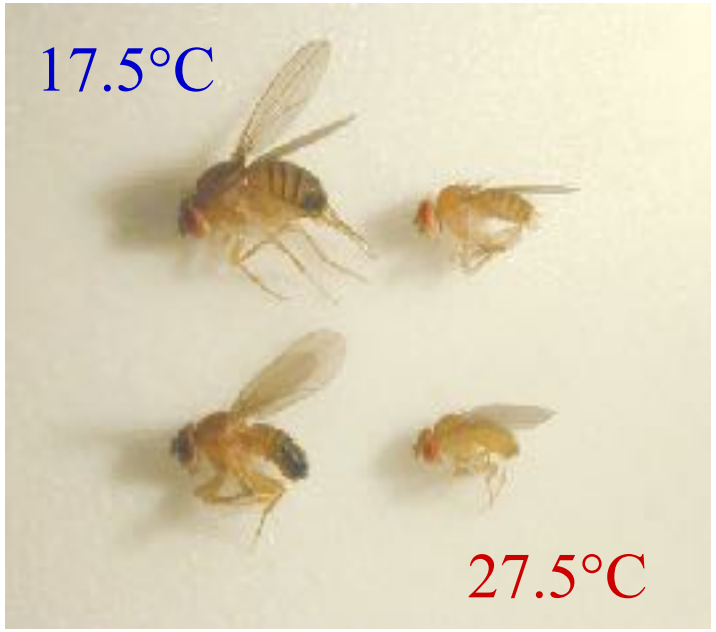
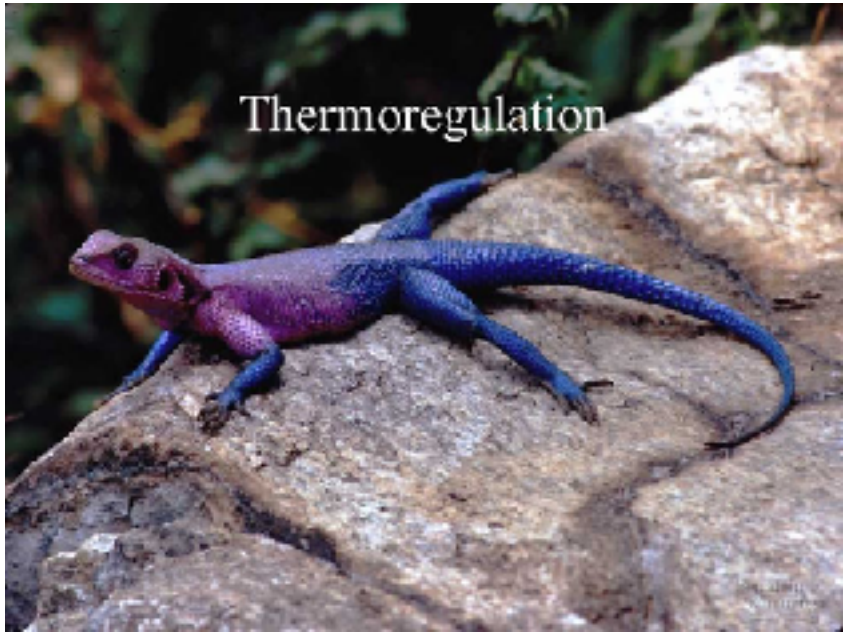
Incorporating plasticity into studies of adaptive evolution

Development



Physiology



Behavior

The First Response of Organisms to Environmental Change

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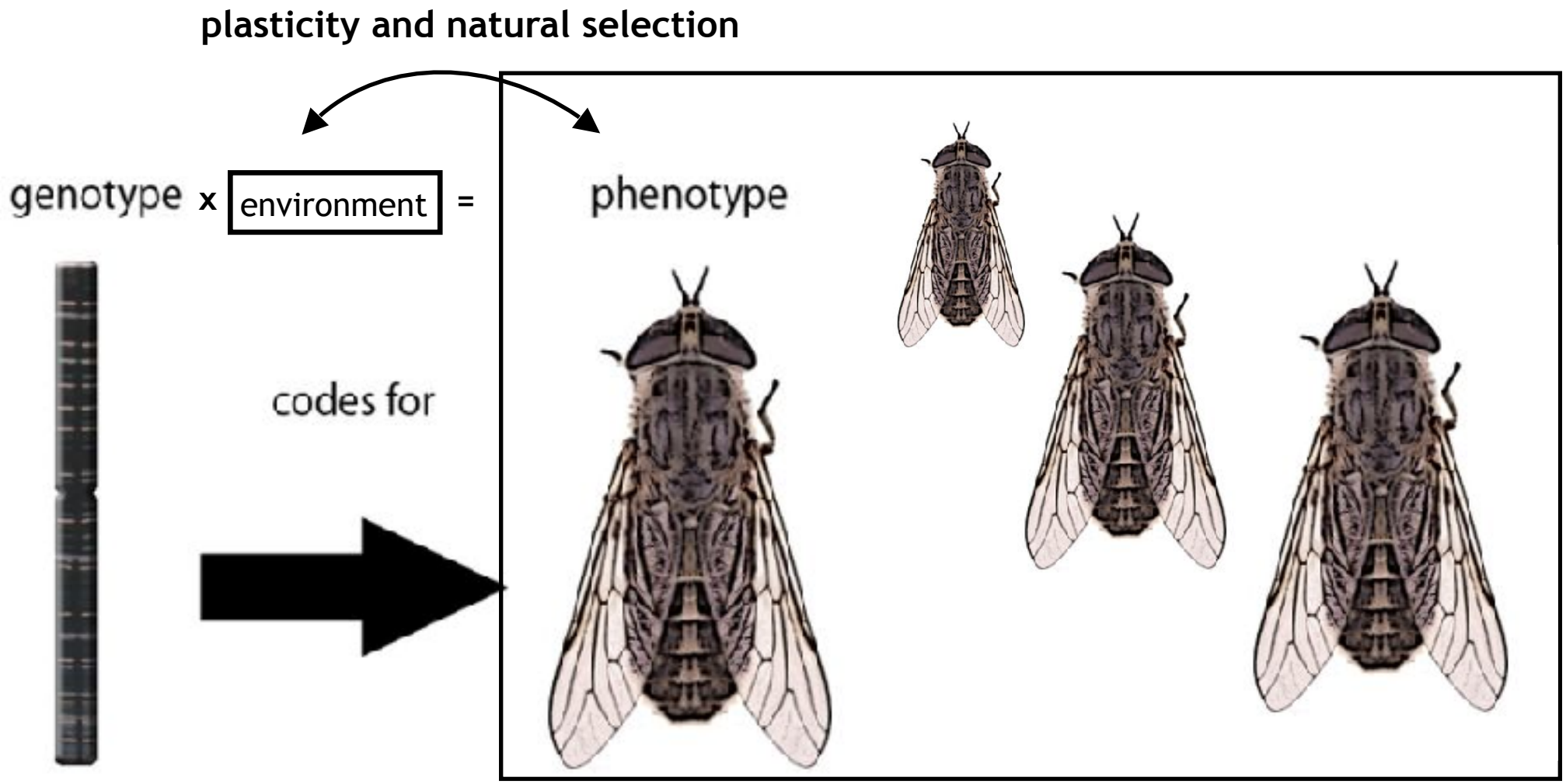
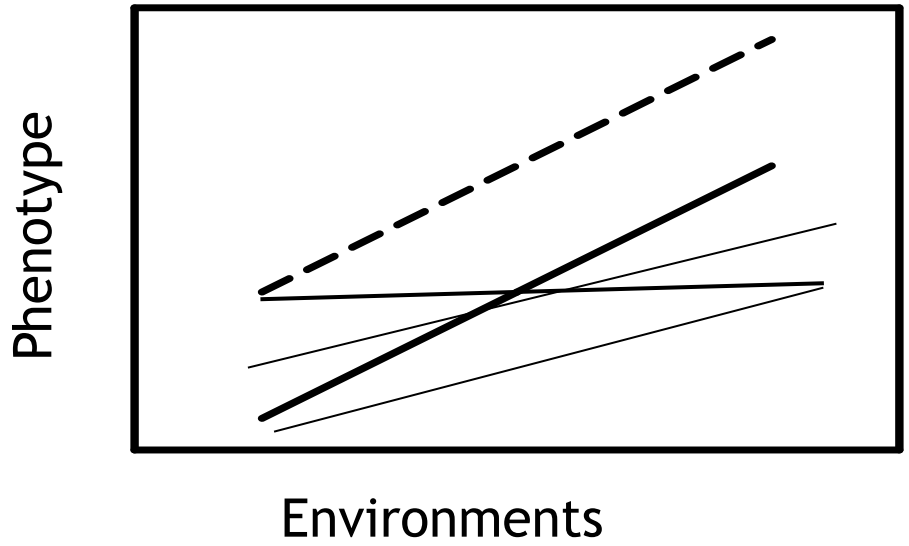
The General Question:
Is there a relationship between environmentally induced phenotypic plasticity and genetically based adaptive evolution?



