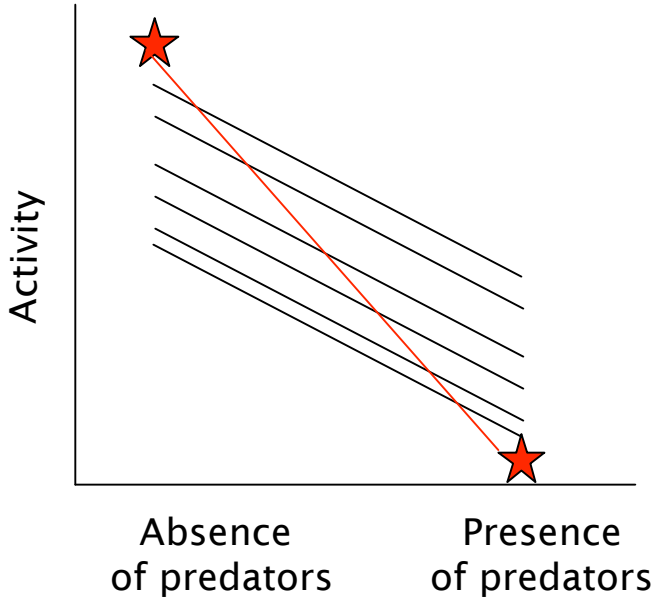
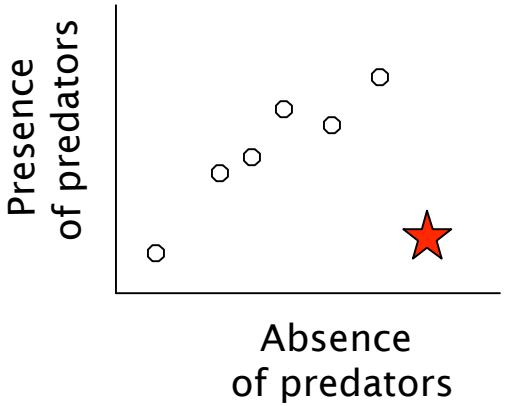
Personality is mysterious from an evolutionary point of view, for three reasons

1. **Why should individuals behave consistently, either through time or across functional contexts?**





Personality suggests cleverness?

Sih et al 2004

Personality is mysterious from an evolutionary point of view, for three reasons

1. **Why should individuals behave consistently, either through time or across functional contexts?**

2. **Why should individuals *differ* in how they behave?**

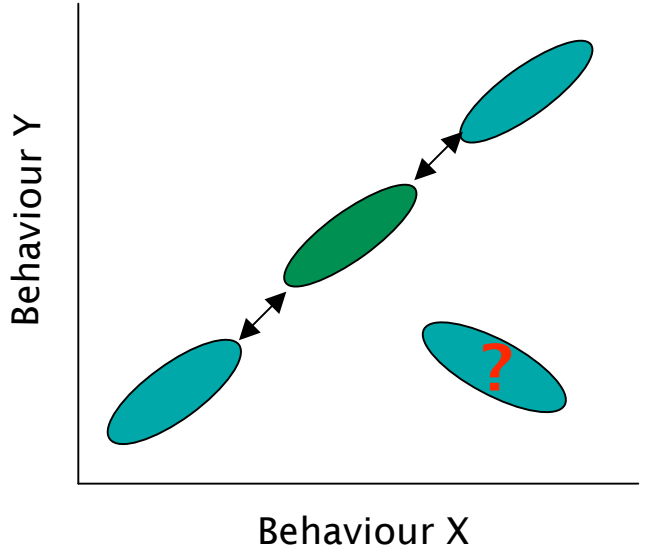
Natural selection erodes heritable variation that is related to fitness

Personality is mysterious from an evolutionary point of view, for three reasons

1. **Why should individuals behave consistently either through time or across functional contexts?**

2. **Why should individuals *differ* in how they behave?**

3. **Evolutionary constraints**



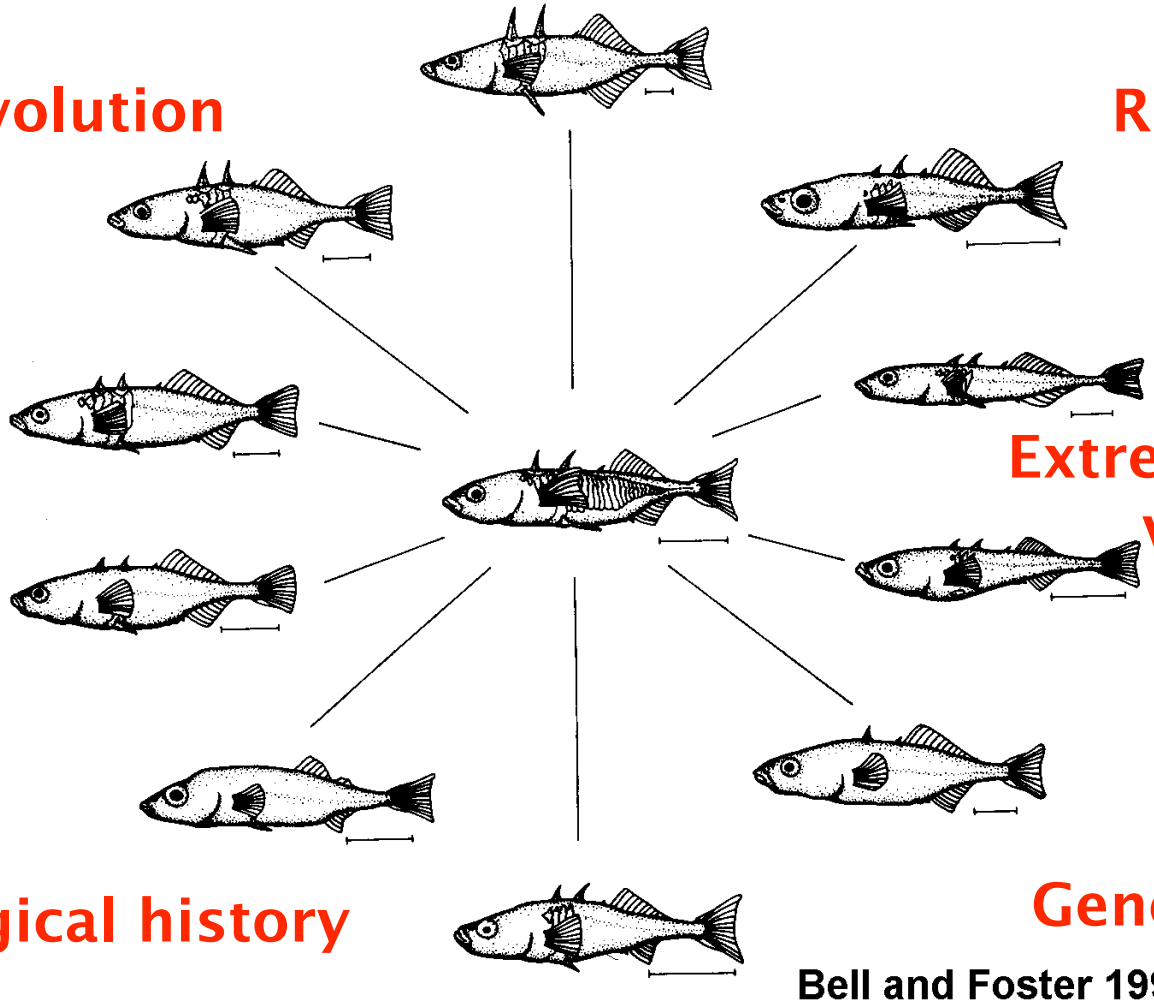
What can the radiation of threespined sticklebacks tell us about the evolution of personality?

