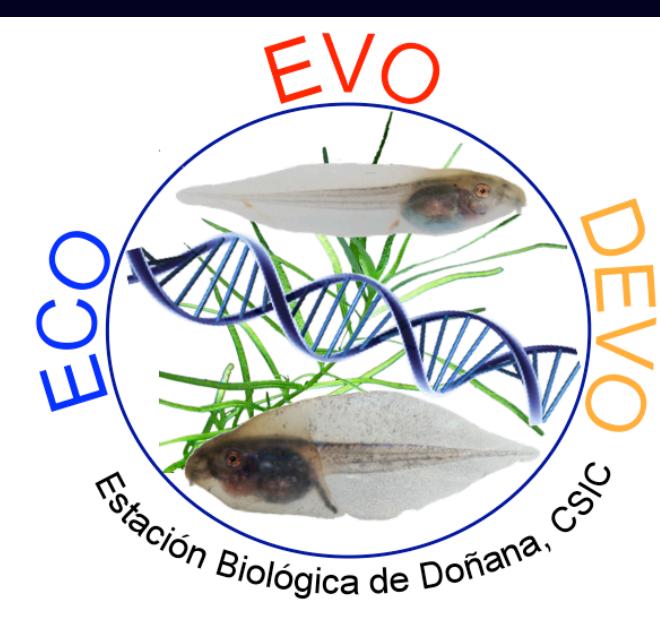
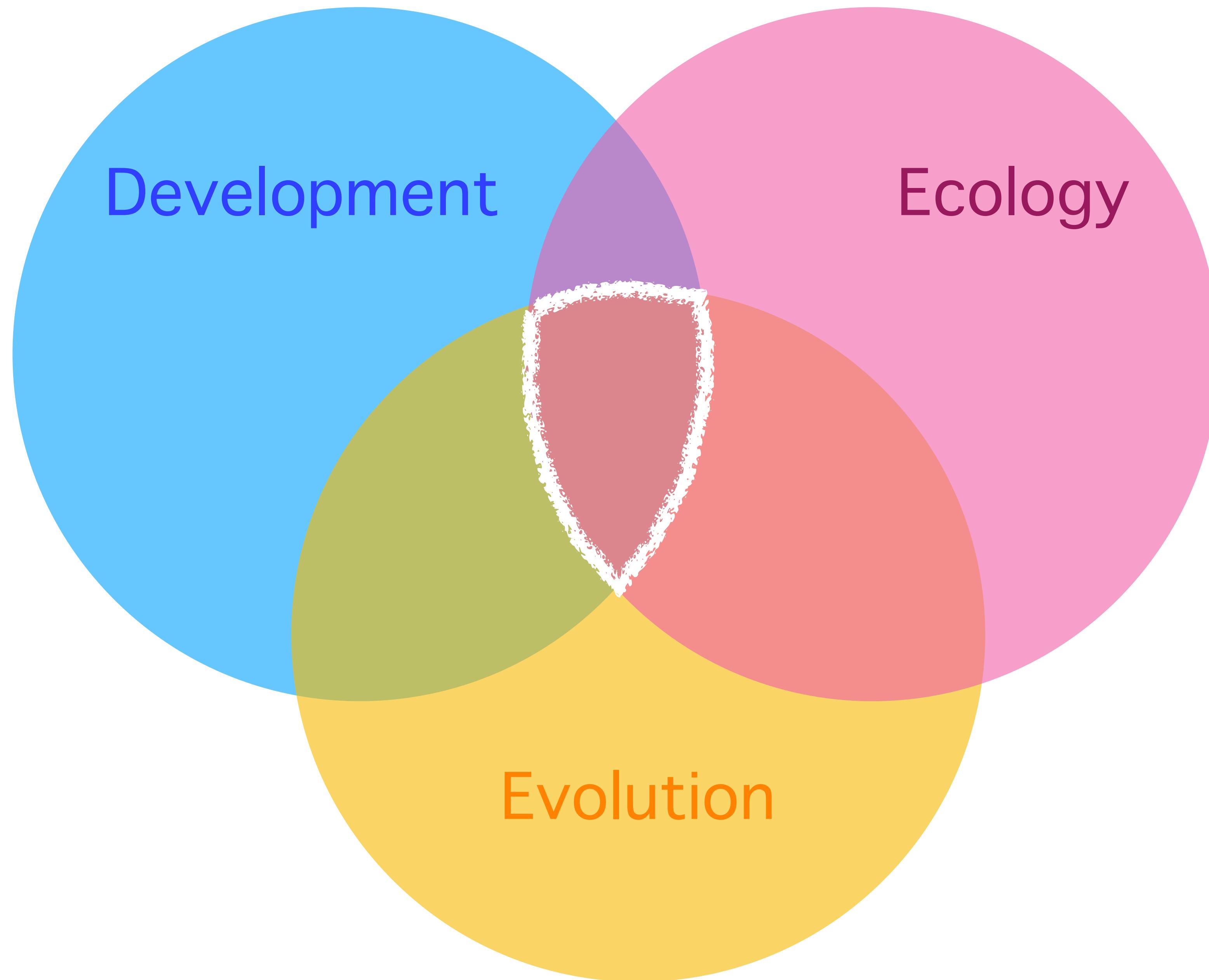




# Aplicaciones y Discusiones en Desarrollo Animal II



Christoph Liedtke  
Ivan Gomez-Mestre  
Estación Biológica de Doñana



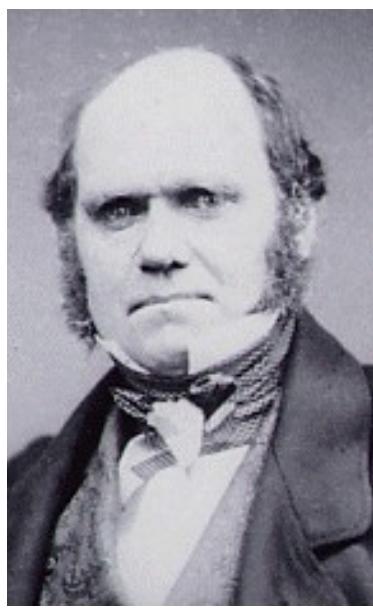
# OUTLINE

- Why Eco-Evo-Devo? - The environment is crucial
- Adaptation and Phenotypic plasticity
- Environmentally-induced transcriptomics
- Genetic accommodation

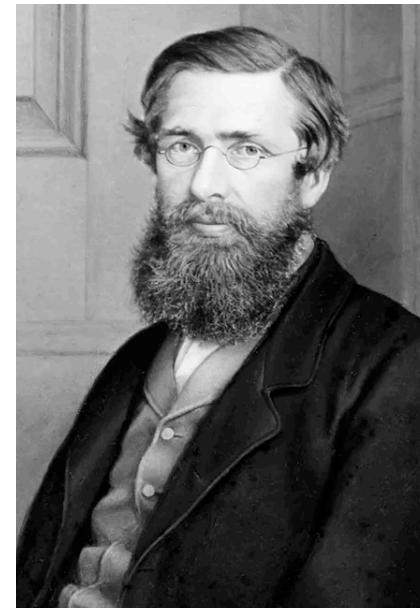
# **What is evolution?**

*“Evolution consists of changes in the heritable traits of a population of organisms as successive generations replace one another.”*

National Academy of Sciences, USA, 2015



Darwin



Wallace



Mendel



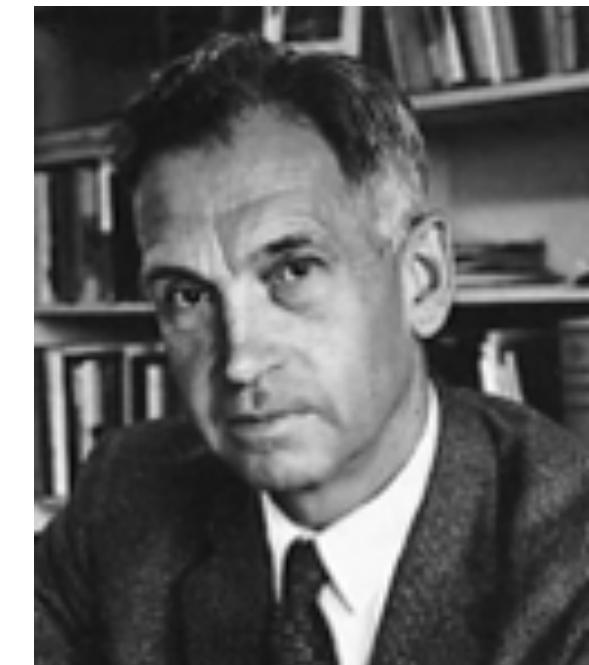
Huxley



Stebbins



Simpson



Mayr



Haldane



Fisher

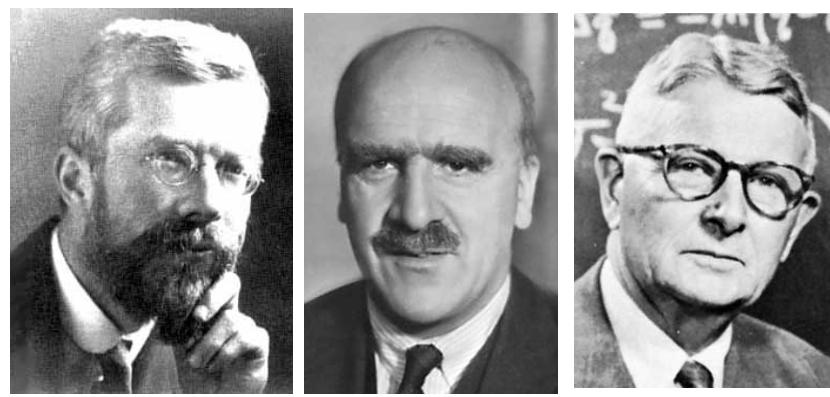


Wright

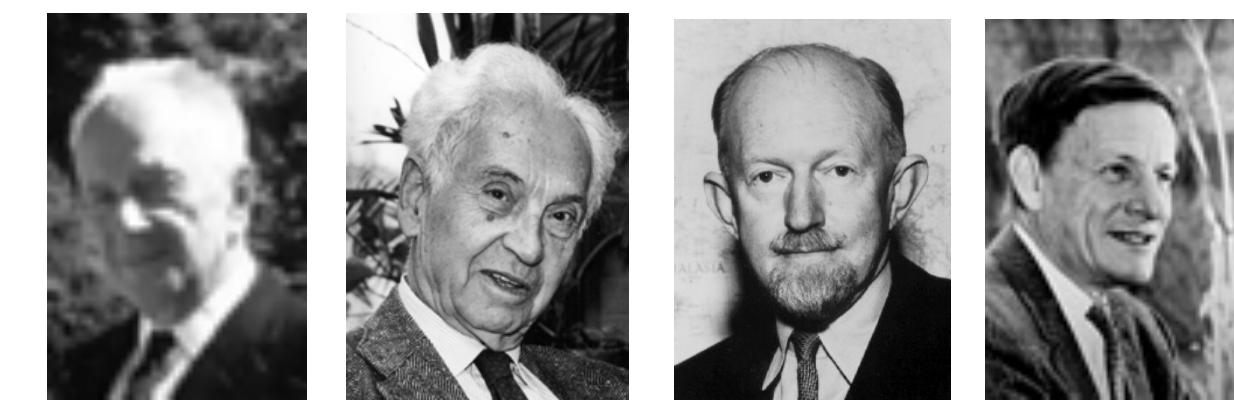


Dobzhansky

# The Modern Synthesis 1936-1947

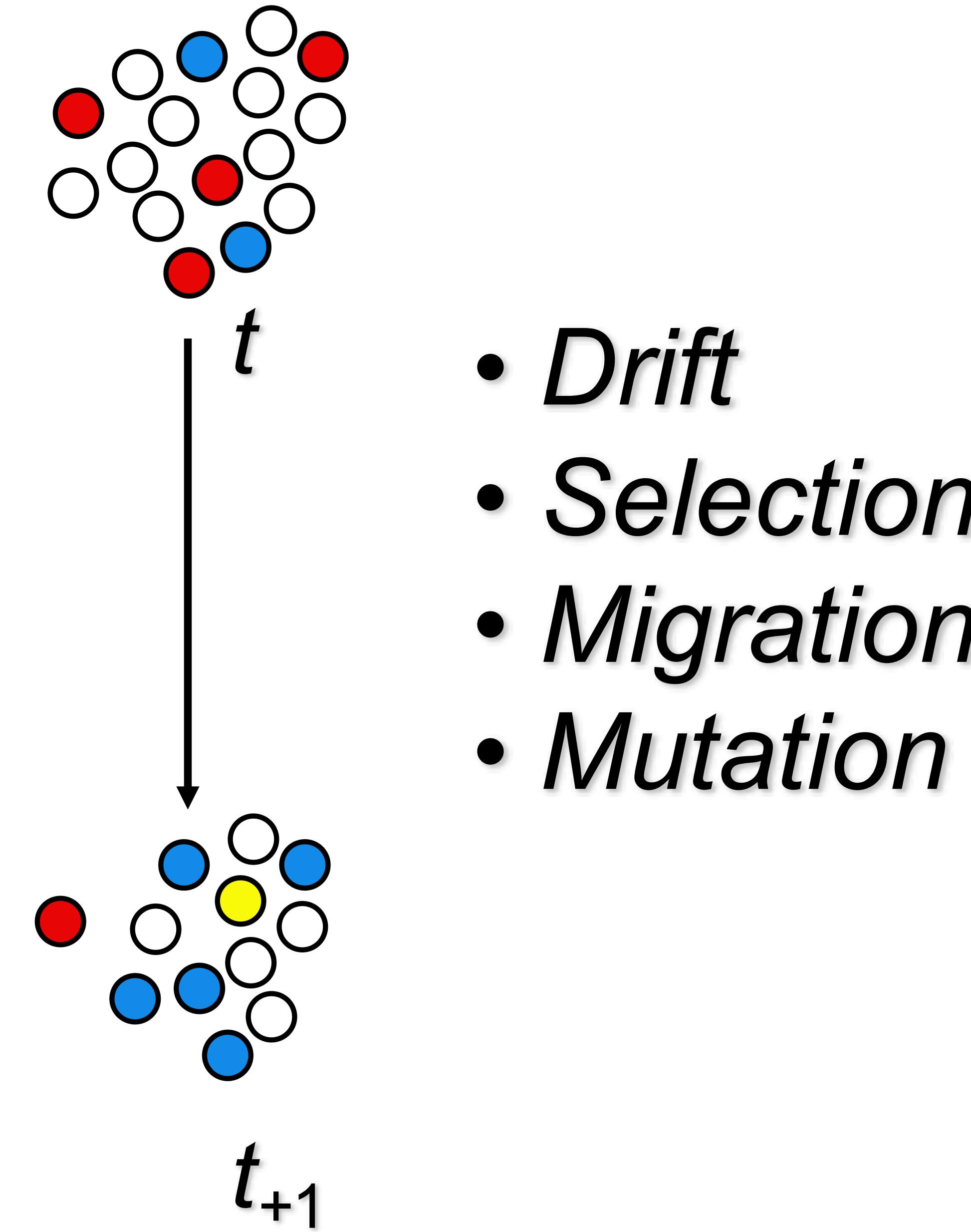


# The Modern Synthesis



- 1) las poblaciones contienen **variación genética aleatoria** que surge por **mutación y recombinación**
- 2) las poblaciones evolucionan mediante **cambios en las frecuencias alélicas** causados por deriva genética, flujo genético y, en especial, selección natural
- 3) la mayor parte de las variantes genéticas tienen un efecto fenotípico pequeño, de manera que los **cambios fenotípicos** resultan **graduales**
- 4) la diversificación sucede mediante el proceso de **especiación**, que es el resultado de un aislamiento reproductor gradual entre poblaciones
- 5) estos procesos, operando a lo largo de escalas de tiempo suficientemente largas, dan lugar a cambios de tal **magnitud** que se agrupan en niveles taxonómicos de mayor orden.

## Descent with heritable modification



Mutation  
Gene flow  
Drift  
Selection

+ 3.8 billion years = MACROEVOLUTION

*'The basic evolutionary mechanisms—mutation, migration, genetic drift, and natural selection—can produce major evolutionary change if given enough time'*

# The Modern Synthesis (1936-1947)



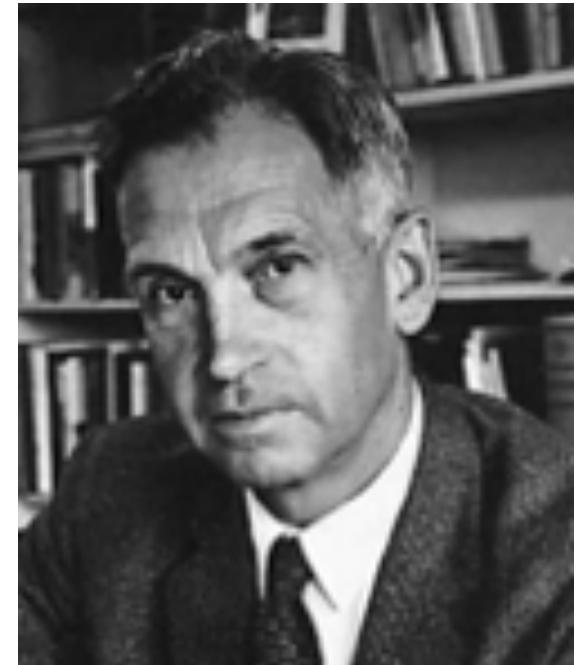
Huxley



Stebbins



Simpson



Mayr



Haldane



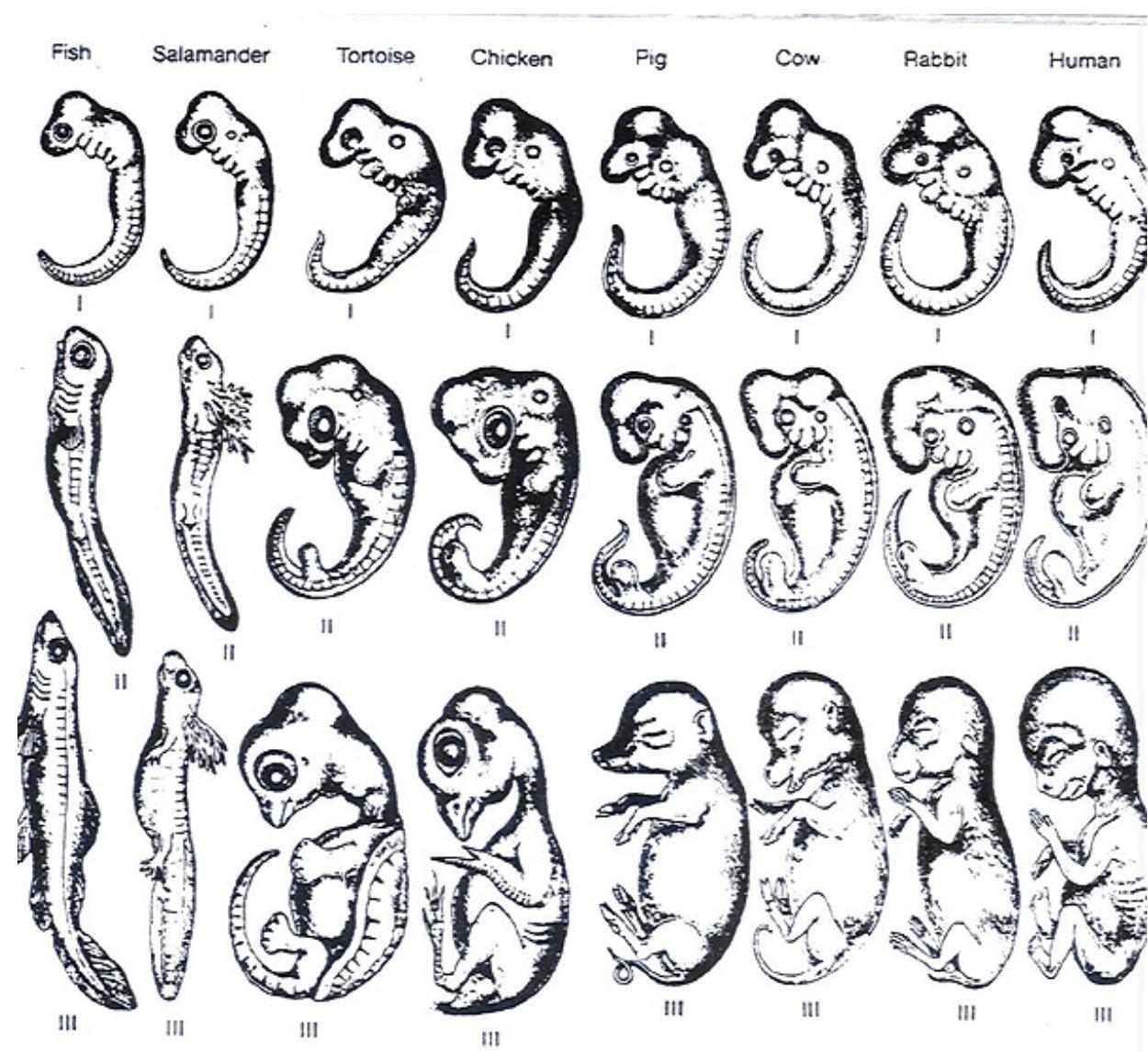
Fisher



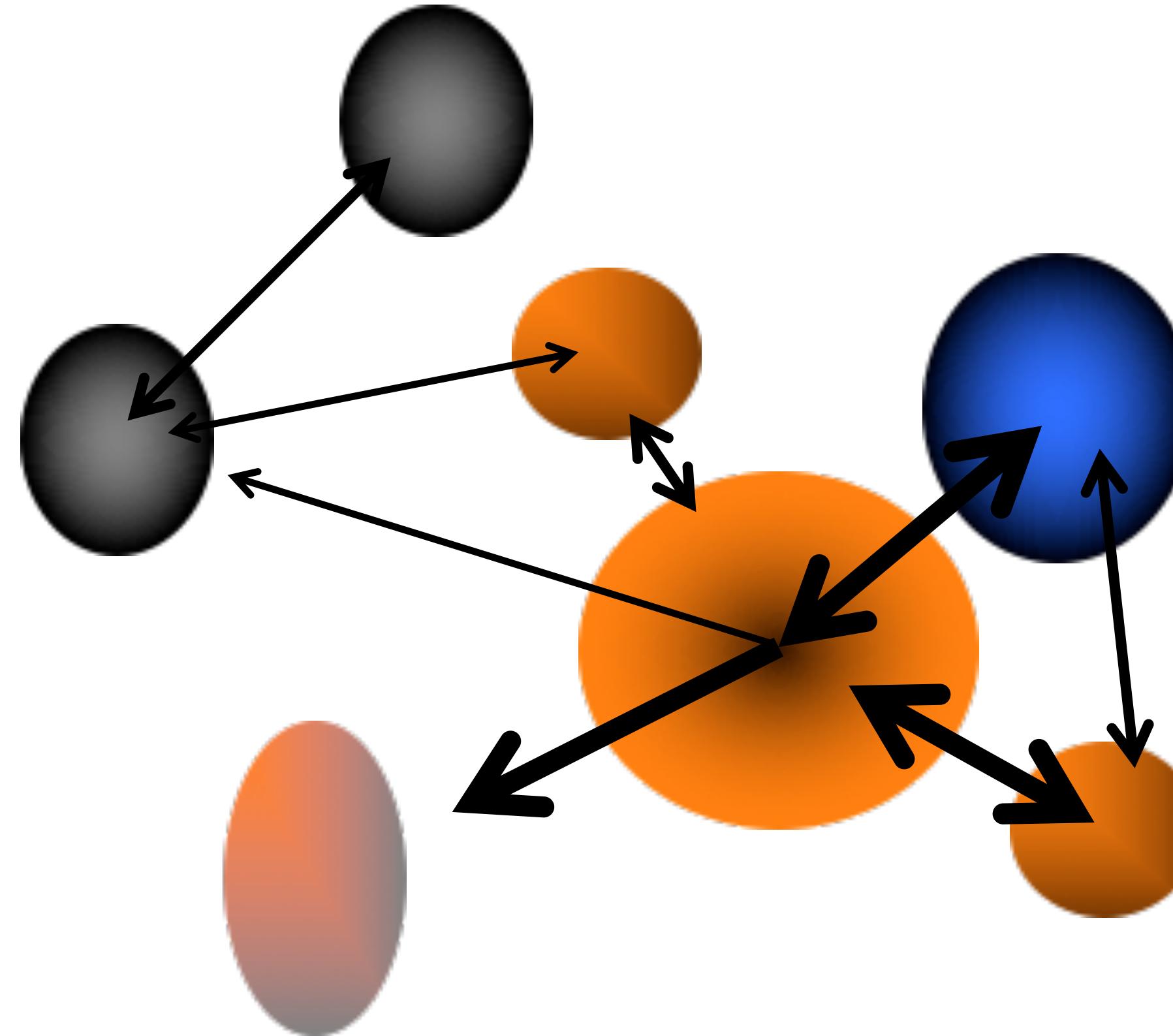
Wright



Dobzhansky



# Environmental heterogeneity helps maintaining genetic variation

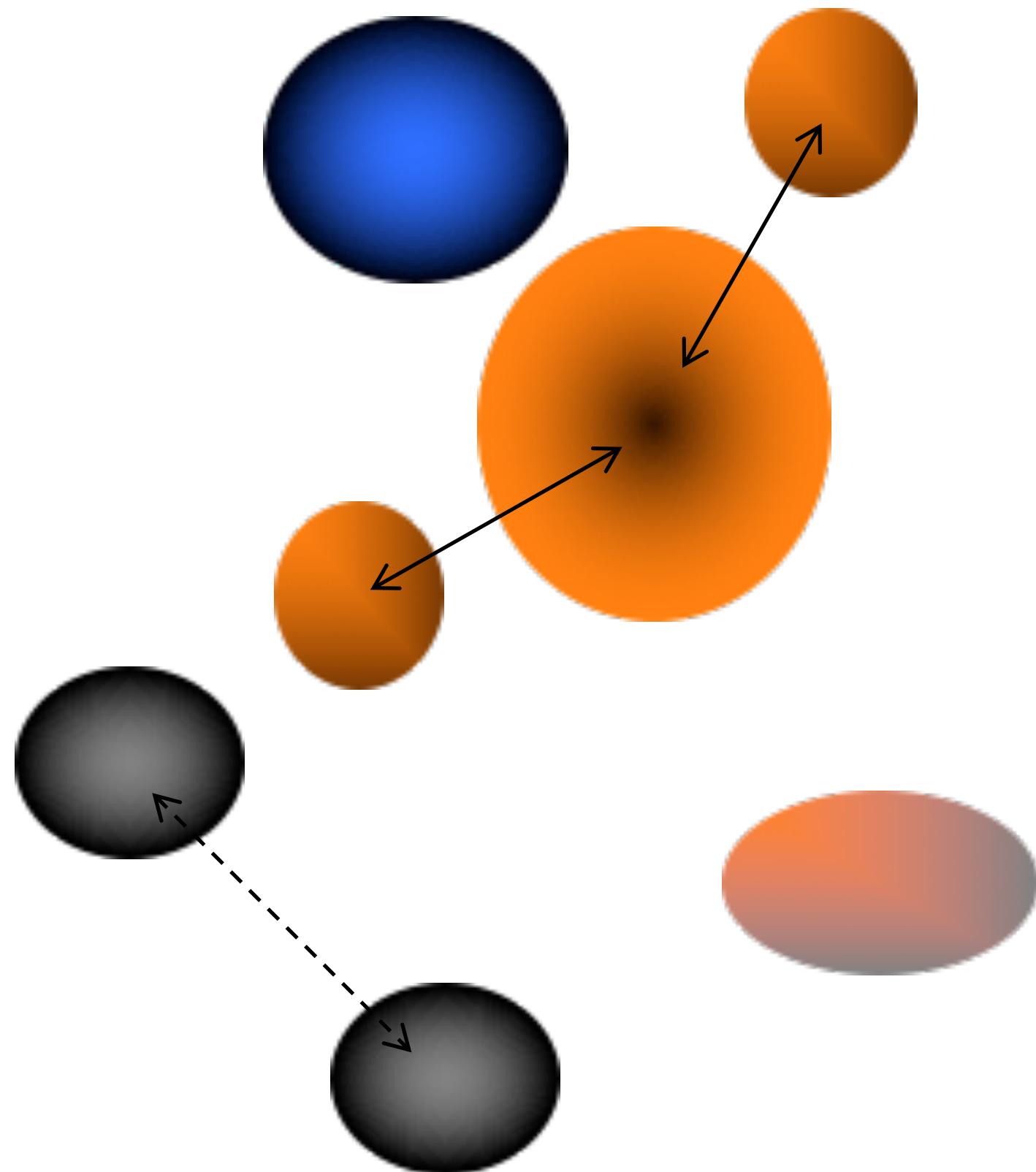


- \* Mutation, recombination
- \* Drift
- \* Gene flow

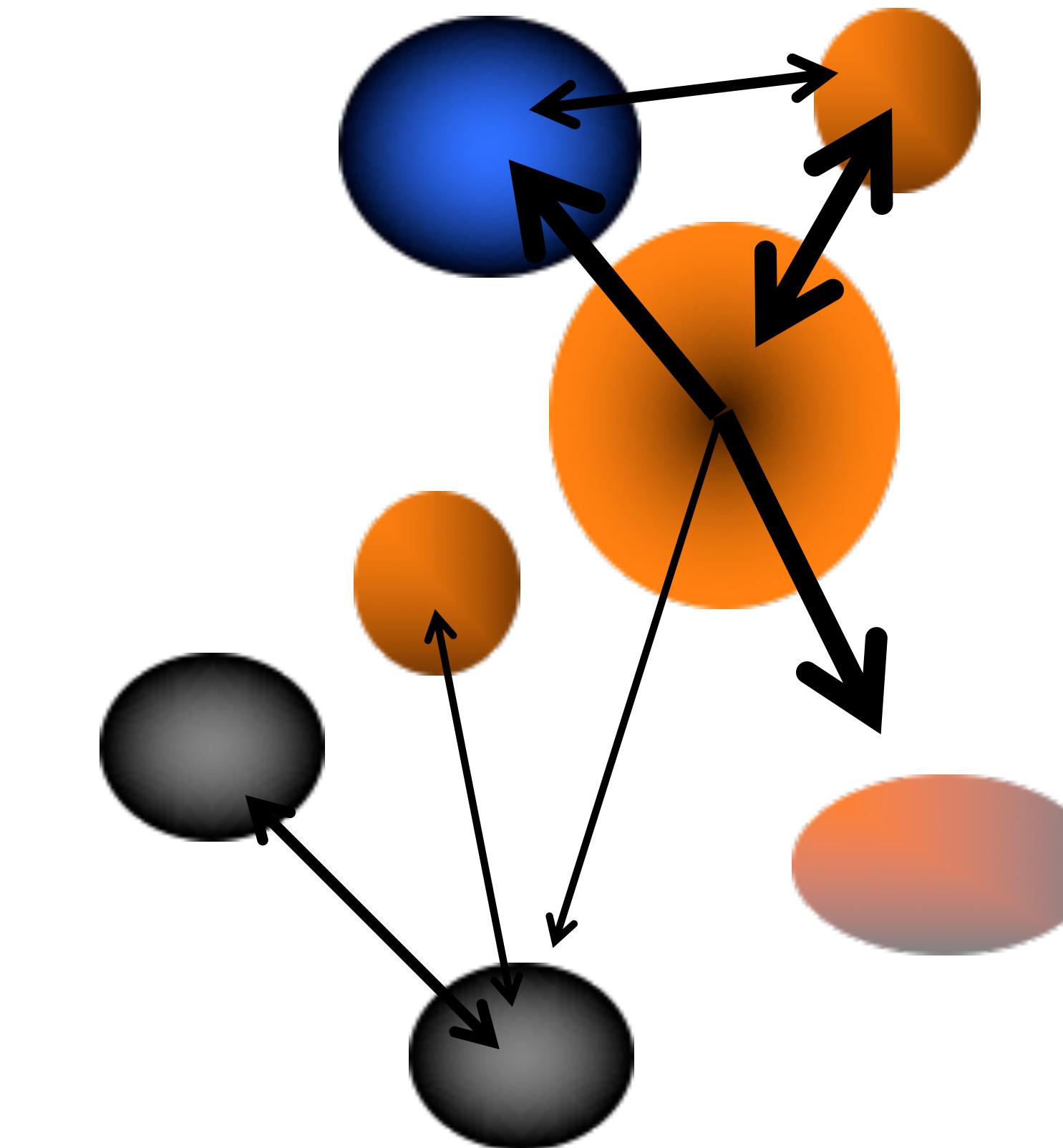
Metapopulation in heterogeneous environment