Background: Terms and Definitions

1. Phenotypic plasticity: the capacity for a genotype to produce different phenotypes in response to different environmental conditions

- **property of the genotype, individual, or other genetic group (clone, RIL, population)**
- **phenotype is predictable depending on the environment (NOT developmental noise)**
- **can be visualized as a line, curve, function, called the ”reaction norm”**



The reaction norm of a trait is the quantitative representation of this continuum as a line or curve that shows the particular way a genotype’s phenotype varies as a function of the environment: (can be adaptive or non-adaptive). A flat reaction norm (slope = 0) is canalized trait.

2. Genotype x Environment Interaction (GxE): Variation among genotypes in how they respond across environments (population level)

Is plasticity an overlooked and major component of adaptive evolution?

J. M. Baldwin

I.I. Schmalhausen

C. H. Waddington

M. J. West-Eberhard

If so, why has it been so challenging to incorporate into traditional neo-Darwinian thinking?

A Problem of Terminology?

J. M. Baldwin – “The Baldwin Effect”

I.I. Schmalhausen – “Theory of Stabilizing Selection”

C. H. Waddington – “Genetic Assimilation”

M. J. West-Eberhard – “Genetic Accommodation”

Standard Theory: Variance Components of a Quantitative Trait

$$V_P = V_G + V_E + V_{G*E}$$

V_P = total phenotypic variation of the segregating population

V_G = genetic variation that contributes to the total phenotypic variation

V_E = environmental contribution to the total phenotypic variation (random, family, maternal effects)

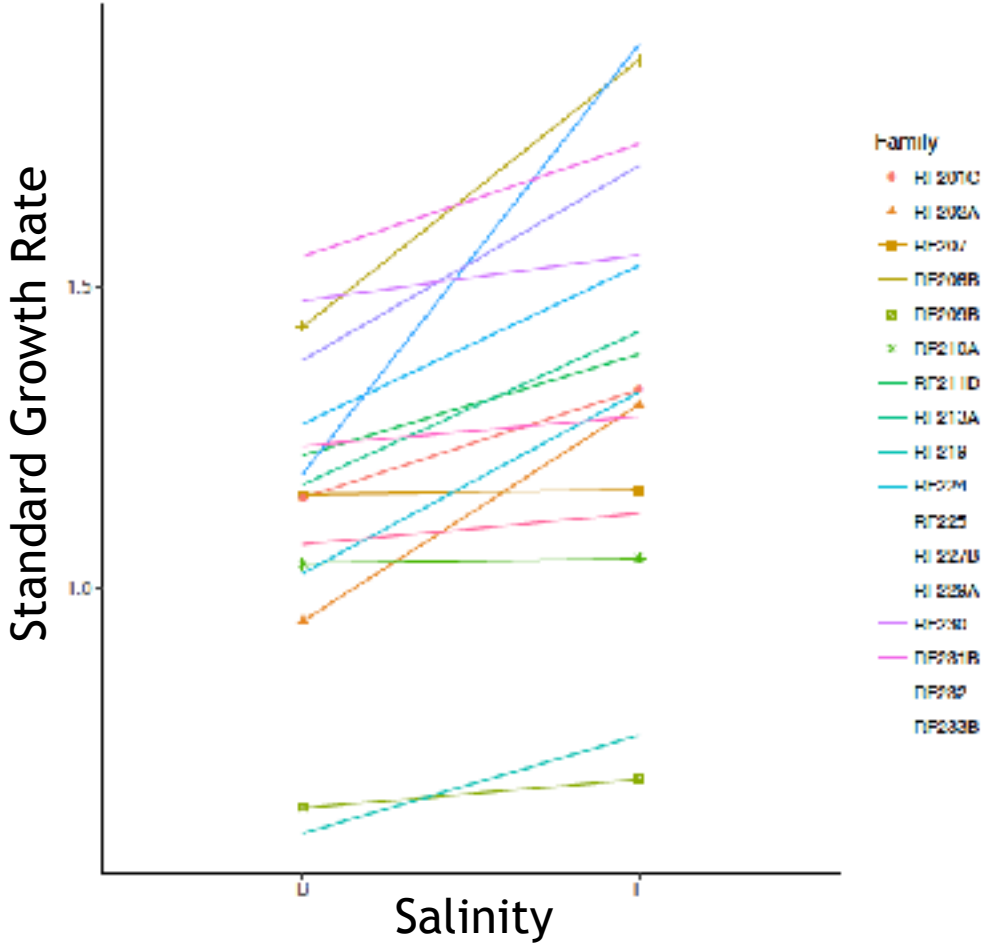
V_{G*E} = variation associated with the genetic and environmental factor interactions

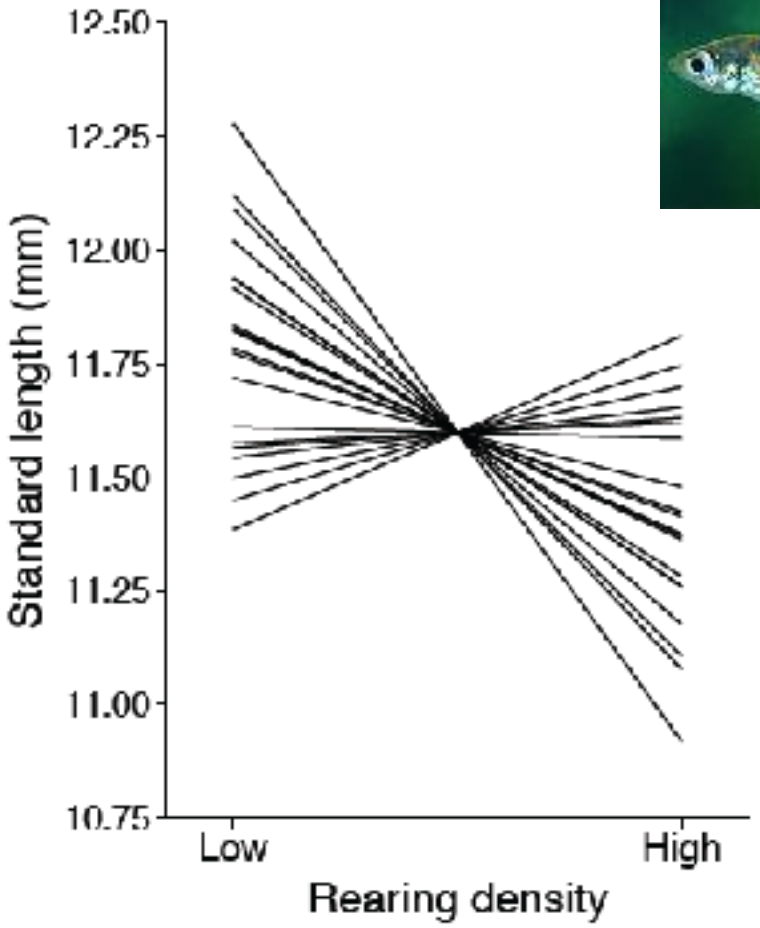
$$H^2 = \frac{V_G}{V_P} =$$ *Heritability (the percent of the total variance explained by relatedness)*

V_{G*E} = *Genetic variation in the plastic response to the environment*

Genotype x Environment Interactions

Typically not all genotypes produce the same phenotype in response to environmental variation, i.e. genetic variation for





So, if plasticity can evolve, what role does it play in adaptive evolution?

How Might Plasticity Influence Adaptive Evolutionary Responses?

$$\Delta z = G\beta$$

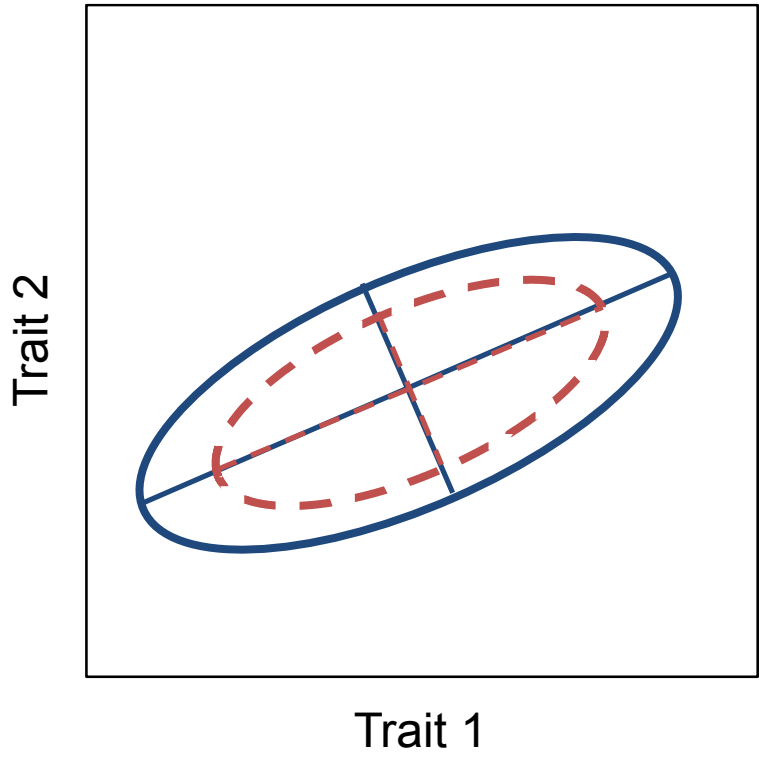
Change in trait mean between generations