Rapid evolution

Replication

Ancestor can be studied

Extreme, adaptive variation



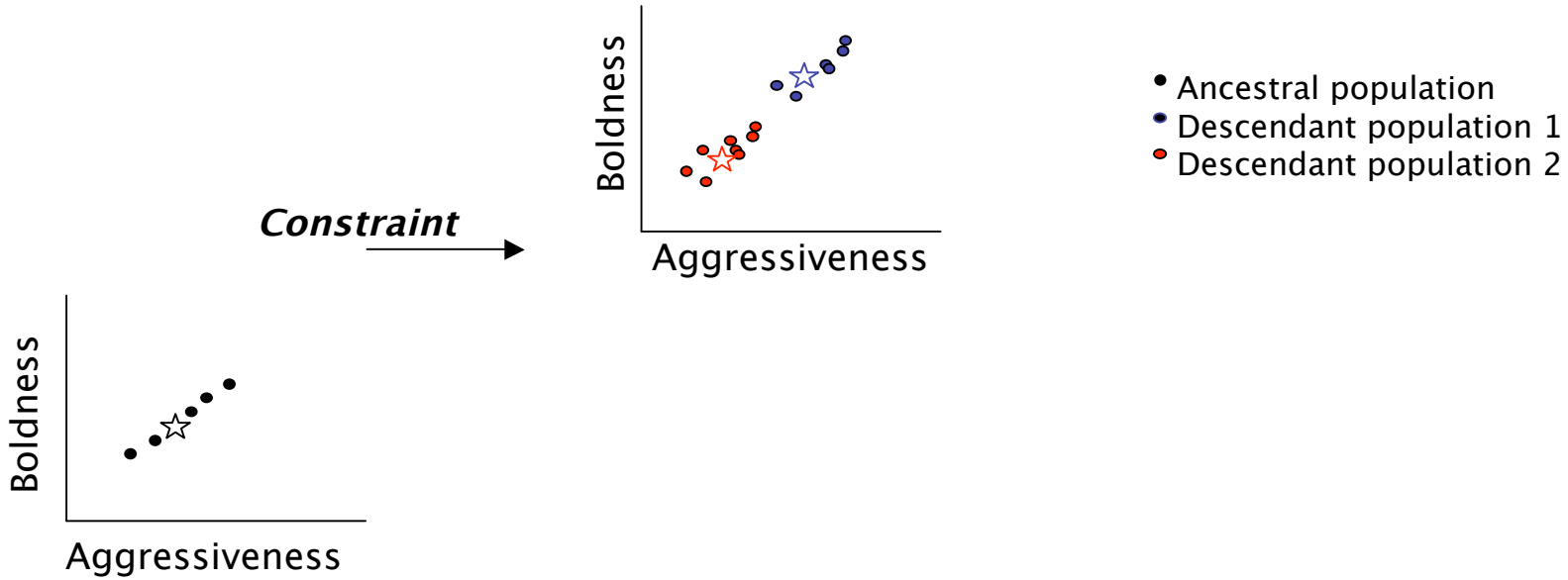
Ethological history

Genomic tools

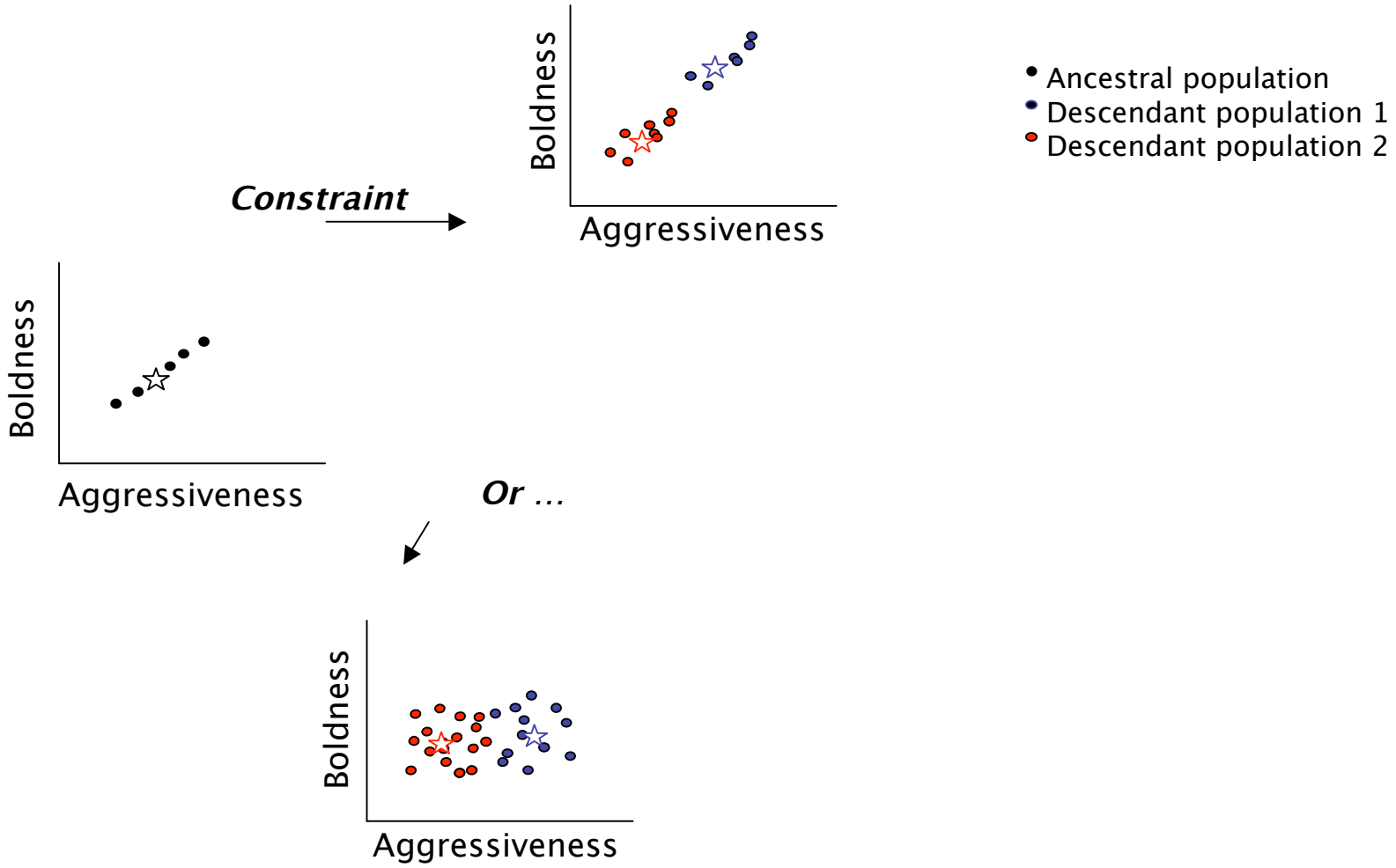
Bell and Foster 1994

The evolutionary fate of correlated traits

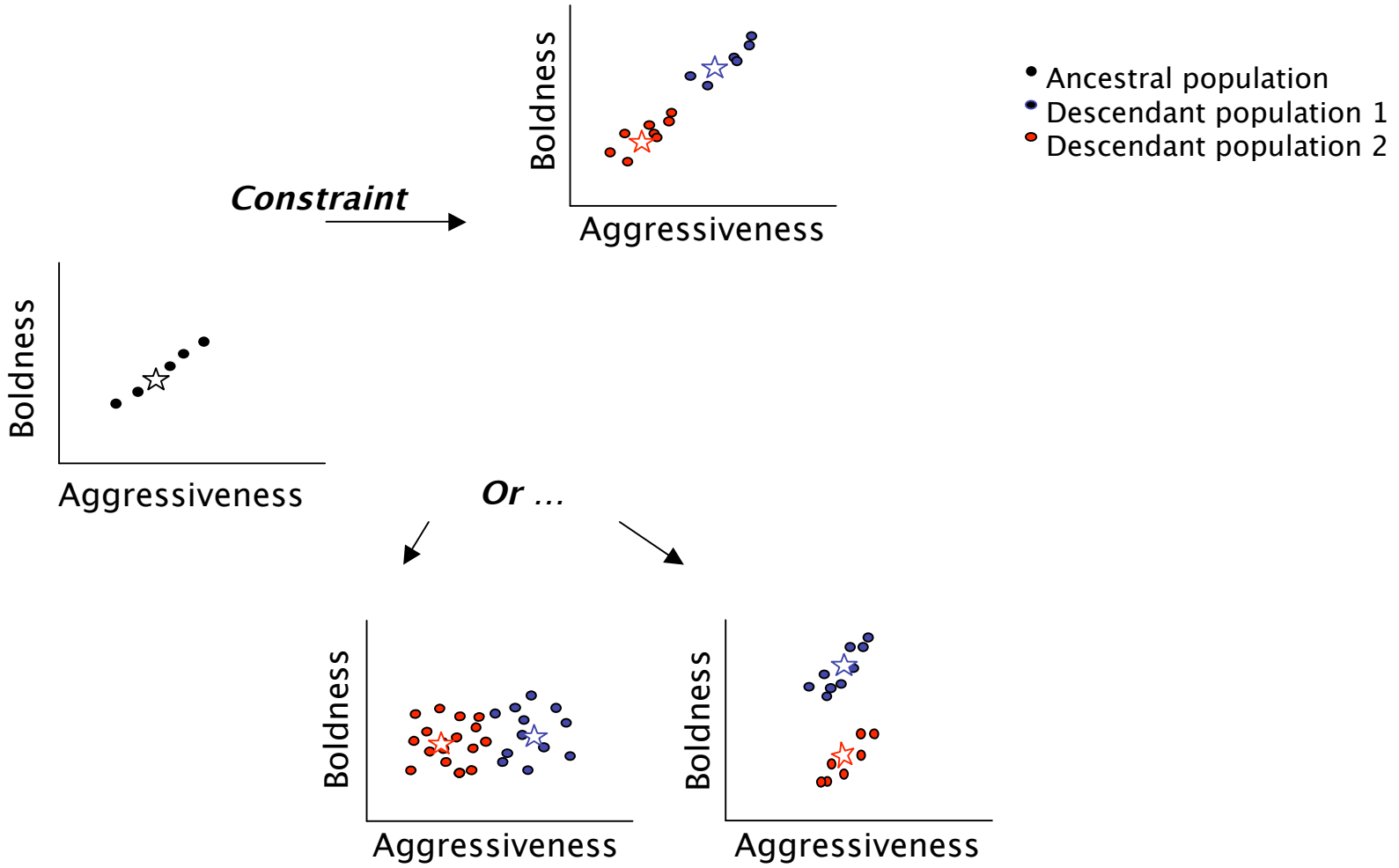
The evolutionary fate of correlated traits



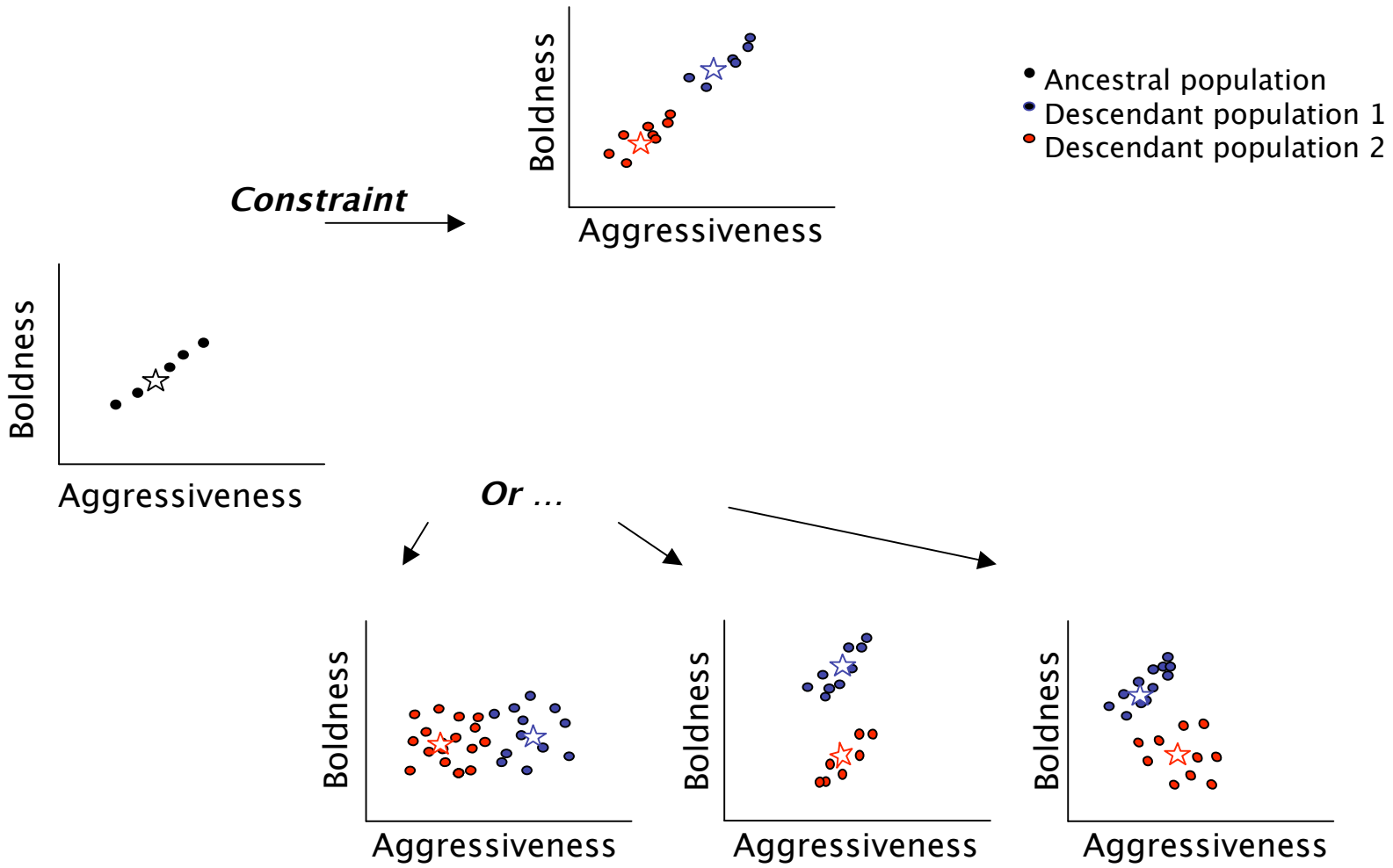
The evolutionary fate of correlated traits



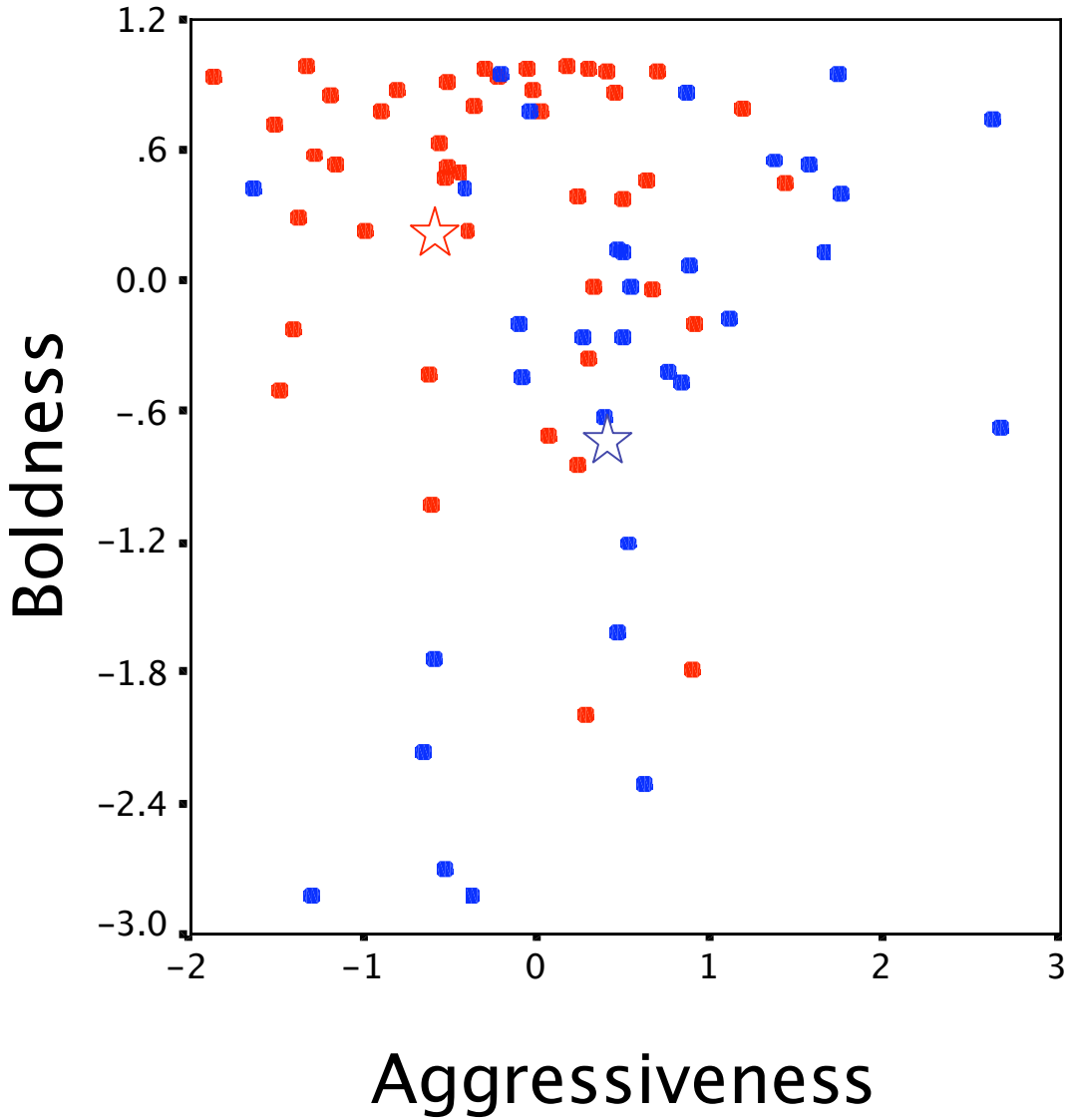
The evolutionary fate of correlated traits



