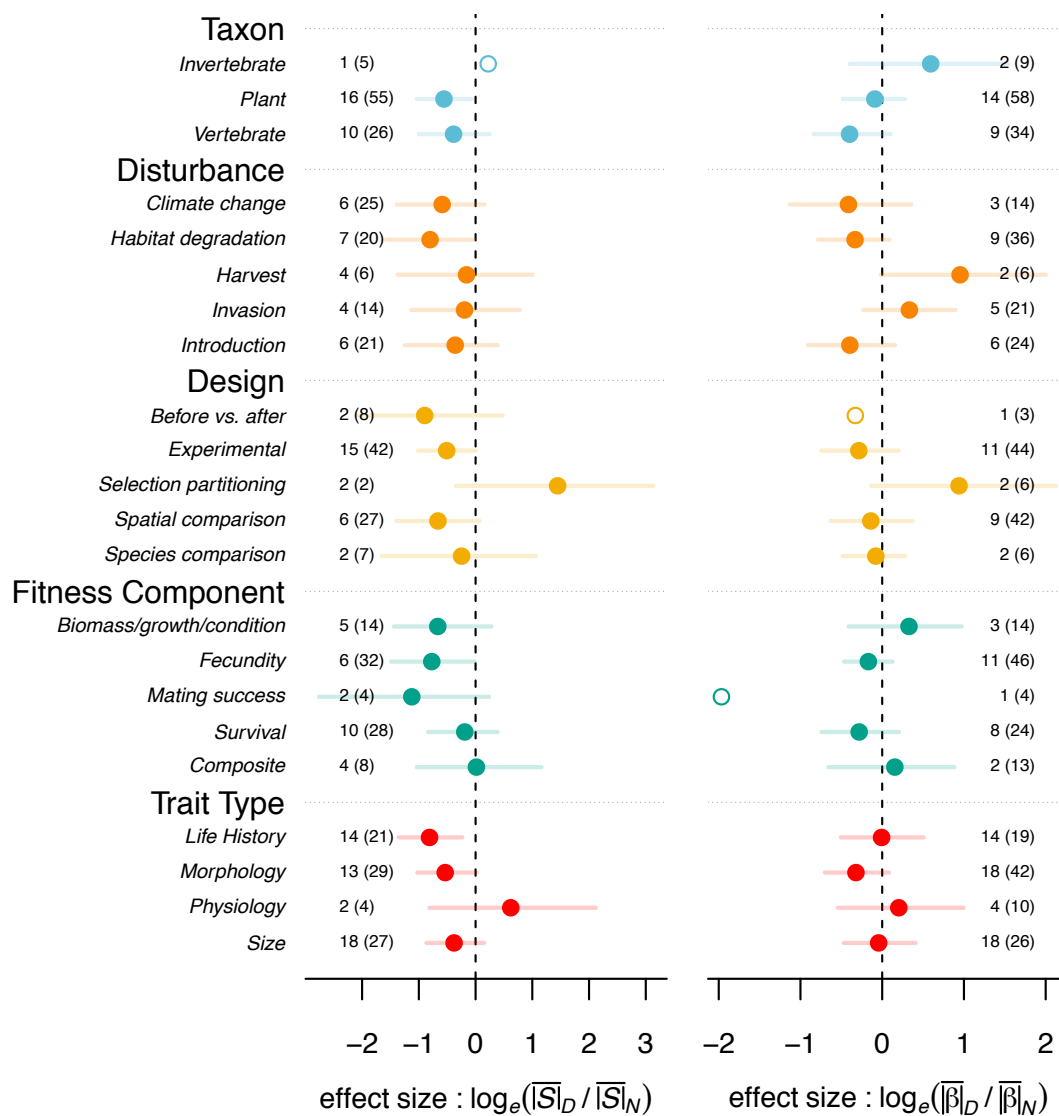
**Figure S1.** Hypothetical example in which a human disturbance reduces the mean absolute fitness of a population of three individuals from 20 to 15 fitness ‘units’. If fitness loss is in purely absolute terms (e.g., all individuals produce 5 fewer offspring; scenario 1 below), then the variance in absolute fitness remains constant and the reduction in mean absolute fitness increases the variance in relative fitness (the opportunity for selection). This is the scenario depicted in Fig. 1B of the main text. In contrast, when fitness loss is purely proportional (e.g., all individuals lose exactly 25 % of their absolute fitness; scenario 2), then the variance in absolute fitness decreases just as much as mean absolute fitness, and the opportunity for selection remains unchanged. If fitness loss is proportional but includes some variation (e.g., individuals lose between 10 and 40% of their absolute fitness; scenario 3), then the opportunity for selection can either increase or decrease. More complex scenarios such as negative feedbacks with decreasing fitness (e.g., mortality or reproductive failure at very low absolute fitness) or fitness loss that correlates with individual absolute fitness (e.g., truncation of upper or lower portion of distribution) would also influence the opportunity for selection.