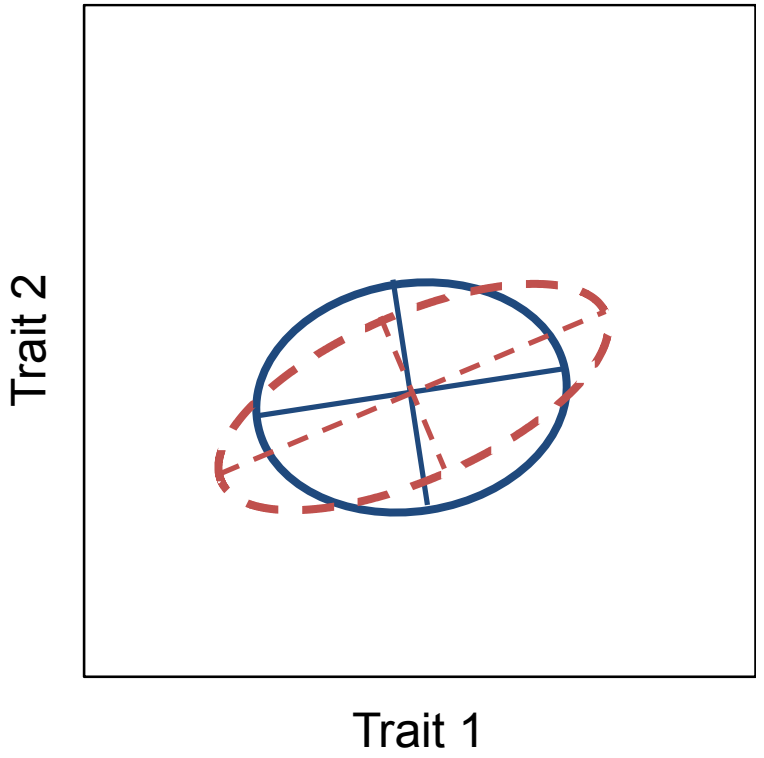
Genetic variance covariance matrix

Selection differential

Lande & Arnold 1983 *Evolution*

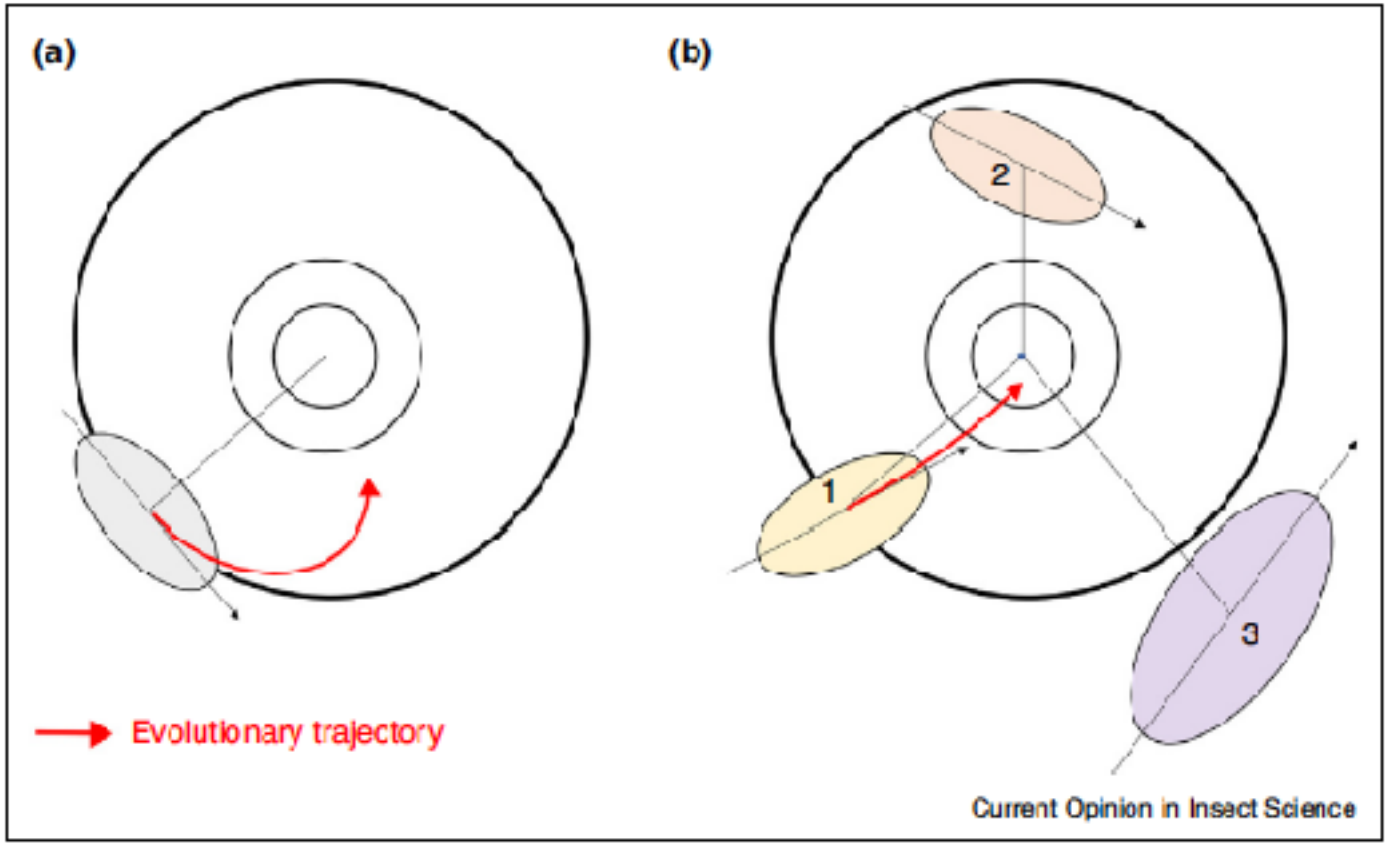
Heritability and Genetic Correlations Between Traits Can Constrain or Bias the Evolution of Traits; How Plastic Are They?





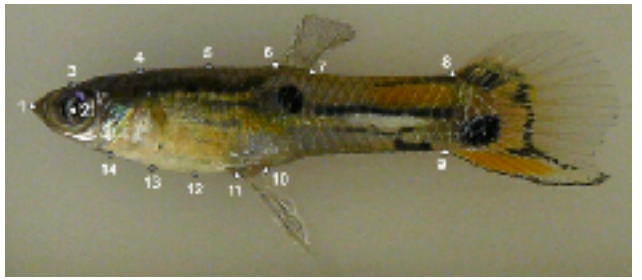
Schluter 1996 Evolution
Sgro & Hoffmann 2004 Heredity
Hansen & Houle 2008

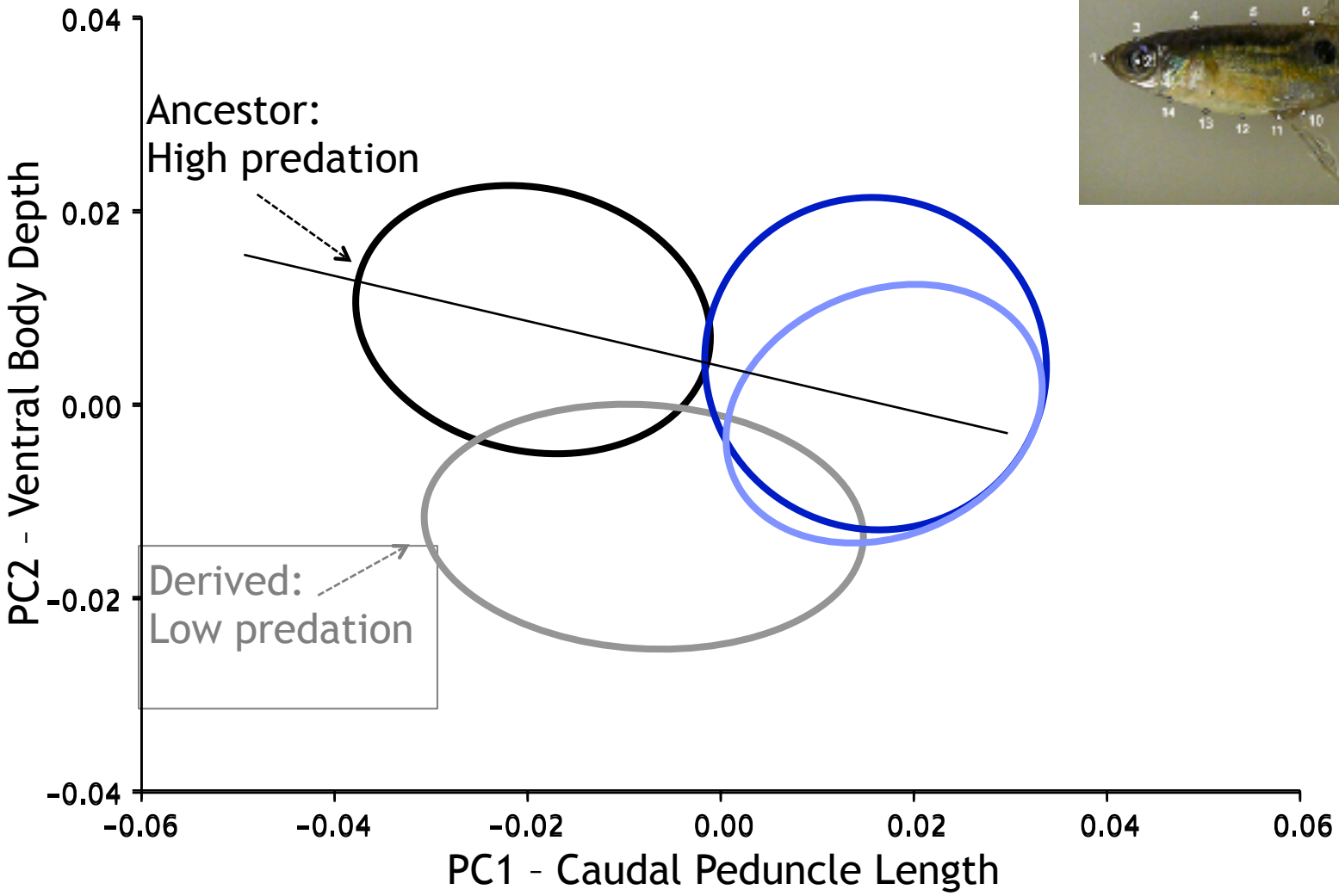
Little Empirical Data For How Patterns of Trait Correlations Change in Response to a New Environment