## Metapopulation Structure Favors Plasticity over Local Adaptation

Sonia E. Sultan<sup>1,\*</sup> and Hamish G. Spencer<sup>2,†</sup>

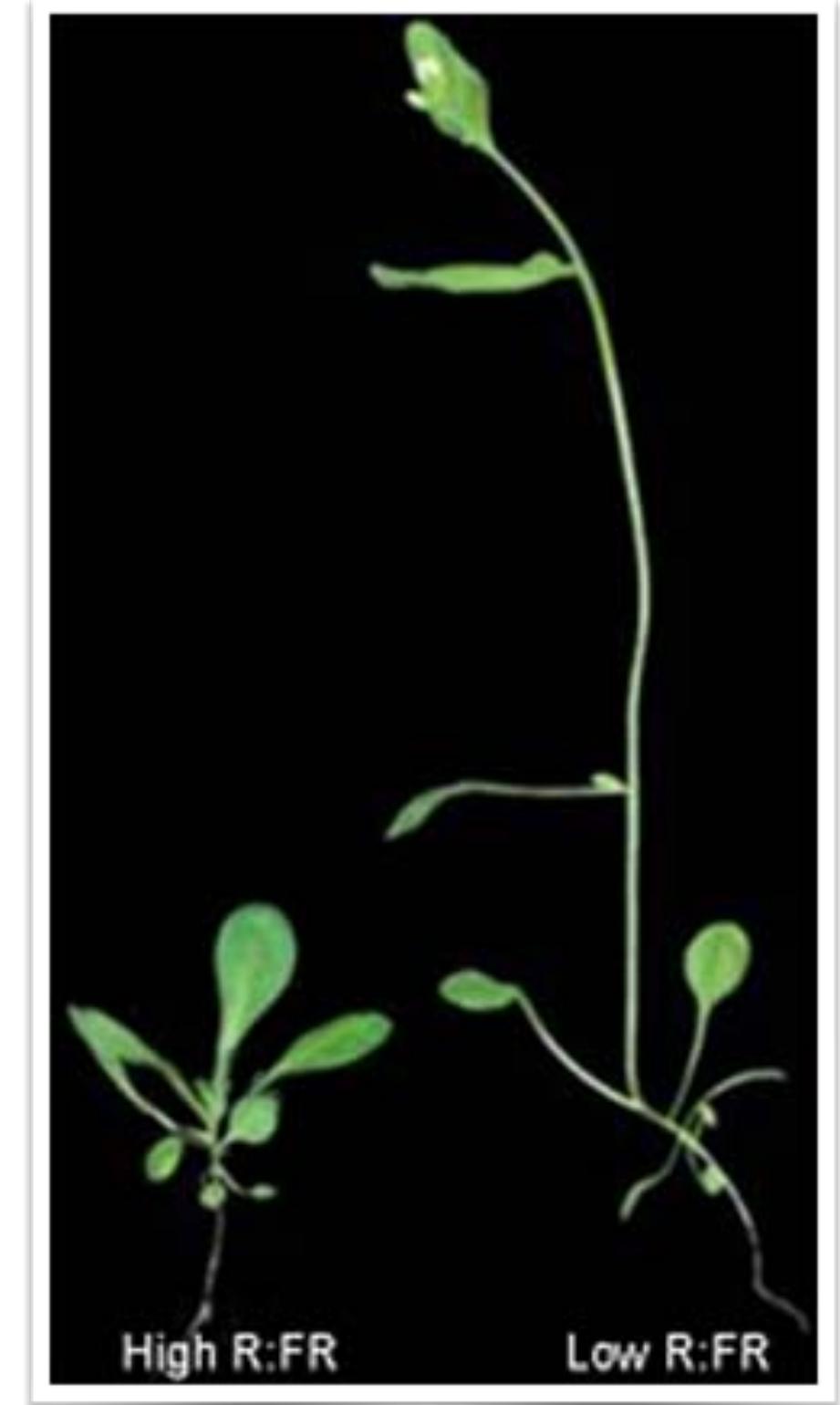
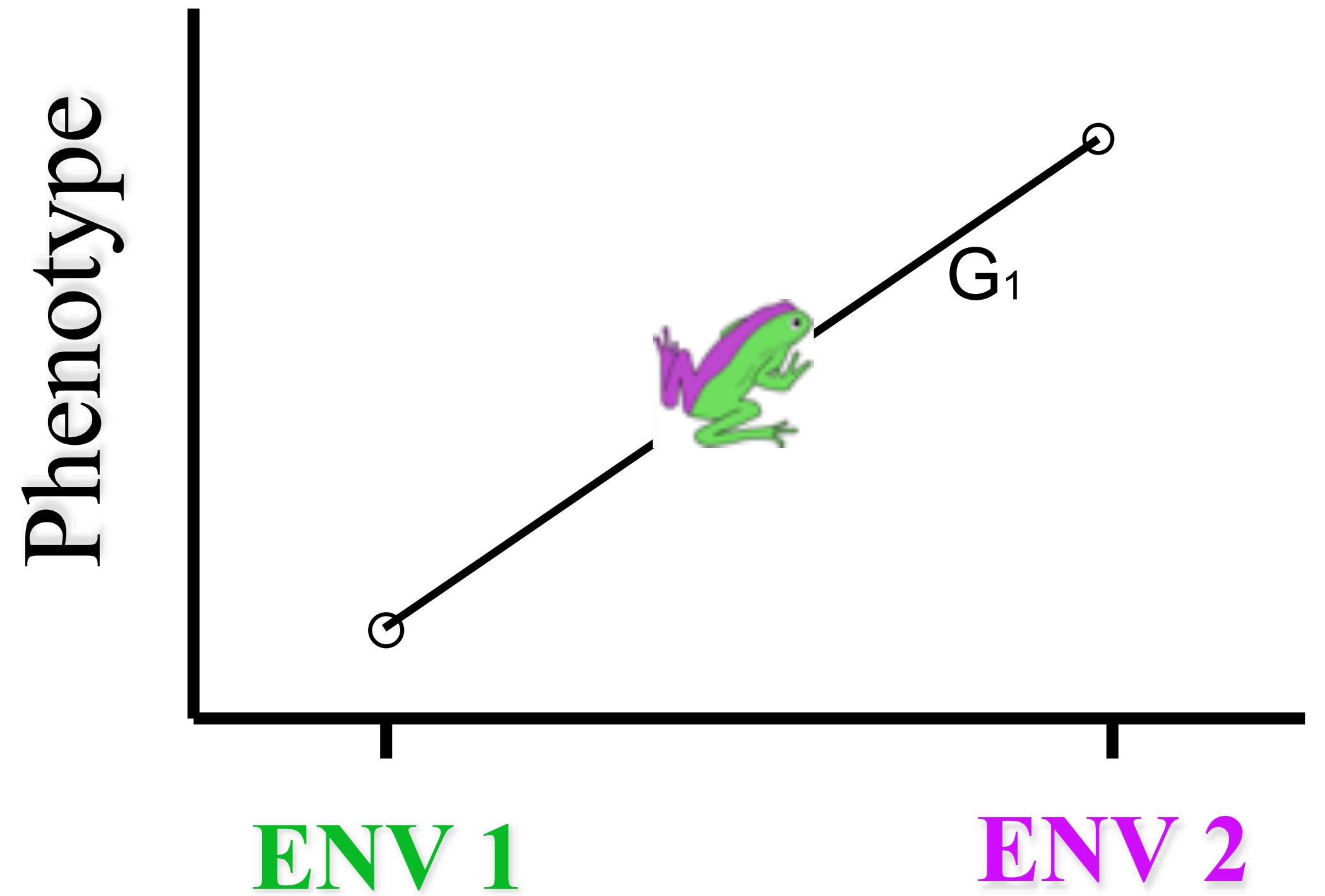


Local adaptation of fixed phenotypes

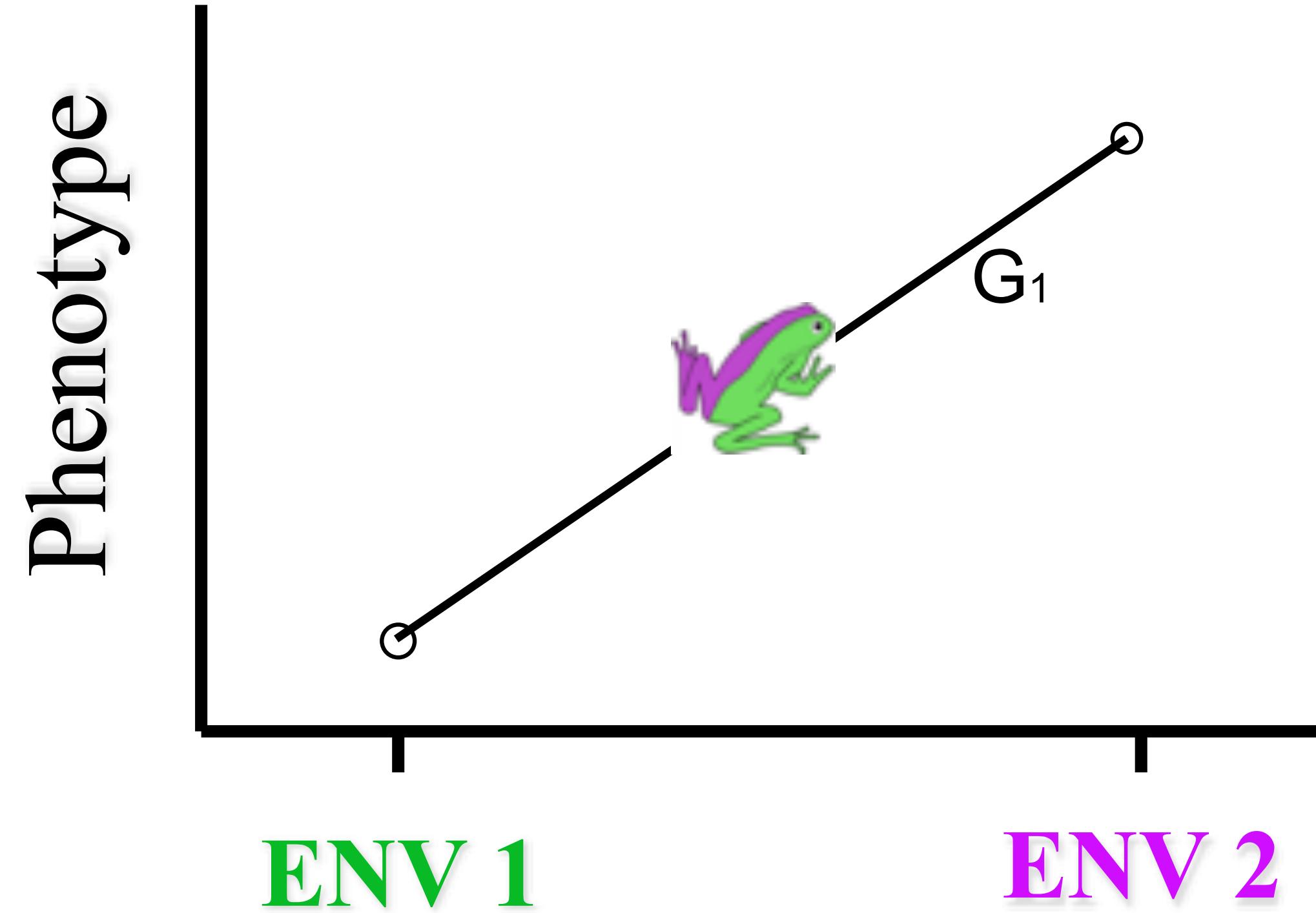


Adaptive phenotypic plasticity

# Phenotypic plasticity



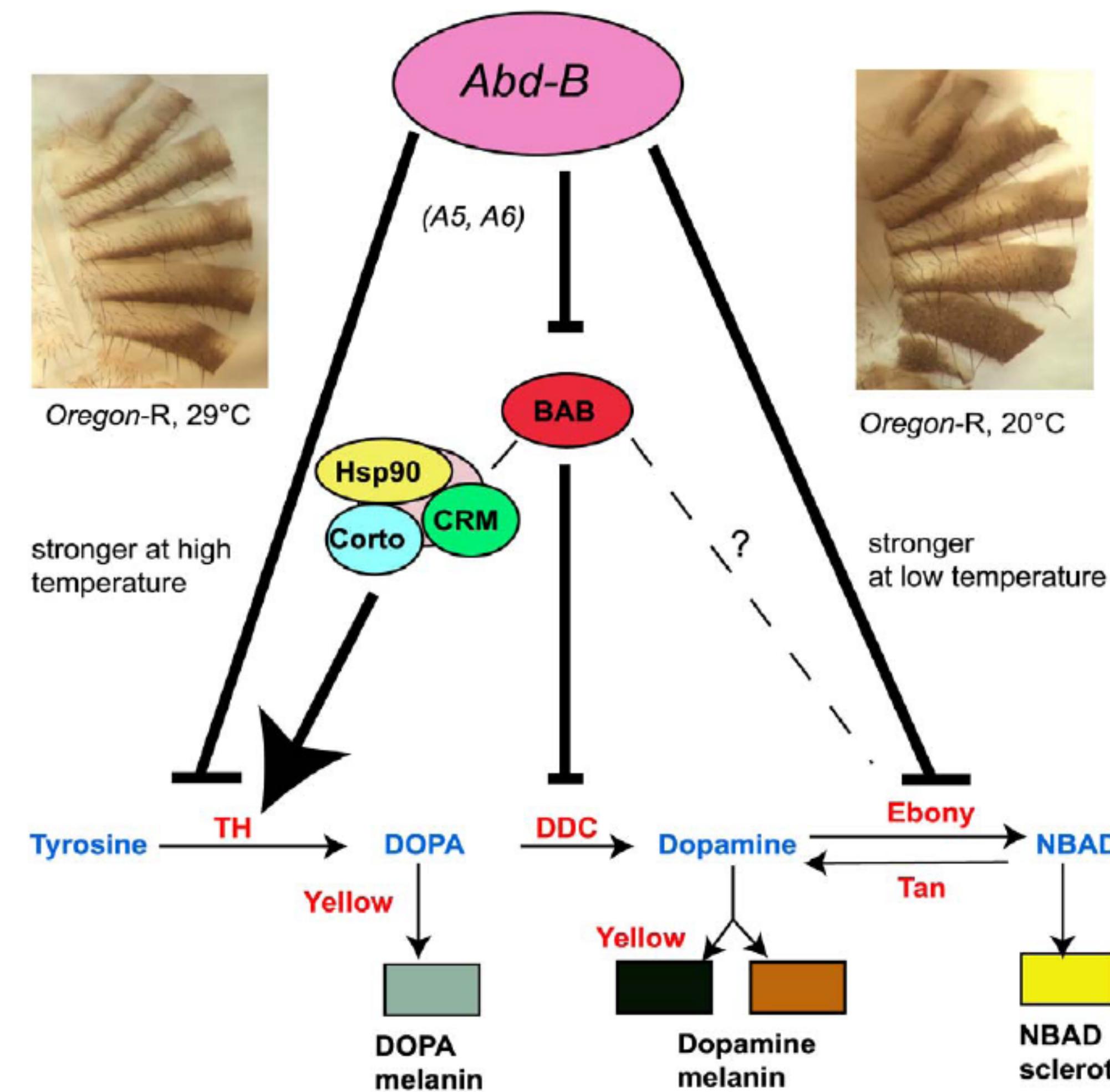
# Adaptive Phenotypic plasticity



If/When:

- ▶ Environmental heterogeneity
- ▶ Fitness trade off
- ▶ Reliable cues
- ▶ Heritable basis
- ▶ Fitness benefits outweigh costs

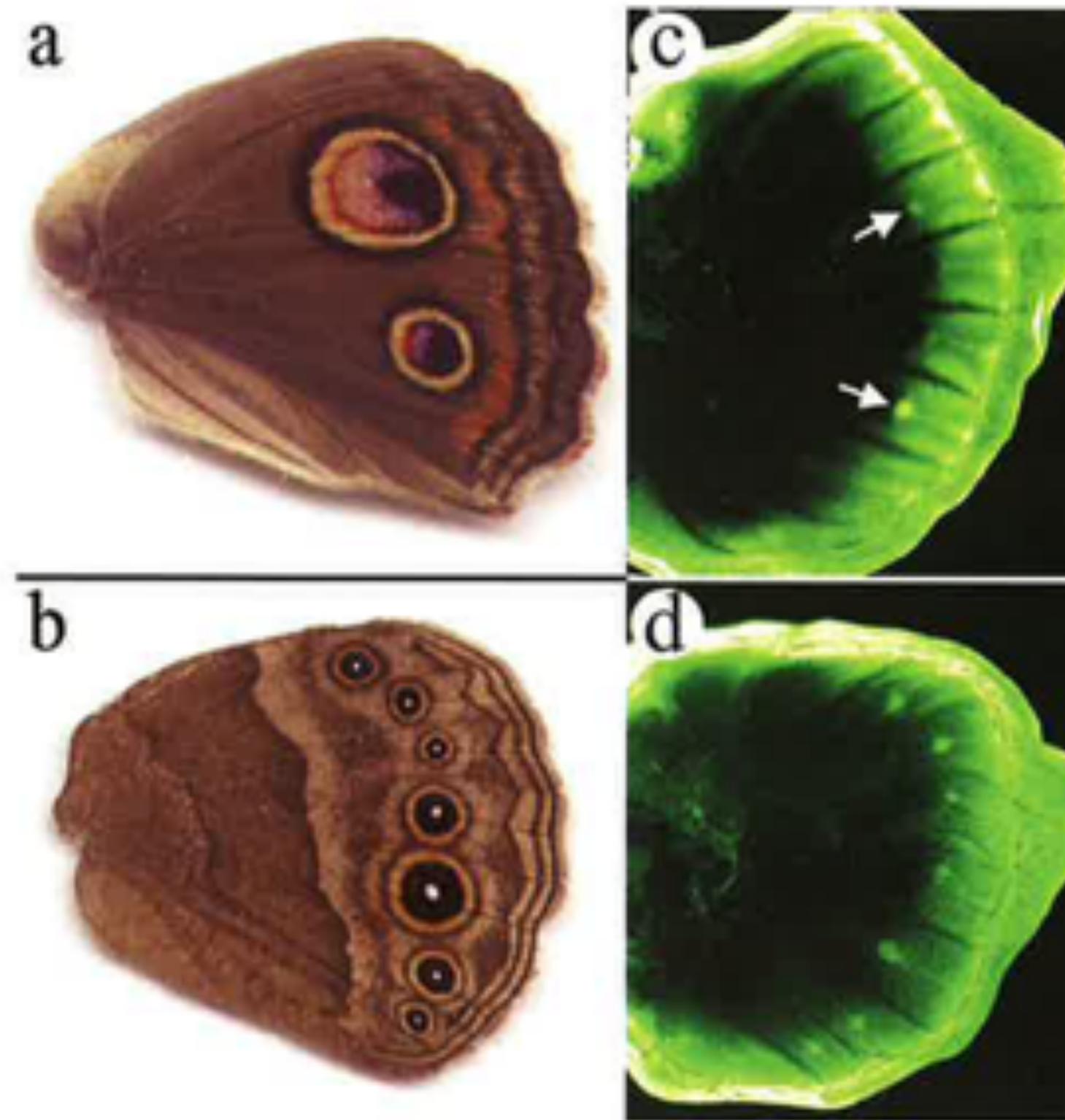
# Environmental input is essential in development



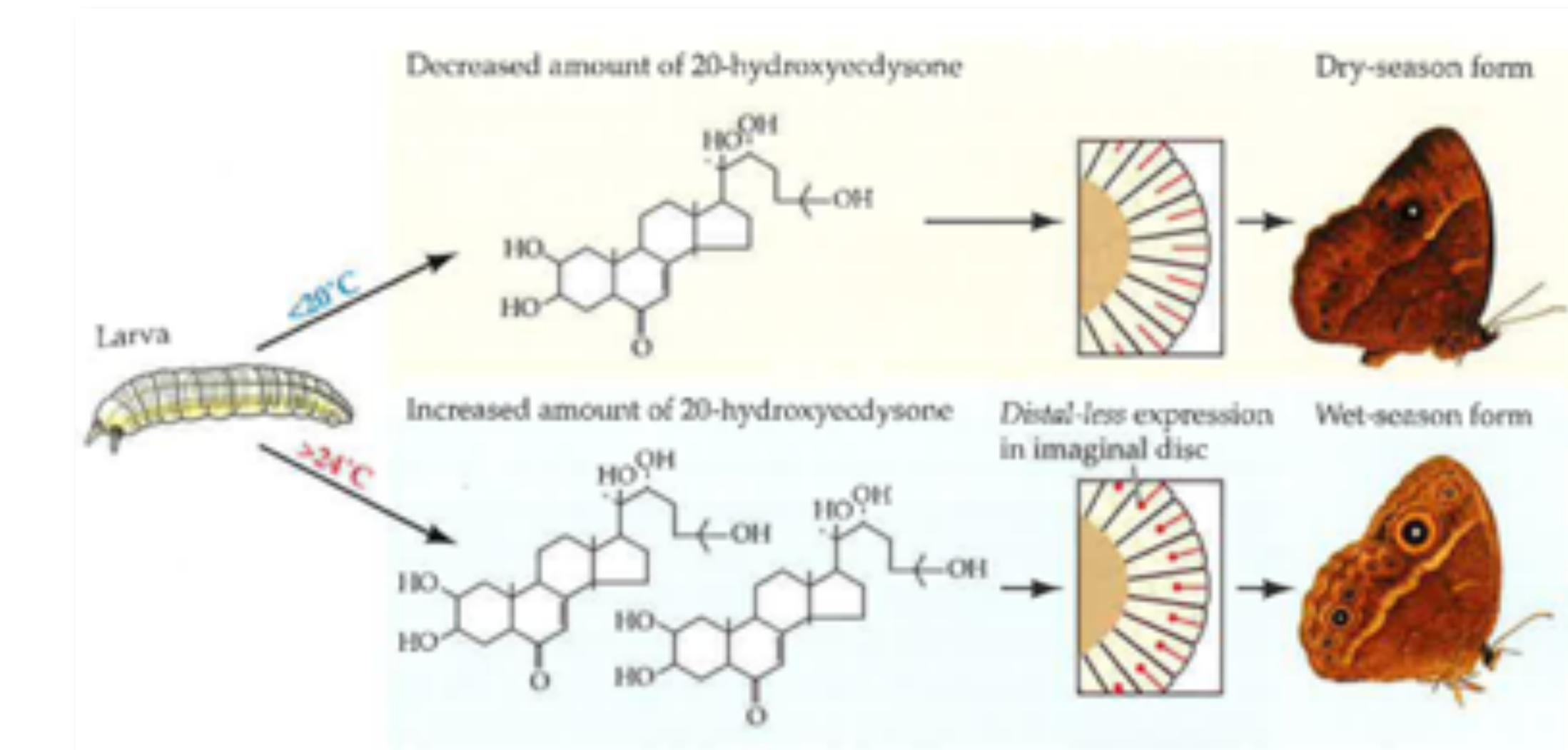
Gibert et al. 2007, PLoS Gen

# Environmental input is essential in development

*Dll* expression marks the formation of eyespots



...but *Dll* expression is dependent upon temperature and results in seasonal morphs



Brakefield & Reitsma 1991

Brakefield et al 1996 *Nature*

# Environmental input is essential in development



**Summer morph**



**Spring morph**

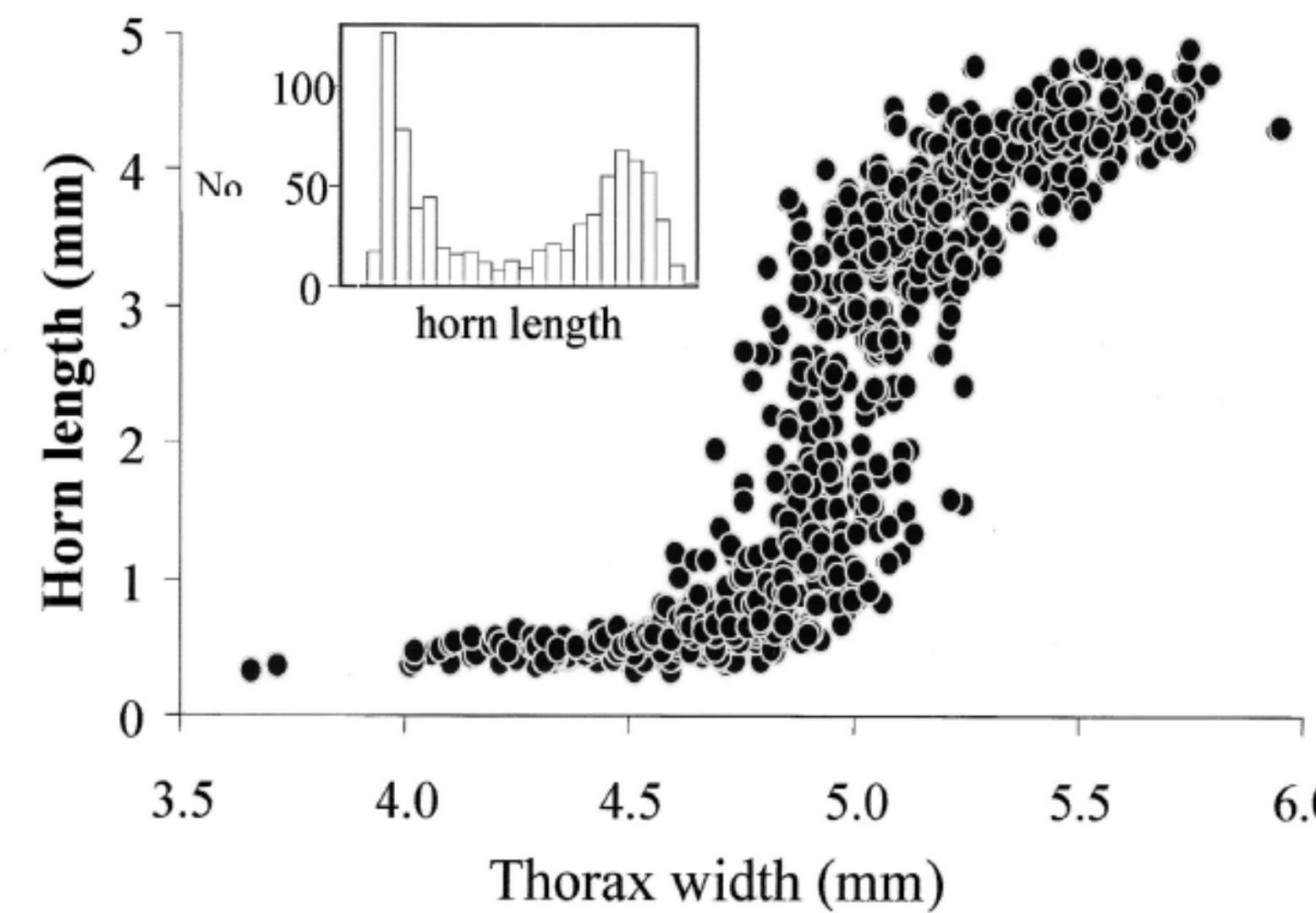
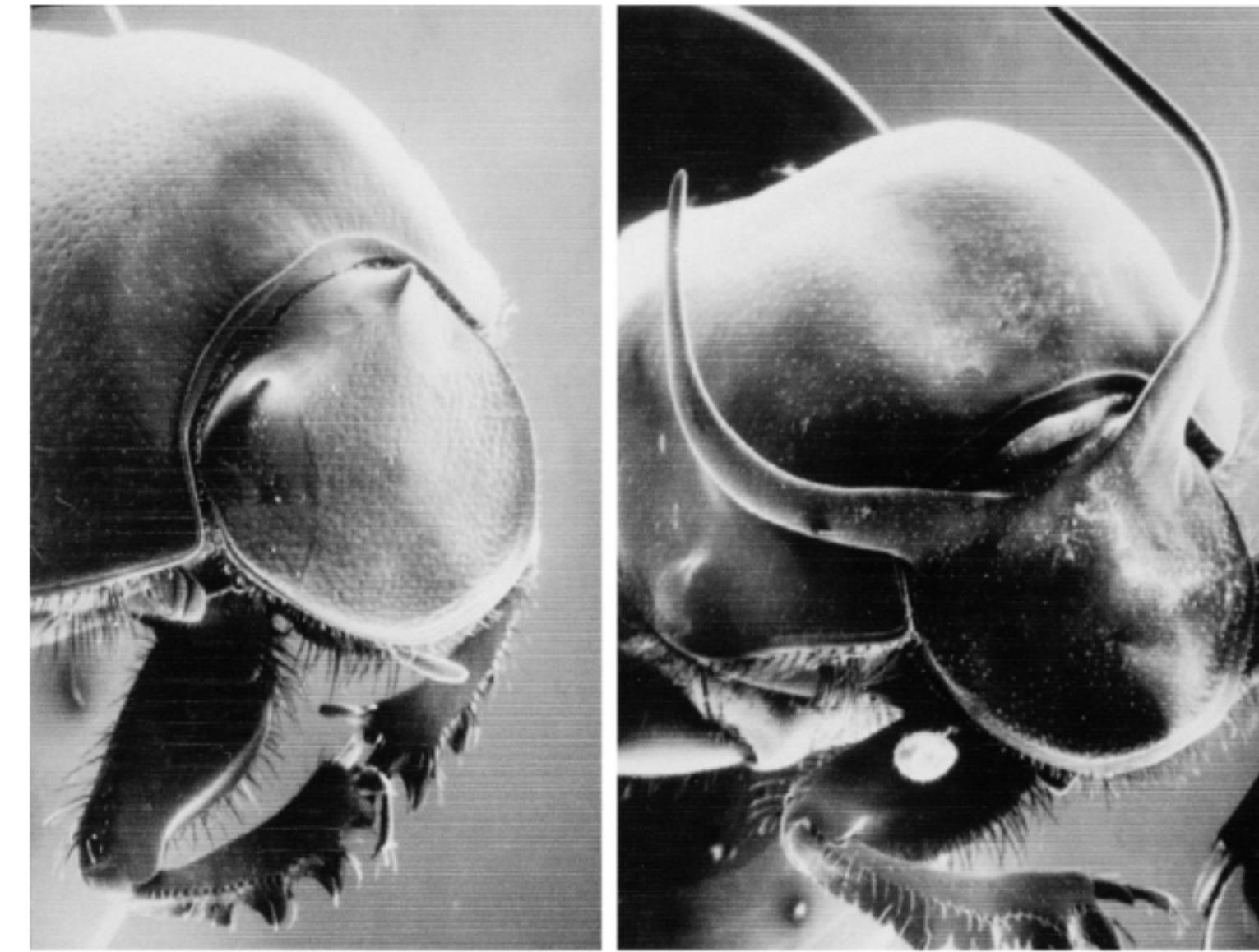
*Araschnia levana*, Windig & Lammar 1999 Evol Ecol