The evolutionary fate of correlated traits



Boldness and aggressiveness were genetically correlated in one population but not another (Bell 2005 *JEB*)



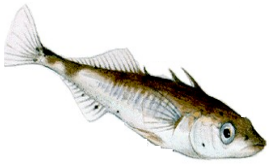
ALSO: Boldness and aggressiveness were uncoupled over ontogeny

(Bell & Stamps 2004 *An Behav)*

- Navarro: r=0.52, n=29, P<0.01
- Putah: r=0.13, n=42, *NS*

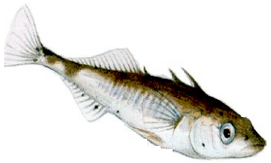
Can experimental exposure to real predation risk generate the syndrome?

With Andy Sih, UC Davis



Can experimental exposure to real predation risk generate the syndrome?

With Andy Sih, UC Davis



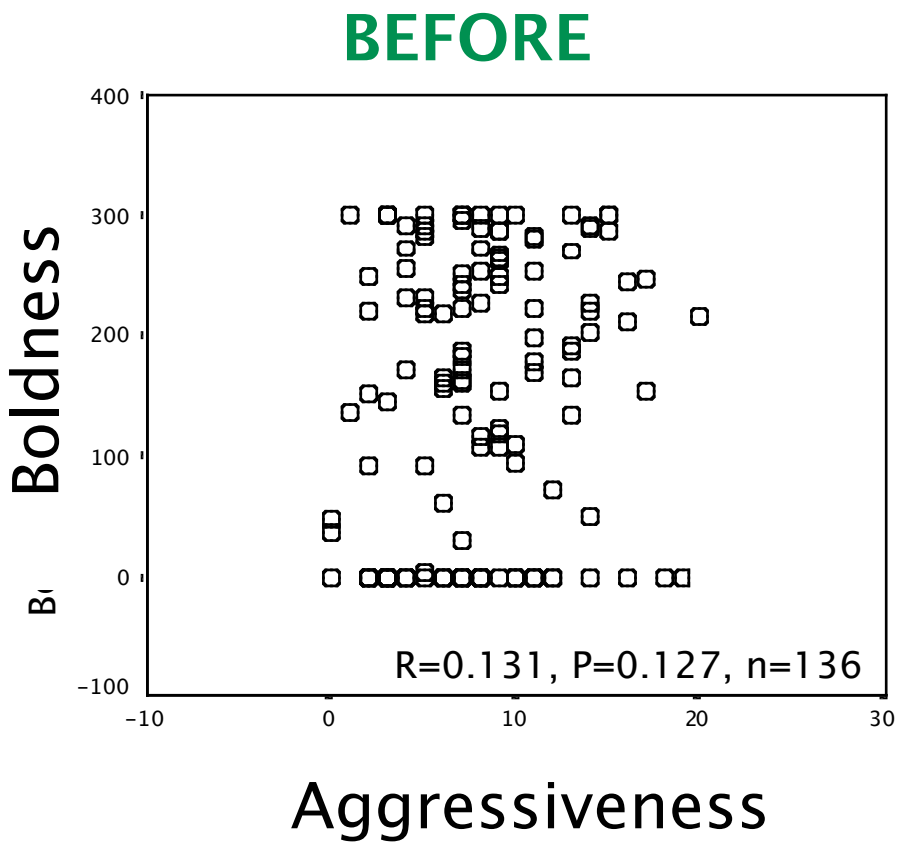
- Measured boldness (time spent eating under predation risk) and aggressiveness (orienting and attacking aconspecific) on individually-marked sticklebacks.

- Placed groups (n=34/pool) of individually-marked fish seminatural pools (n=4 replicate pools) with trout. Control: No trout.

- Removed trout when 1/2 of the sticklebacks had been consumed.

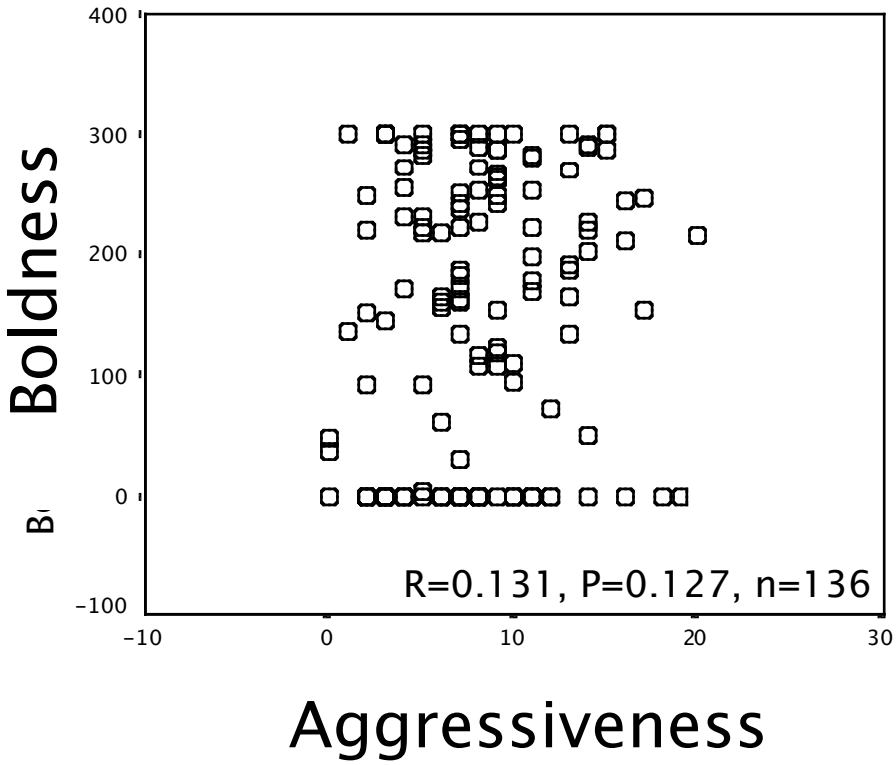
- Re-measured survivors.

Boldness and aggressiveness were not correlated with each other ‘before’

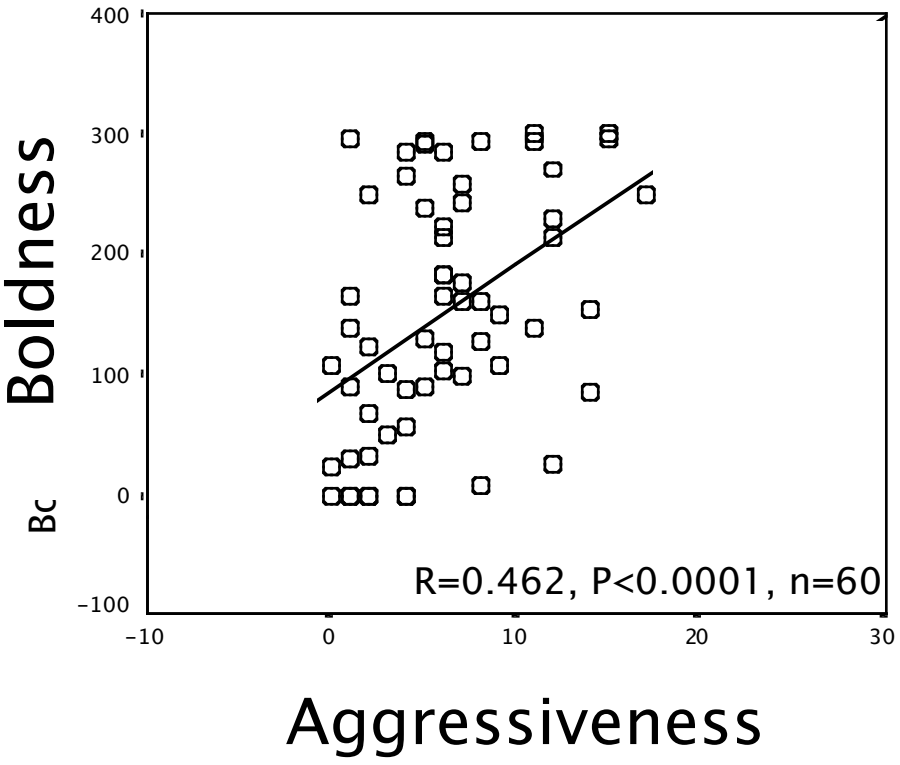


Predation generated the syndrome!