Gibert, Debat, & Ghalambor 2019

Plasticity in Trait Correlations Following Introduction to a New Environment





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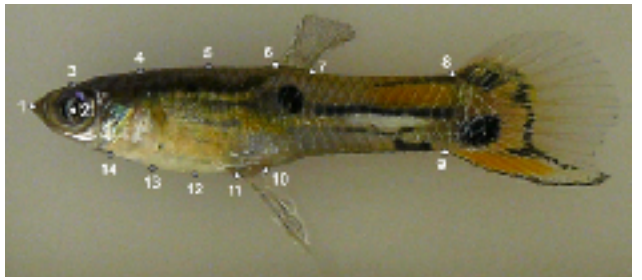
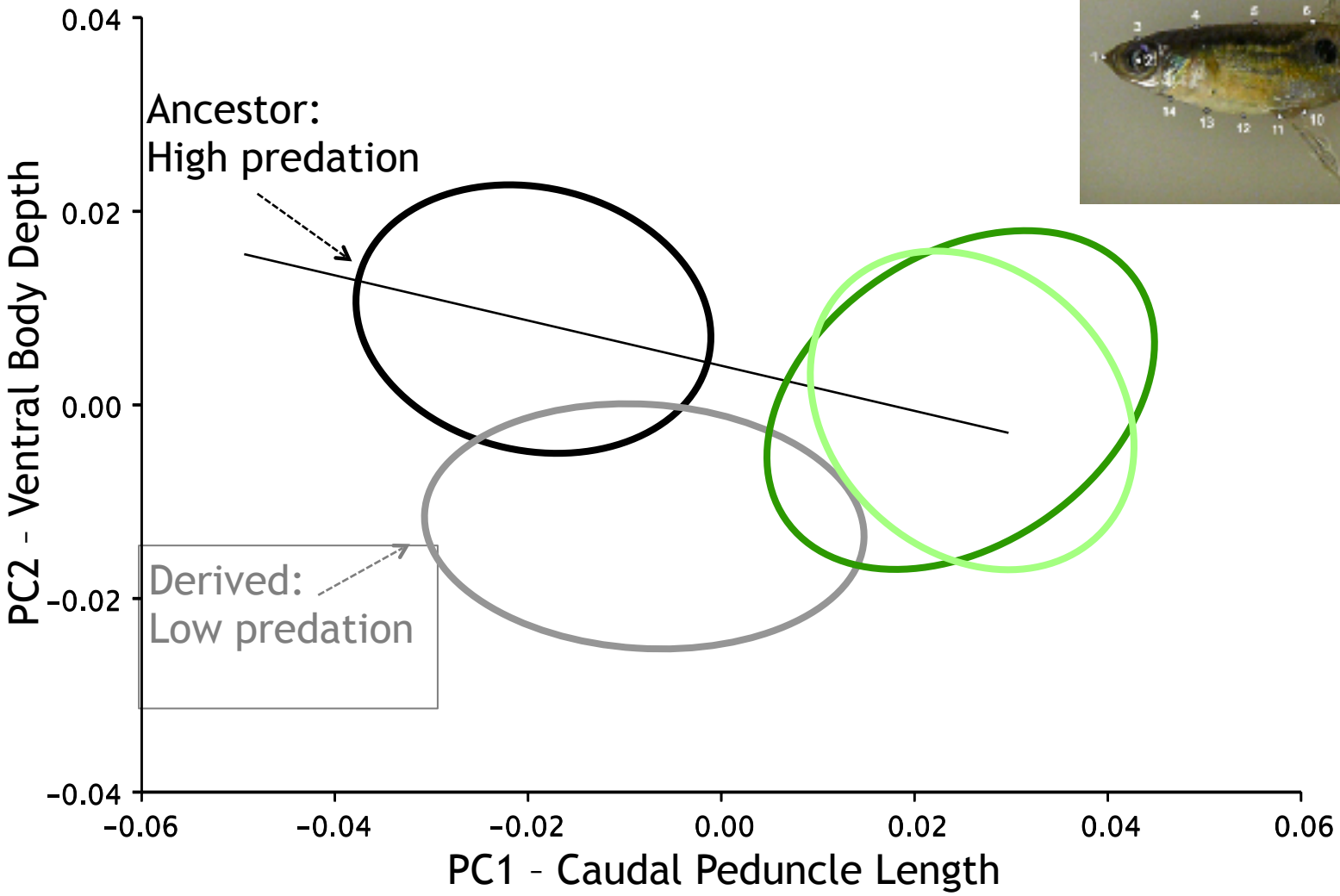
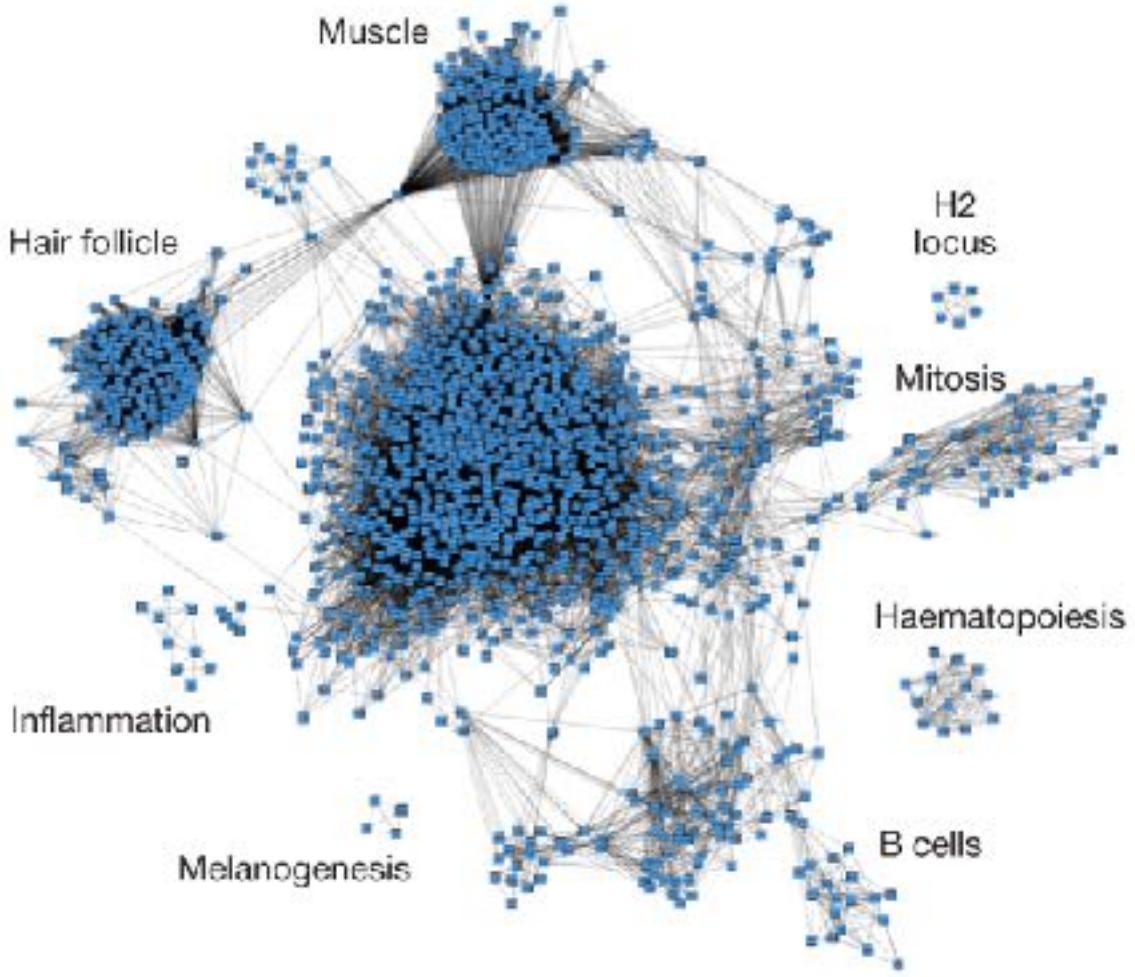