# Environmental input is essential in development



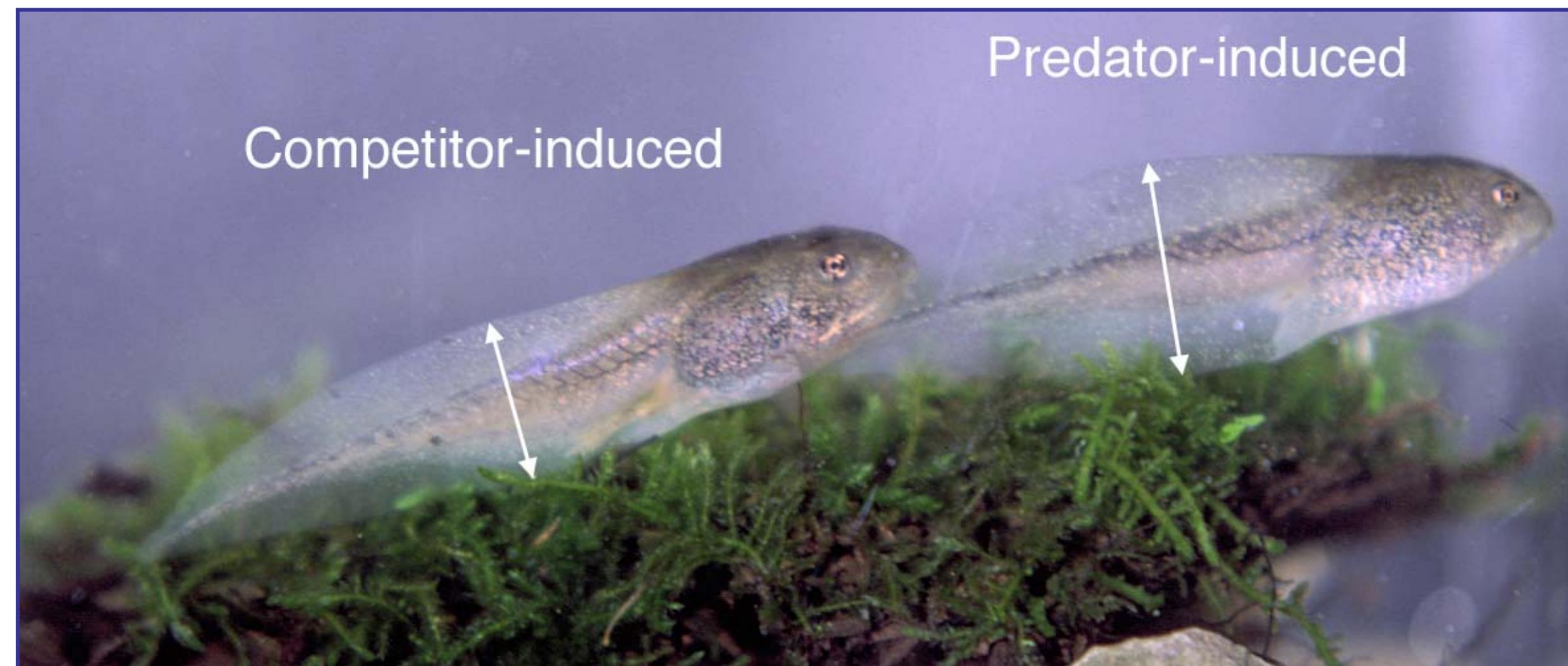
Nemoria arizonaria, Greene 1989 Nature

# Environmental input is essential in development



Moczek Lab

# Environmental input is essential in development

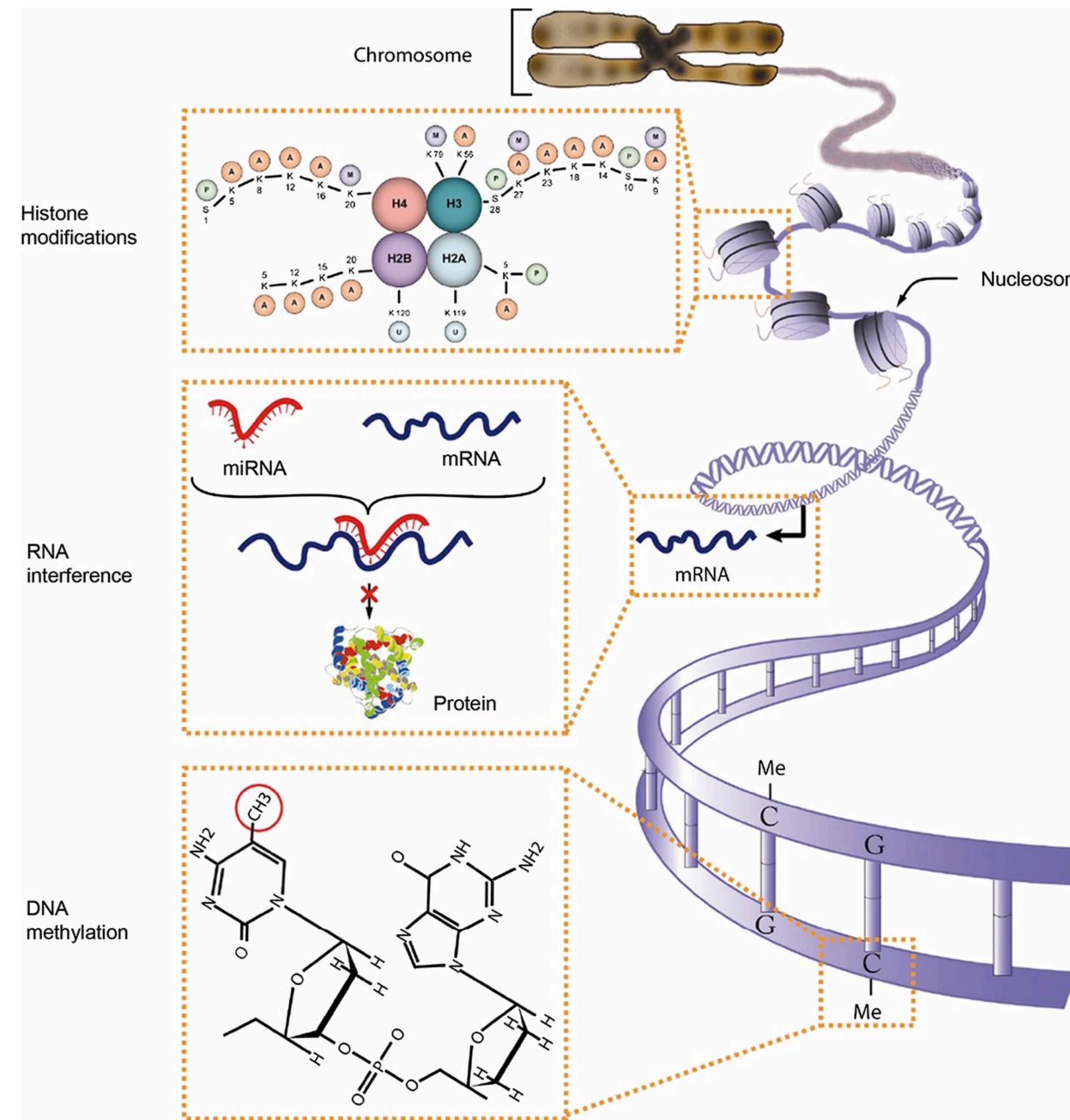


Relyea Lab

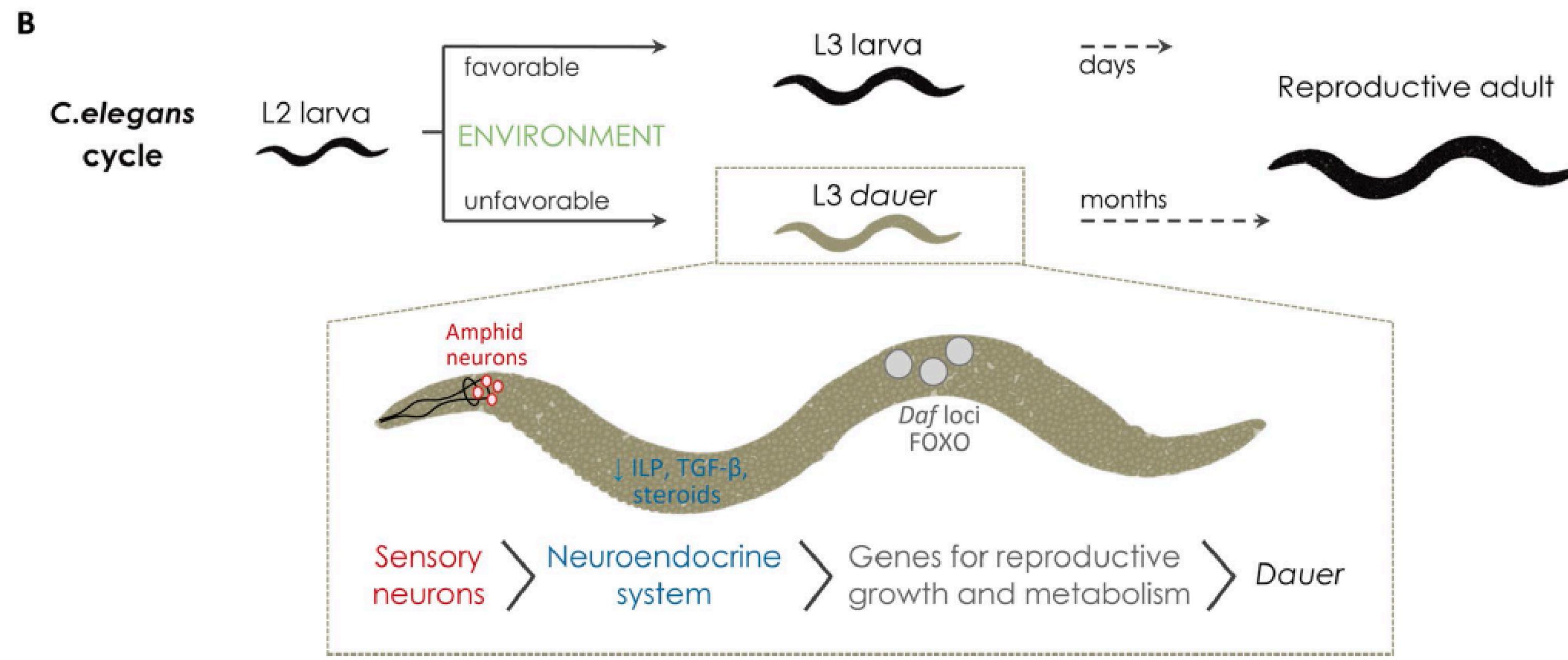
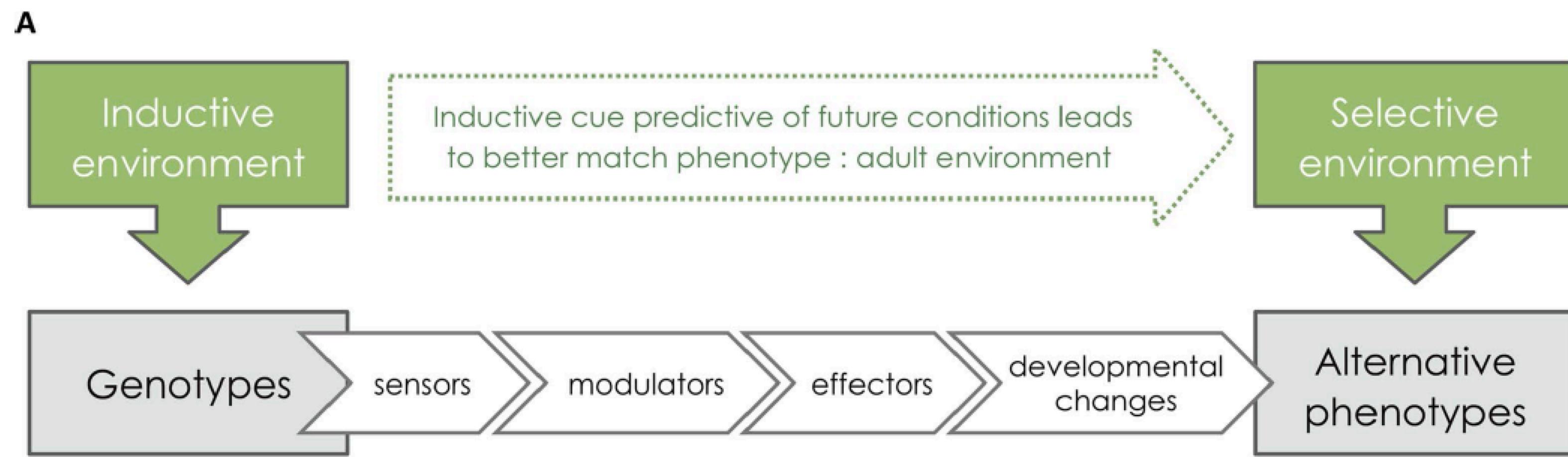


Eco-Evo-Devo  
EBD

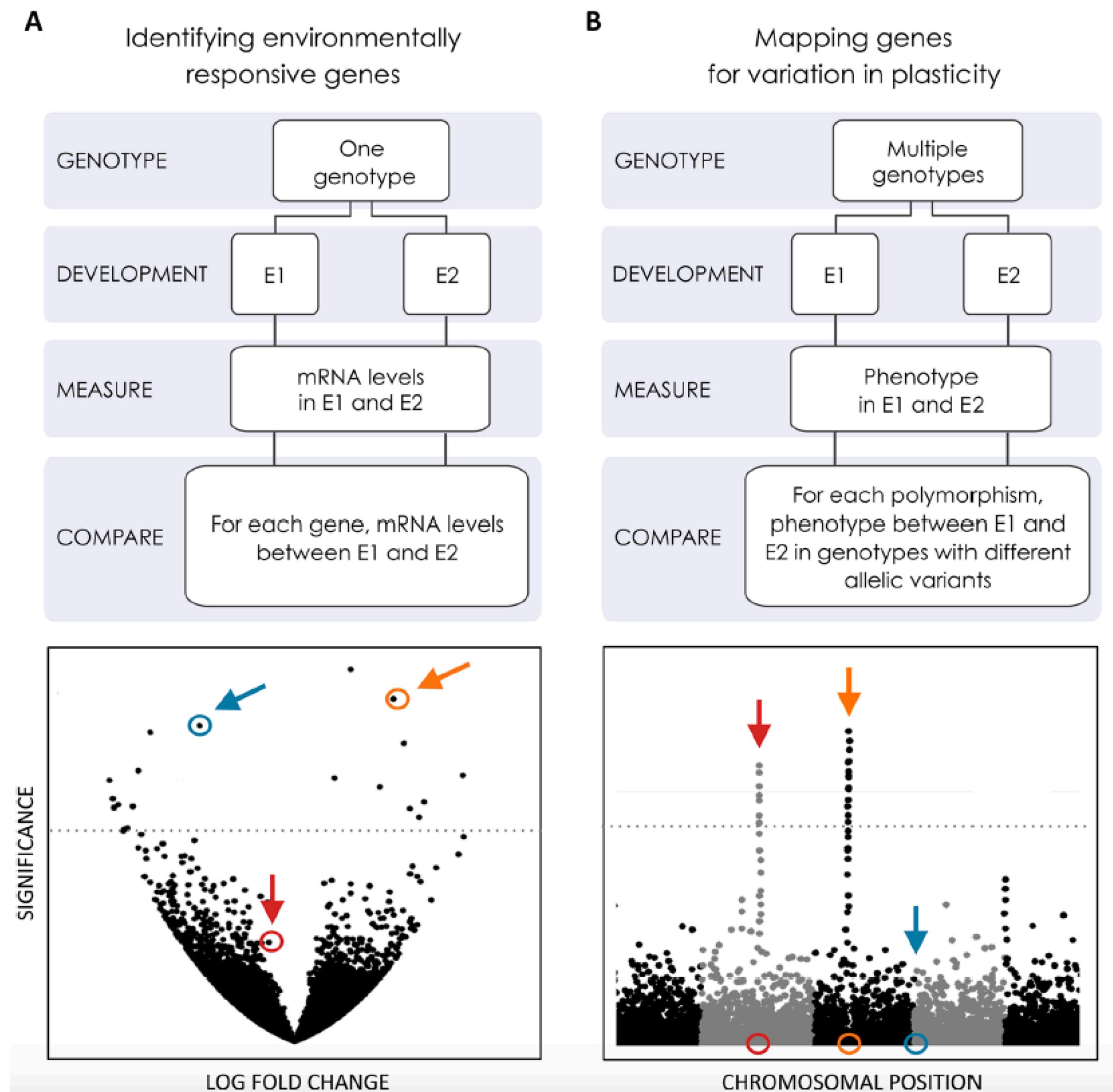
# Epigenetic changes translate environmental input into changes in gene expression



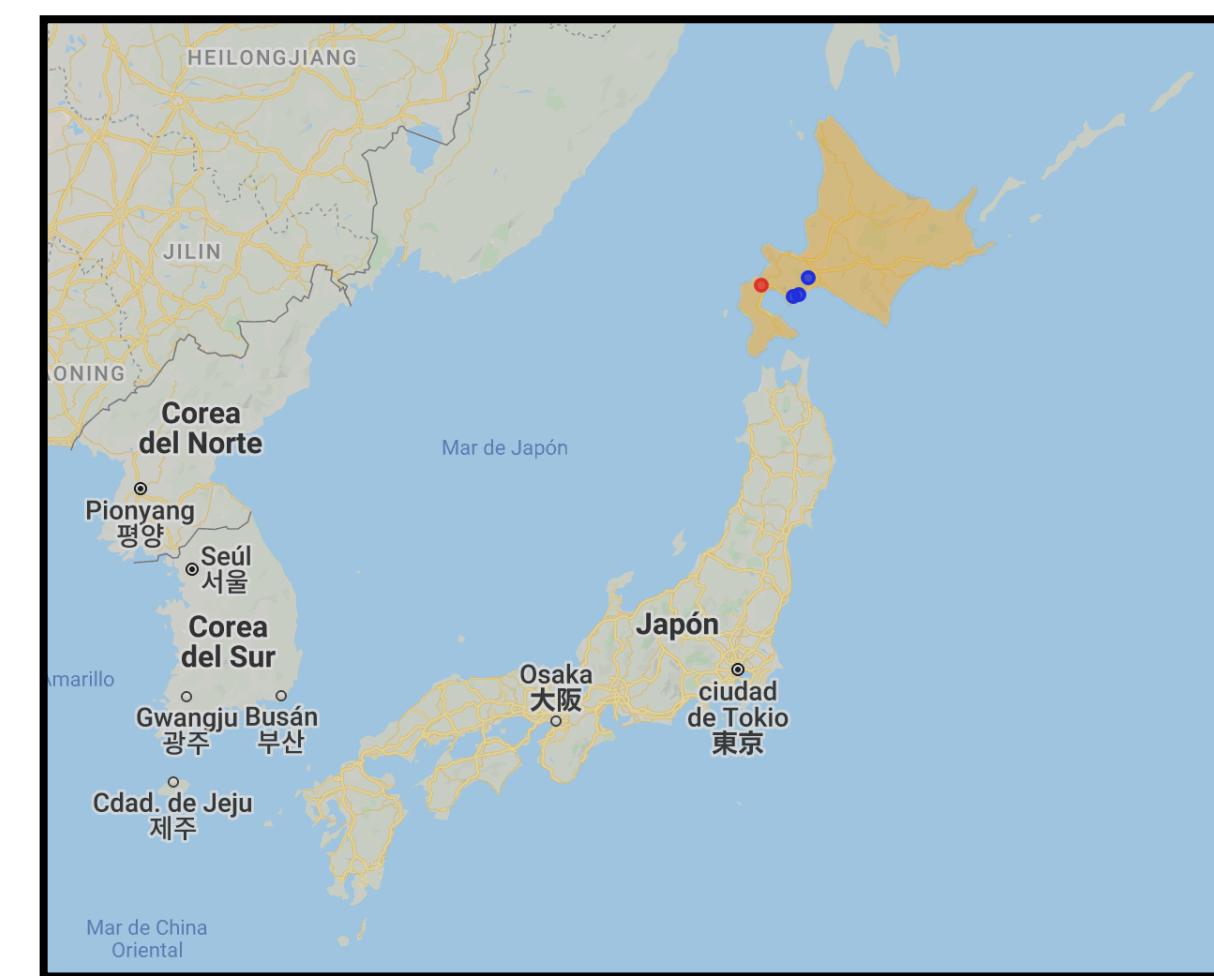
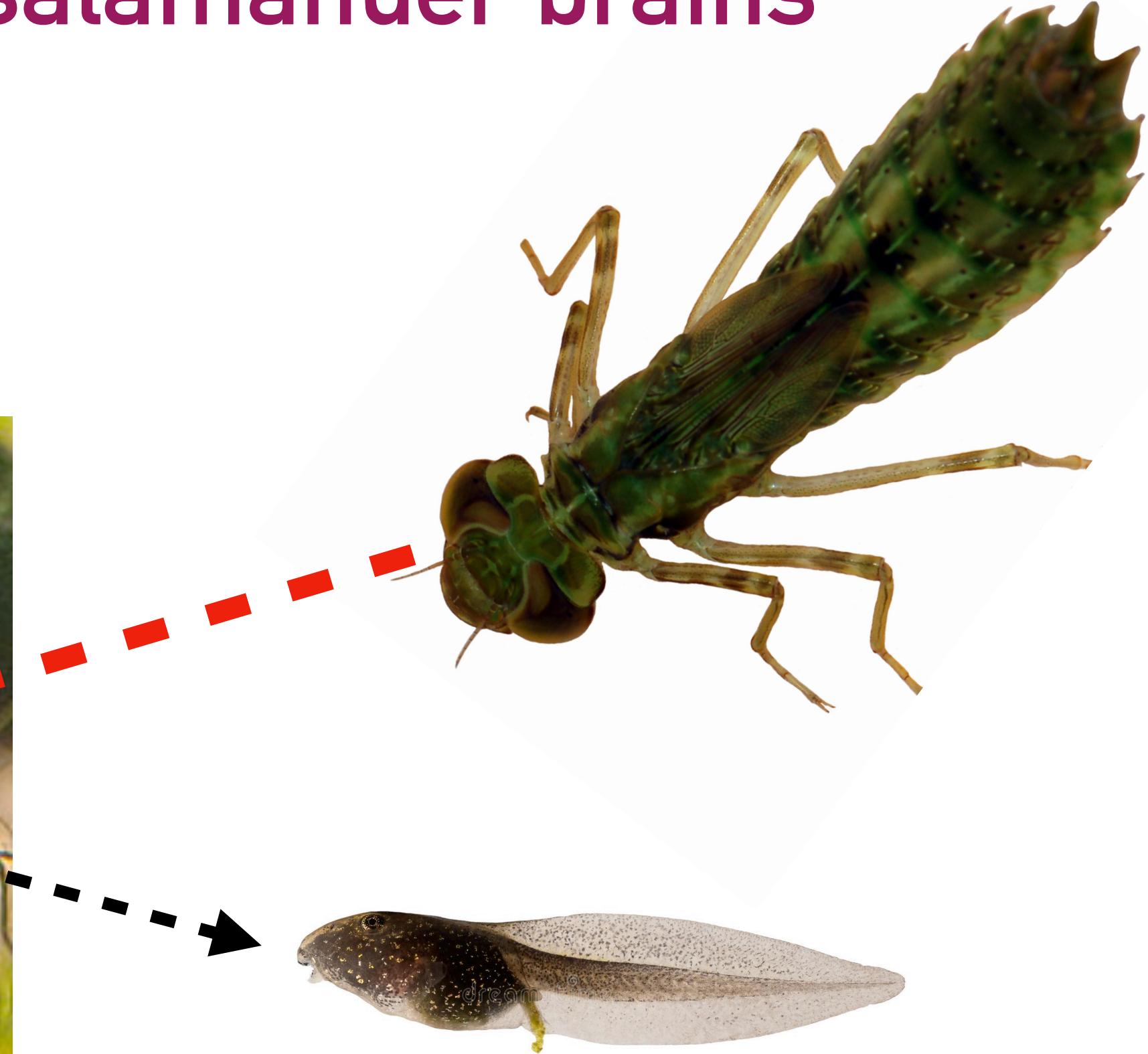
# Environment > Genotype > Phenotype



# Molecular quest for plasticity: transcriptomics and mapping studies



# Predator- and prey-driven gene expression in salamander brains

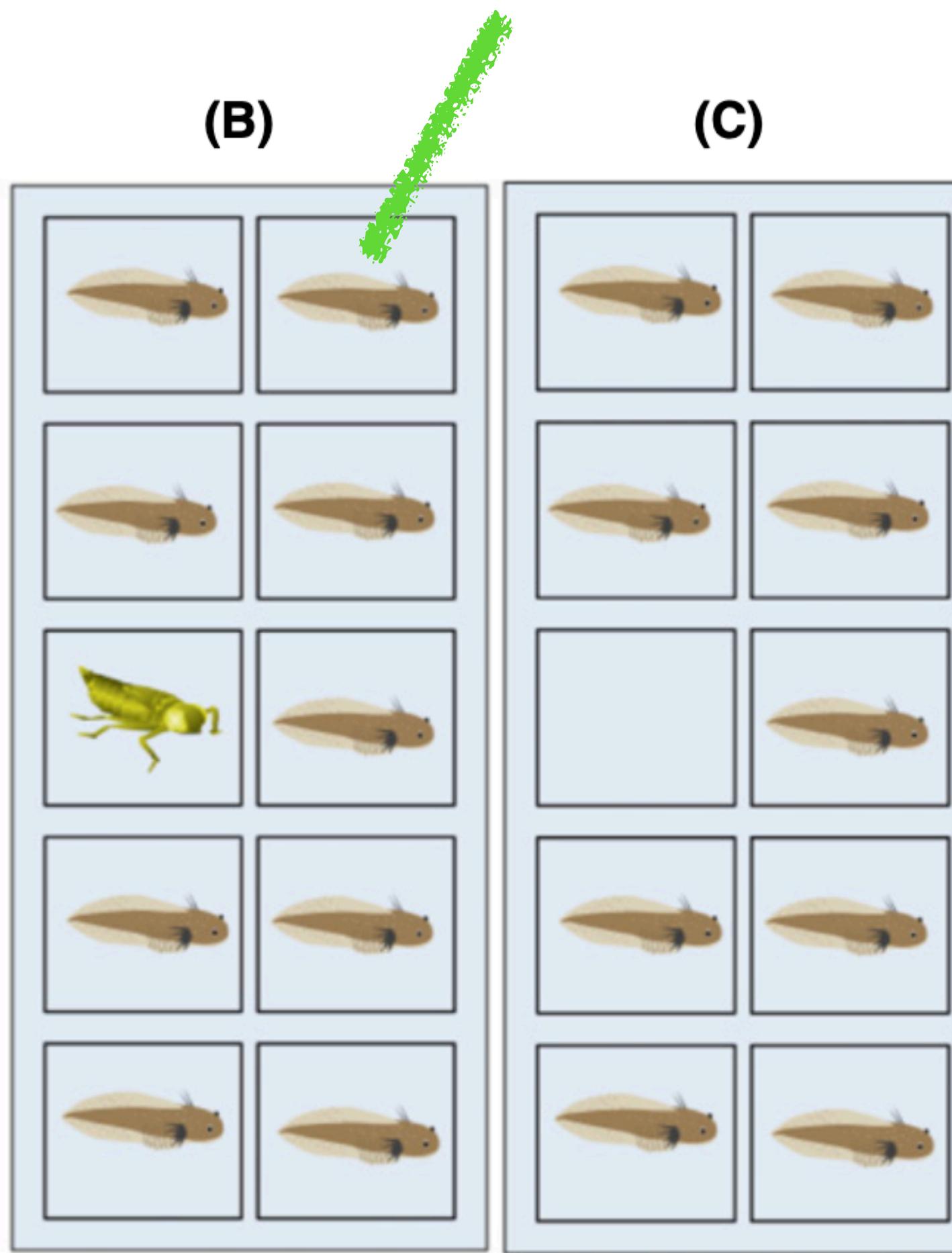


# Predator- and prey-driven gene expression in salamander brains

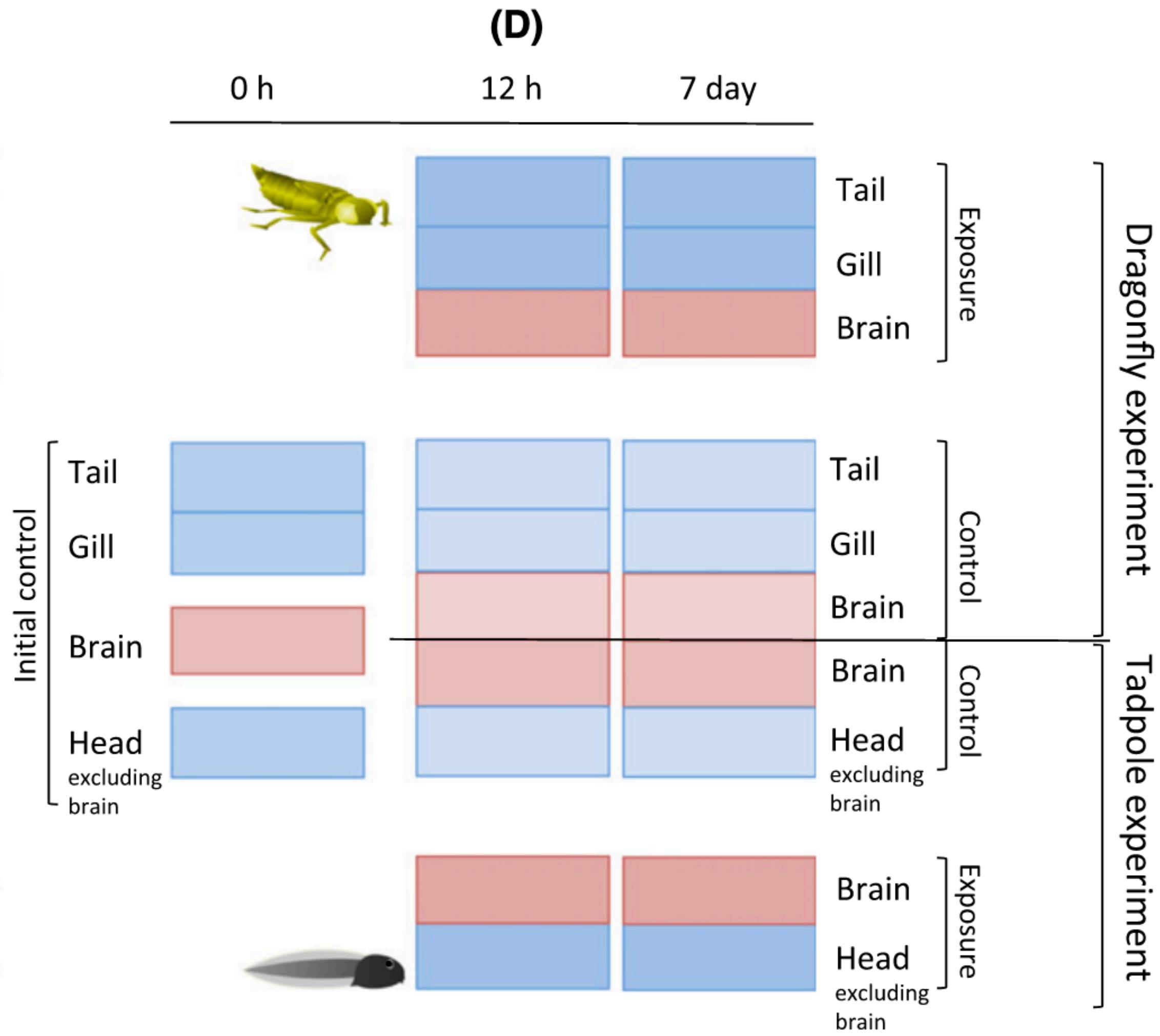
*Rana pirica*



*Hynobius retardatus*



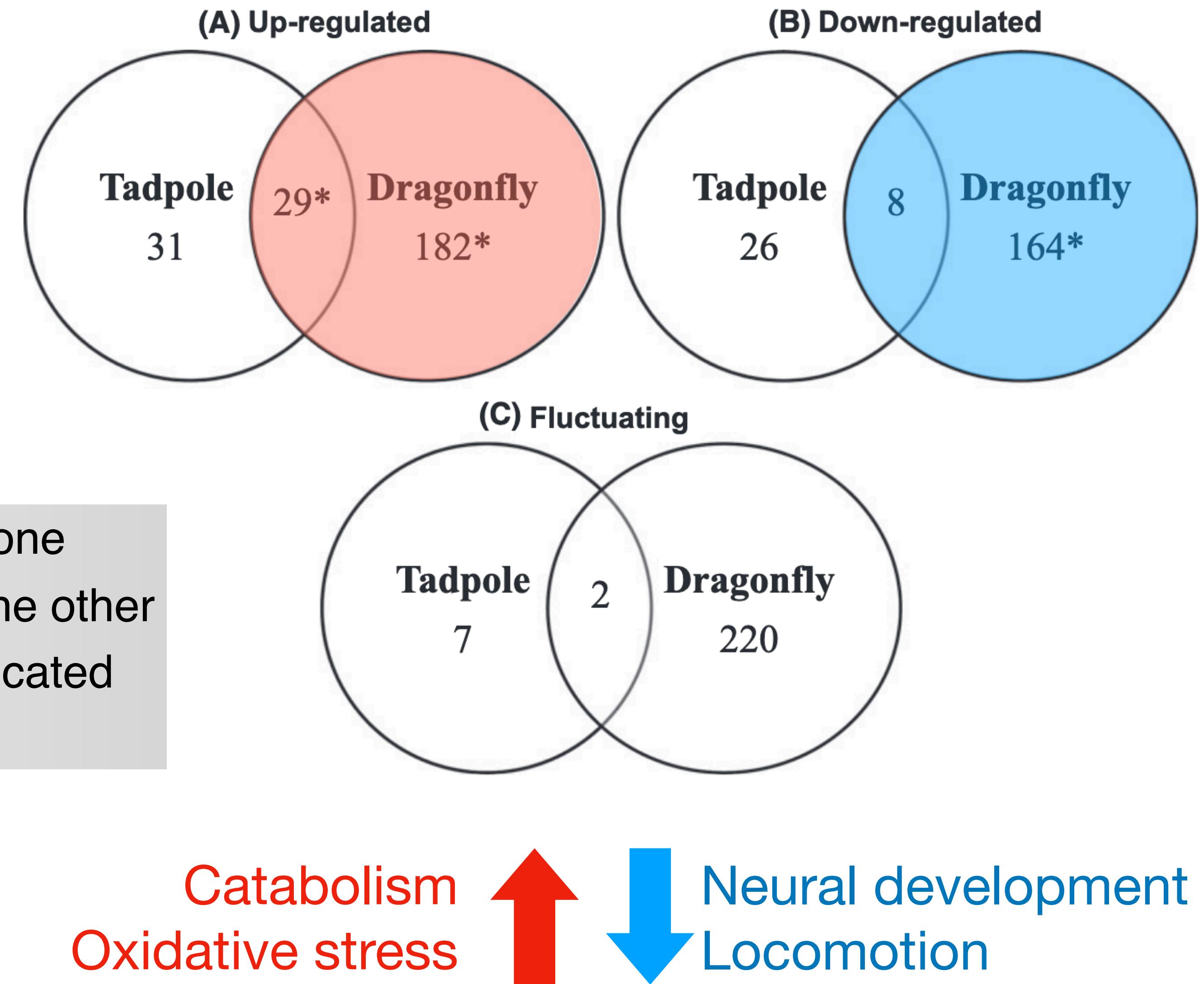
(C)



# Predator- and prey-driven gene expression in salamander brains



“If more genes are involved in the expression of one alternative phenotype than in the expression of the other [...], the former plasticity may require more complicated developmental changes”



# Transcriptomics of salinity adaptation in a treefrog



ORIGINAL ARTICLE

MOLECULAR ECOLOGY WILEY

## Molecular mechanisms of local adaptation for salt-tolerance in a treefrog

Molly A. Albecker | Adam M. M. Stuckert | Christopher N. Balakrishnan |  
Michael W. McCoy

“These animals and their spawn are immediately killed (with the exception as far as known, of one Indian species) by sea-water.”