BEFORE

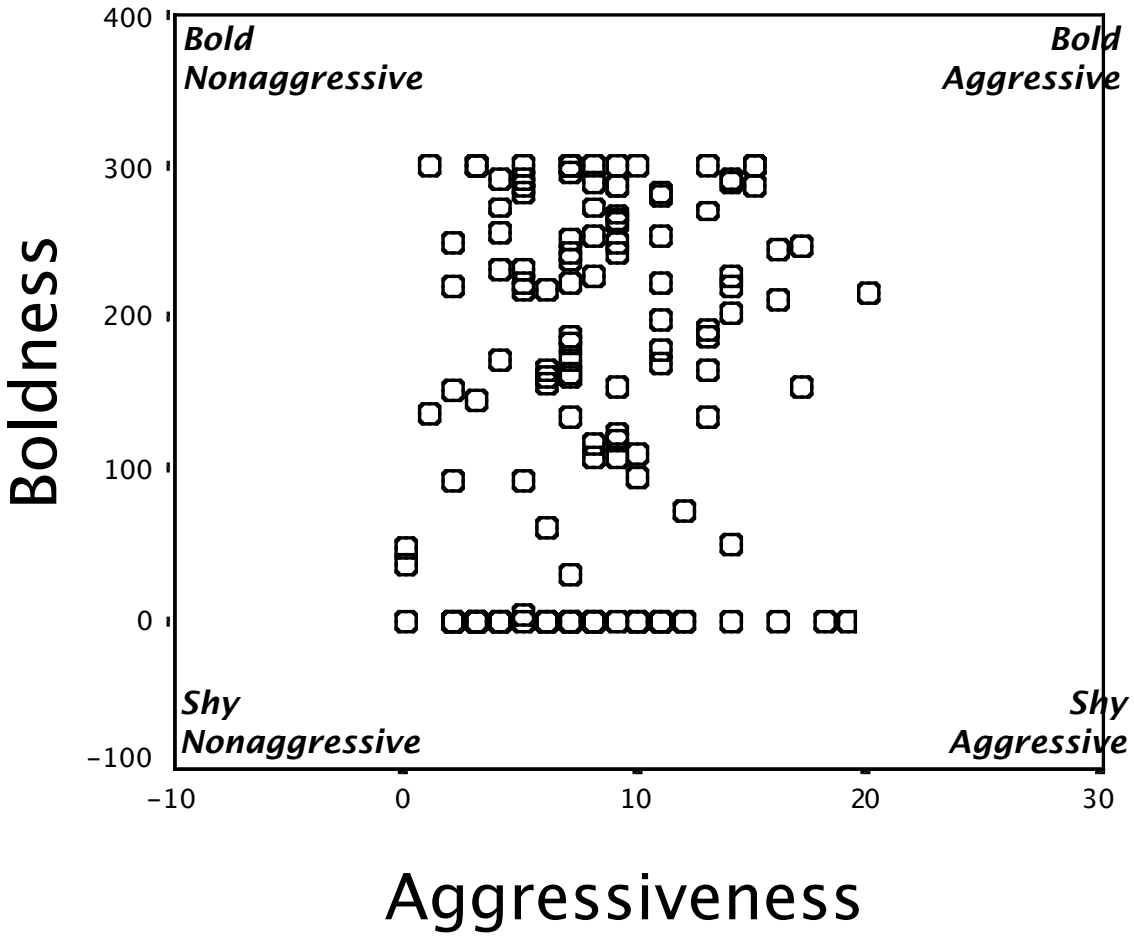


AFTER

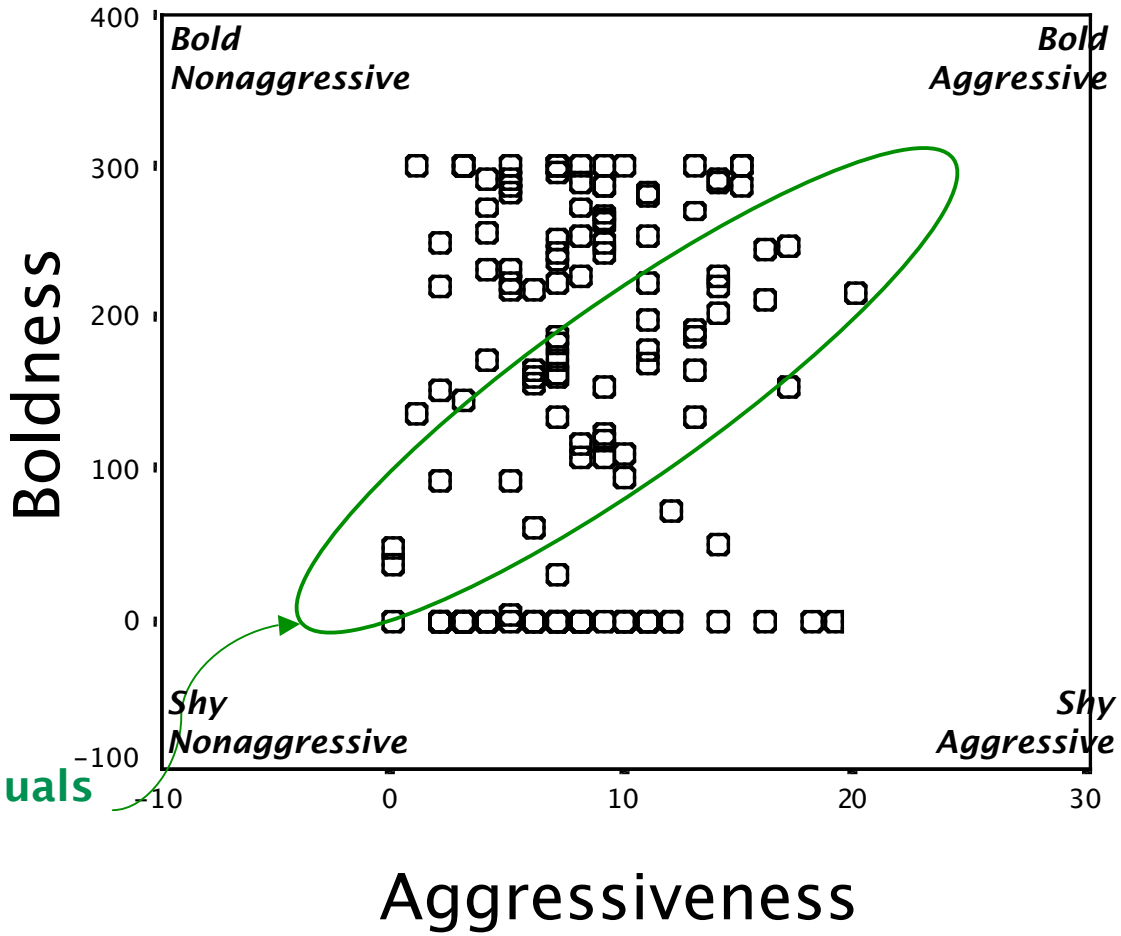


Control: Before NS, After NS
Tank: NS

Two ways this could have happened

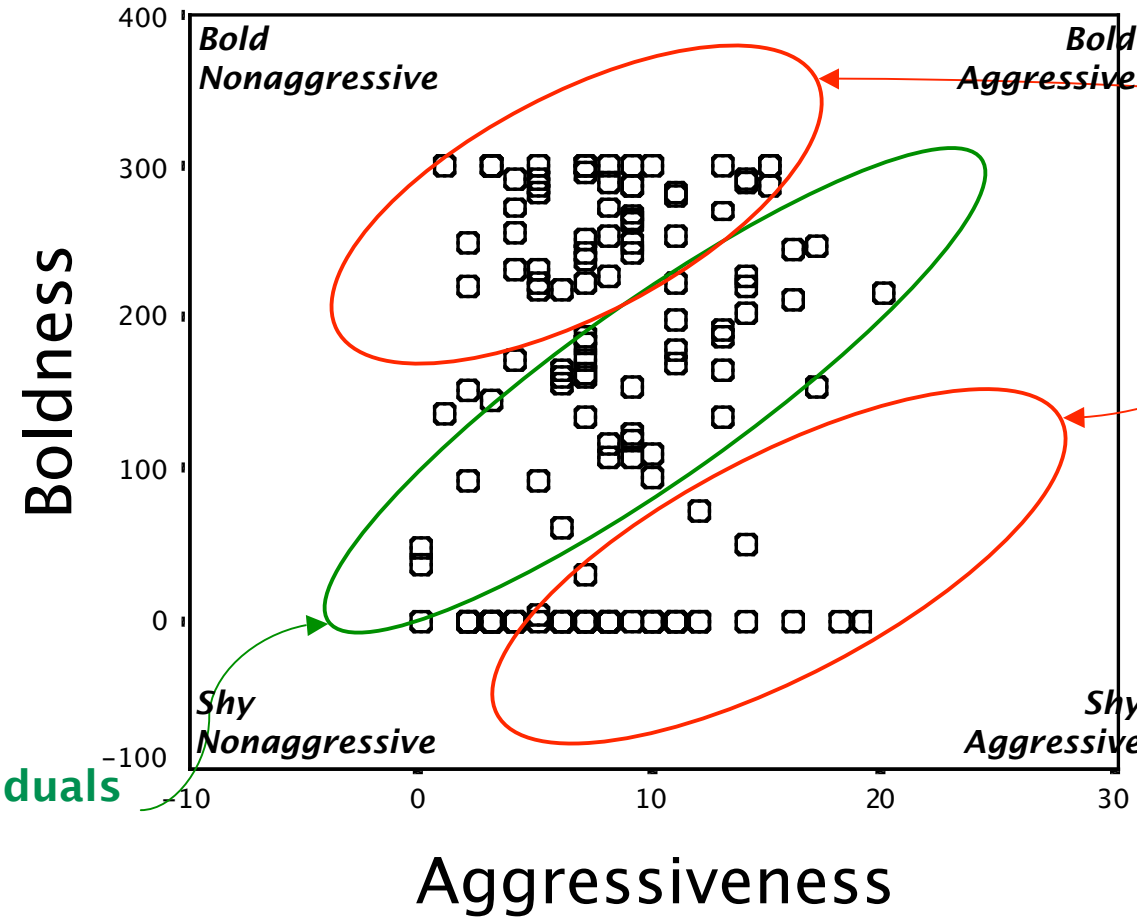


Two ways this could have happened
1. Selection via disproportionate survivorship



These individuals survived

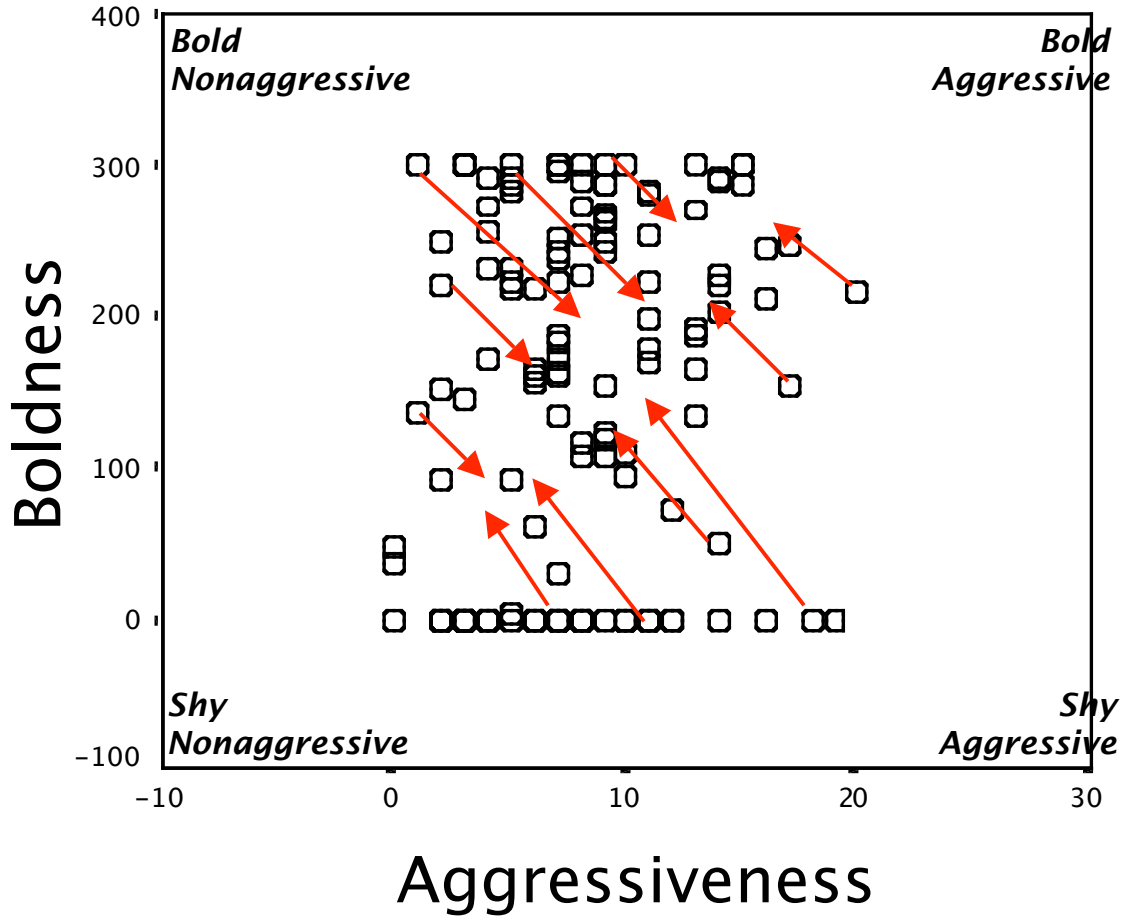
Two ways this could have happened
1. Selection via disproportionate survivorship



These individuals died

These individuals survived

Two ways this could have happened
2. Behavioural plasticity



Directional selection favored increased aggressiveness, decreased boldness

Directional, stabilizing and correlational selection gradients ($\beta \pm$ standard error) from multiple logistic regression. Model χ^2 =7.477, 5 *df*, n=122, *p*=0.188.