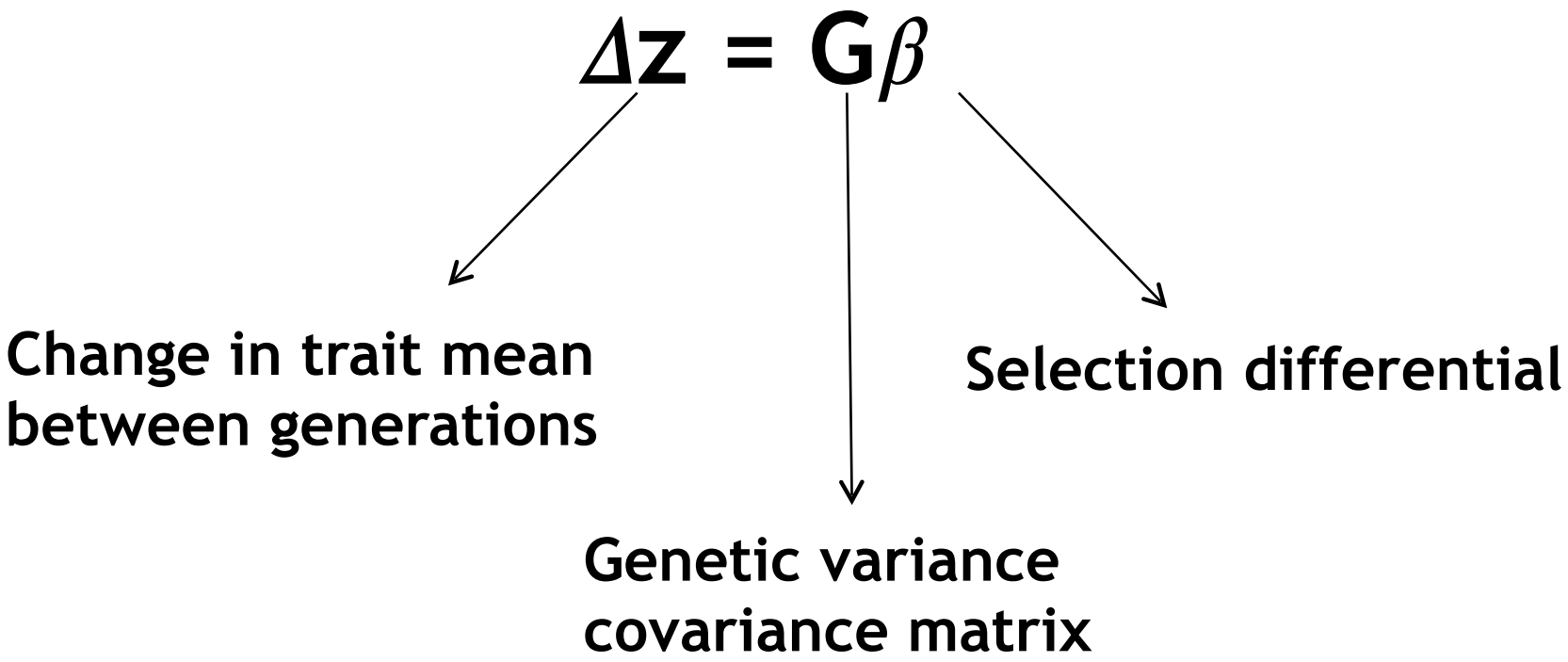


Visual Representation of a Gene Network: Plastic and Under Selection



DA Quigley *et al.* (2009) *Nature*
Bedford & Hartl (2009) *PNAS*

How Might Plasticity Influence Adaptive Evolutionary Responses?



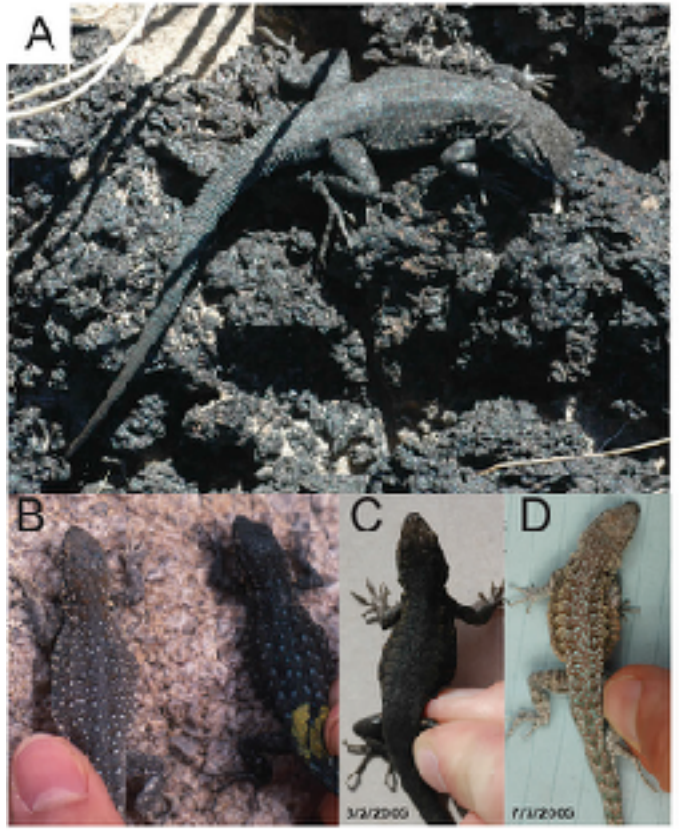
Lande & Arnold 1983 *Evolution*

Adaptive Phenotypic Plasticity
Phenotypic Change in the Same Direction Favored by Selection

Limb length in *Anolis*
Losos et al. 2000

Body shape in Stickleback
Wund et al. 2008

Thermal acclimation
Angiletta 2009

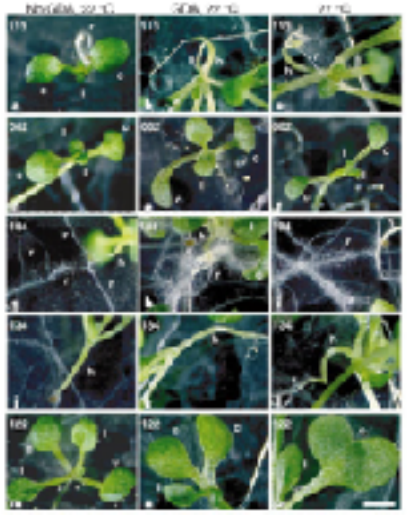


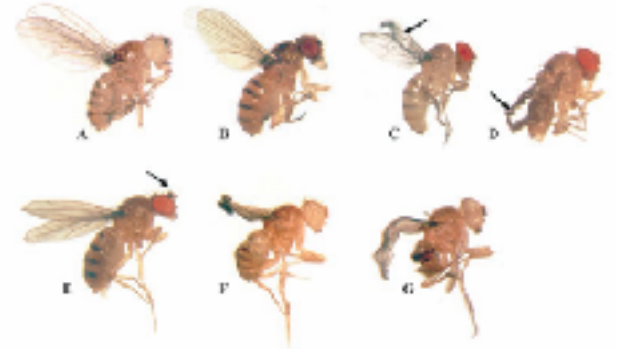
Color in *Uta* lizards
Corl et al. 2018

Non-Adaptive Phenotypic Plasticity
Phenotypic Change Opposing the Direction Favored by Selection

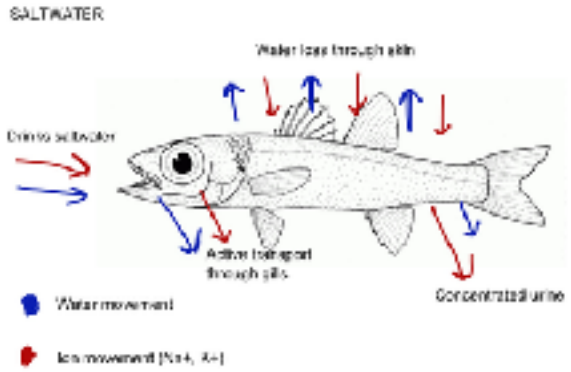
Sexual coloration in Salmon
Craig and Foote 2001