—Charles Darwin (1872)

# Transcriptomics of salinity adaptation in a treefrog



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*Herpetological Monographs*, 29, 2015, 1–27  
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## OCCURRENCE OF AMPHIBIANS IN SALINE HABITATS: A REVIEW AND EVOLUTIONARY PERSPECTIVE

GARETH R. HOPKINS<sup>1</sup> AND EDMUND D. BRODIE, JR

*Department of Biology and the Ecology Center, Utah State University, Logan, UT 84322, USA*

# Transcriptomics of salinity adaptation in a treefrog

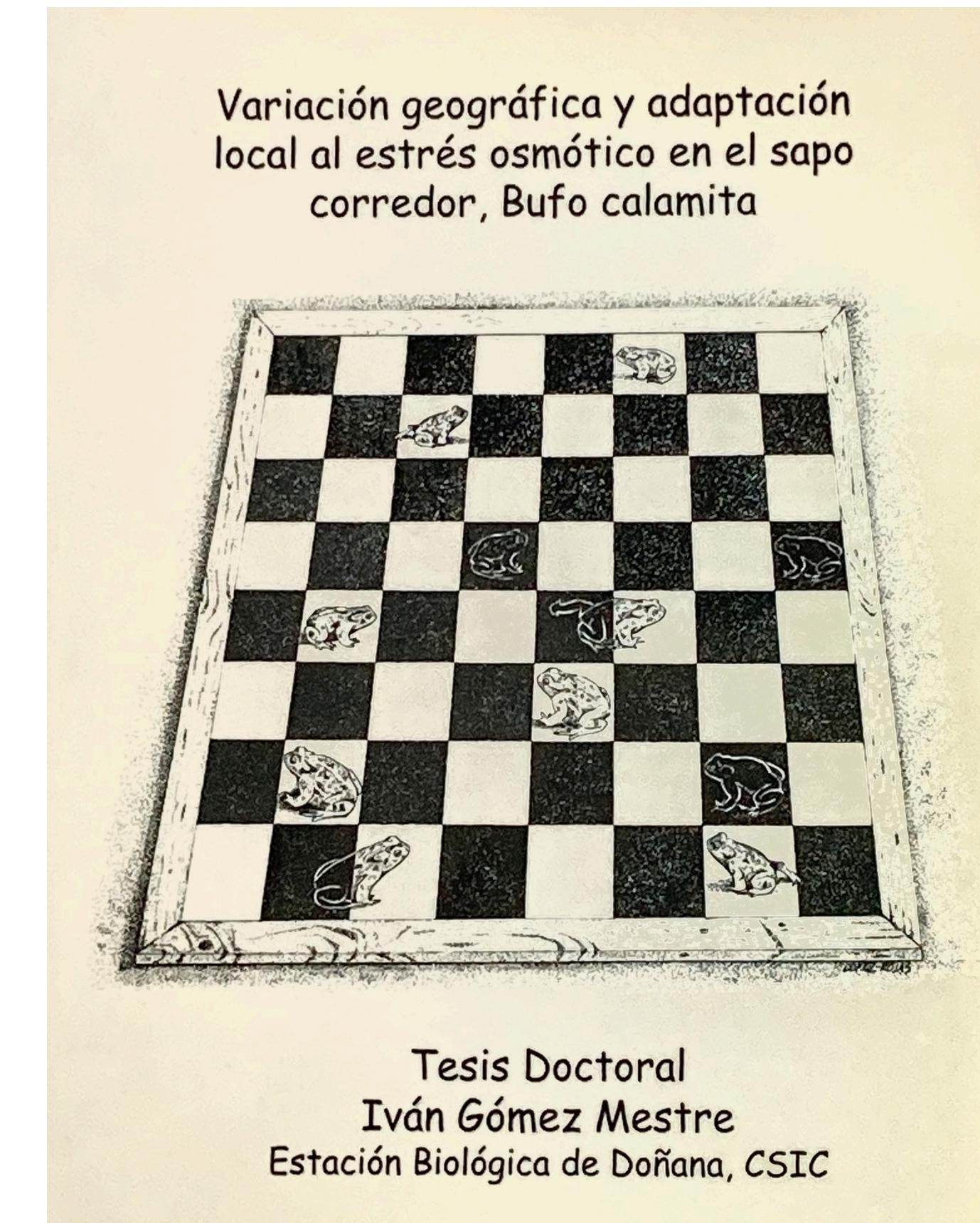


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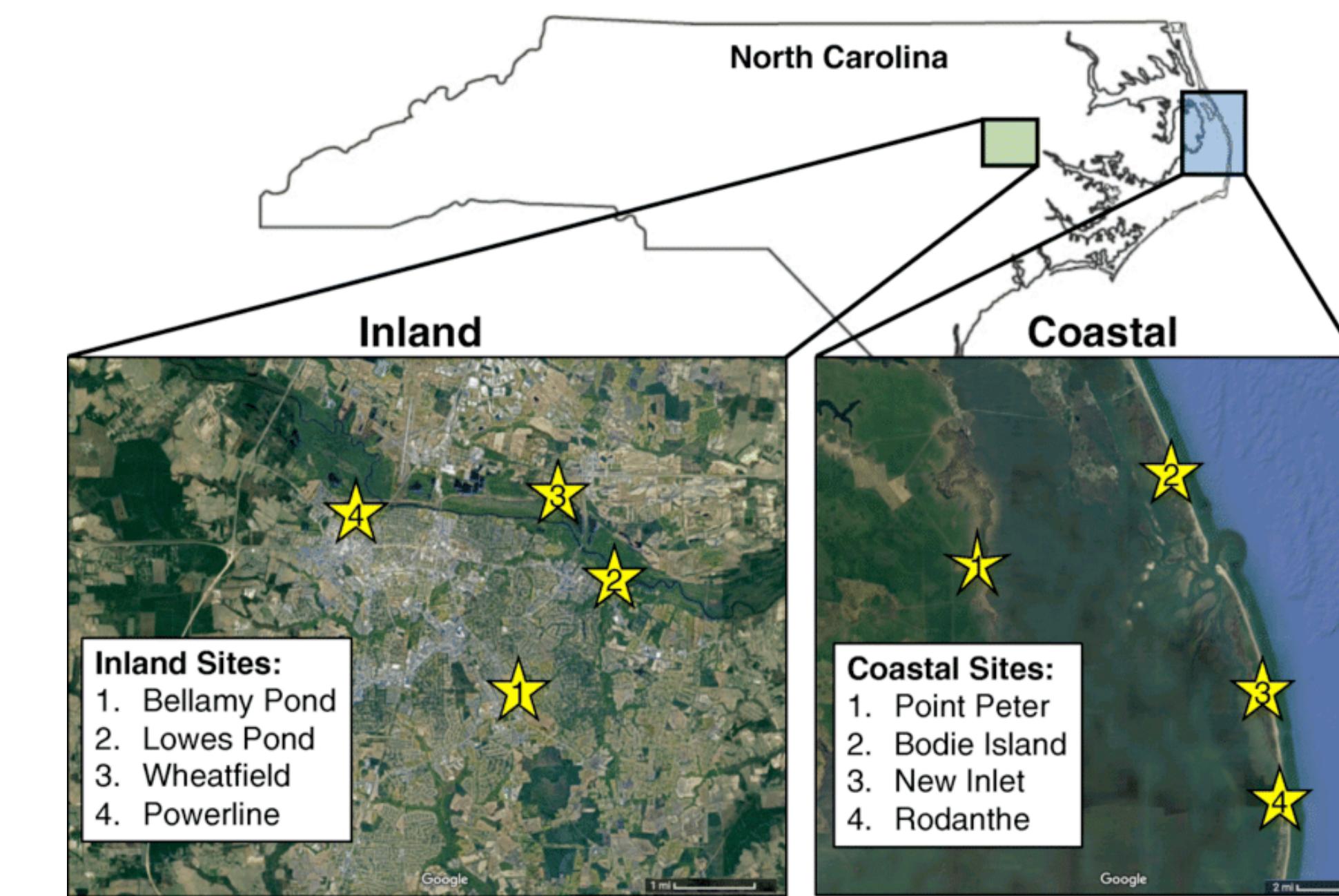


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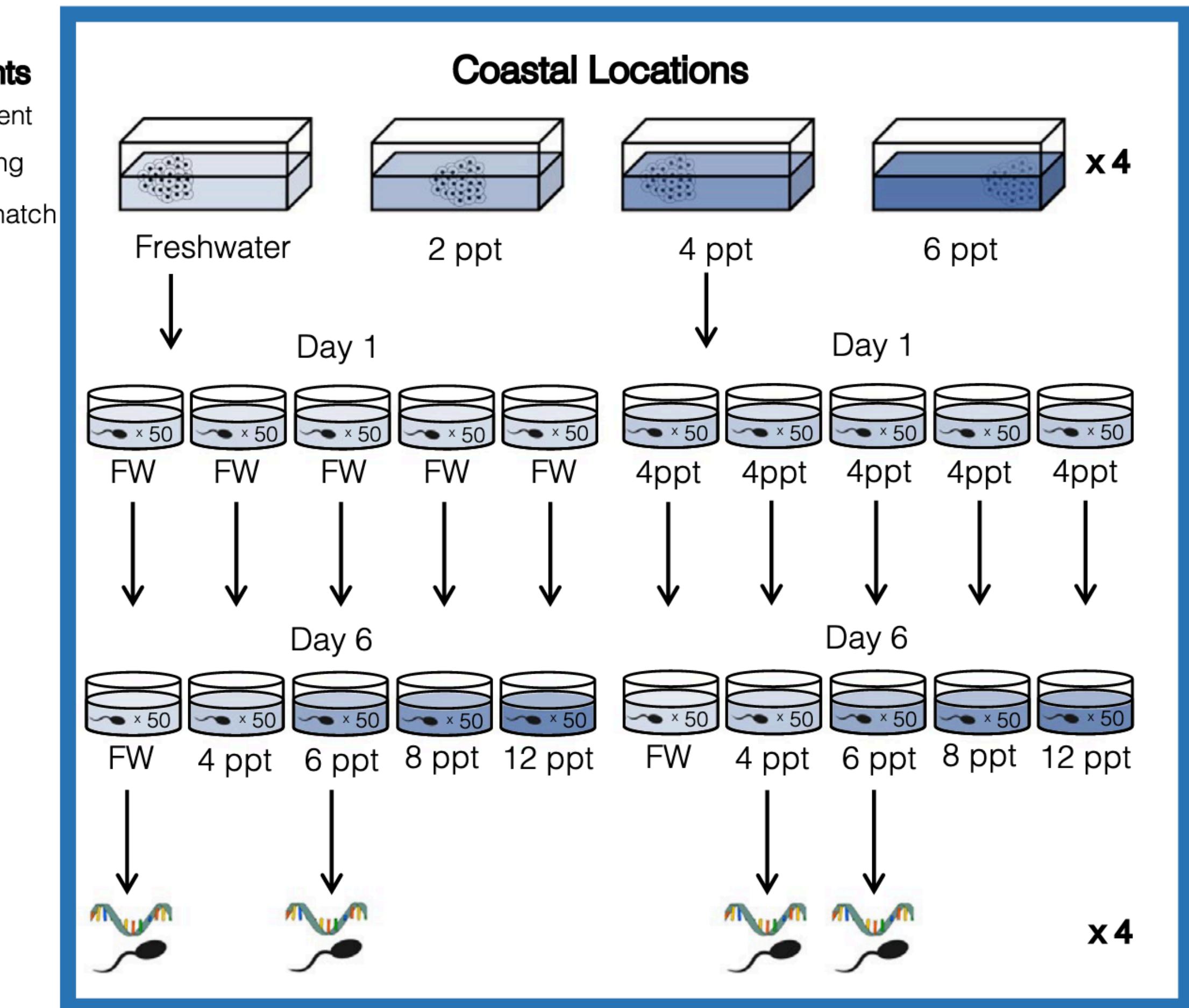
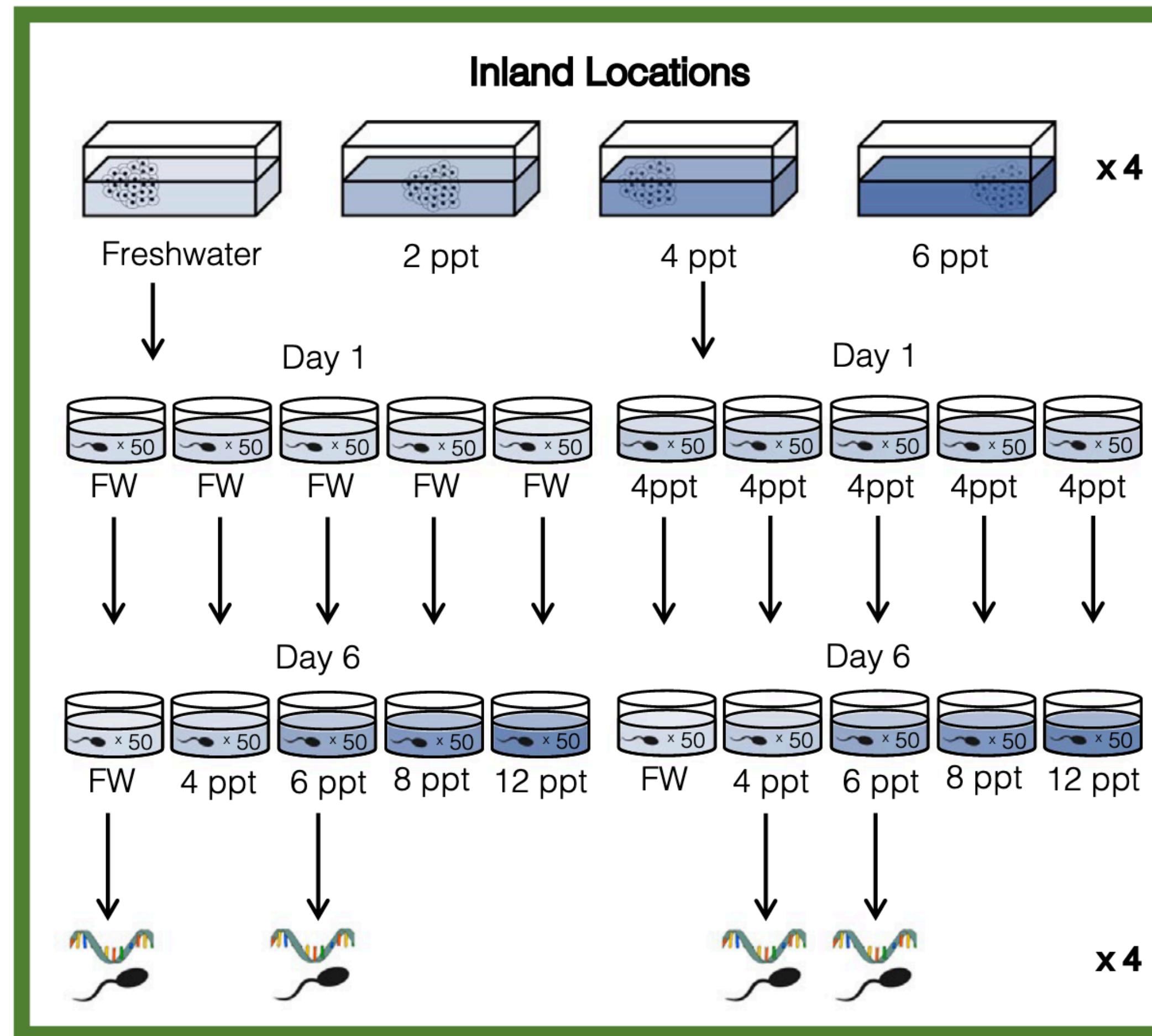
MOLECULAR ECOLOGY WILEY

## Molecular mechanisms of local adaptation for salt-tolerance in a treefrog

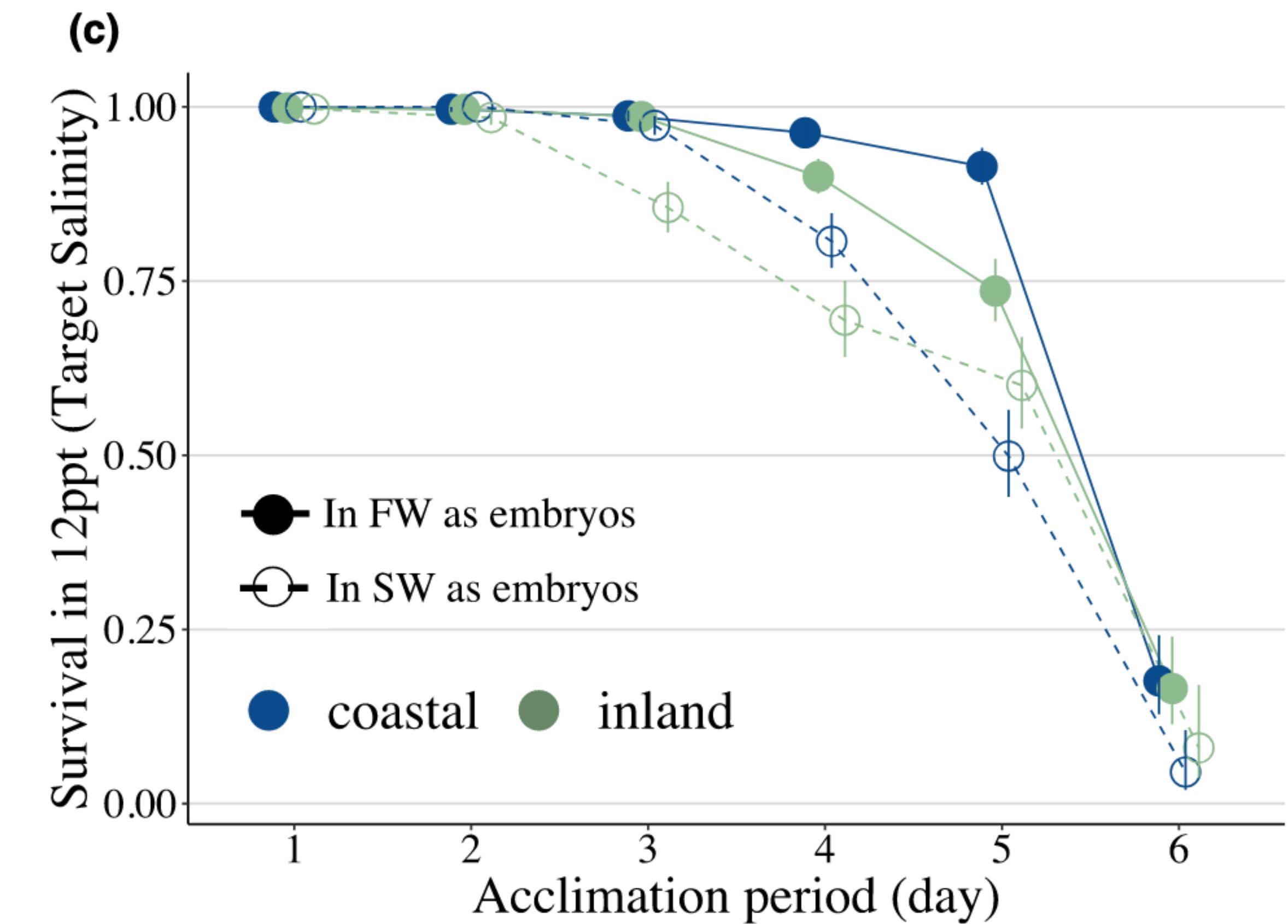
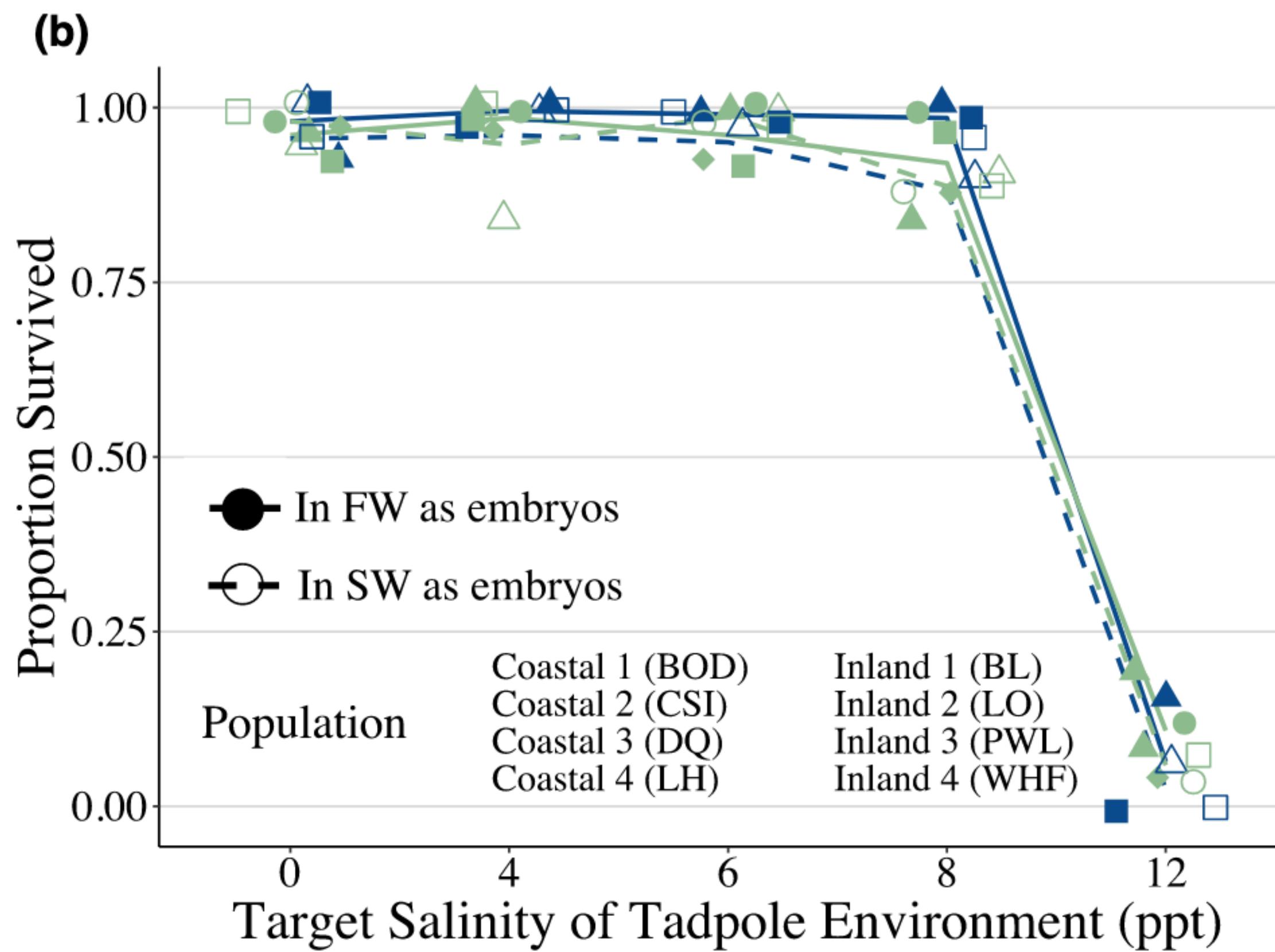
Molly A. Albecker | Adam M. M. Stuckert | Christopher N. Balakrishnan |  
Michael W. McCoy



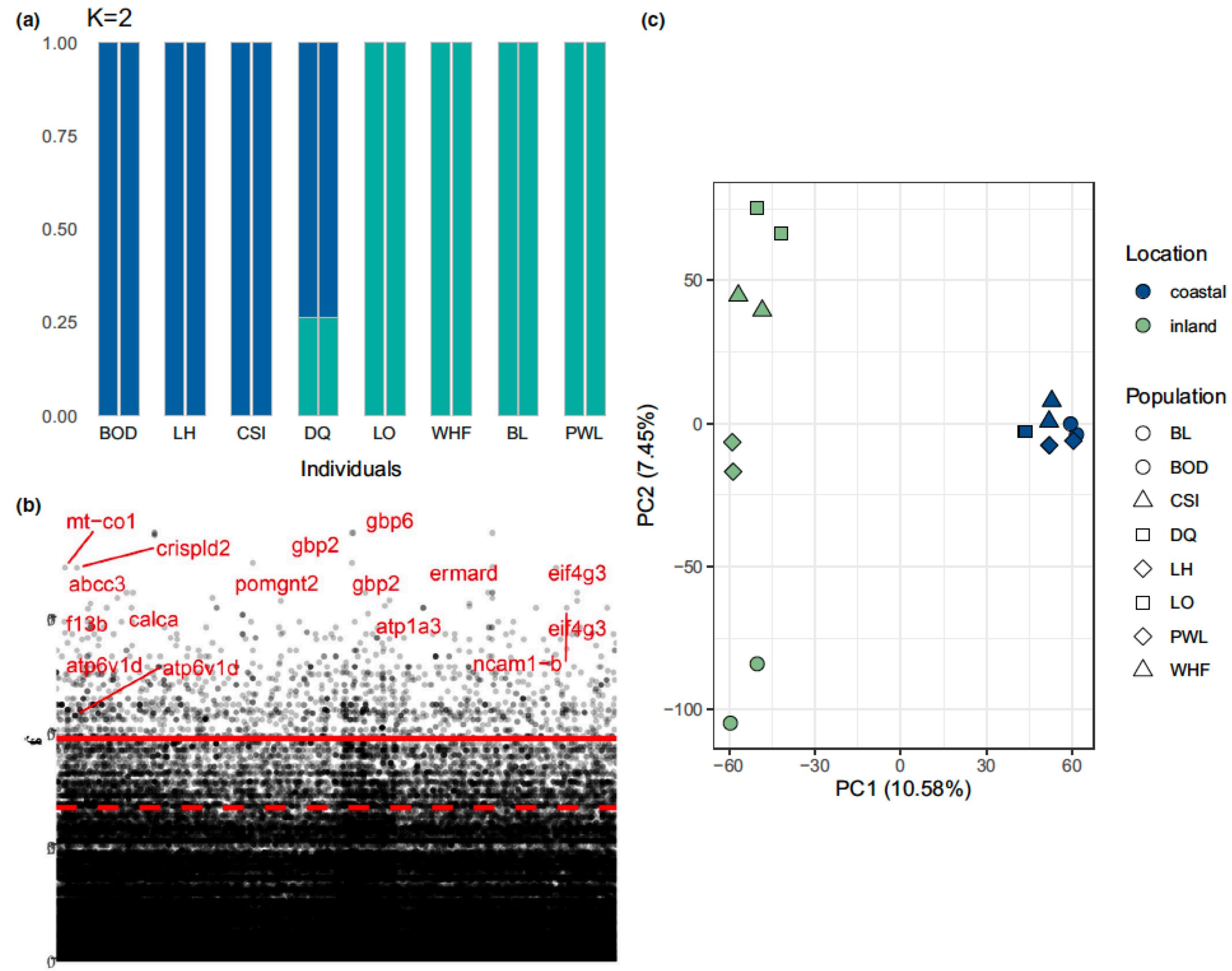
# Transcriptomics of salinity adaptation in a treefrog



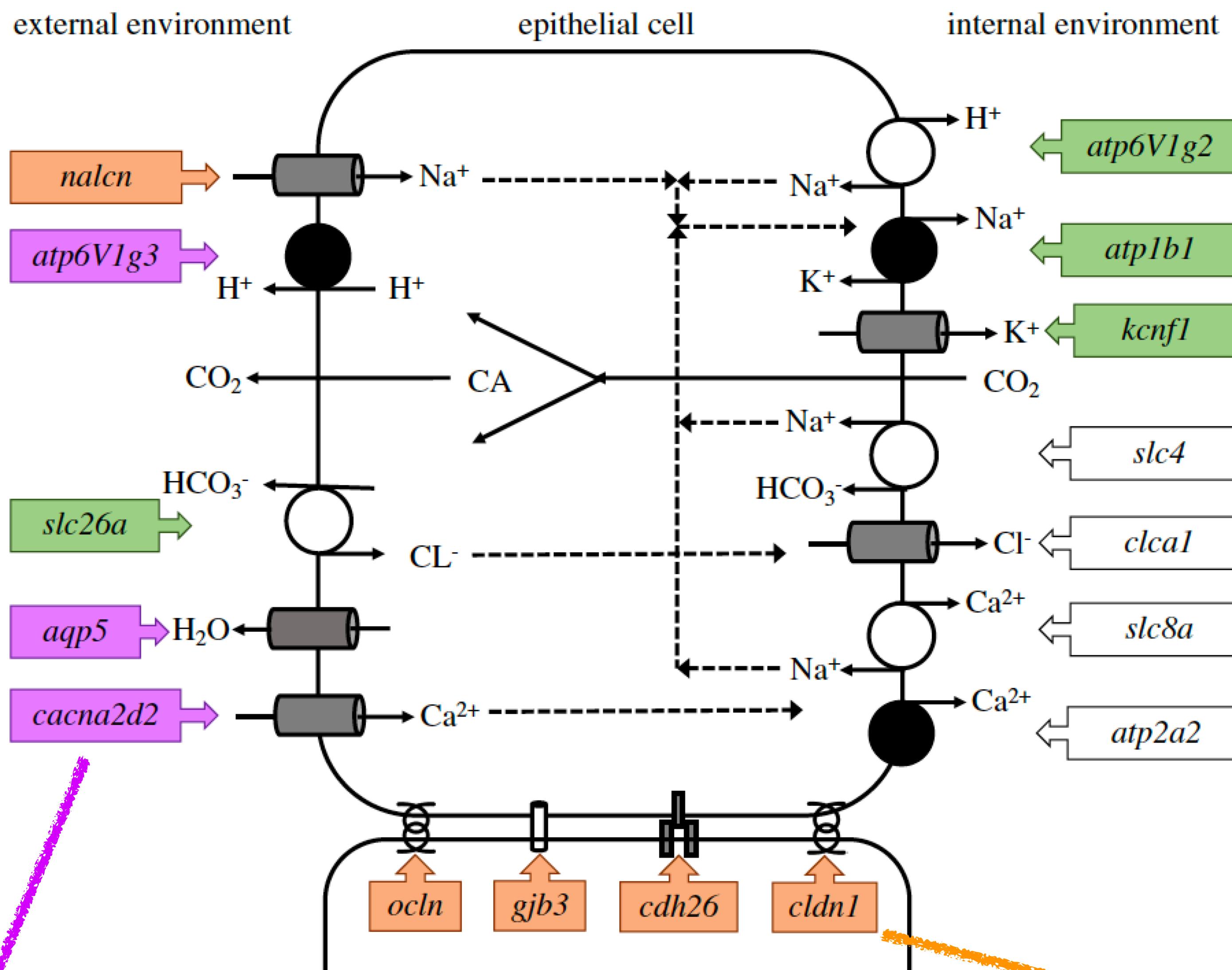
# Transcriptomics of salinity adaptation in a treefrog



# Transcriptomics of salinity adaptation in a treefrog



# Transcriptomics of salinity adaptation in a treefrog



Upregulated in coastal populations

Also gpd1:  
Glycerol as osmolyte

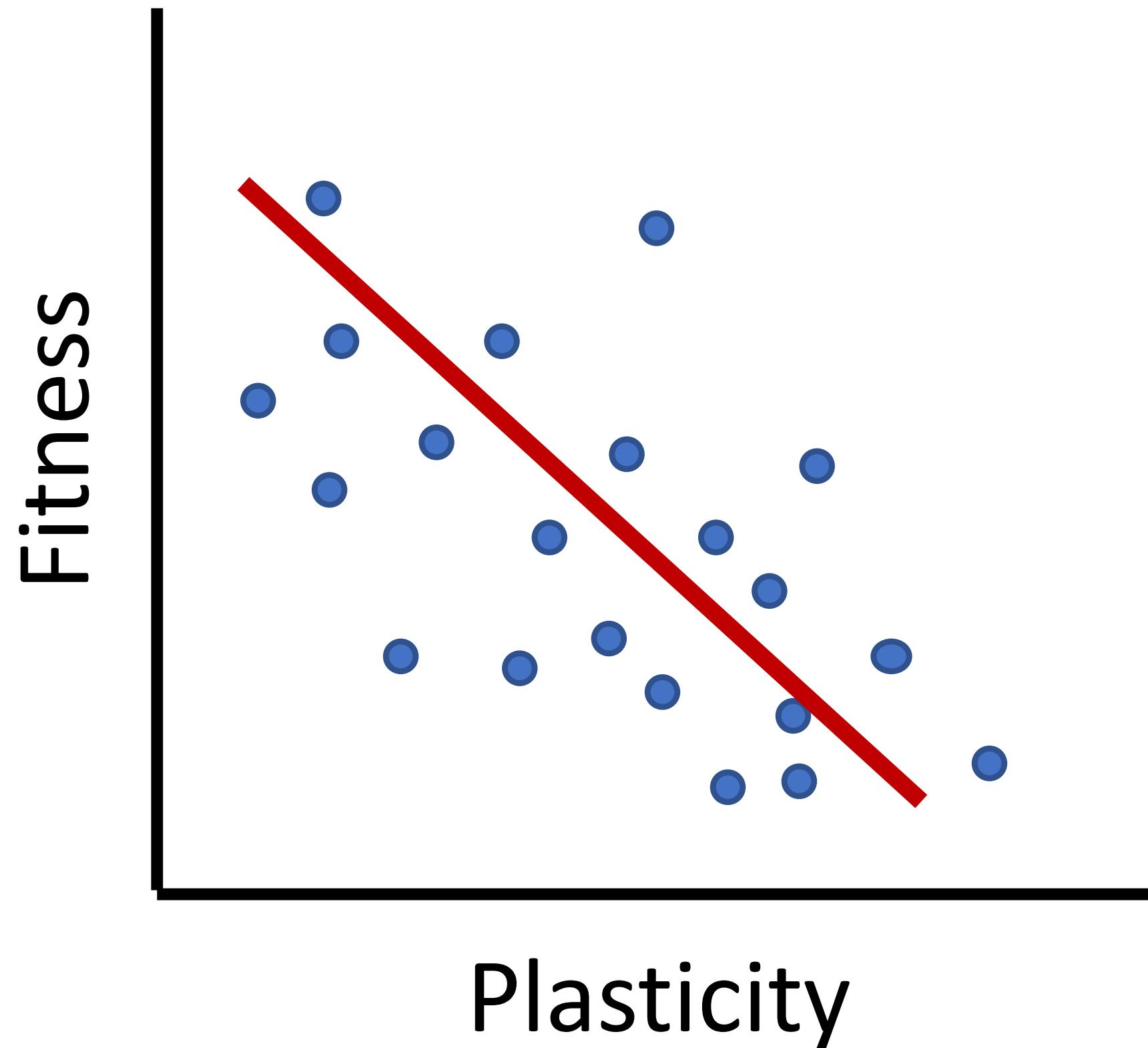
Regulated by salinity exposure

Downregulated in coastal populations in FW

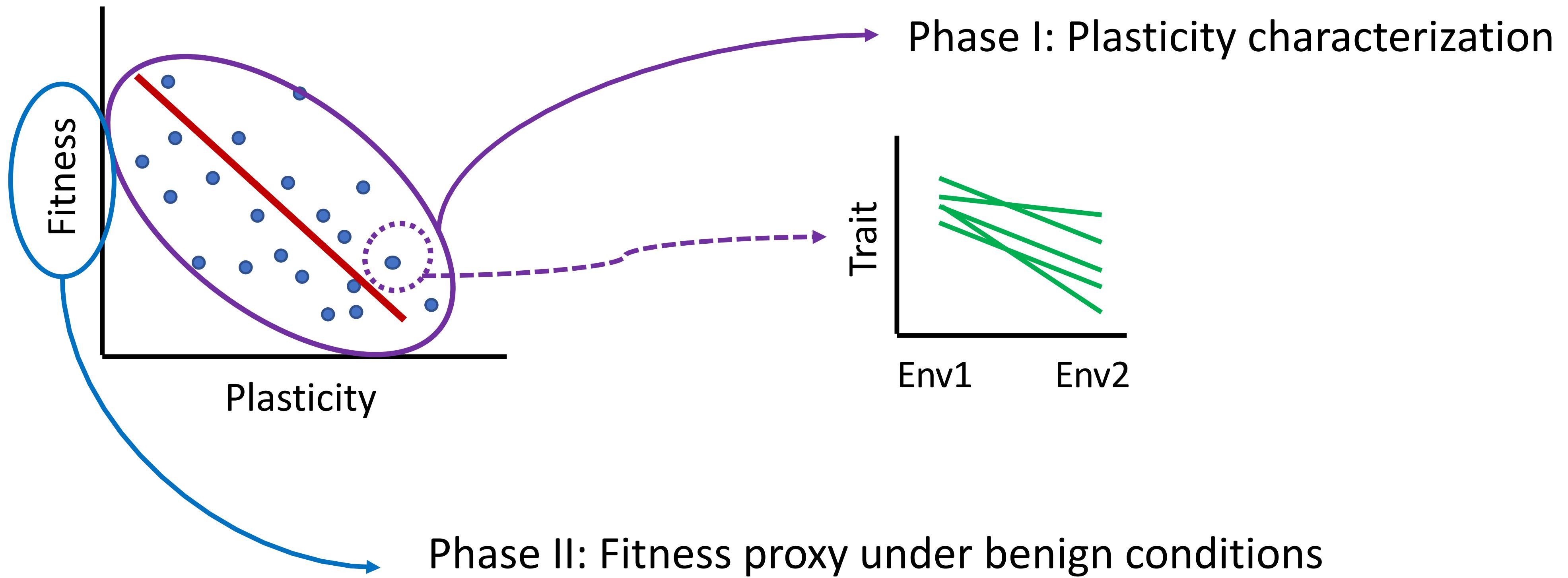
Why do we see plasticity being gained and lost at an evolutionary scale?