	<b>Disturbed conditions</b>			
	<b>Natural conditions</b>	<b>Scenario 1: purely absolute loss (-5 units)</b>	<b>Scenario 2: purely proportional loss (-25%)</b>	<b>Scenario 3: noisy proportional (-10 to -40%)</b>
<i>Individual absolute fitness</i>	10 – 20 – 30	5 – 15 – 25	7.5 – 15 – 22.5	6 – 15 – 24
<i>Mean absolute fitness</i>	20	15	15	15
<i>Variance in absolute fitness</i>	100	100	56.25	81
<i>Individual relative fitness</i>	0.5 – 1 – 1.5	0.33 – 1 – 1.66	0.5 – 1 – 1.5	0.4 – 1 – 1.6
<i>Variance in relative fitness (opportunity for selection)</i>	0.25	0.44	0.25	0.36

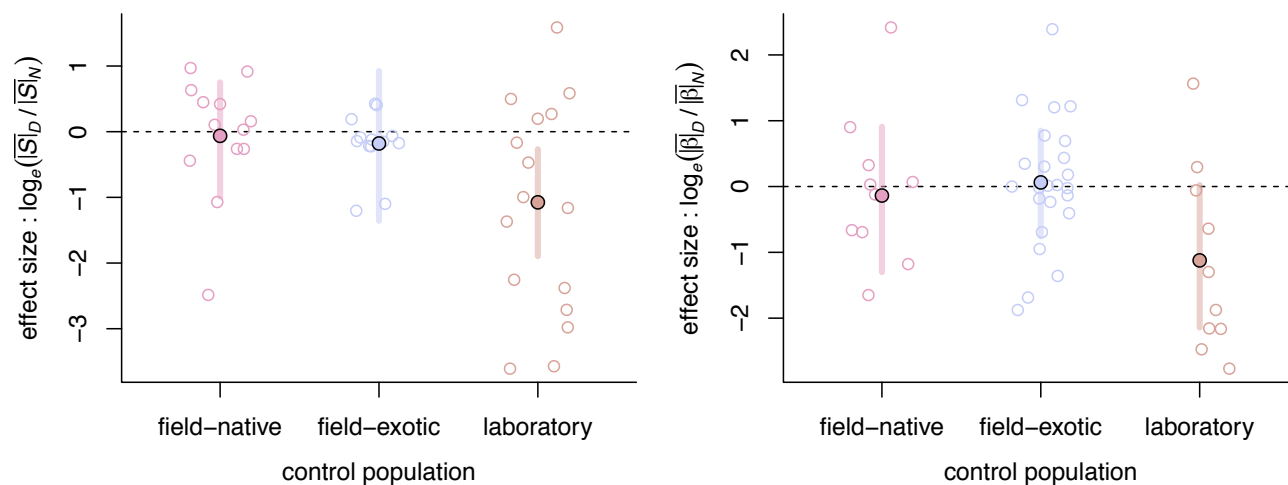
**Figure S2.** Maximum selection strength (measured as  $|S|$  or  $|\beta|$ ) averaged by system or by trait and by disturbance conditions (distinguishing harvested from non-harvested systems). Each line corresponds to a system or a trait. Gray lines are systems or traits for which disturbed conditions represent a disturbance other than harvest. Red lines are for harvested systems/traits, and dotted lines correspond to the subset of those that are fisheries (cod and pike). Circles indicate the mean taken across all systems or traits of a given disturbance type, in the corresponding disturbance conditions. Red and blue symbols respectively correspond to the mean of red and grey lines (harvest vs. other disturbance). Error bars = s.e.m.