Body Temperature in *Anolis*
Huey et al. 2003



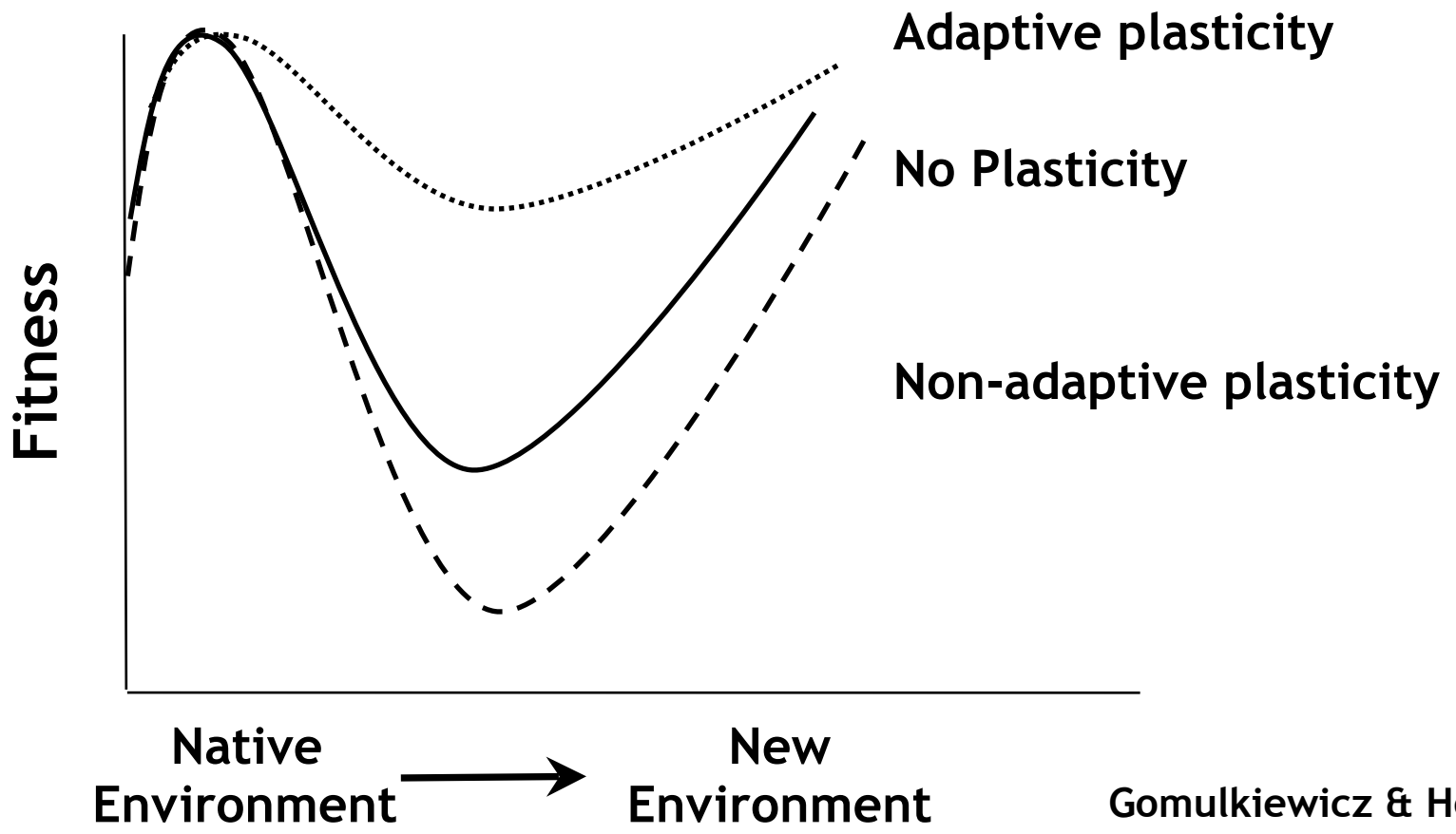


Temperature stress on development
Queitsch et al. 2002, Avila et al. 2008



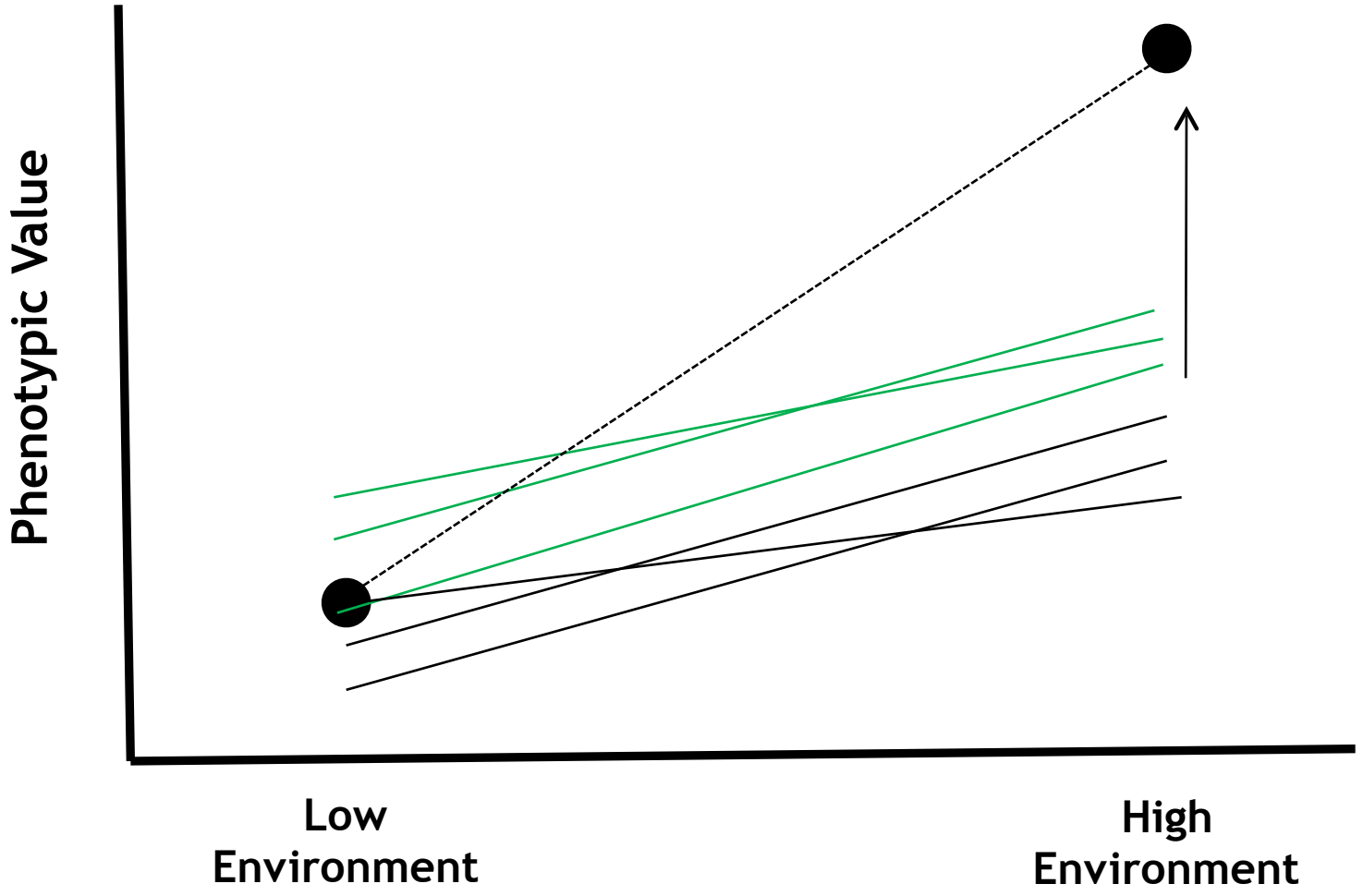
Challenge of homeostasis
Schulte 2014

How Plasticity Can Alter the Strength of Selection Following a Sudden Change in Environment



Gomulkiewicz & Holt 1995
Lande 2009
Chevin et al. 2013

Adaptive Plasticity and The Evolution of Reaction Norms: The Environment as a Cue For Changing Phenotypes