Is it costly????

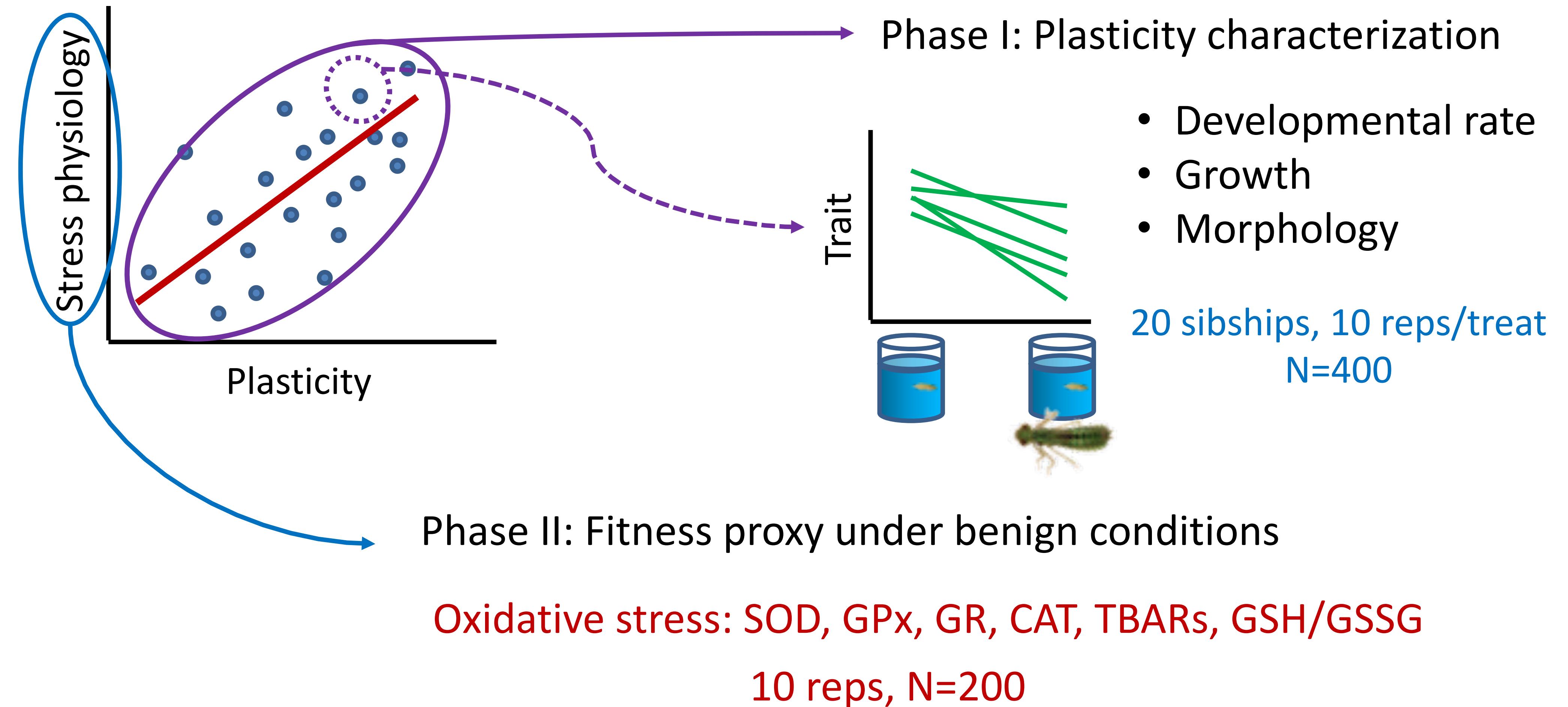
# Is adaptive plasticity costly?



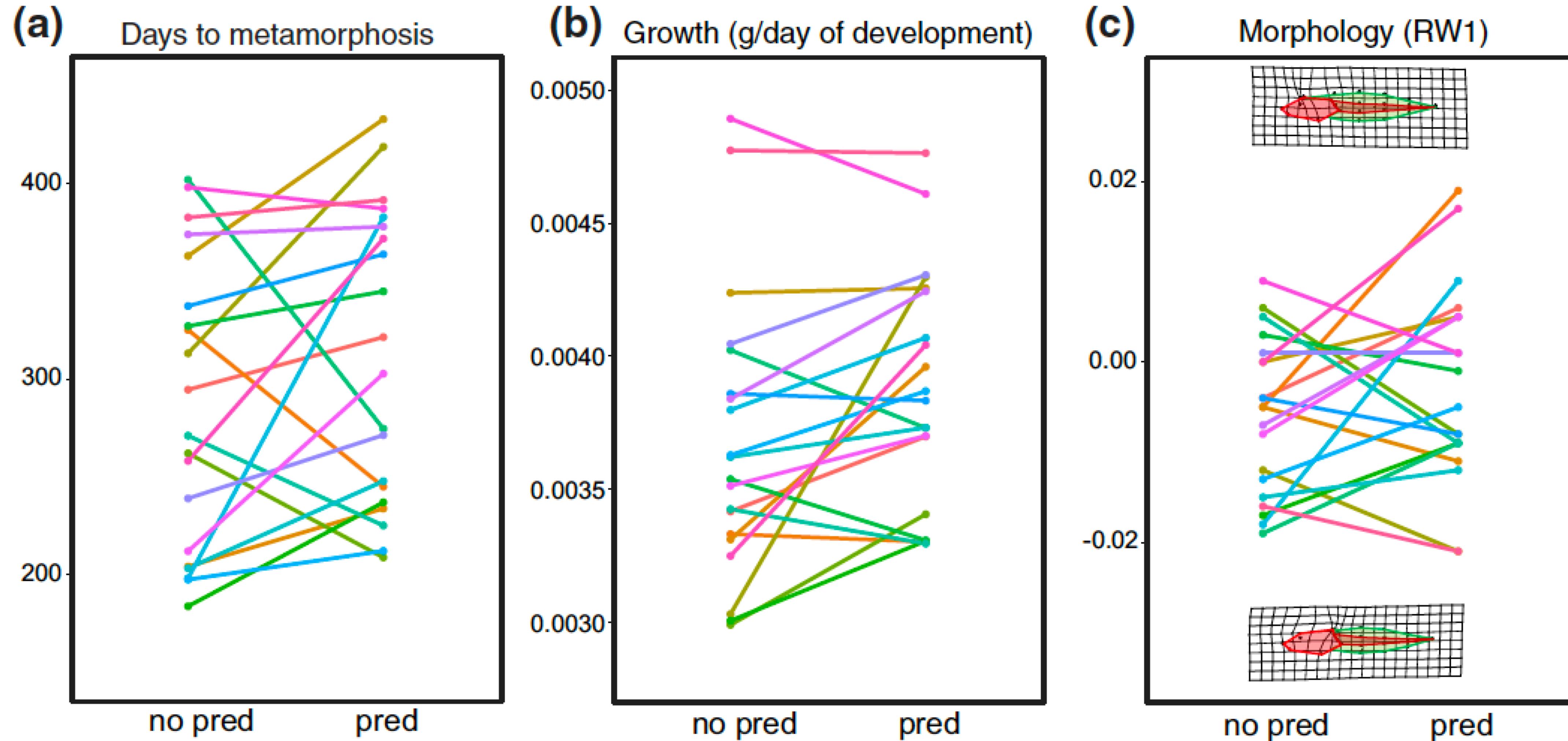
# Is adaptive plasticity costly?



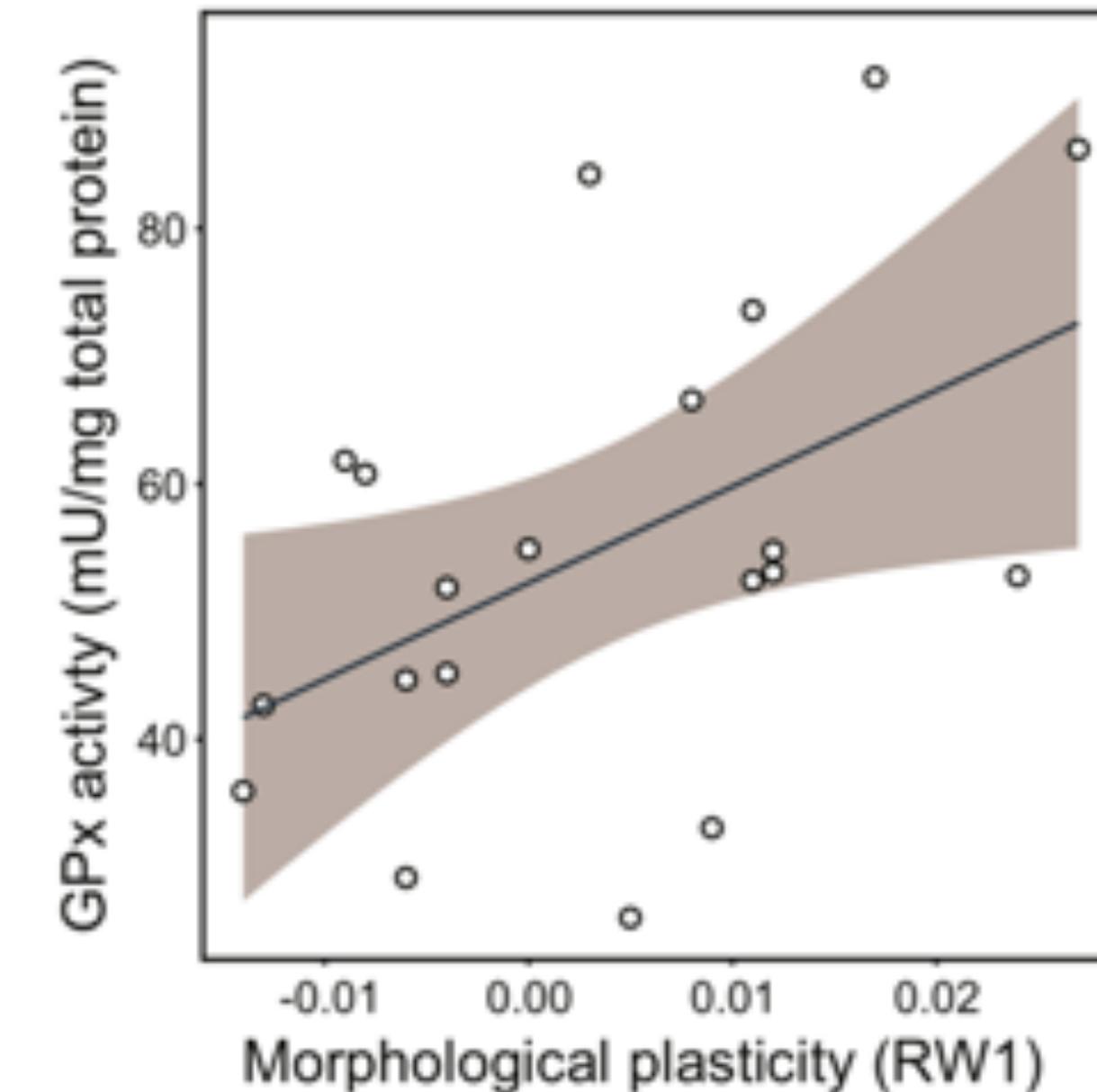
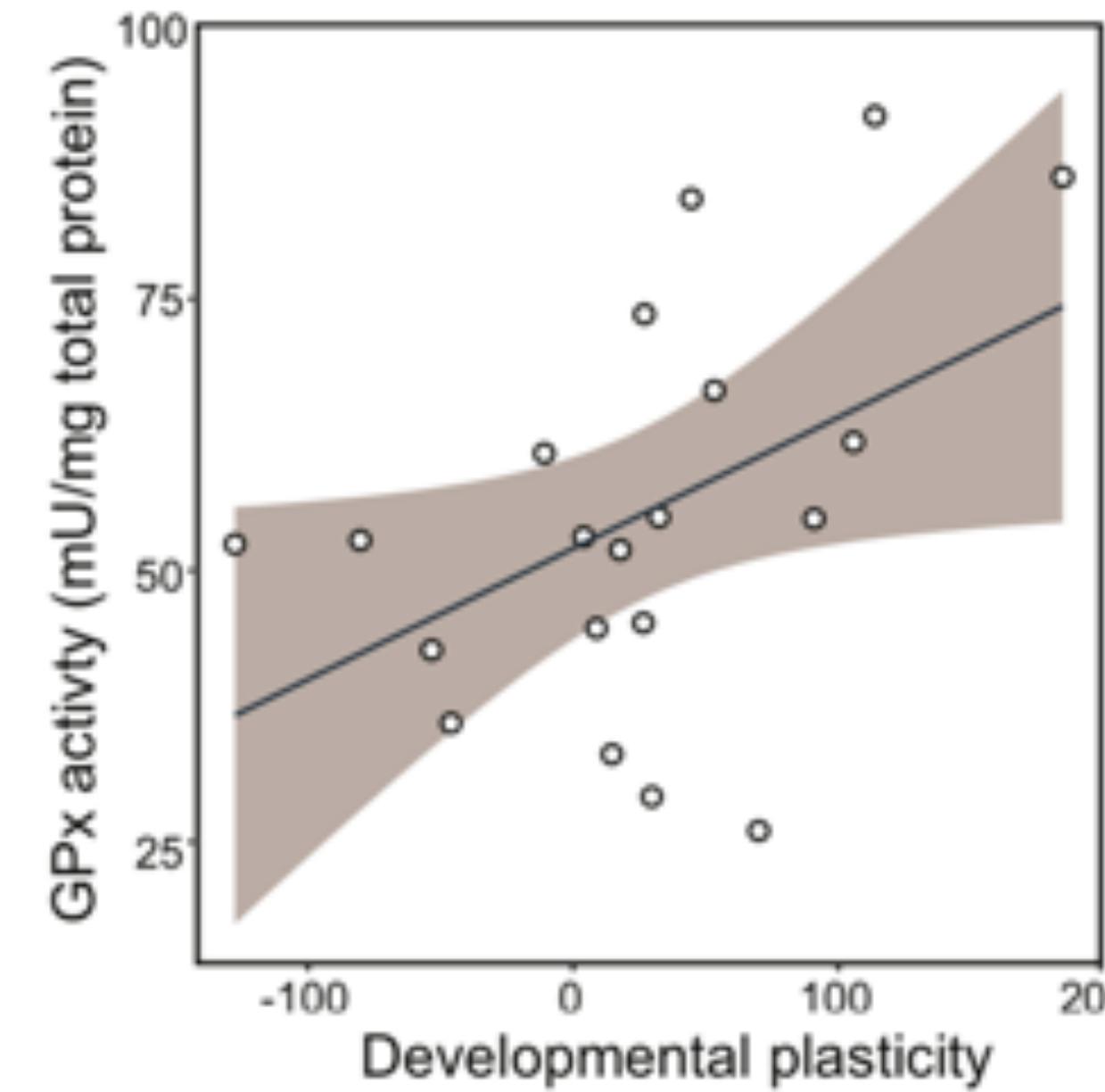
# Is adaptive plasticity costly?



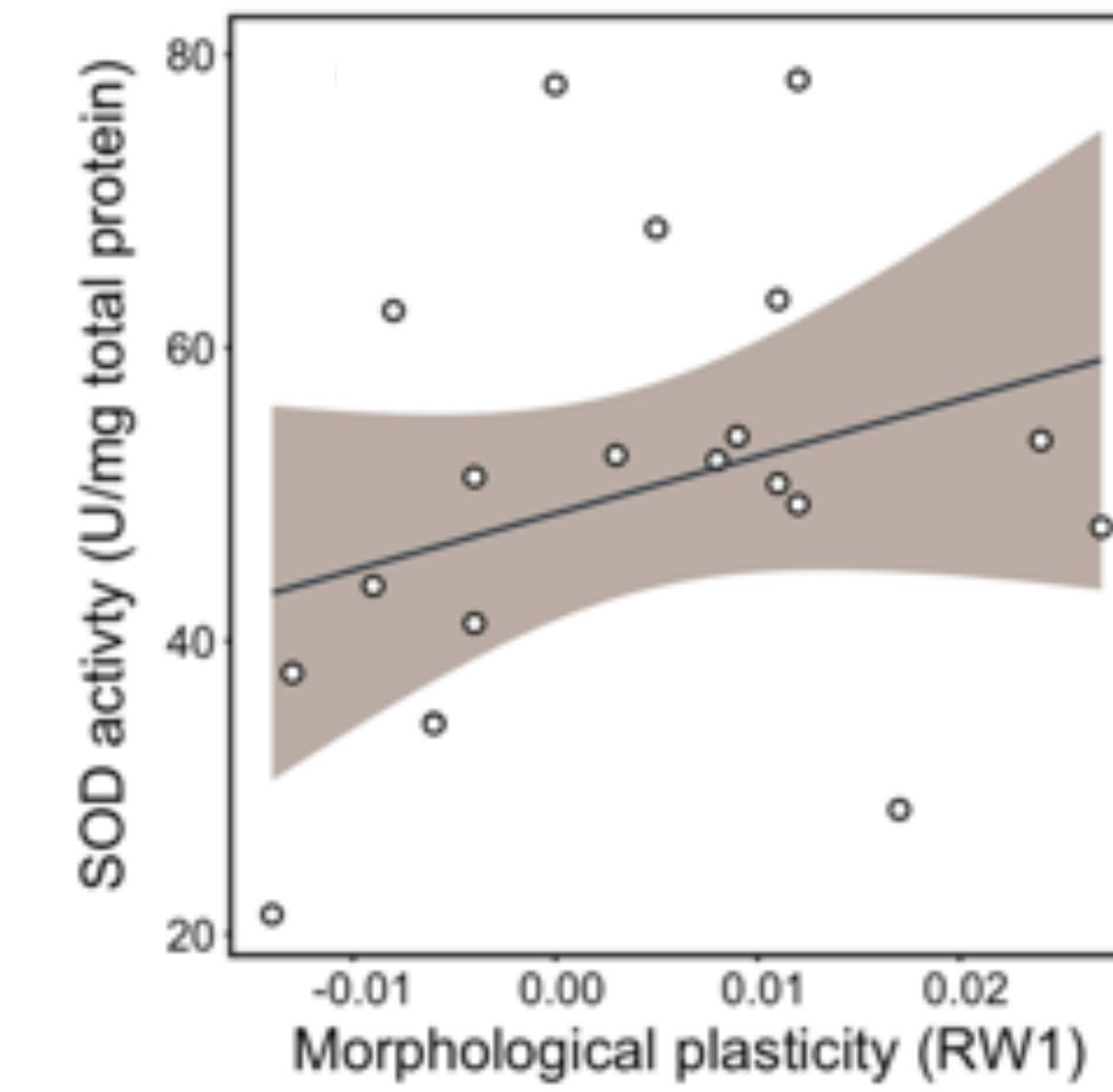
# Is adaptive plasticity costly?



# Is adaptive plasticity costly?



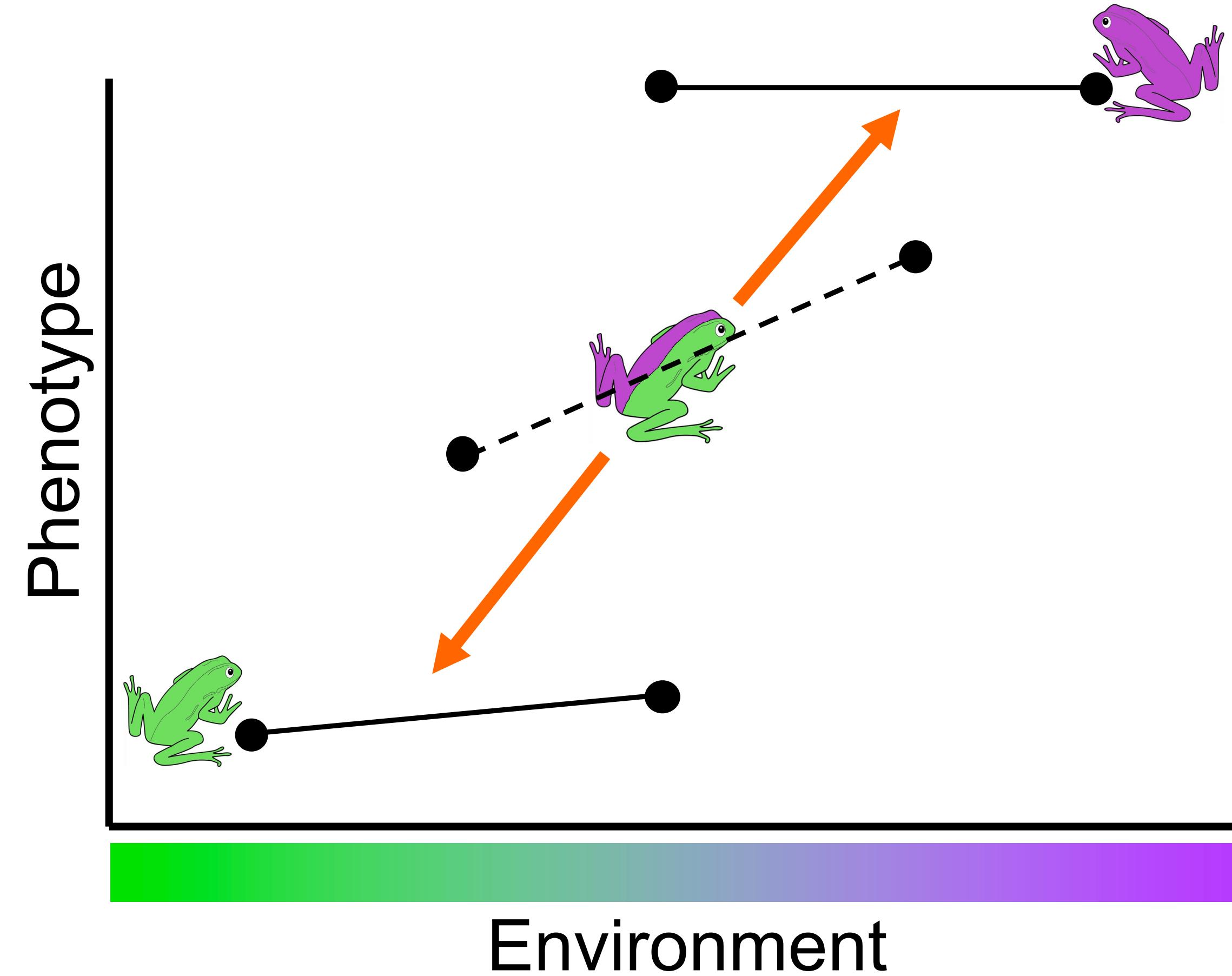
Genotypes with greater plasticity  
incur higher oxidative stress



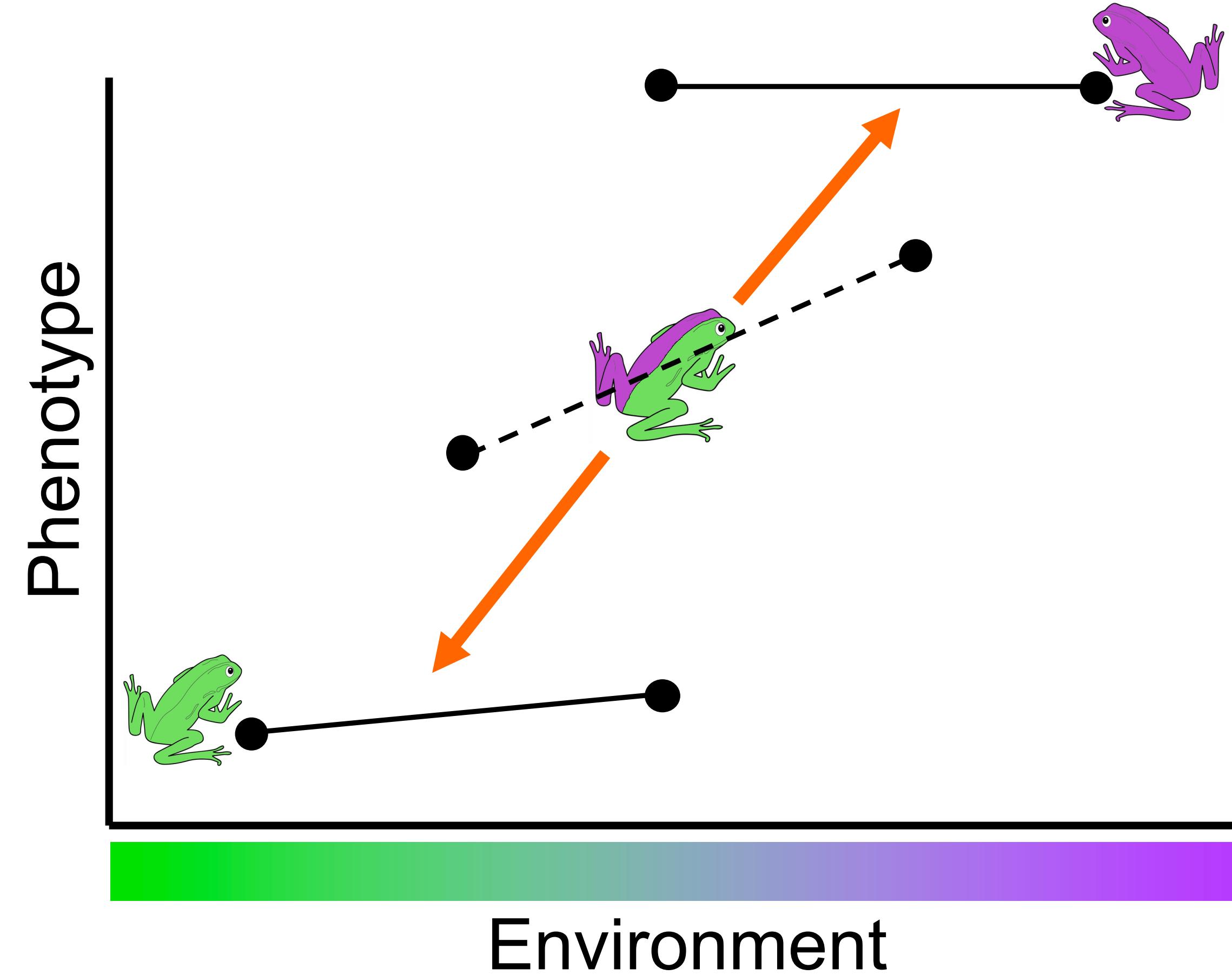
Ok, organisms alter their gene expression in response to environmental changes...

so what?