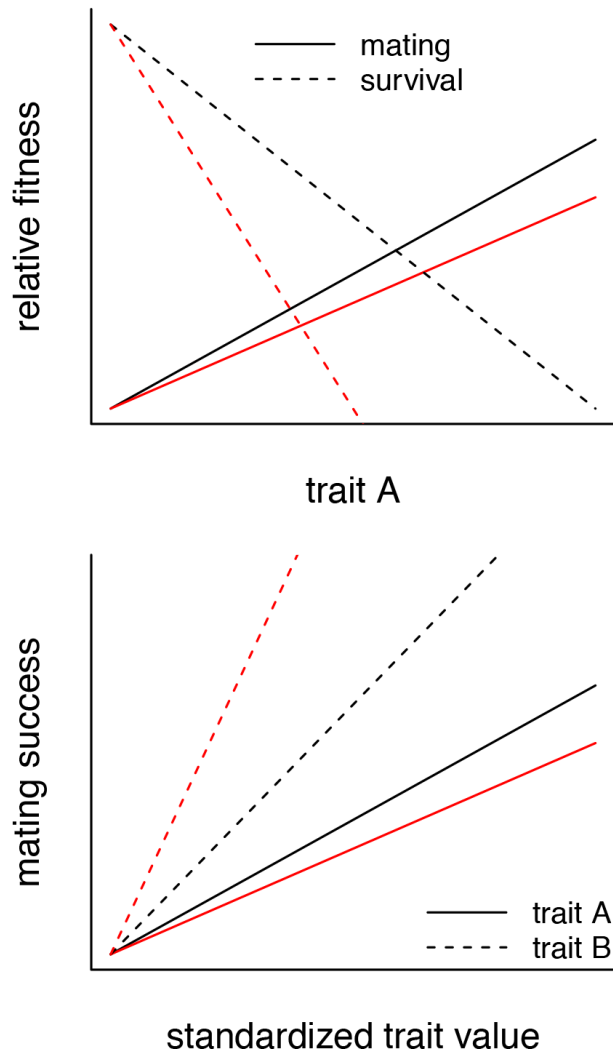
**Figure S3.** Effect of disturbance on selection strength across a variety of system properties. An effect size (log response ratio) of disturbance was calculated for each trait, after averaging coefficients for traits with multiple estimates per disturbance conditions, and then analyzed with Bayesian mixed models including system as a random effect. Separate models were fitted for the five different groupings (taxon, disturbance, experimental design, fitness component, and trait type) and two types of selection coefficients ( $S$  and  $\beta$ ). Symbols represent the estimated posterior means with 95% credible intervals; symbols left of the vertical dotted line are grouping classes for which selection was weaker in disturbed than in natural conditions. Open symbols show the mean effect size for grouping classes with a single system, which were excluded from models. The small numbers denote the number of systems (and effect sizes) in each grouping class. Note that for  $S$ , the two systems with a ‘selection partitioning’ design are the two fisheries (while for  $\beta$  these include one fishery and one mammalian population).