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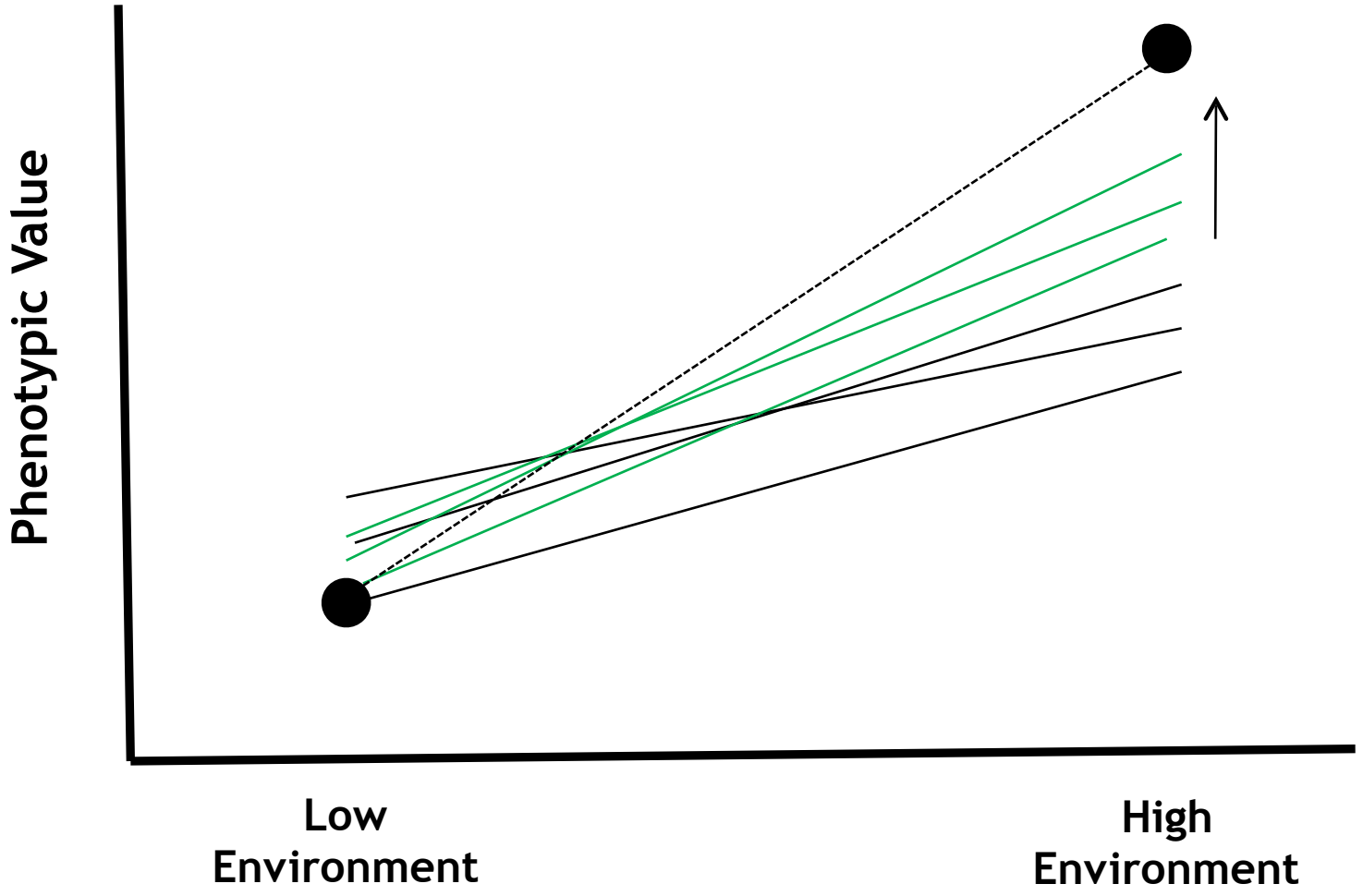
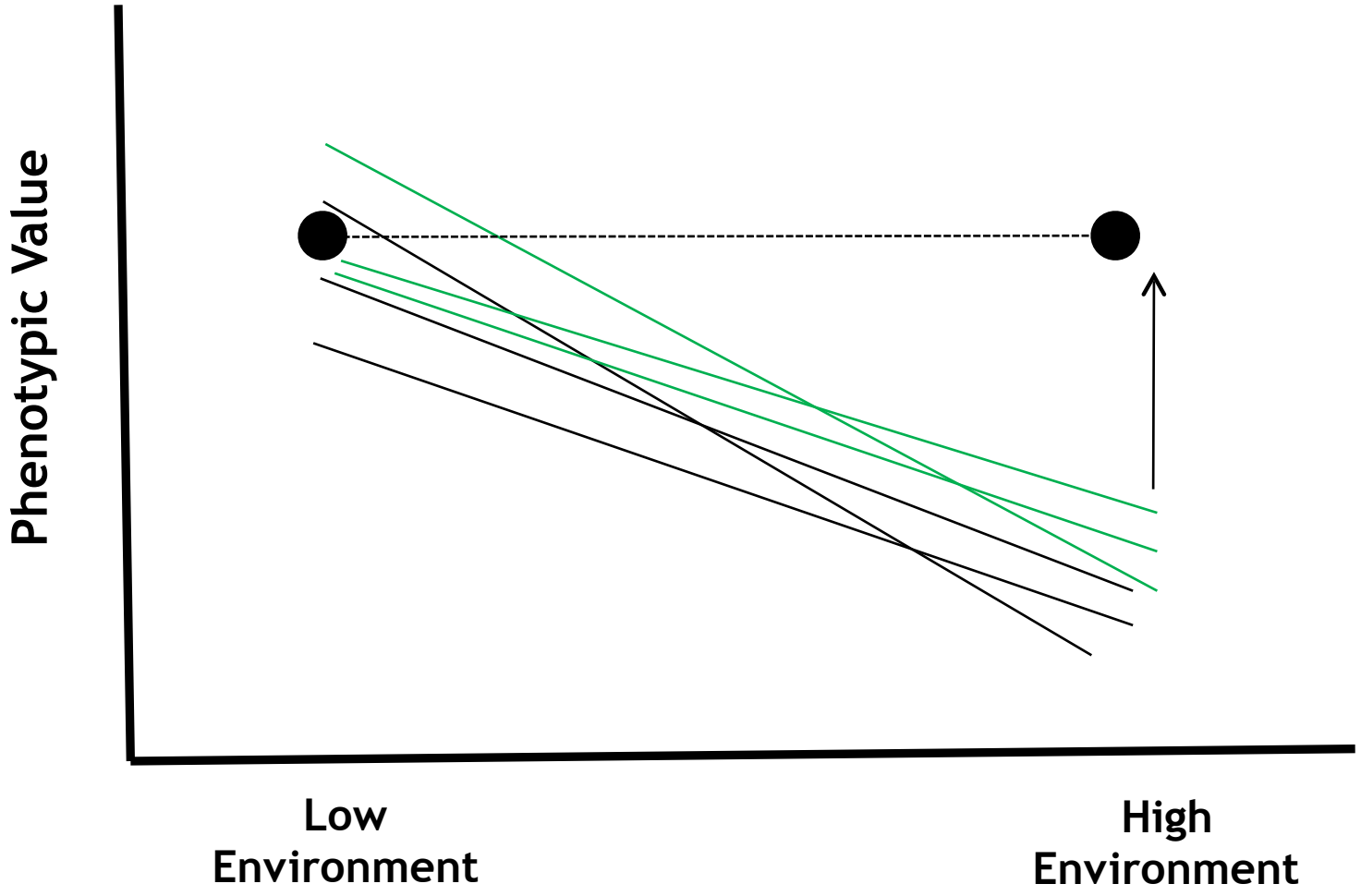
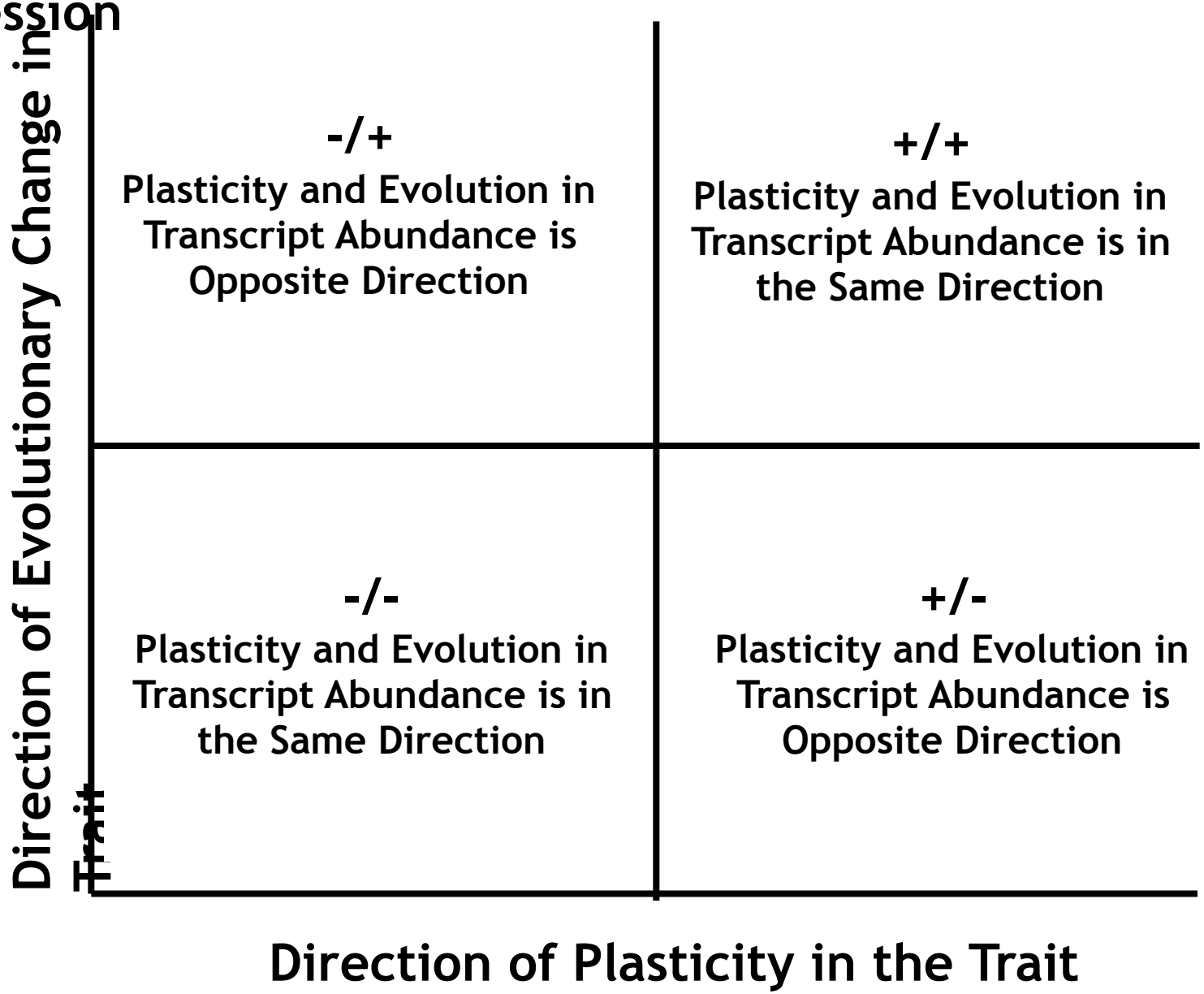