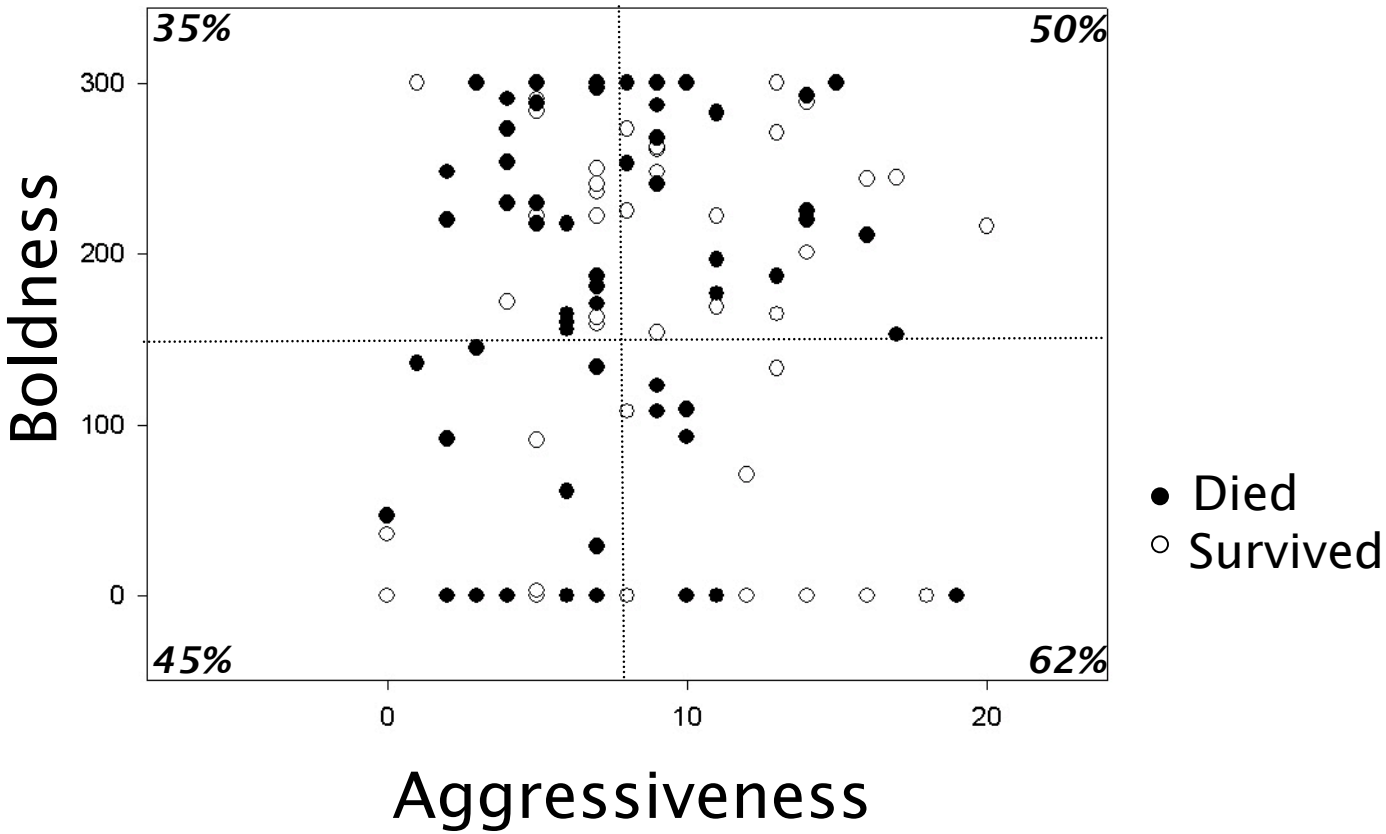
Aggressiveness

Boldness

	$\beta \pm$ SE	*p*
# Orients	0.432 ± 0.212	0.04
Time eating	-0.330 ± 0.202	0.05
# Orients * Time eating	0.095 ± 0.193	0.62
# Orients^2	-0.111 ± 0.156	0.47
Time eating^2	0.258 ± 0.294	0.38
Constant	-0.285 ± 0.368	0.43

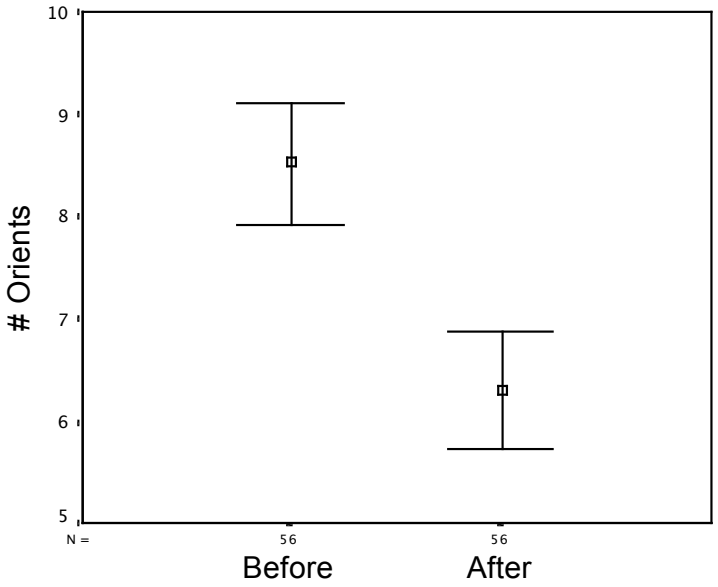
Bell & Sih 2007 *Ecology Letters*

Selection or plasticity?

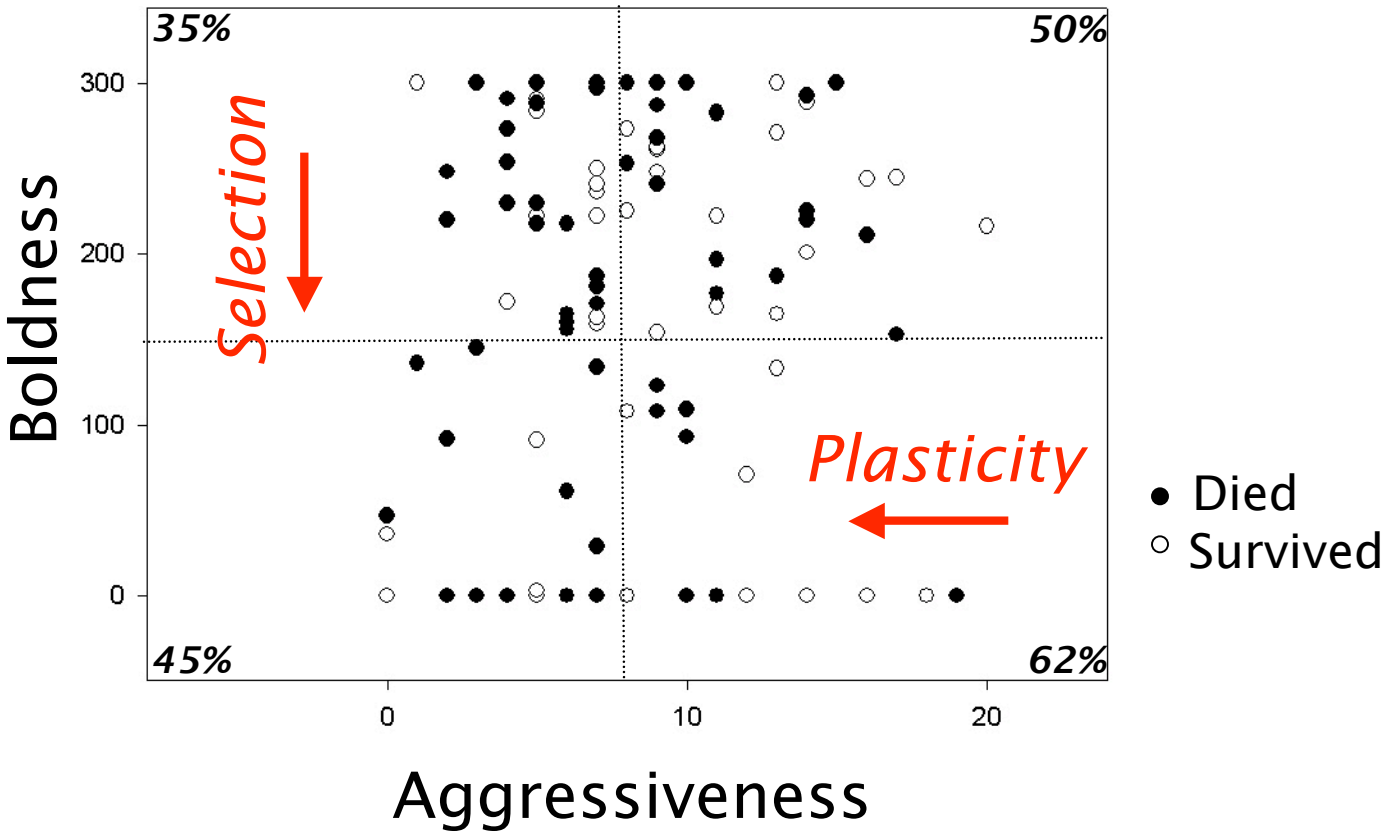


THERE WAS SELECTION, BUT IT WASN'T CORRELATIONAL

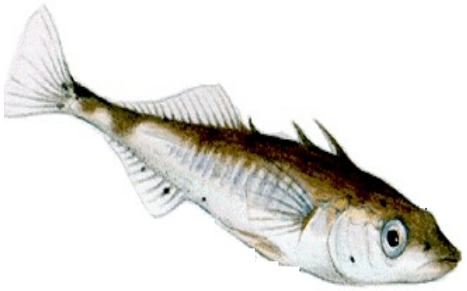
Sticklebacks became less aggressive



Selection and plasticity



Can experimental exposure to real predation risk generate the syndrome?



- Boldness and aggressiveness were not packaged together as a syndrome 'before' exposure to real predation risk.
- The boldness-aggressiveness behavioural syndrome appeared among the survivors.
- Both selection and plasticity generated the syndrome.

Can we make generalizations about the magnitude of consistent individual differences in behavior in non-human animals?

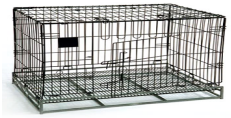
A repeatability estimate (the intraclass correlation coefficient) compares the extent of within versus between-individual variation.

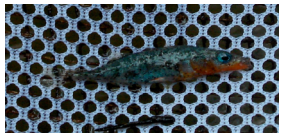
We analyzed 759 repeatability estimates from 114 studies on 98 species.

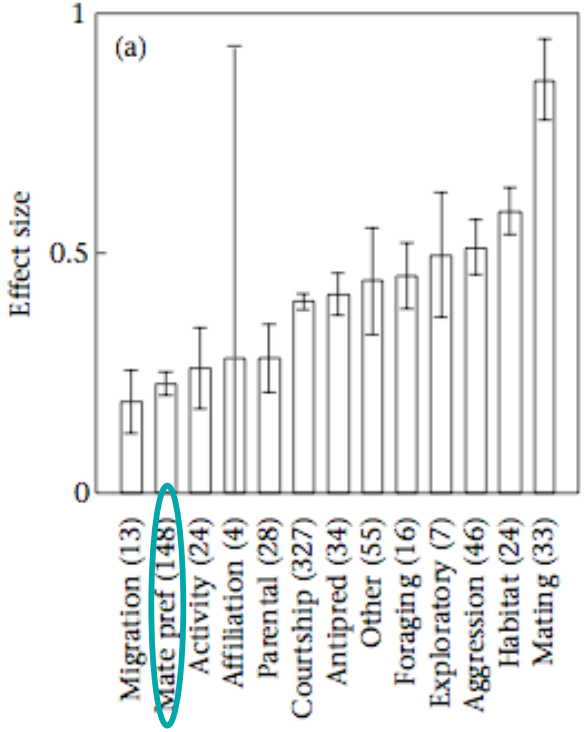
Factors: behaviour, taxa, age, number of measurements, field or lab study, sex

Bell, Hankison & Laskowski
2009 *Animal Behaviour*

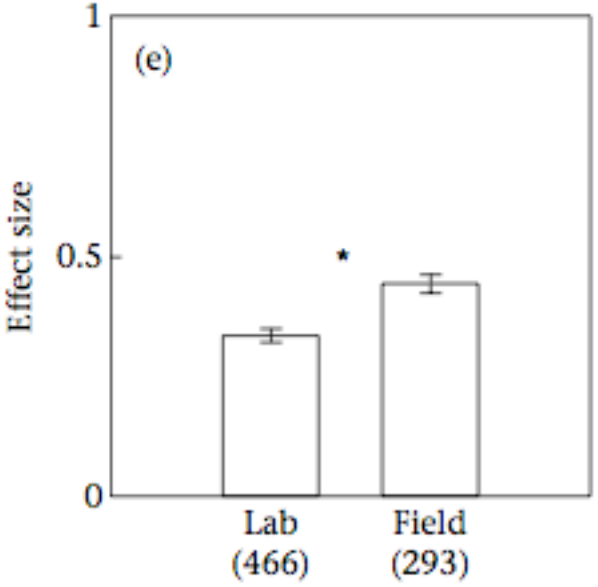
We can make some generalizations from the data



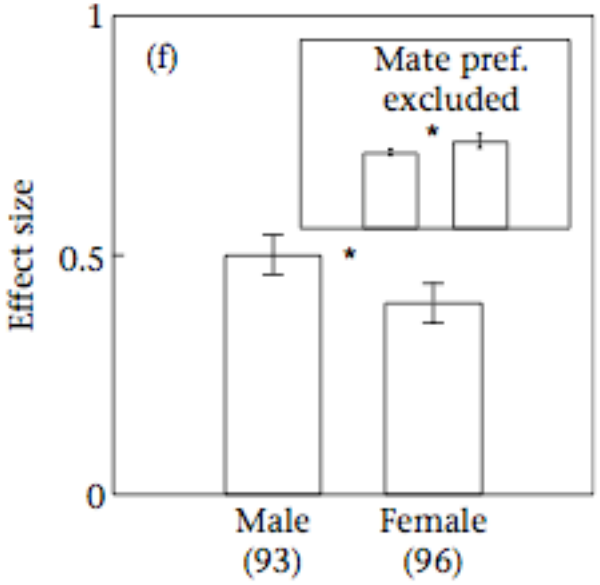




Some behaviours were more repeatable than others



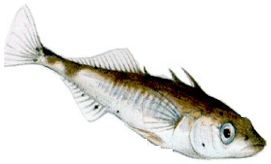
Behaviours measured in the field were more repeatable than behaviours measured in the lab



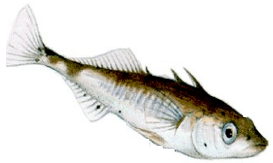
Sex differences?