# Ancestral plasticity can diverge under selection into constitutive differences



# Ancestral plasticity can diverge under selection into constitutive differences: Genetic accommodation



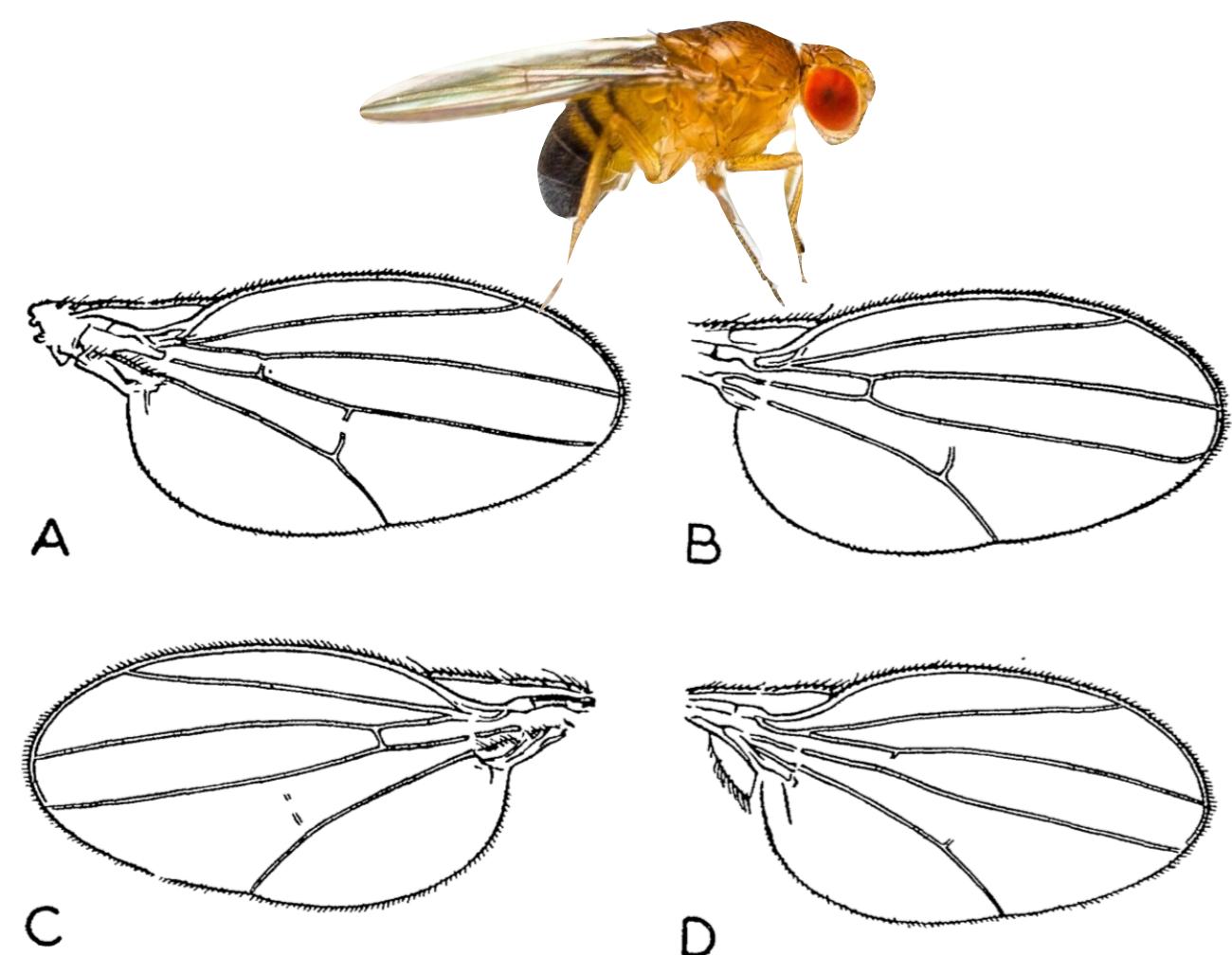
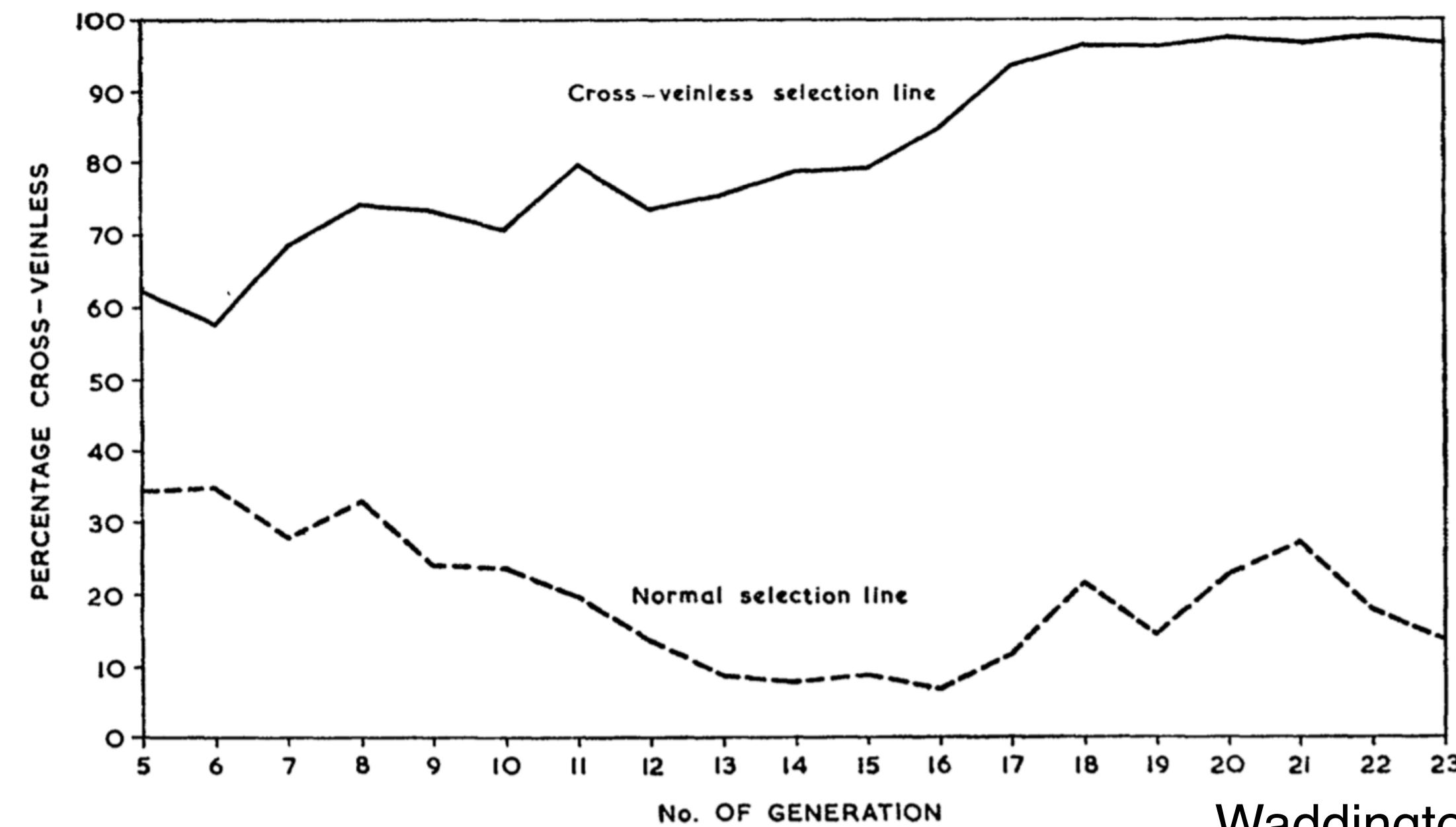
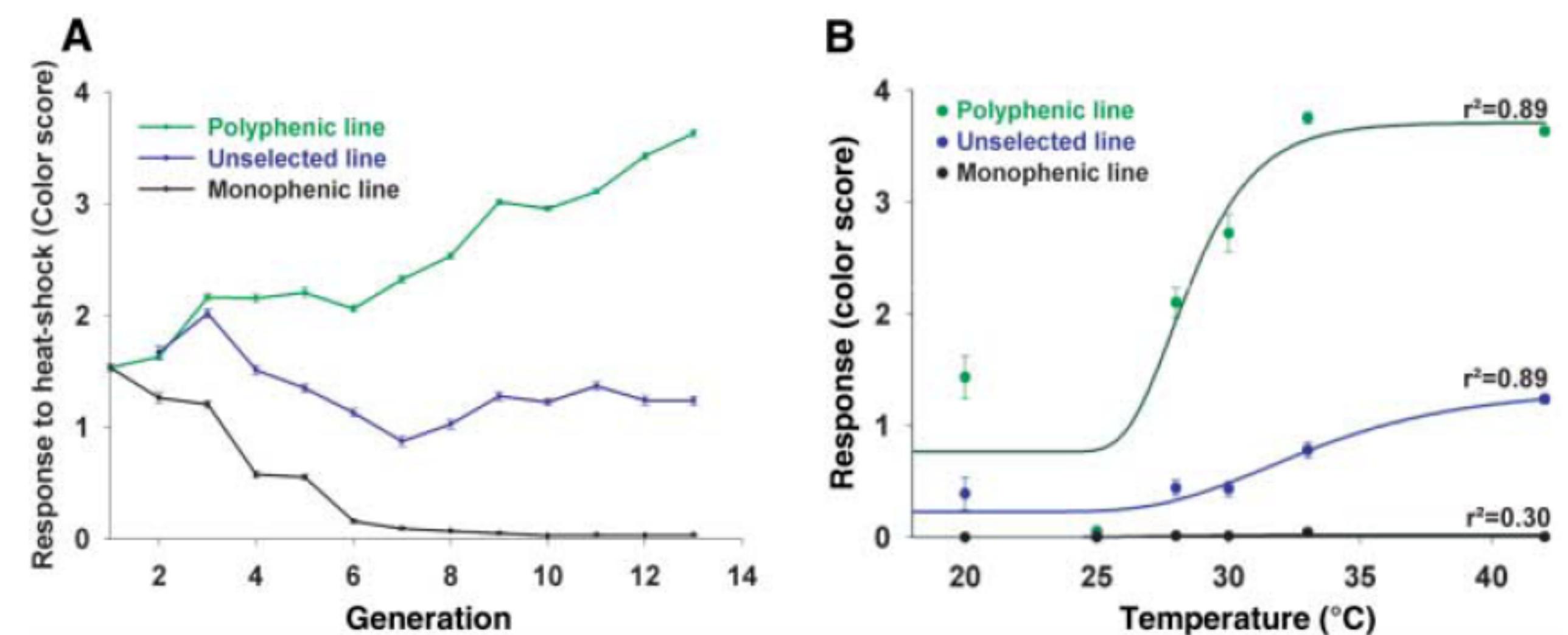


FIG. 1. Four crossveinless wings: *a* grade 4, *b* grade 3, *c* grade 2, *d* grade 1.

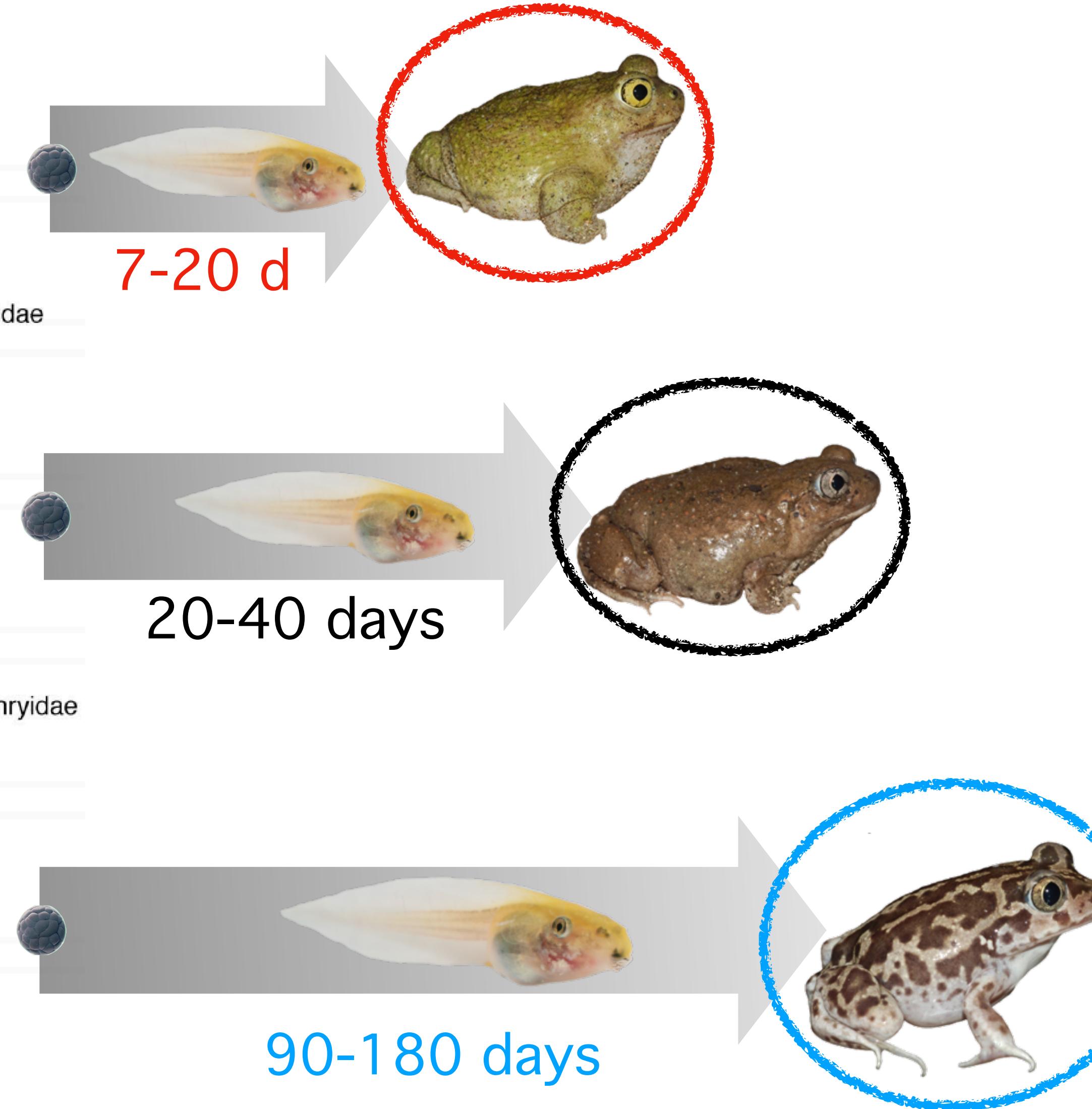
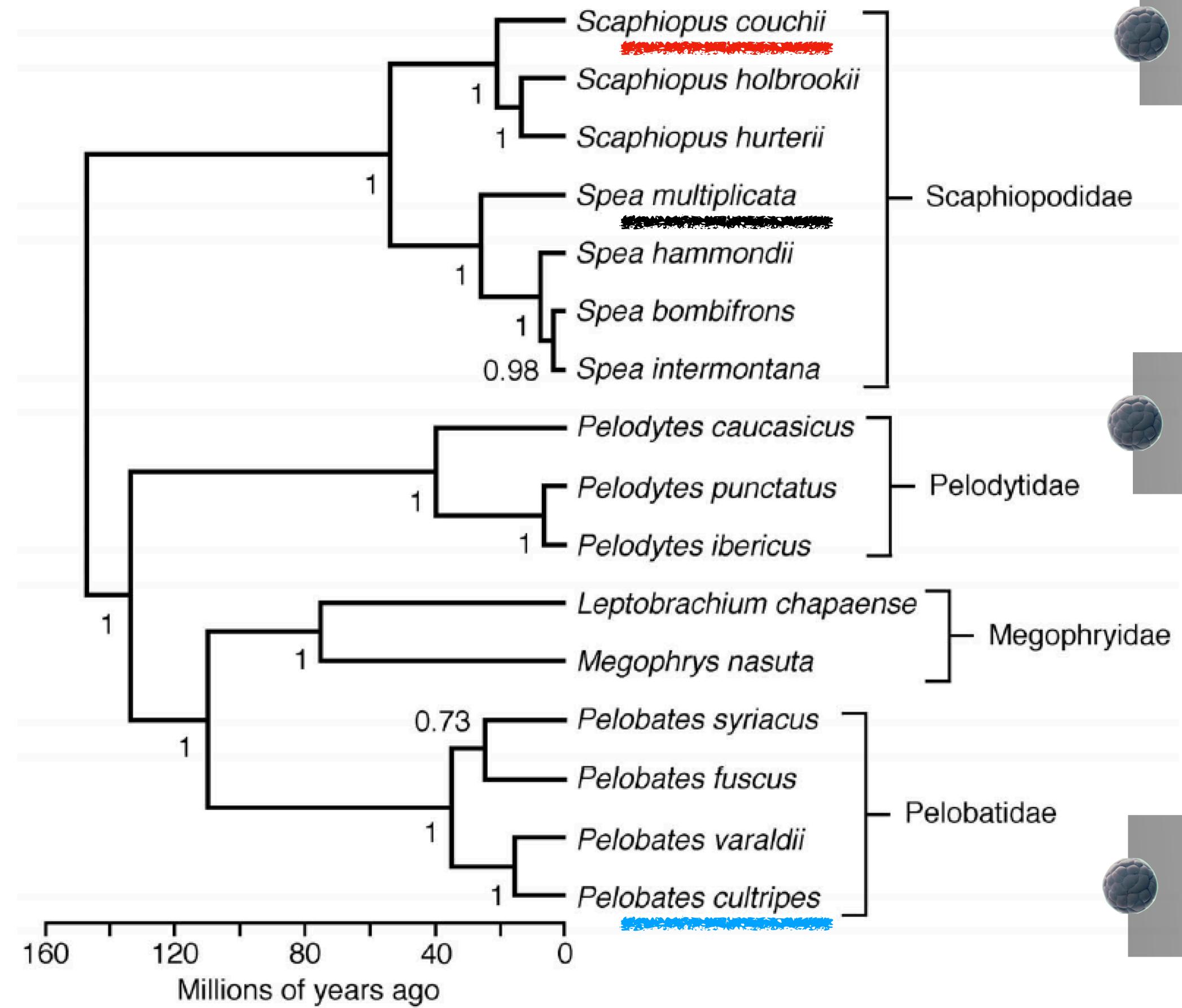


Waddington 1953 Evolution

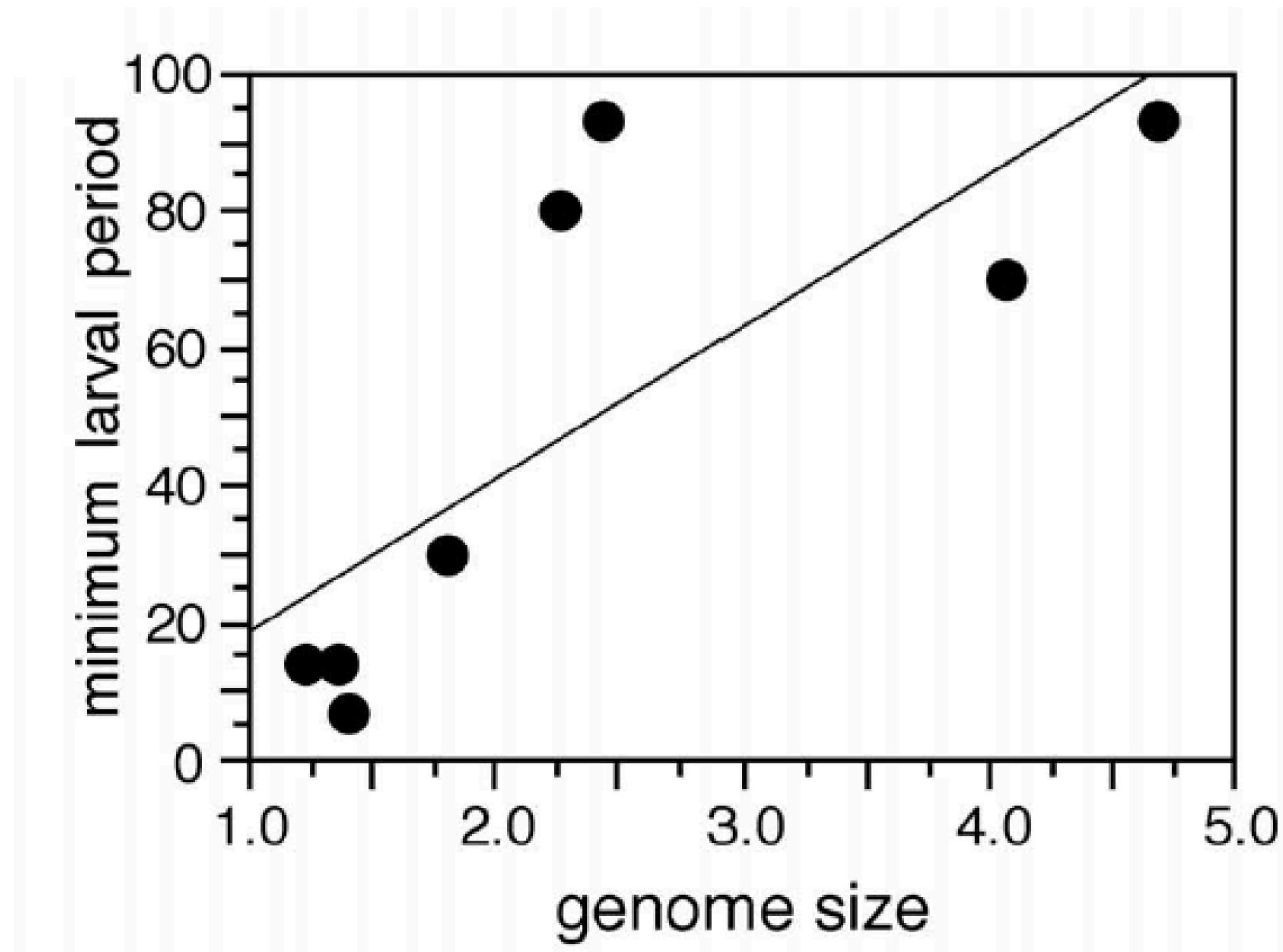
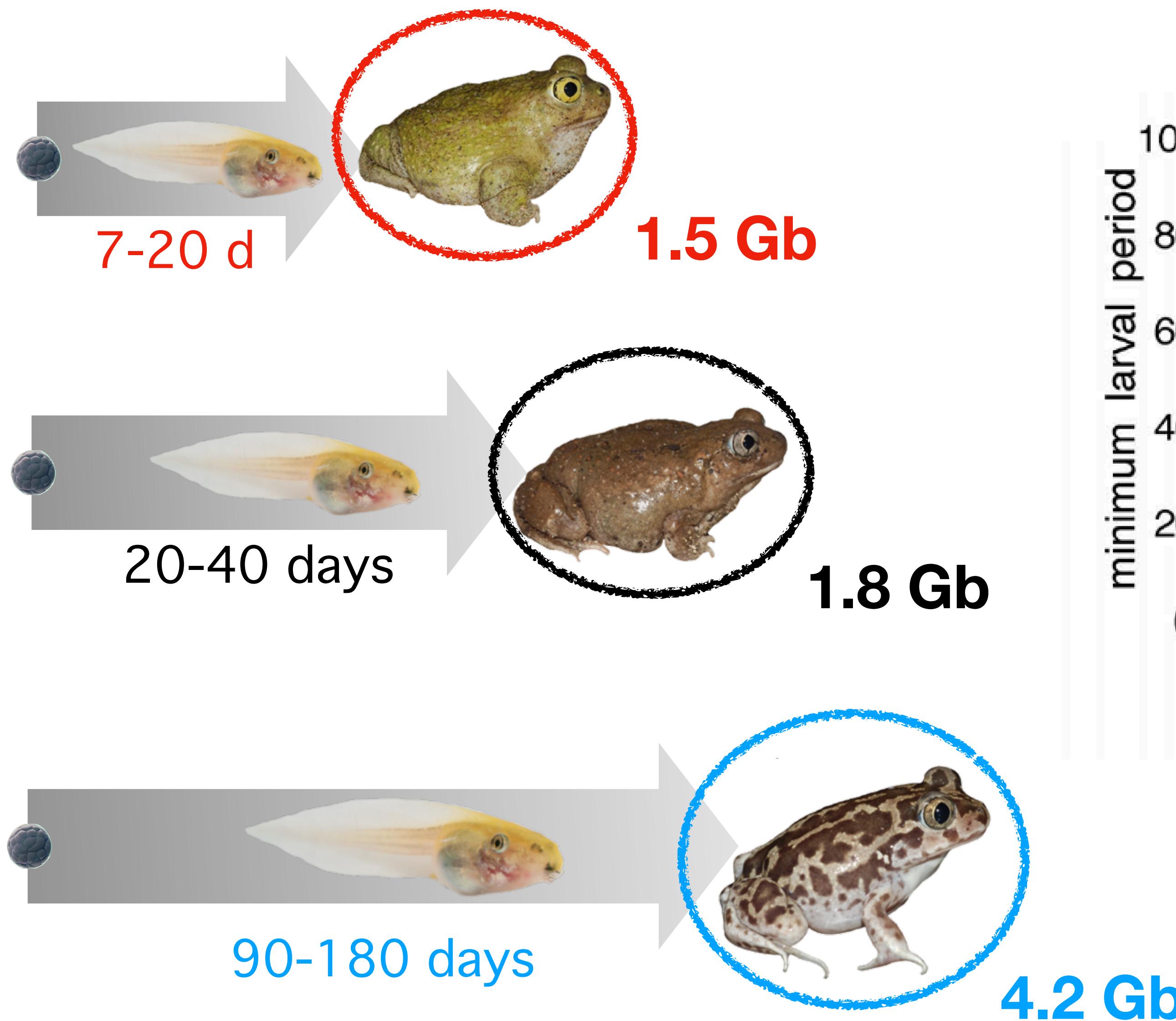


Suzuki & Nijhout 2006 Science

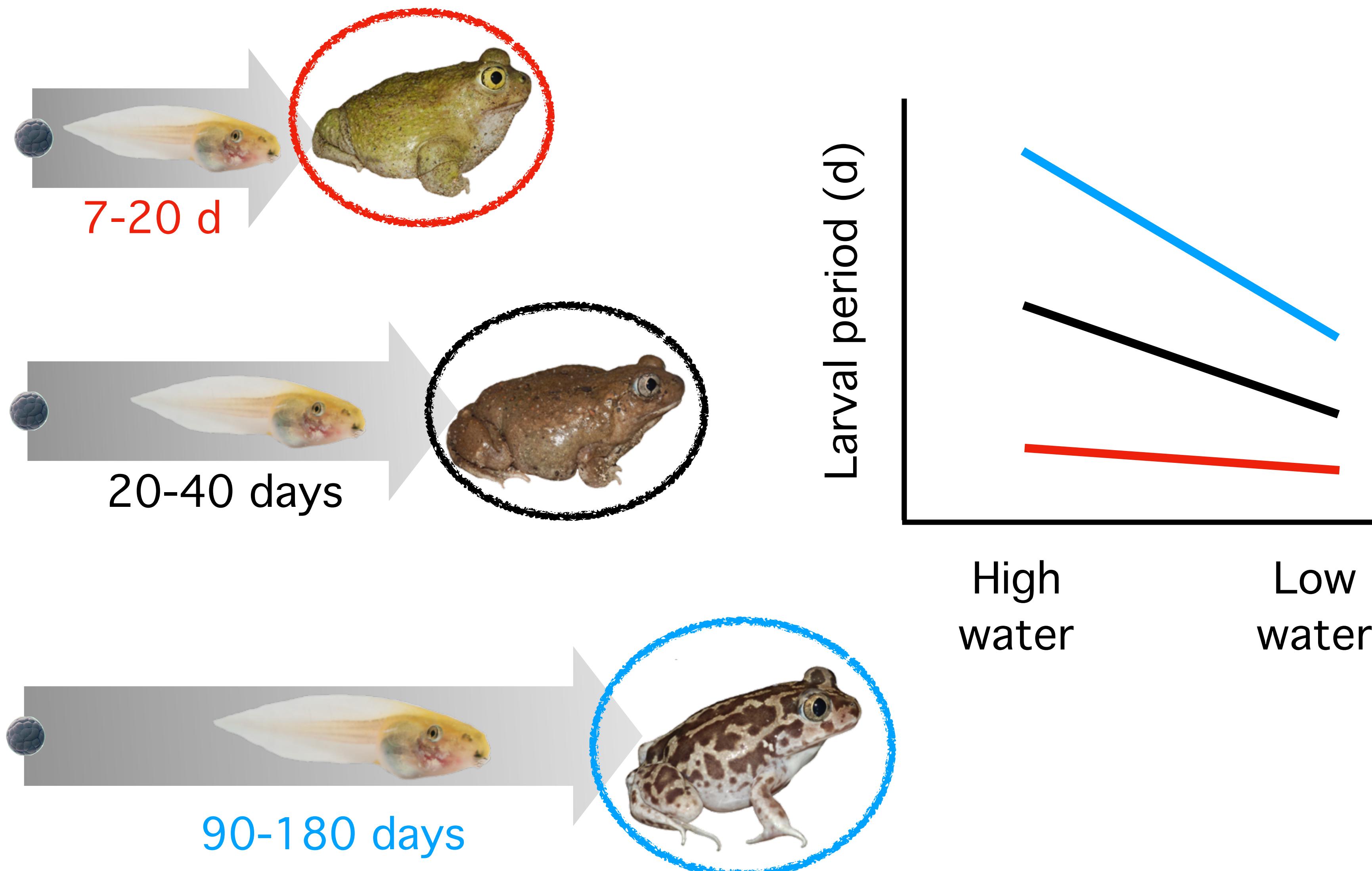
# Evolutionary divergence in developmental rate - Spadefoot toads



# Larval period is positively associated with genome size

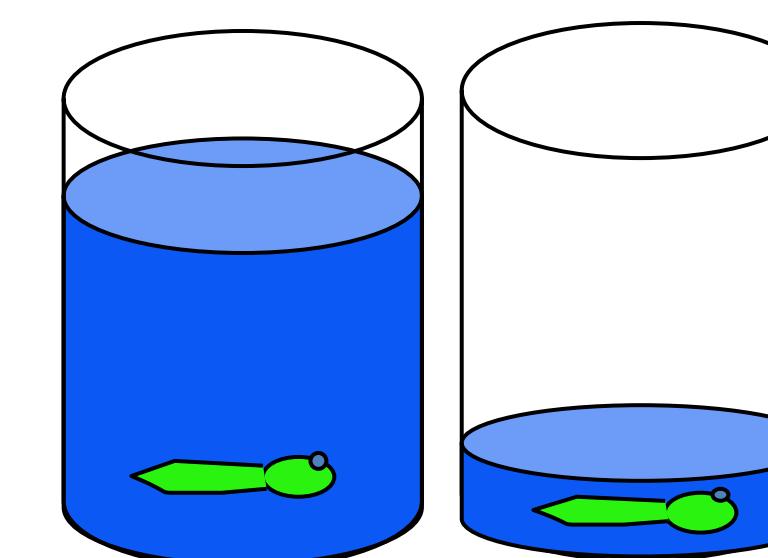
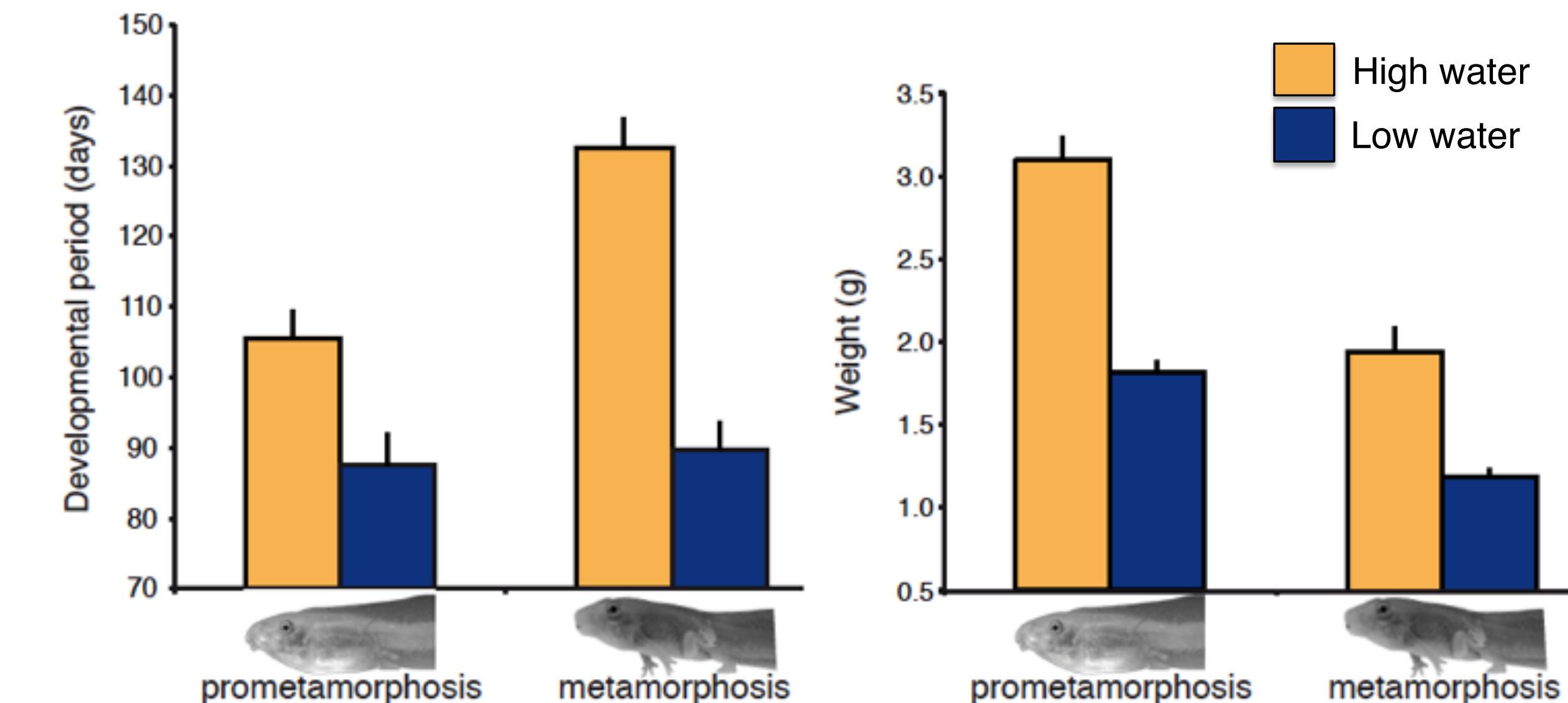
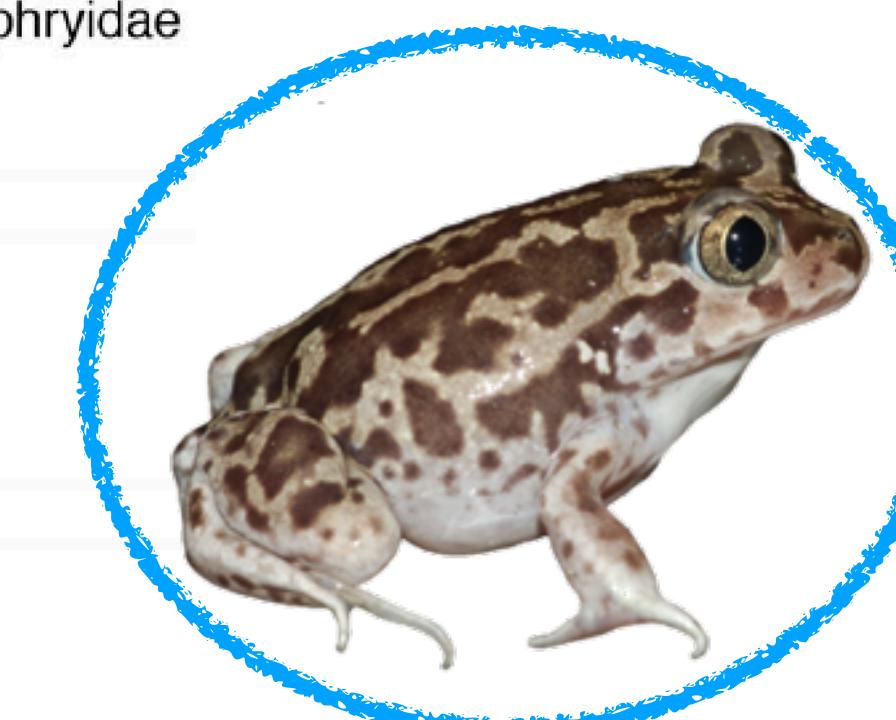
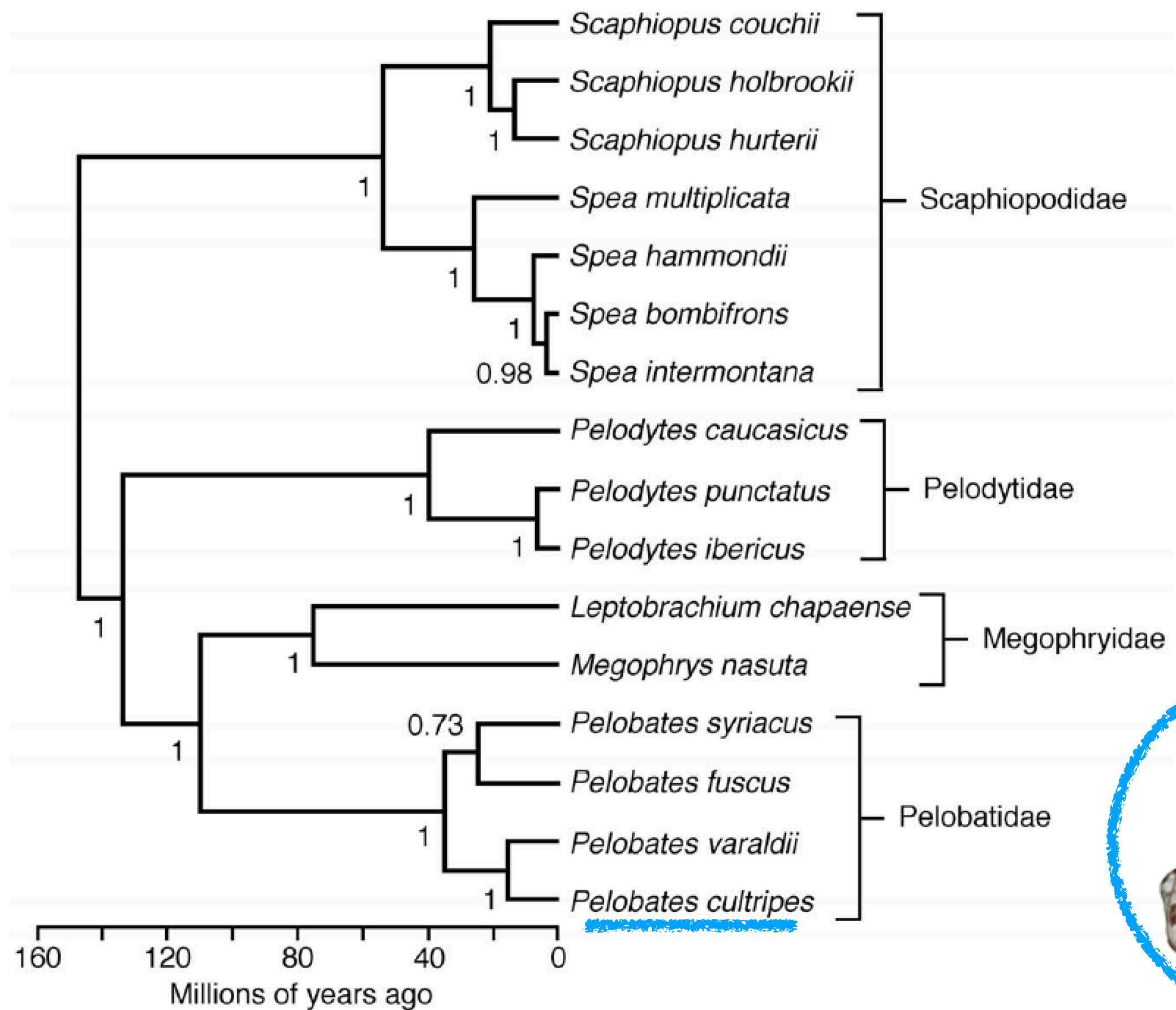