Non-Adaptive Plasticity and Selection for Homeostasis: Selection to Buffer Phenotypes From the Environment

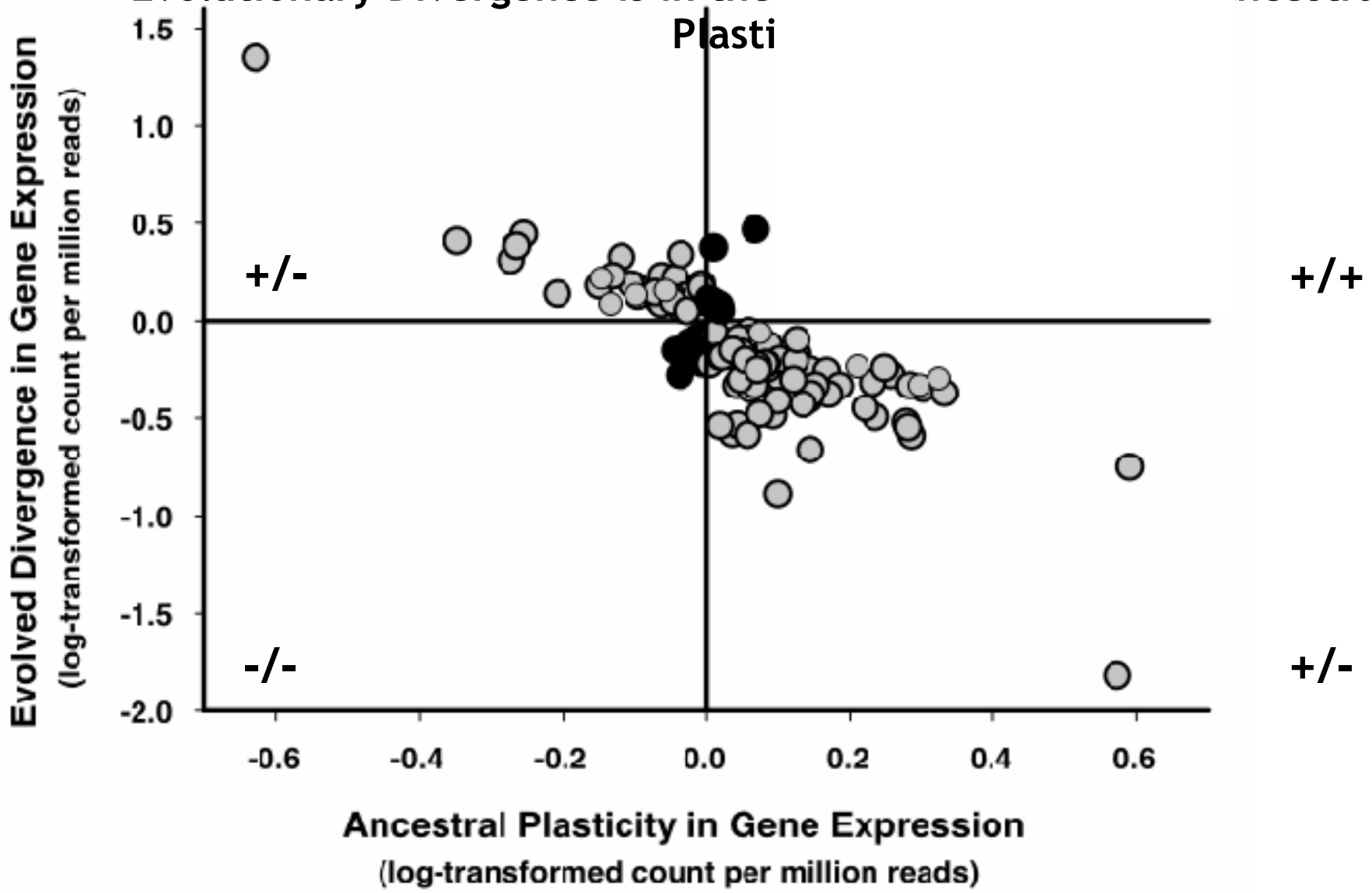


Possible Relationship Between Plasticity and Evolution in Gene Expression



135 Genes That Rapidly Evolve Exhibit Non-Adaptive Plasticity

Evolutionary Divergence is in the [illegible] Ancestral Plasti



Ghalambor et al. (2015) *Nature*

Most Traits Appear to Show Adaptive Plasticity
But the Traits Showing Non-Adaptive Plasticity Evolve More Quickly

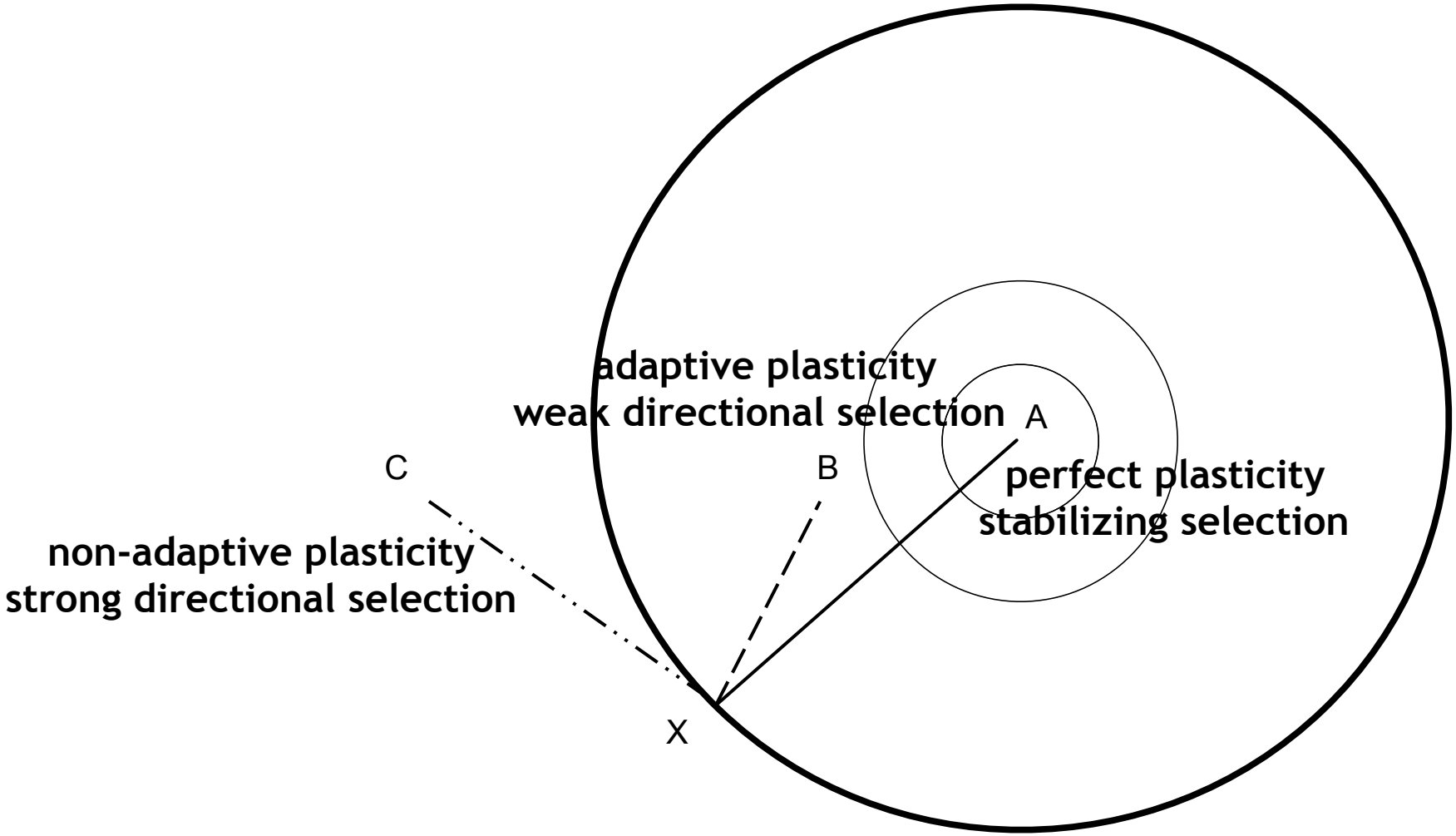
Adaptive Plasticity
co-gradient or synergistic selection
selection

- shoaling behavior
- size at maturity
- head shape
- color patterns
- resting metabolic rate
- some aspects of body shape
- number of facial neuromasts

Non-Adaptive Plasticity
counter gradient or antagonistic

growth rate
some aspects of body shape
initial patterns of gene expression

Does Plasticity Facilitate or Constrain Adaptive Evolution? It Depends on the Type of Plasticity and the Strength of Selection



Incorporating Phenotypic Plasticity into Evolutionary Studies

Should we avoid using terms like genetic assimilation, genetic accommodation, and the Baldwin Effect?

Will a role for plasticity in adaptive evolution be more commonly embraced if we strive to demonstrate that many evolutionary mechanisms are context or environmentally dependent?

$$\Delta\bar{z} = \mathbf{G}\beta$$

Recombination rate plasticity: revealing mechanisms by design

$$h^2 = \frac{\sigma_G^2}{\sigma_P^2}$$

Plasticity of Animal Genome Architecture Unmasked by Rapid Evolution of a Pelagic Tunicate

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