Bell et al 2009 *An Behav*

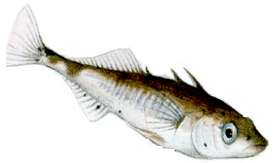
Some current projects in the lab….



Individual differences in response to a changing food resource (Kate Laskowski)

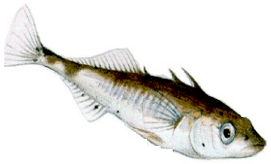


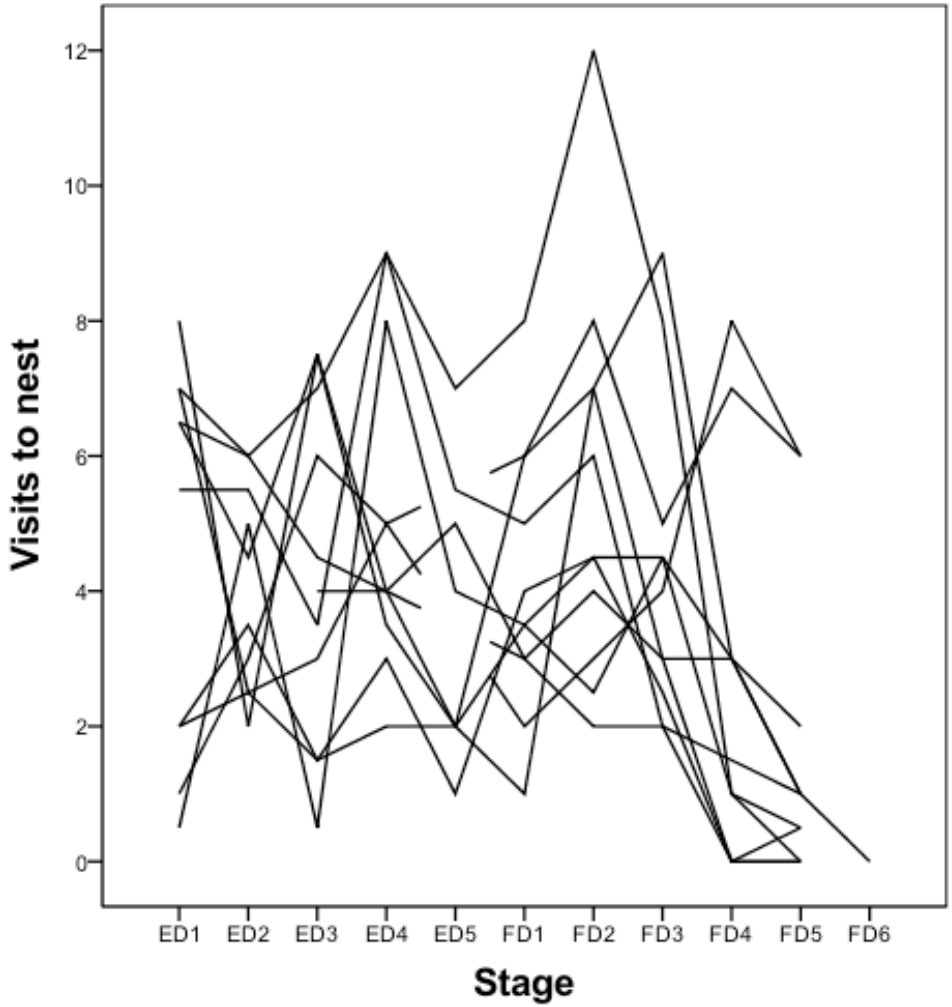
Individual differences in response to a changing food resource (Kate Laskowski)



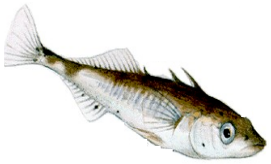
Individual differences in parenting behaviors (Laura Stein)

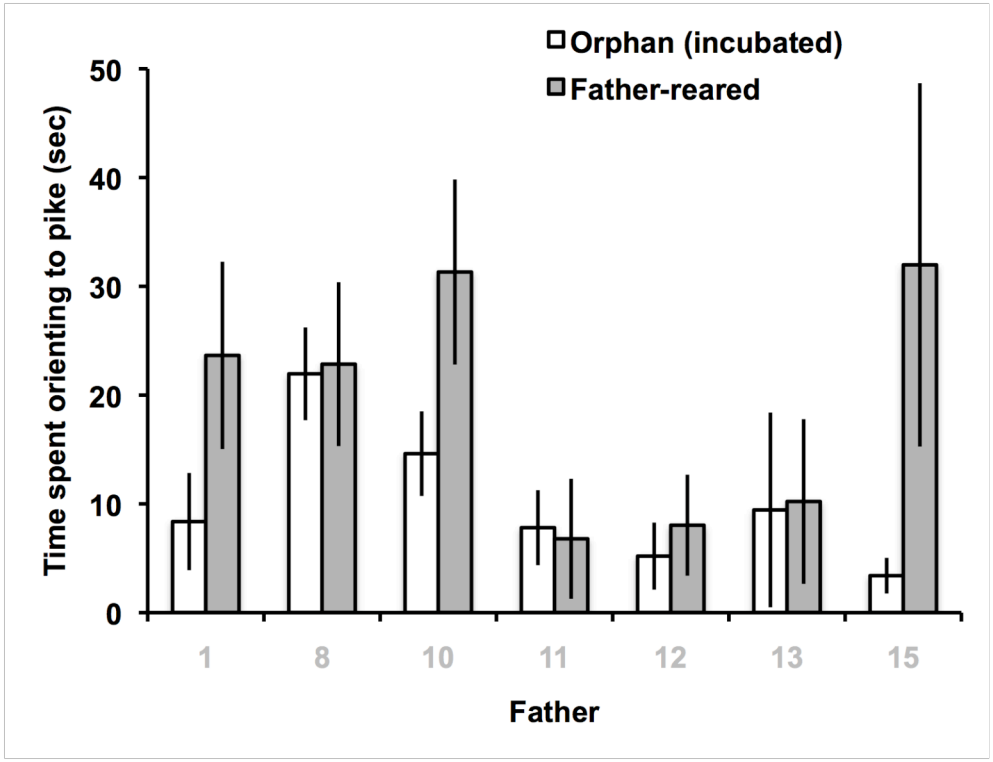
Individual differences in parenting behaviors (Laura Stein)





… and their consequences for offspring (Katie McGhee)



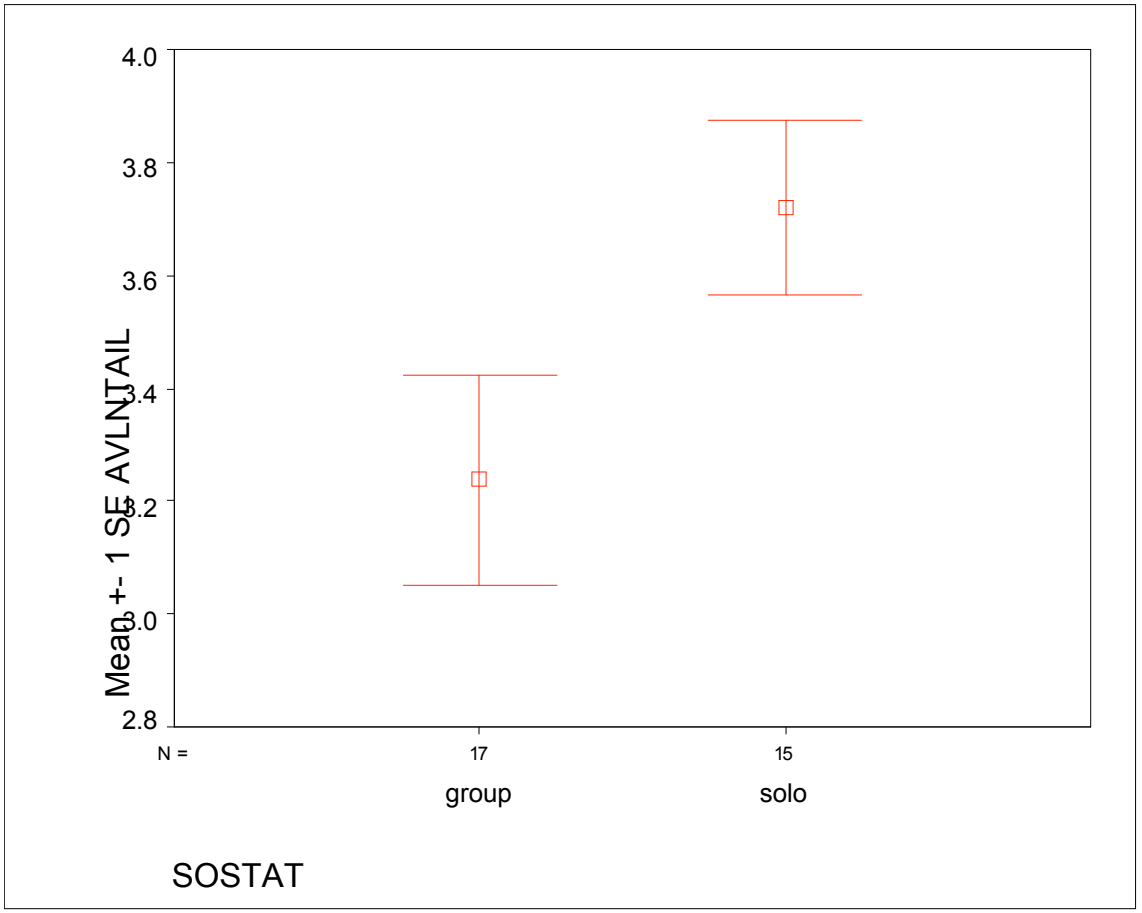


Individual differences in the latency to emerge and explore a novel environment *in the field* (Simon Pearish)

Individual differences in the latency to emerge and explore a novel environment *in the field* (Simon Pearish)

r=0.67, n=32
individuals
measured 3x

Individuals collected in groups emerged faster and explored more



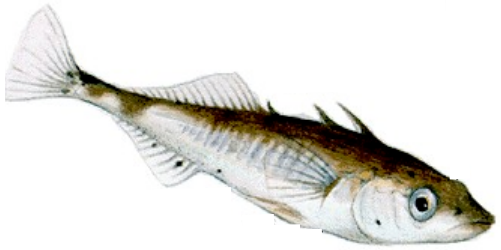
Next: Diet?
Individual specialization?