# Species have evolved different degrees of developmental plasticity

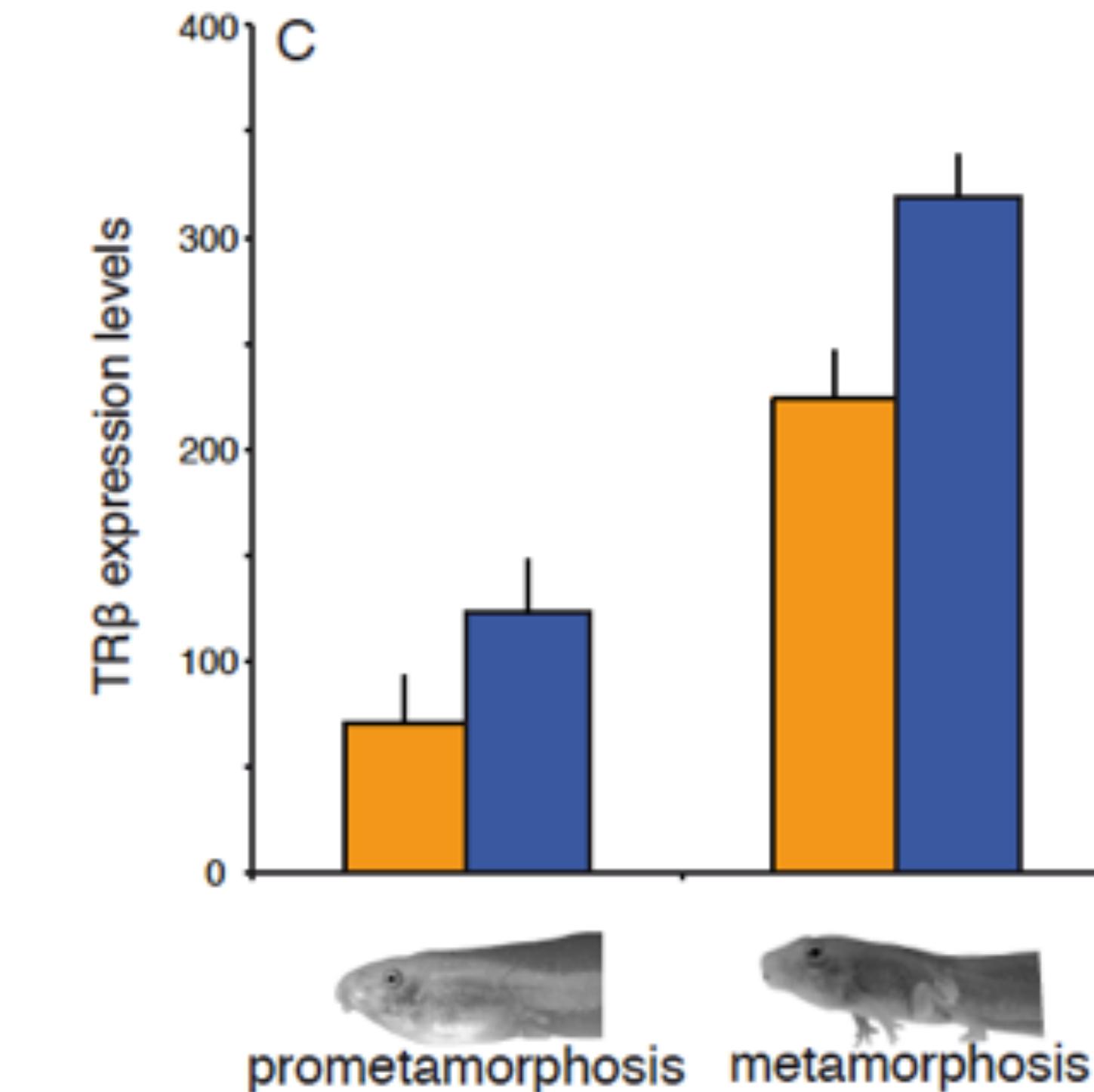
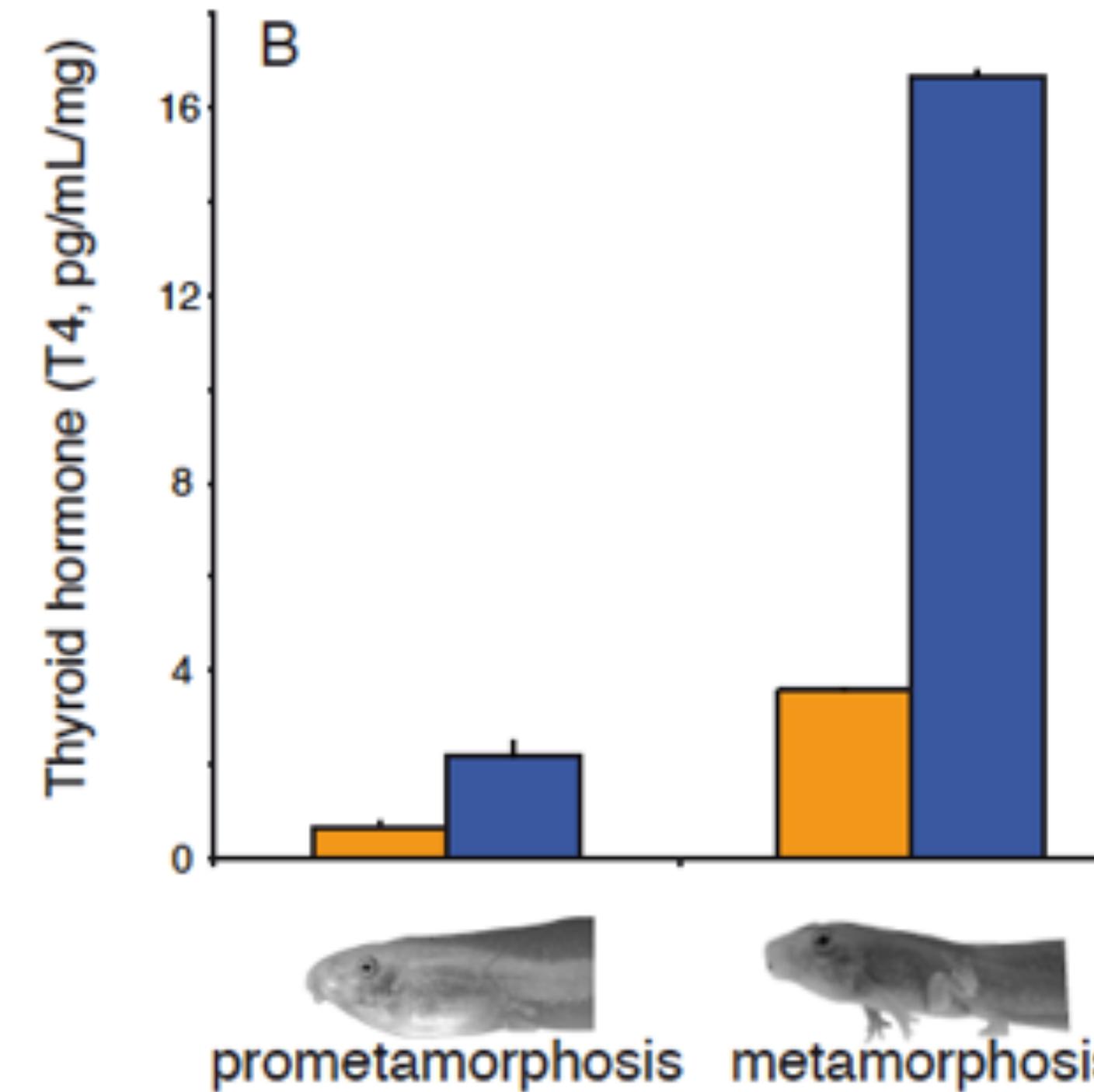
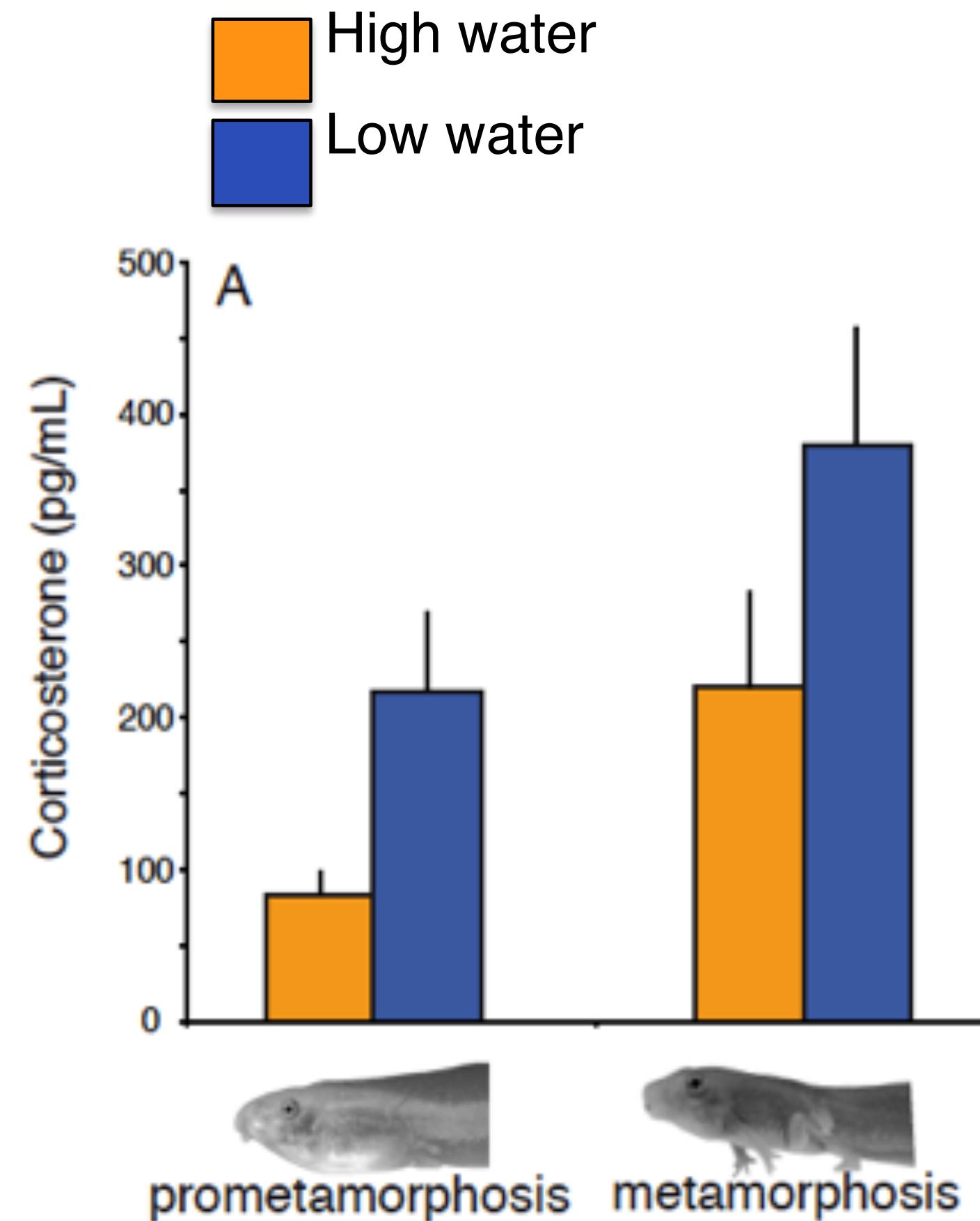


Gomez-Mestre & Buchholz PNAS 2006  
Kulkarni et al. J Evol Biol 2011

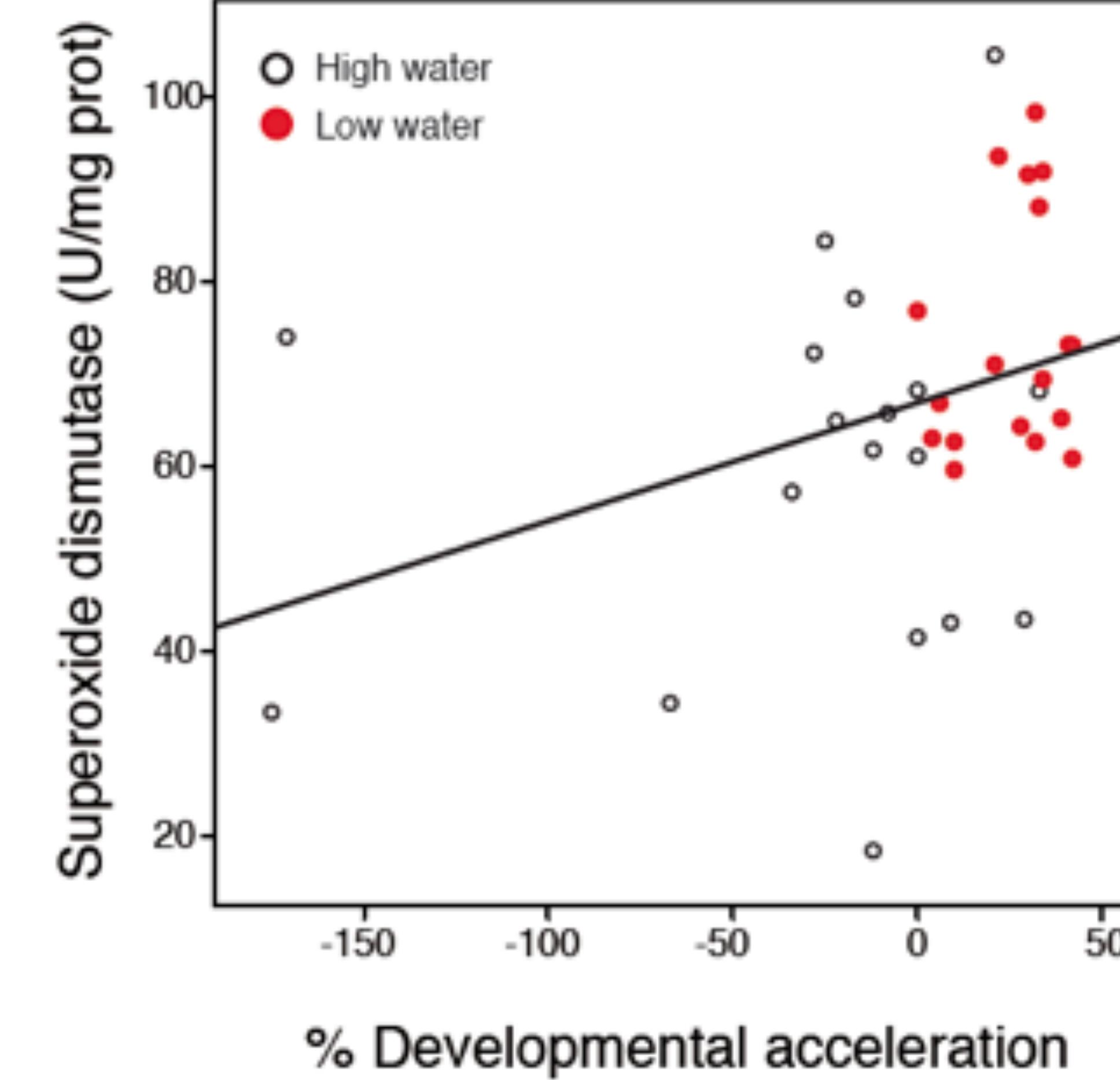
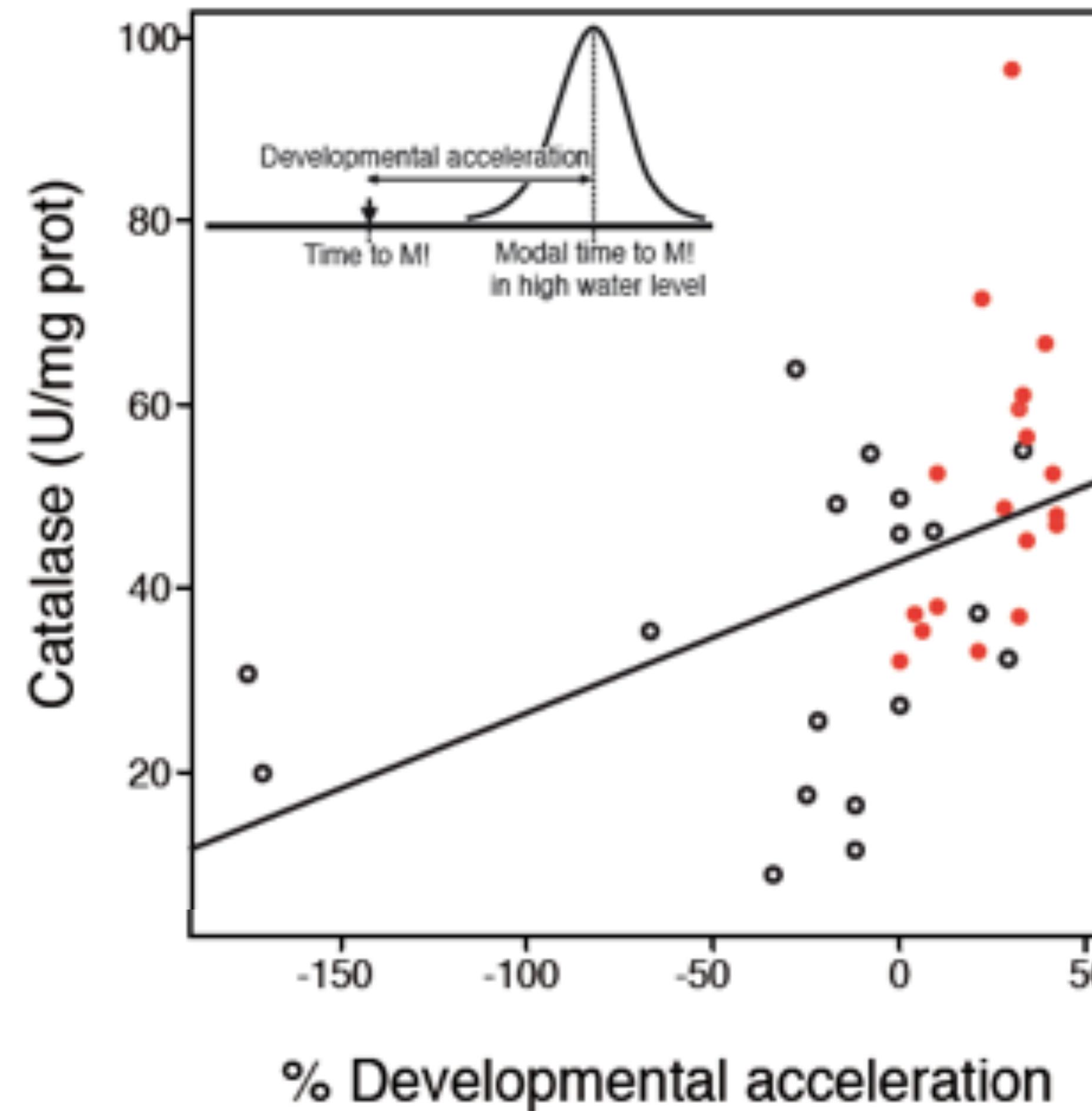
# Pelobates can accelerate >30% when at risk of pond drying



# Pelobates accelerates by increasing CORT, TH, and TR $\beta$



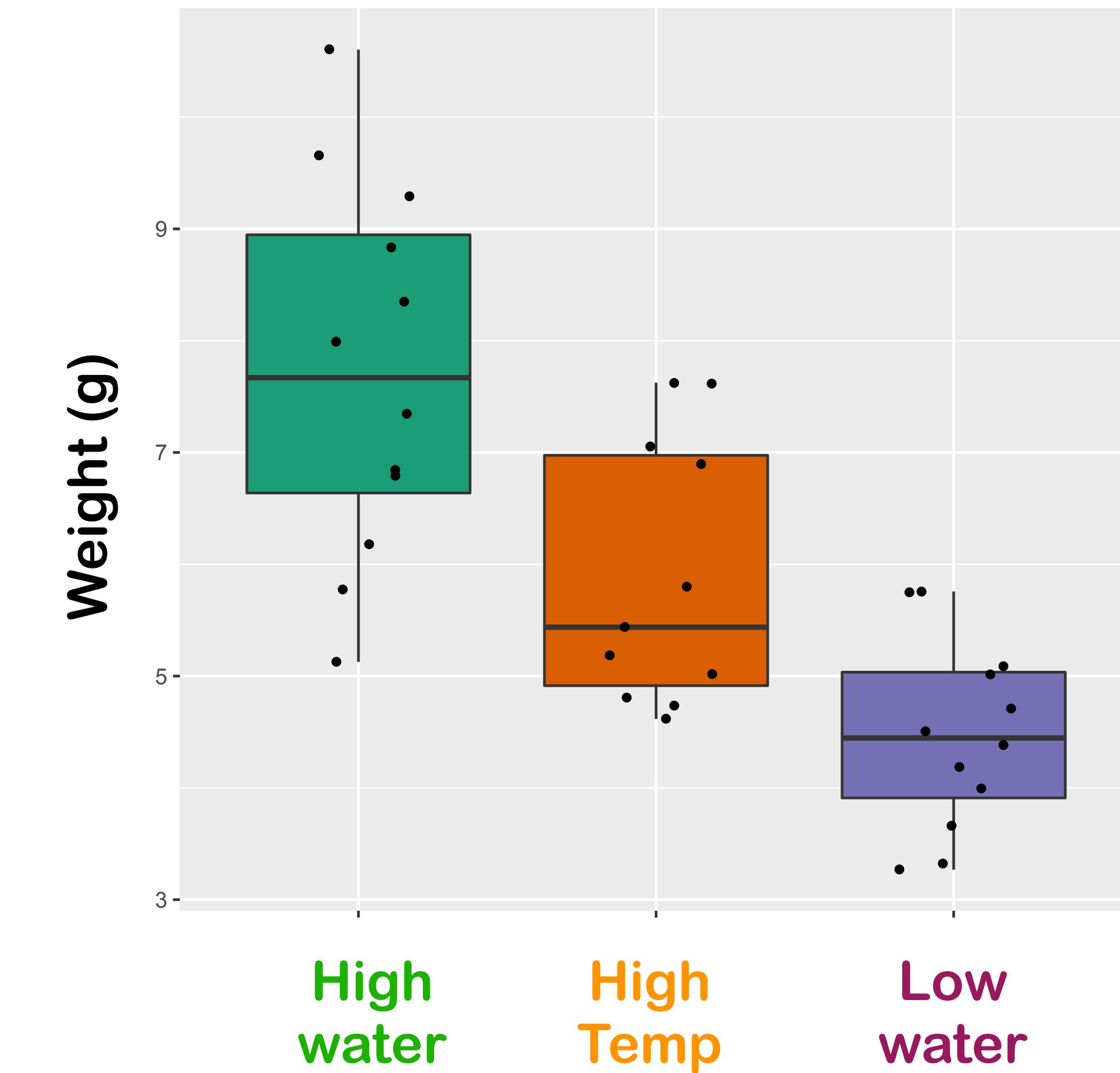
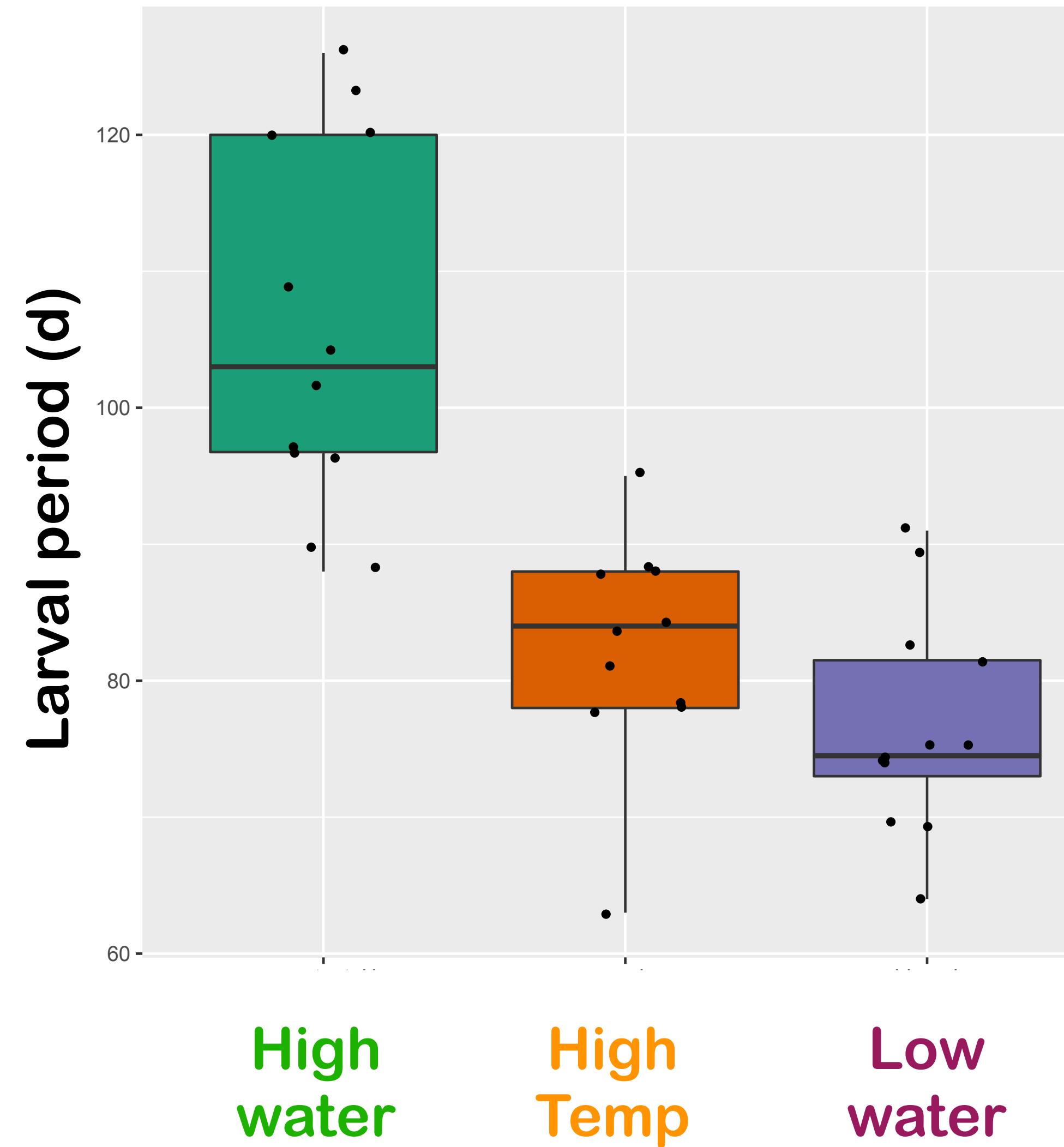
...but doing so incurs oxidative stress



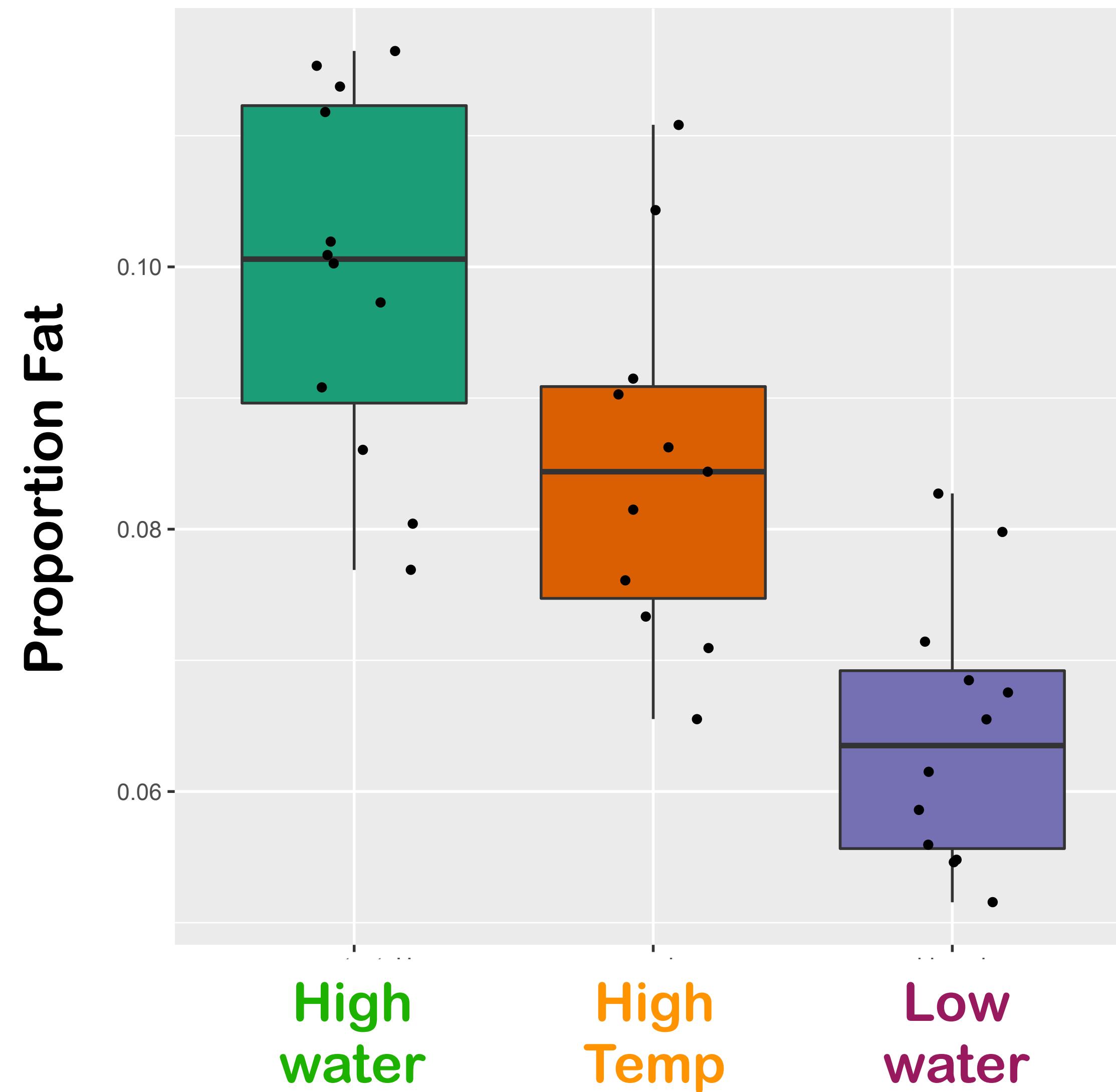
# As ponds dry up, temperature rises and water level drops