**Figure S4.** Effect of disturbance on selection strength in experimental studies, grouped based on the type of control population used to measure selection in natural conditions. Open symbols are effect sizes, i.e. log response ratios of selection strength in disturbed vs. natural conditions for individual traits. Positive values on the y axis indicate traits for which disturbance increased selection strength while negative values indicate traits for which disturbance decreased selection strength. Filled symbols with error bars indicate the results of Bayesian mixed models (mode and 95% credible intervals of posterior distributions) estimating mean values in each context. Human impacts on selection strength were estimated using either selection differentials (left) or gradients (right).



**Figure S5.** Hypothetical example of selection in control (black) and disturbed (red) conditions, showing how human impacts on selection strength (the slope of a line) can vary among fitness components and traits. In the top panel, a human disturbance weakens selection on trait A via mating success, but that same disturbance strengthens selection even more (on the same trait) via another fitness component (survival). In the bottom panel, the same disturbance that weakens selection on trait A via mating success also strengthens selection on trait B via the same fitness component.



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*We also extracted anthropogenic selection coefficients from the following references, but these had to be discarded from the analysis due to a lack of 'natural' coefficients:*

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*Finally, we also obtained unpublished data on harvest-induced selection in bighorn sheep (Ovis Canadensis) from Gabriel Pigeon and Marco Festa-Bianchet (Université de Sherbrooke, Canada). These data, also included in the selection database, were the following:*

<b>trait</b>	<b>conditions</b>	<b>selection coefficient</b>	<b>standard error</b>
body mass	Harvest	0.0331	0.0441
horn length	Harvest	-0.0234	0.047
horn base circumference	Harvest	0.0477	0.0496
body mass	Harvest	0.0503	0.0398
horn length	Harvest	0.0076	0.0385
horn base circumference	Harvest	-0.026	0.043
body mass	Harvest	0.0539	0.0349
horn length	Harvest	-0.0413	0.0337
horn base circumference	Harvest	0.0434	0.0364
body mass	Harvest	0.0334	0.0307
horn length	Harvest	0.0039	0.031
horn base circumference	Harvest	0.0303	0.0325
body mass	Harvest	-7.00E-04	0.0453
horn length	Harvest	-0.1907	0.0805
horn base circumference	Harvest	0.1655	0.0805
body mass	Harvest	0.1215	0.0359
horn length	Harvest	-0.1755	0.0449
horn base circumference	Harvest	0.0368	0.0426
body mass	Harvest	0.0364	0.0338
horn length	Harvest	-0.1189	0.0397
horn base circumference	Harvest	0.0057	0.0392
body mass	Harvest	-0.0081	0.0393
horn length	Harvest	-0.0547	0.0385
horn base circumference	Harvest	0.0154	0.0365
body mass	No Harvest	0.4376	0.1099
horn length	No Harvest	-0.1238	0.1016
horn base circumference	No Harvest	-0.1014	0.1136
body mass	No Harvest	0.3824	0.131
horn length	No Harvest	-0.2306	0.1065
horn base circumference	No Harvest	-0.1338	0.1265
body mass	No Harvest	0.2365	0.0765
horn length	No Harvest	-0.0043	0.076
horn base circumference	No Harvest	-0.1356	0.0711
body mass	No Harvest	0.1508	0.0962
horn length	No Harvest	0.0159	0.0797
horn base circumference	No Harvest	-0.1557	0.0821
body mass	No Harvest	0.206	0.2021
horn length	No Harvest	-0.3354	0.3651

horn base circumference	No Harvest	0.1127	0.2995
body mass	No Harvest	0.1826	0.2611
horn length	No Harvest	-0.6164	0.339
horn base circumference	No Harvest	0.313	0.2947
body mass	No Harvest	0.0338	0.1579
horn length	No Harvest	-0.0952	0.1678
horn base circumference	No Harvest	-0.041	0.1467
body mass	No Harvest	-0.2958	0.1397
horn length	No Harvest	-0.3349	0.0716
horn base circumference	No Harvest	0.4396	0.1528

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