Searching the genome for the source of a behavioral syndrome in threespined sticklebacks

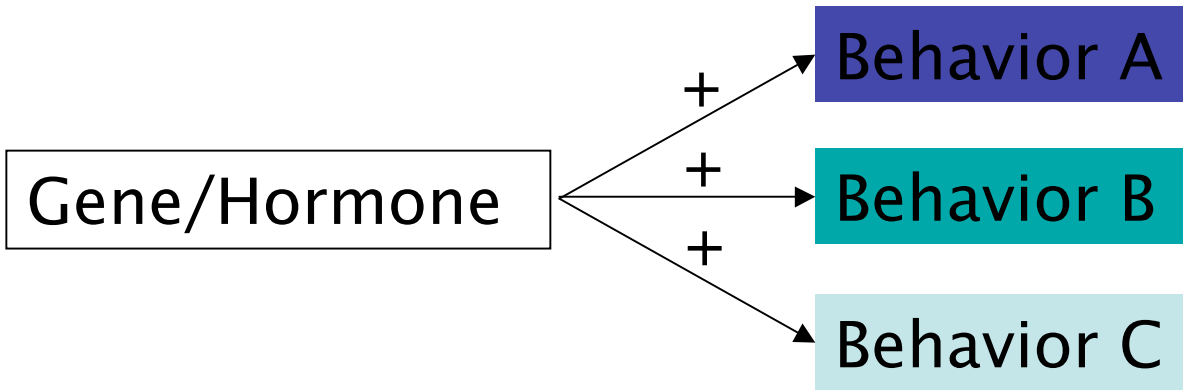
Alison M. Bell, Y. Osee Sanogo
Integrative Biology, University of Illinois

Pengfei Yu, Dan Xie, Sheng Zhong
Bioengineering, University of Illinois

Mark Band
Keck Center, University of Illinois



Pleiotropy is the textbook cause of a behavioral syndrome



Aggressive behavior

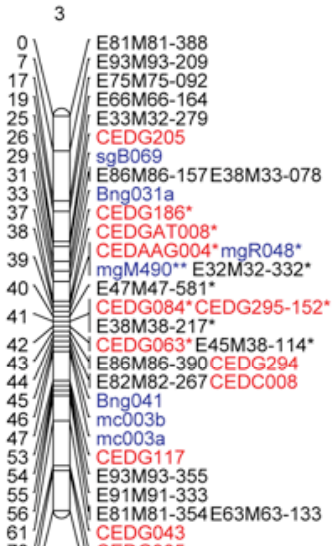
Parental behavior

How to study pleiotropy?

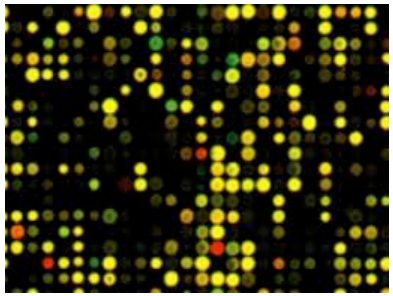
- Quantitative genetics, genetic correlations

$$r_{Ax,y} = \frac{b_{xy}}{\sqrt{b_x b_y}}.$$

- QTL mapping, gene association



- Whole genome expression



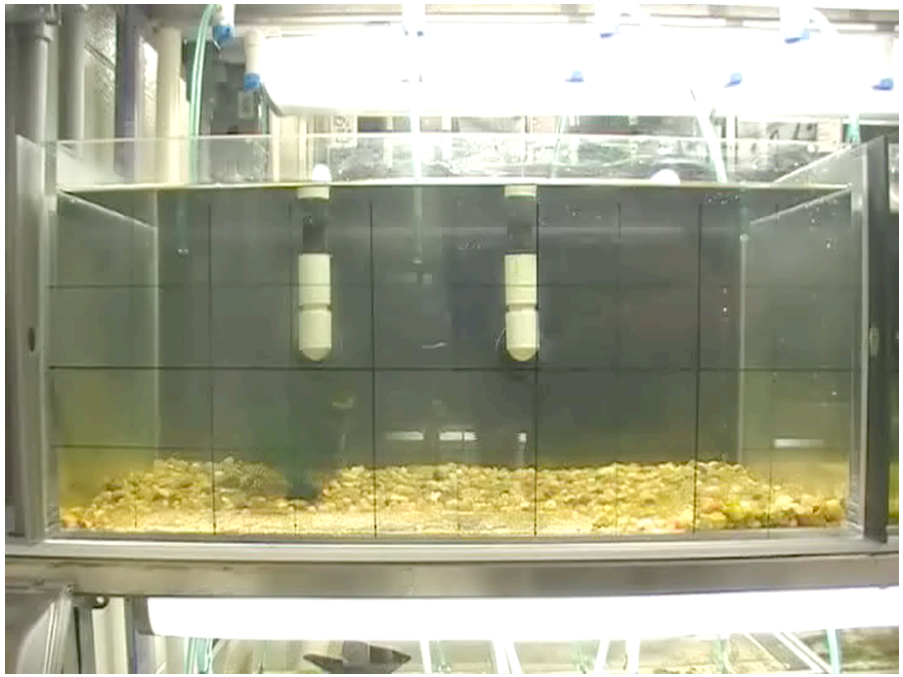
Hypothesis: Boldness toward predators and aggressiveness toward conspecifics are positively correlated because the same molecular mechanisms are involved in behavioral reactions to both predators and conspecifics.

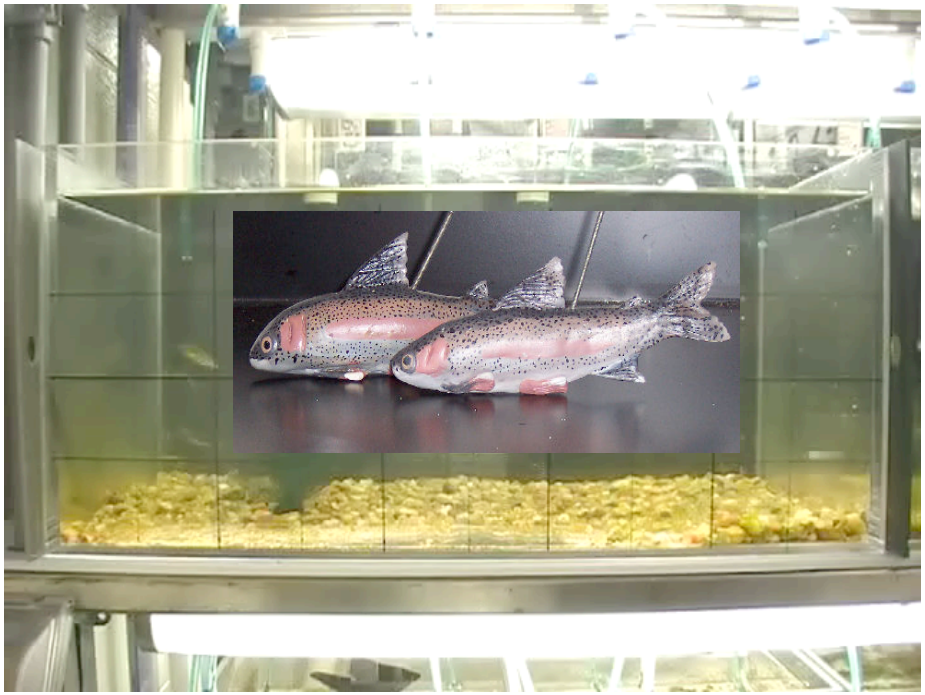
General strategy

- Use whole genome expression data to identify differentially expressed genes in response to predators and conspecifics.
- Look for genes that are shared.
- Search the genome for common regulatory motifs.

Methods: Response to predators

- Exposed sticklebacks to predator cues for six days
  - Control: no cues of predators
- mRNA from whole brain on day 7
- N=5 control, 5 experimental, 10 arrays
- 385K probe high density NimbleGen single-color microarray





Methods: Response to a conspecific

- Exposed nesting male sticklebacks to a territorial intruder for 15 min
  - Control: empty flask
- Extracted mRNA from 4 brain regions 30 minutes after intruder removed
- N=5 control, n=4 experimental individuals, 40 arrays in loop design
- 44K probe, two-color Agilent microarrays

*Differentially expressed genes in response to **predators***

ID	logFC	AveExpr	t	P.Value
ENSGACT0000	3.96400072	6.80965806	7.71100353	2.00E-06
ENSGACT0000	-1.71111924	8.93053751	-6.26911607	1.99E-05
ENSGACT0000	1.27767463	5.87794484	6.22591536	2.14E-05
ENSGACT0000	1.47331778	5.65367305	6.16392829	2.38E-05
ENSGACT0000	-1.82268859	7.5873738	-5.99099515	3.21E-05
ENSGACT0000	2.61609287	6.7582394	5.85897362	4.03E-05
ENSGACT0000	2.9095063	7.90325068	5.74846965	4.90E-05
ENSGACT0000	-1.28103675	10.9963008	-5.71616589	5.18E-05
ENSGACT0000	-1.45118577	7.046863	-5.48148213	7.88E-05
ENSGACT0000	1.06389949	6.60877028	5.44587923	8.40E-05
ENSGACT0000	-1.04482182	7.83176392	-5.40878232	8.98E-05
ENSGACT0000	-1.15796511	5.21660596	-5.40700538	9.01E-05
ENSGACT0000	-1.25706822	7.90217103	-5.36477497	9.73E-05
ENSGACT0000	-1.43729735	10.2231468	-5.29313488	0.00011086
ENSGACT0000	1.17374329	9.60978592	5.1922135	0.00013337
ENSGACT0000	1.05453454	8.14411738	5.16103391	0.00014124
ENSGACT0000	1.05604658	10.4382316	4.9724209	0.00020039
ENSGACT0000	-1.07846171	7.59630601	-4.92435043	0.00021924
ENSGACT0000	0.96311602	11.4608616	4.86194777	0.00024647
ENSGACT0000	-1.77662012	6.99994263	-4.84837968	0.00025284
ENSGACT0000	-1.22630355	6.95061188	-4.82925672	0.00026211
ENSGACT0000	1.18014254	9.16346671	4.78670981	0.00028402
ENSGACT0000	-1.79854069	10.5330242	-4.7092631	0.0003289
ENSGACT0000	-1.47308447	7.25243051	-4.68123254	0.00034689
ENSGACT0000	1.38980207	9.08624235	4.66131544	0.00036029
ENSGACT0000	0.96704301	8.56739755	4.65501676	0.00036464
ENSGACT0000	-1.28621653	5.42774887	-4.64463586	0.00037193
ENSGACT0000	1.21975293	7.22679384	4.64122004	0.00037436
ENSGACT0000	1.7233546	11.7544607	4.62591384	0.00038545
ENSGACT0000	-0.96649046	5.55239457	-4.62394378	0.0003869
ENSGACT0000	1.18801288	5.35343288	4.62336862	0.00038732
			0469	0.00039476
			8087	0.00040688
			7767	0.00042121
			9109	0.00043206
			1402	0.00043237
			2372	0.00043787
			6026	0.00043851
			1583	0.00045082
			4474	0.00045583
			5674	0.0004596
			2734	0.00047835
			6584	0.0004797
			6383	0.00048834
			8818	0.00049809
			0326	0.00050872

*Differentially expressed genes in response to a **conspecific***

Name	logFC	AveExpr	t	P.Value
ENSGACT0000	1.53699956	8.55975345	4.62764701	5.26E-05
ENSGACT0000	1.46255835	8.45454696	4.72708923	3.92E-05
ENSGACT0000	1.38815535	8.30059369	4.68097654	4.49E-05
ENSGACT0000	1.73538325	8.44857306	5.66347968	8.60E-06
ENSGACT0000	0.52885135	6.98584997	4.89515758	2.38E-05
ENSGACT0000	0.62399932	7.01595991	4.52349969	7.14E-05
ENSGACT0000	-0.71415381	11.2909507	-4.63982281	5.07E-05
ENSGACT0000	2.03656931	7.94275716	5.80702091	1.57E-06
ENSGACT0000	1.51147429	7.73648503	6.74560726	9.73E-08
ENSGACT0000	-0.68461468	8.77225459	-4.84728232	2.75E-05
ENSGACT0000	0.28205416	6.94793683	5.03528721	4.08E-05
ENSGACT0000	-0.75393092	7.70287065	-4.35904739	0.00011563
ENSGACT0000	-1.07371357	7.73734707	-5.35410858	1.84E-05
ENSGACT0000	-0.77885333	6.9476131	-5.91263028	4.68E-06
ENSGACT0000	-0.7428225	7.33317776	-4.71229381	9.17E-05
ENSGACT0000	-0.63735243	7.80541663	-4.29425443	0.00013965
ENSGACT0000	-1.72459378	10.4241775	-4.93919214	2.09E-05
ENSGACT0000	-1.51201562	10.7788351	-4.56648403	6.30E-05
ENSGACT0000	-0.75914885	6.92851184	-5.78316616	1.68E-06
ENSGACT0000	-0.67543919	6.92804603	-4.18144716	0.00019371
ENSGACT0000	1.66679674	9.37491742	5.14375697	3.11E-05
ENSGACT0000	0.83530847	13.4748094	4.72761741	3.91E-05
ENSGACT0000	1.00349112	13.2062186	4.25138774	0.00015818
ENSGACT0000	-1.34685001	7.86247332	-5.28038768	2.22E-05
ENSGACT0000	-1.0983276	11.8291236	-4.54210242	6.76E-05
ENSGACT0000	-0.88736034	11.4406665	-4.31096401	0.00013302
ENSGACT0000	0.6656206	8.29392013	4.17018873	0.00020012
ENSGACT0000	0.50211368	8.66918733	4.42506912	9.53E-05
ENSGACT0000	0.38353182	9.78453306	4.22244662	0.00017203
ENSGACT0000	-1.17449125	8.72349206	-4.52948619	0.0001451
ENSGACT0000	-0.44789614	8.34775216	-4.99854484	4.47E-05
ENSGACT0000	0.59757929	9.84414604	5.00200698	4.43E-05
ENSGACT0000	0.58569949	8.13500543	4.17236049	0.00019887
ENSGACT0000	0.63086789	9.27170965	4.2674784	0.00015095
ENSGACT0000	0.58722091	8.01995173	4.17459693	0.00019758
ENSGACT0000	-1.5469682	7.37196514	-5.38540332	1.71E-05
ENSGACT0000	-1.22689152	6.90958149	-5.73872075	7.15E-06
ENSGACT0000	-0.68166903	6.94858525	-5.63630045	2.61E-06
ENSGACT0000	-0.46580229	7.03483345	-4.31263304	0.00013238
ENSGACT0000	-0.76386438	7.19029991	-5.94174115	1.05E-06
ENSGACT0000	-0.92557084	7.43980589	-6.00562874	8.68E-07
ENSGACT0000	-0.83628694	7.72481566	-5.16231387	1.08E-05
ENSGACT0000	-0.99624592	7.63446231	-5.28766443	7.40E-06
ENSGACT0000	0.70138835	8.63219863	4.72706112	8.83E-05
ENSGACT0000	-0.56300685	7.67575255	-5.44748485	4.59E-06

Are there any genes on both lists?

Differentially expressed genes in response to a predator

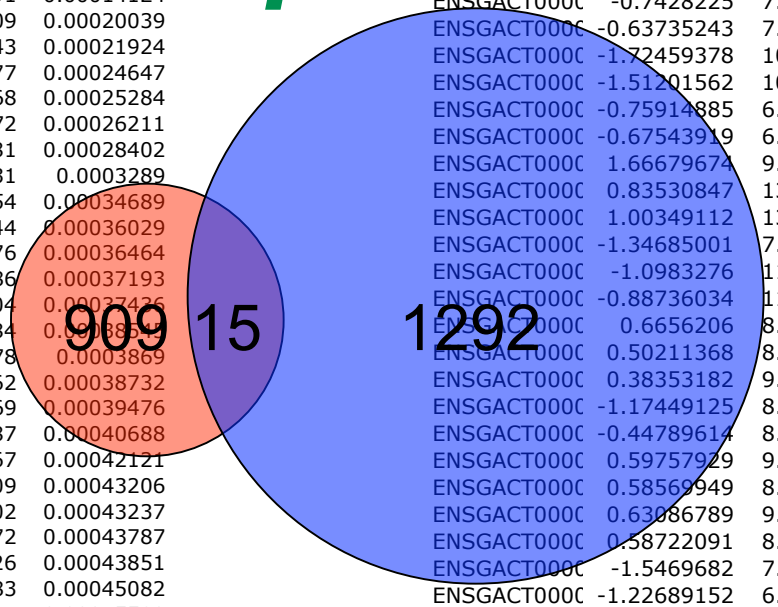
ID	logFC	AveExpr	t	P.Value
ENSGACT0000	3.96400072	6.80965806	7.71100353	2.00E-06
ENSGACT0000	-1.71111924	8.93053751	-6.26911607	1.99E-05
ENSGACT0000	1.27767463	5.87794417	6.25915768	2.14E-05
ENSGACT0000	1.47331778	5.89573715	6.16392829	2.18E-05
ENSGACT0000	-1.82268859	7.5873738	-5.99099515	3.21E-05
ENSGACT0000	2.61609287	6.7582394	5.85897362	4.03E-05
ENSGACT0000	2.9095063	7.90325068	5.74846965	4.90E-05
ENSGACT0000	-1.28103675	10.9963008	-5.71618381	5.18E-05
ENSGACT0000	-1.45118577	7.046863	-5.48144121	7.88E-05
ENSGACT0000	1.06389949	6.60877028	5.44587923	8.40E-05
ENSGACT0000	-1.04482182	7.83176392	-5.40878232	8.98E-05
ENSGACT0000	-1.15796511	5.21660596	-5.40700538	9.01E-05
ENSGACT0000	-1.25706822	7.90217103	-5.36477497	9.73E-05
ENSGACT0000	-1.43729735	10.2231468	-5.29313488	0.00011086
ENSGACT0000	1.17374329	9.60978592	5.1922135	0.00013337
ENSGACT0000	1.05453454	8.14411738	5.16103391	0.00014124
ENSGACT0000	1.05604658	10.4382316	4.9724209	0.00020039
ENSGACT0000	-1.07846171	7.59630601	-4.92435043	0.00021924
ENSGACT0000	0.96311602	11.4608616	4.86194777	0.00024647
ENSGACT0000	-1.77662012	6.99994263	-4.84837968	0.00025284
ENSGACT0000	-1.22630355	6.95061188	-4.82925672	0.00026211
ENSGACT0000	1.18014254	9.16346671	4.78670981	0.00028402
ENSGACT0000	-1.79854069	10.5330242	-4.7092631	0.0003289
ENSGACT0000	-1.47308447	7.25243051	-4.68123254	0.00034689
ENSGACT0000	1.38980207	9.08624235	4.66131544	0.00036029
ENSGACT0000	0.96704301	8.56739755	4.65501676	0.00036464
ENSGACT0000	-1.28621653	5.42774887	-4.64463586	0.00037193
ENSGACT0000	1.21975293	7.22679384	4.64122004	0.00037436
ENSGACT0000	1.7233546	11.7544607	4.62591384	0.00038559
ENSGACT0000	-0.96649046	5.55239457	-4.62394378	0.0003869
ENSGACT0000	1.18801288	5.35343288	4.62336862	0.00038732
ENSGACT0000	-1.14871759	5.45177113	-4.61340469	0.00039476
ENSGACT0000	1.42495573	8.22709944	4.59758087	0.00040688
ENSGACT0000	1.04471947	5.7608261	4.57947767	0.00042121
ENSGACT0000	1.06904589	6.47656381	4.56619109	0.00043206
ENSGACT0000	1.30521539	6.94758214	4.56581402	0.00043237
ENSGACT0000	0.93537996	6.55639315	4.55922372	0.00043787
ENSGACT0000	0.91413447	6.47630261	4.55846026	0.00043851
ENSGACT0000	-1.12913415	6.68136437	-4.54401583	0.00045082
ENSGACT0000	1.38258806	9.20343883	4.53824474	0.00045583
ENSGACT0000	1.21428229	6.36987912	4.53395674	0.0004596
ENSGACT0000	0.91870473	6.73292996	4.51312734	0.00047835
ENSGACT0000	1.14304683	7.7299686	4.5116584	0.0004797
ENSGACT0000	1.13953425	5.14171384	4.50236383	0.00048834
ENSGACT0000	1.33234962	7.66072363	4.49208818	0.00049809
ENSGACT0000	1.12315127	5.57353927	4.48110326	0.00050872

Differentially expressed genes in response to a conspecific

Name	logFC	AveExpr	t	P.Value
ENSGACT0000	1.53699956	8.55975345	4.62764701	5.26E-05
ENSGACT0000	1.46255835	8.45454696	4.72708923	3.92E-05
ENSGACT0000	1.38855555	8.30659369	4.68097654	4.49E-05
ENSGACT0000	1.7338825	8.41857306	5.66347968	8.60E-06
ENSGACT0000	0.52885135	6.98584997	4.89515758	2.38E-05
ENSGACT0000	0.62299932	7.01595991	4.52349969	7.14E-05
ENSGACT0000	-0.7141381	11.2909507	-4.63982281	5.07E-05
ENSGACT0000	2.3656931	7.94275716	5.80702091	1.57E-06
ENSGACT0000	1.51117429	7.73648503	6.74560726	9.73E-08
ENSGACT0000	-0.68461468	8.77225459	-4.84728232	2.75E-05
ENSGACT0000	0.28205416	6.94793683	5.03528721	4.08E-05
ENSGACT0000	-0.75393092	7.70287065	-4.35904739	0.00011563
ENSGACT0000	-1.07371357	7.73734707	-5.35410858	1.84E-05
ENSGACT0000	-0.77885333	6.9476131	-5.91263028	4.68E-06
ENSGACT0000	-0.7428225	7.33317776	-4.71229381	9.17E-05
ENSGACT0000	-0.63735243	7.80541663	-4.29425443	0.00013965
ENSGACT0000	-1.72459378	10.4241775	-4.93919214	2.09E-05
ENSGACT0000	-1.51201562	10.7788351	-4.56648403	6.30E-05
ENSGACT0000	-0.75914885	6.92851184	-5.78316616	1.68E-06
ENSGACT0000	-0.67543919	6.92804603	-4.18144716	0.00019371
ENSGACT0000	1.66679674	9.37491742	5.14375697	3.11E-05
ENSGACT0000	0.83530847	13.4748094	4.72761741	3.91E-05
ENSGACT0000	1.00349112	13.2062186	4.25138774	0.00015818
ENSGACT0000	-1.34685001	7.86247332	-5.28038768	2.22E-05
ENSGACT0000	-1.0983276	11.8291236	-4.54210242	6.76E-05
ENSGACT0000	-0.88736034	11.4406665	-4.31096401	0.00013302
ENSGACT0000	0.6656206	8.29392013	4.17018873	0.00020012
ENSGACT0000	0.50211368	8.66918733	4.42506912	9.53E-05
ENSGACT0000	0.38353182	9.78453306	4.22244662	0.00017203
ENSGACT0000	-1.17449125	8.72349206	-4.52948619	0.0001451
ENSGACT0000	-0.44789614	8.34775216	-4.99854484	4.47E-05
ENSGACT0000	0.59757929	9.84414604	5.00200698	4.43E-05
ENSGACT0000	0.58569949	8.13500543	4.17236049	0.00019887
ENSGACT0000	0.63086789	9.27170965	4.2674784	0.00015095
ENSGACT0000	0.58722091	8.01995173	4.17459693	0.00019758
ENSGACT0000	-1.5469682	7.37196514	-5.38540332	1.71E-05
ENSGACT0000	-1.22689152	6.90958149	-5.73872075	7.15E-06
ENSGACT0000	-0.68166903	6.94858525	-5.63630045	2.61E-06
ENSGACT0000	-0.46580229	7.03483345	-4.31263304	0.00013238
ENSGACT0000	-0.76386438	7.19029991	-5.94174115	1.05E-06
ENSGACT0000	-0.92557084	7.43980589	-6.00562874	8.68E-07
ENSGACT0000	-0.83628694	7.72481566	-5.16231387	1.08E-05
ENSGACT0000	-0.99624592	7.63446231	-5.28766443	7.40E-06
ENSGACT0000	0.70138835	8.63219863	4.72706112	8.83E-05
ENSGACT0000	-0.56300685	7.67575255	-5.44748485	4.59E-06

Are there any genes on both lists?

A few



Transcription factors (TFs)

- TFs regulate the expression of other genes by binding to the promoter region of a gene.
- The TF binding site sequence is conserved.
- We searched the genome upstream (1500bp) of our *candidate genes* to look for binding sites of 570 TFs, and compared them to the promoter regions of *other genes*.

Dan Xie, Bioengineering

Transfac, Prima V1.0
UCSC Genome Browser
(Stickleback, gasAcu1)

We identified TF motifs for both up- and down-regulated genes

Predator	Conspecific		
Up (24)	Up (52)		
Down (26)	Down (22)		

Some motifs were common to responses to both predators and a conspecific

Predator	Conspecific	Overlapping motifs	Transcription factors
Down (26)	Up (52)	2	ETS, OCT-1
Up (24)	Up (52)	4	AP-4, MCM1, Pax-6, OCT-1
Down (26)	Down (22)	2	HSF, OCT-1
Up (24)	Down (22)	2	Skn-1, OCT-1

What's next?

Compare 'baseline' gene expression between different behavioral types of individuals or populations.

Hypothesis: The same set of genes discriminates between shy vs bold individuals/populations, and nonaggressive vs aggressive individuals/ populations