# Both temperature and pond drying induce faster development



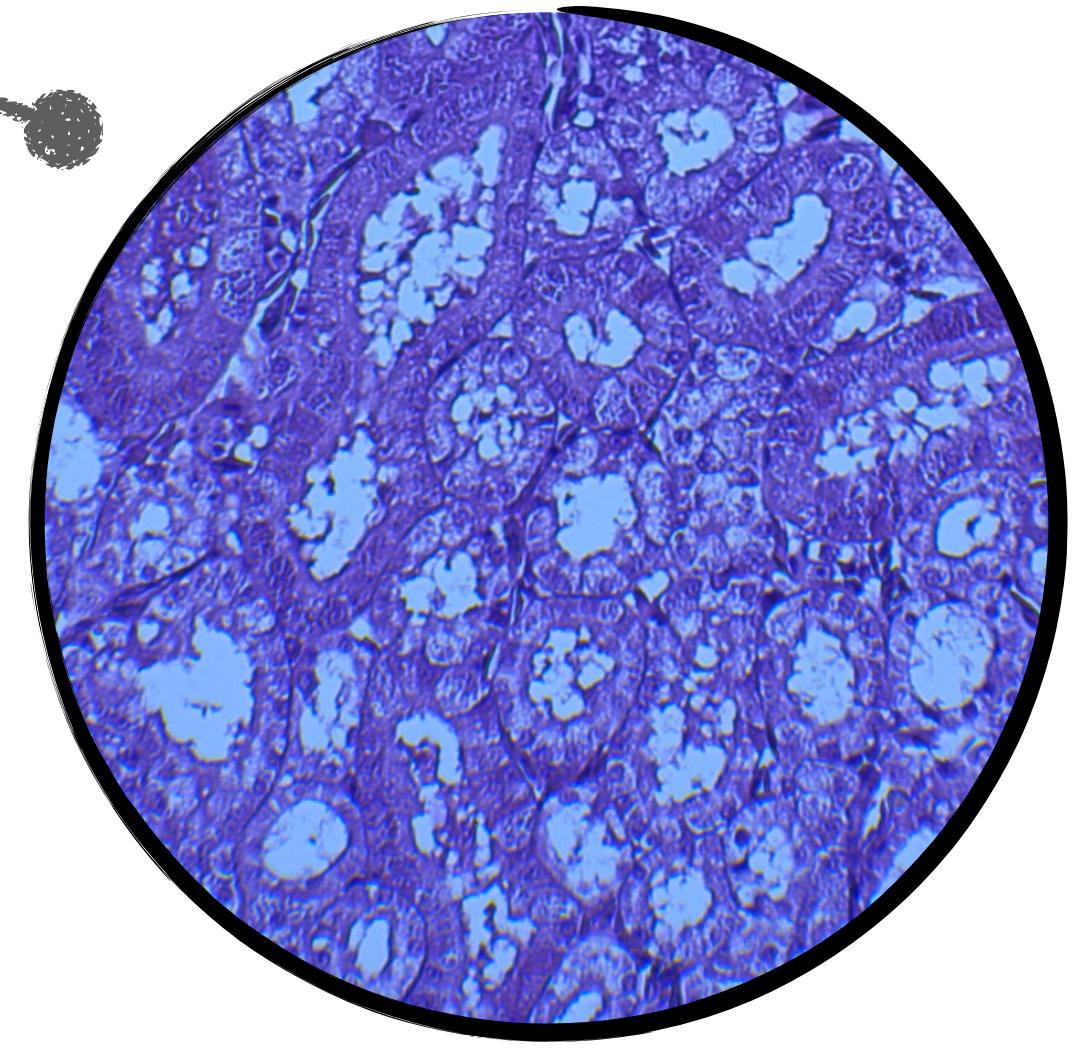
# Pond drying seems to have a greater impact



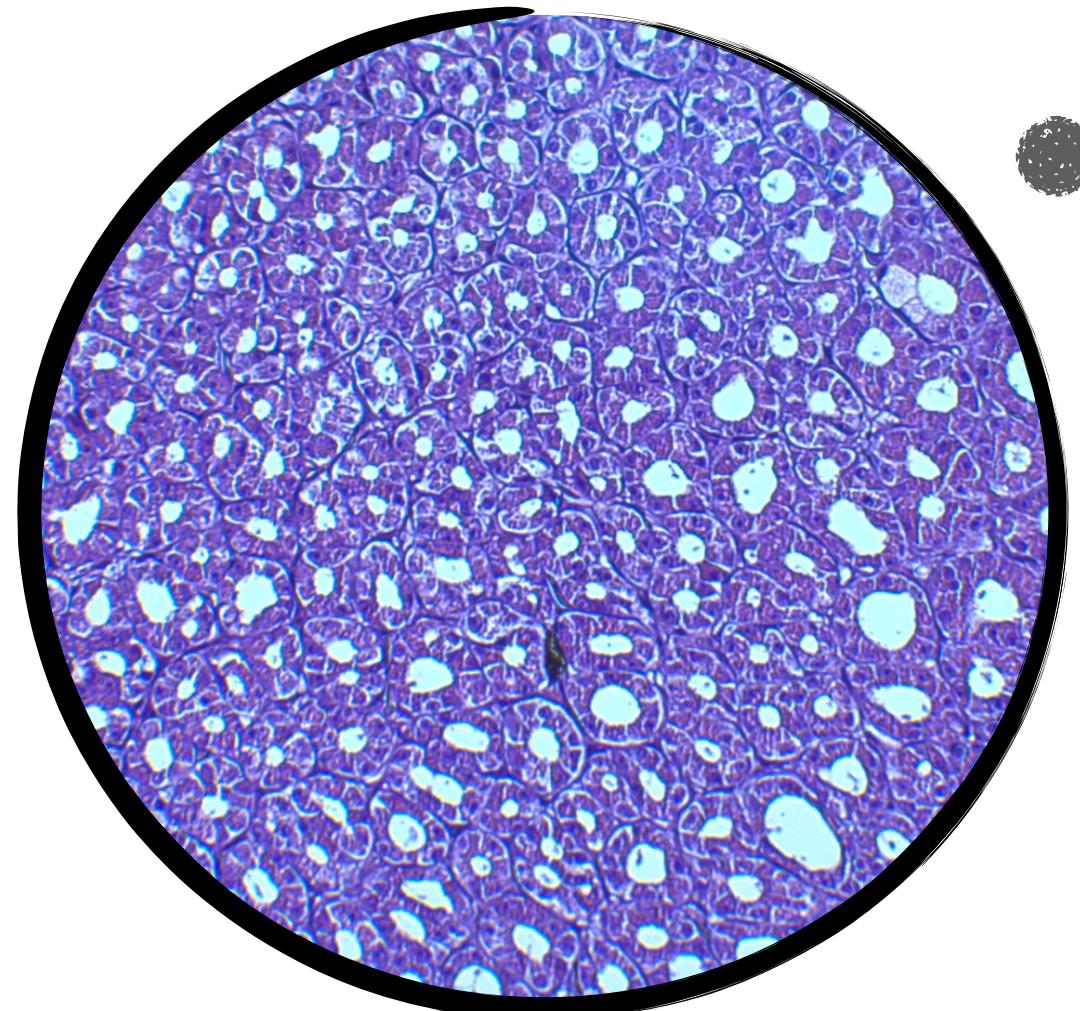
## Changes in cell size



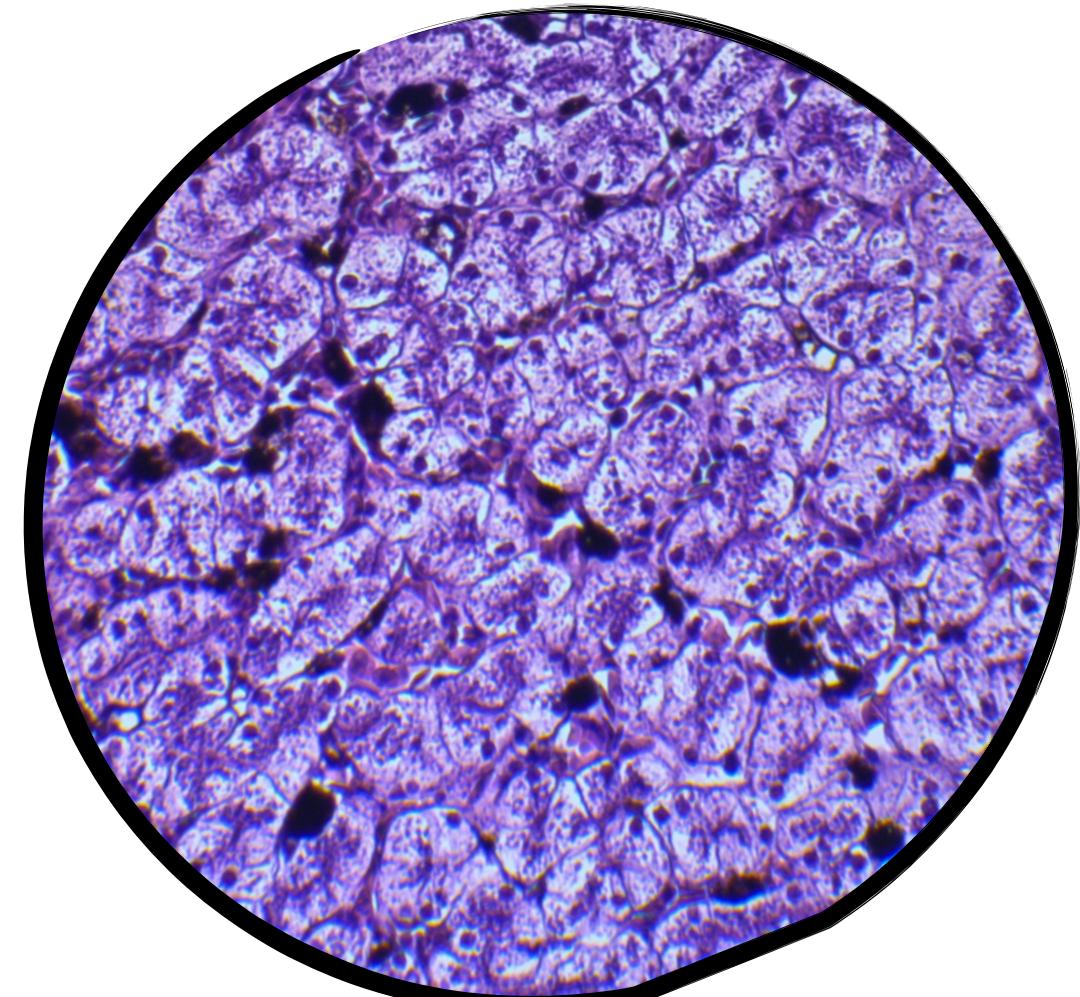
Kidney



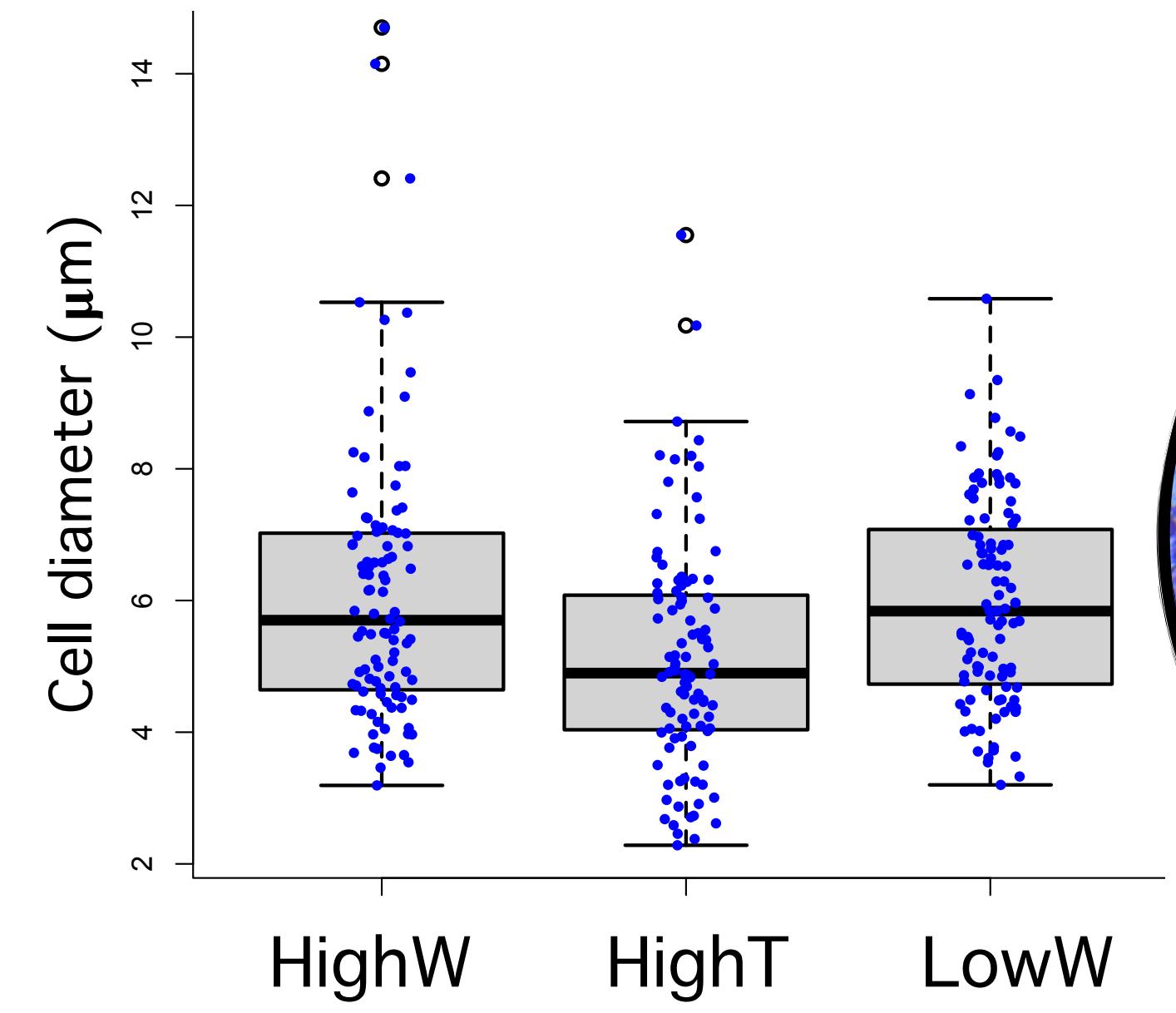
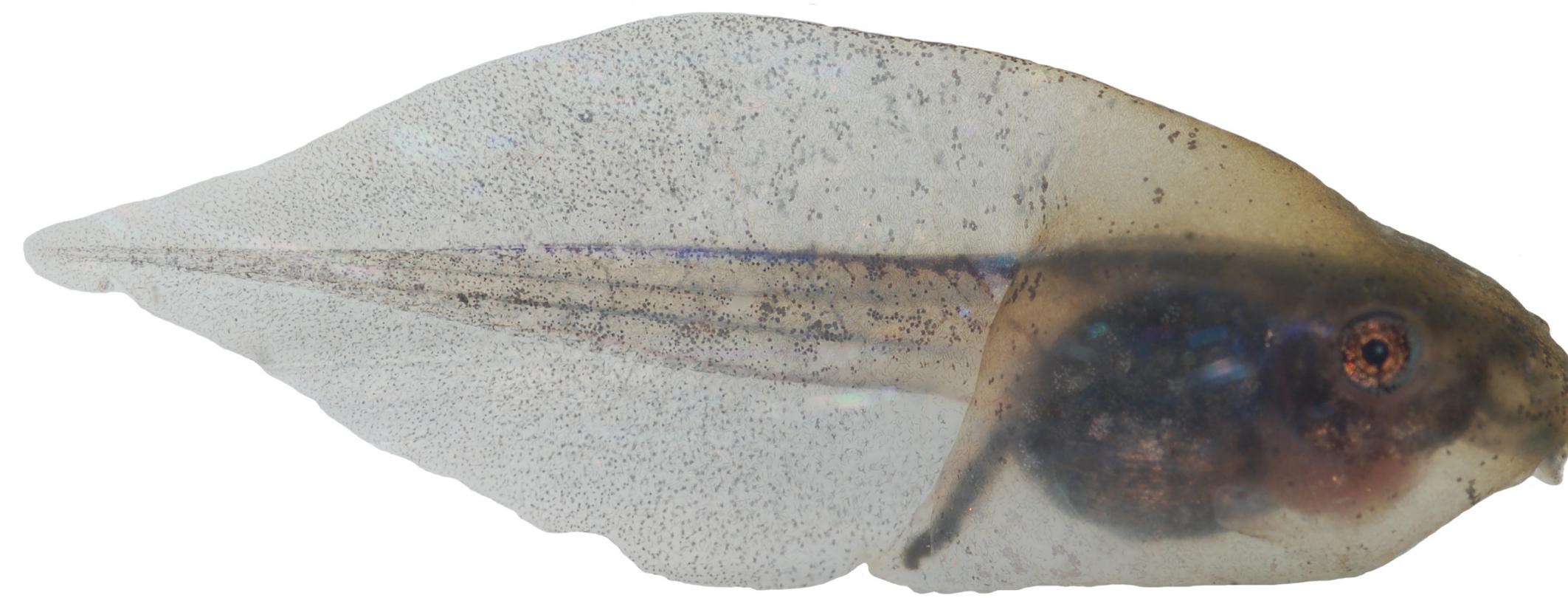
Gut



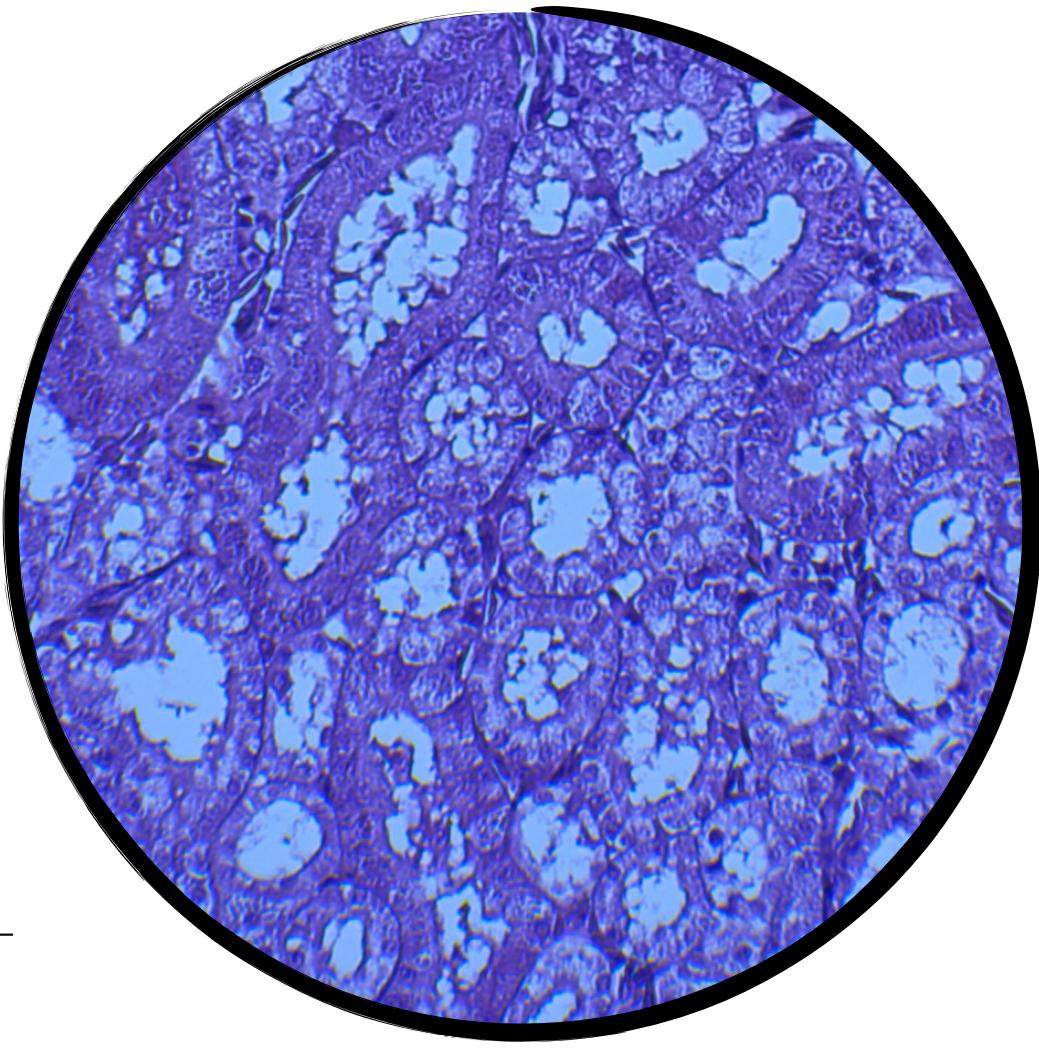
Liver



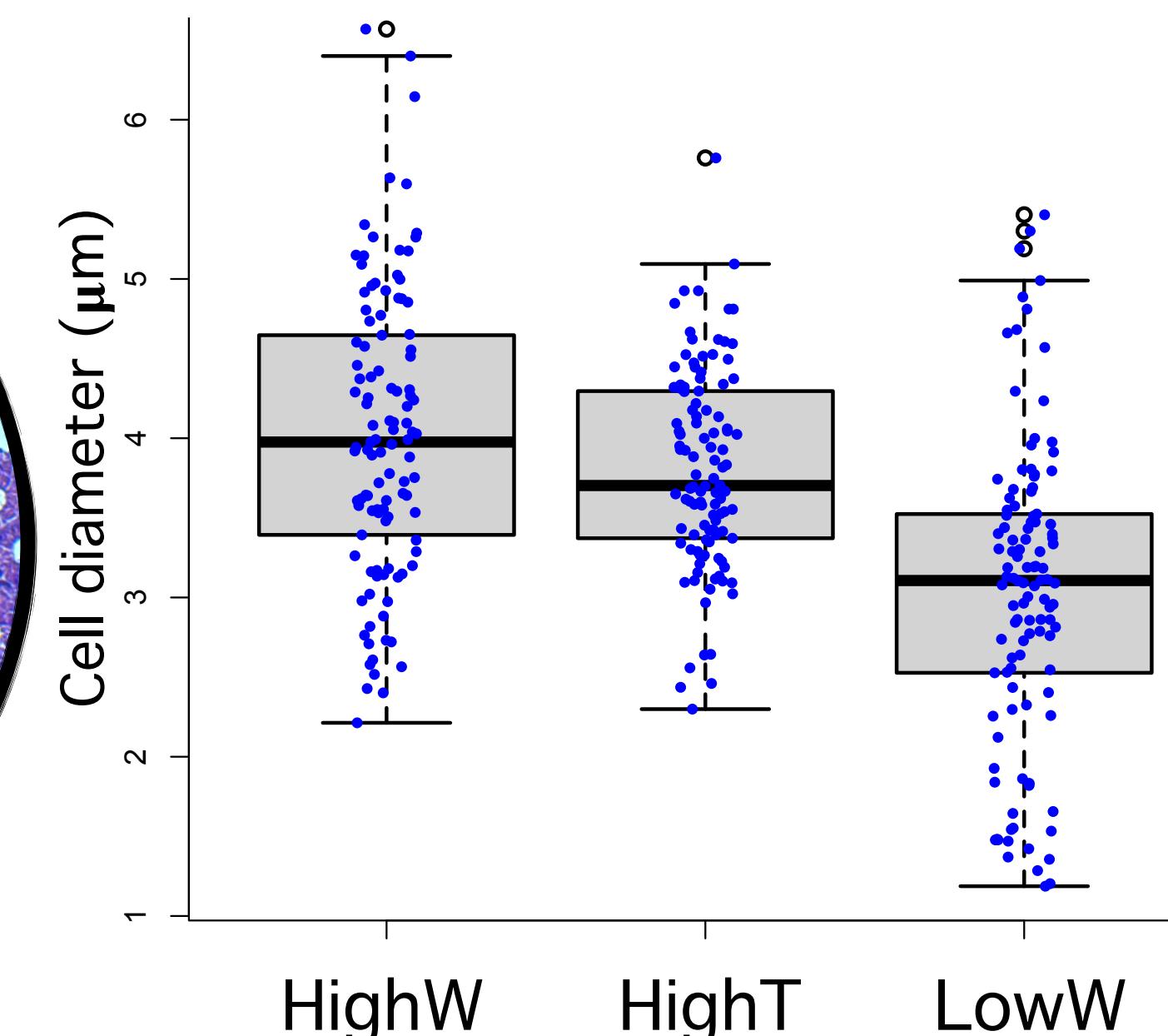
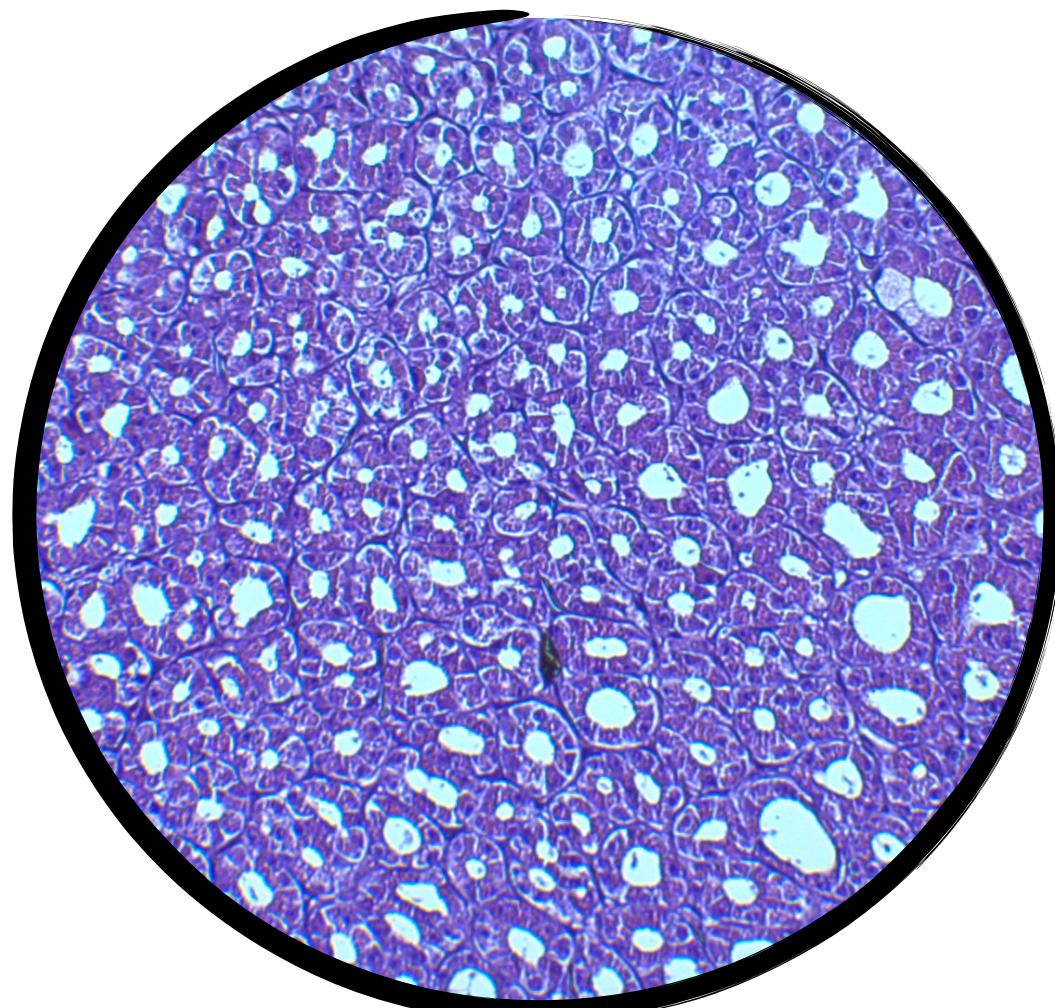
# Changes in cell size across tissues?



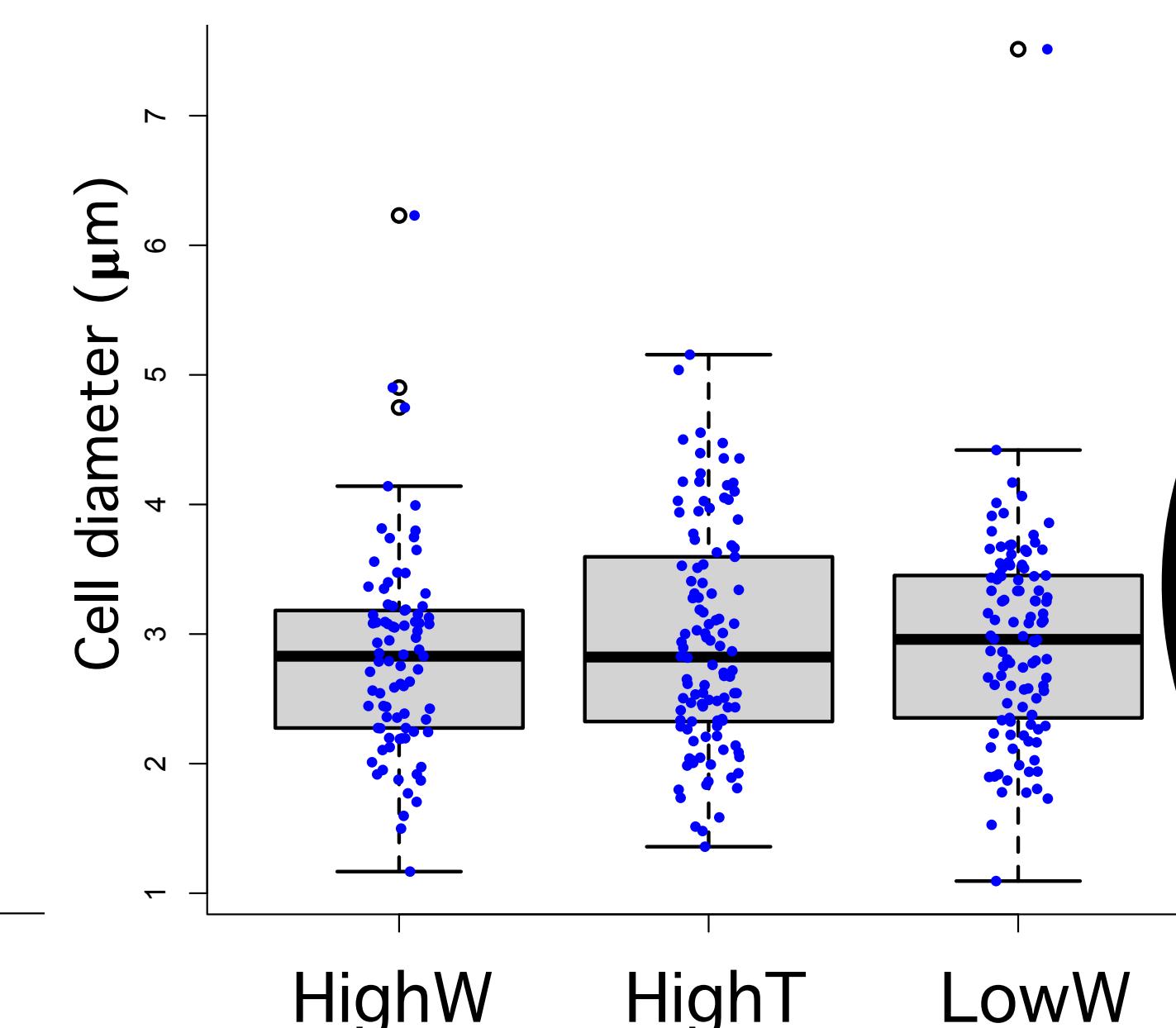
Kidney



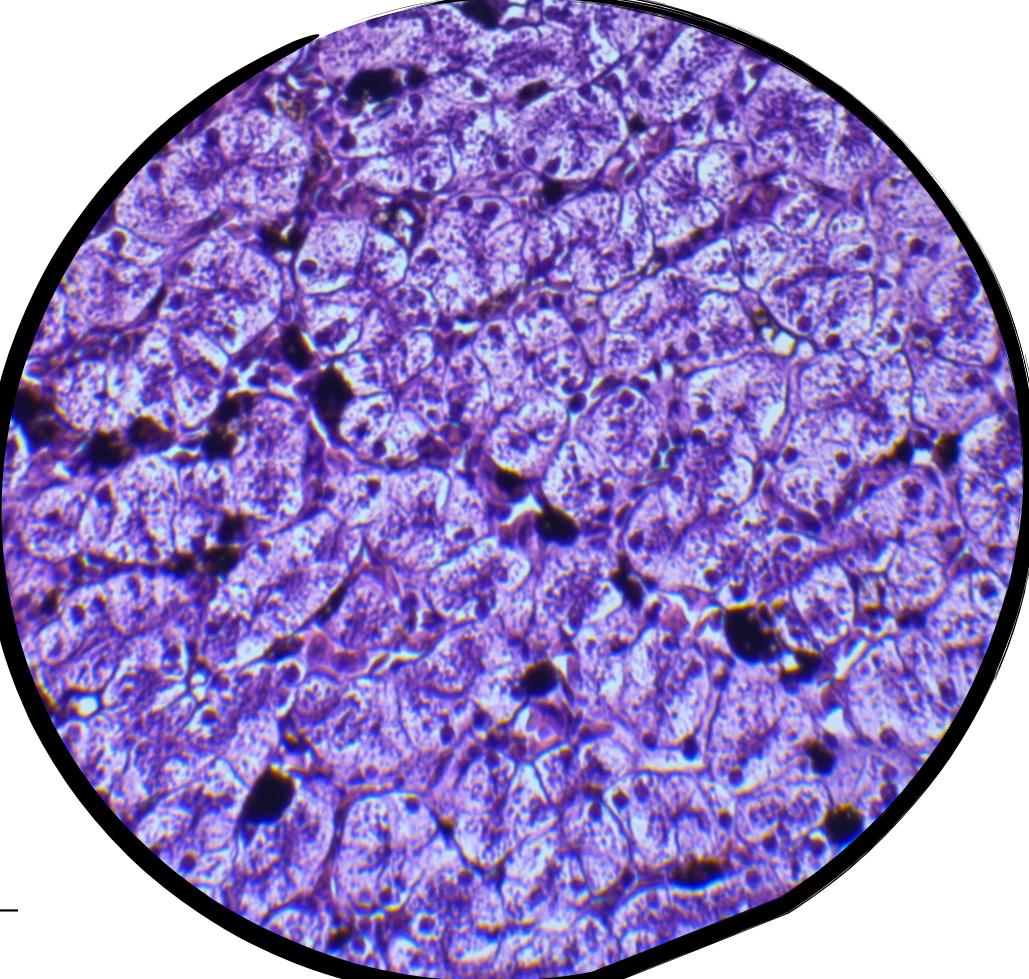
Gut



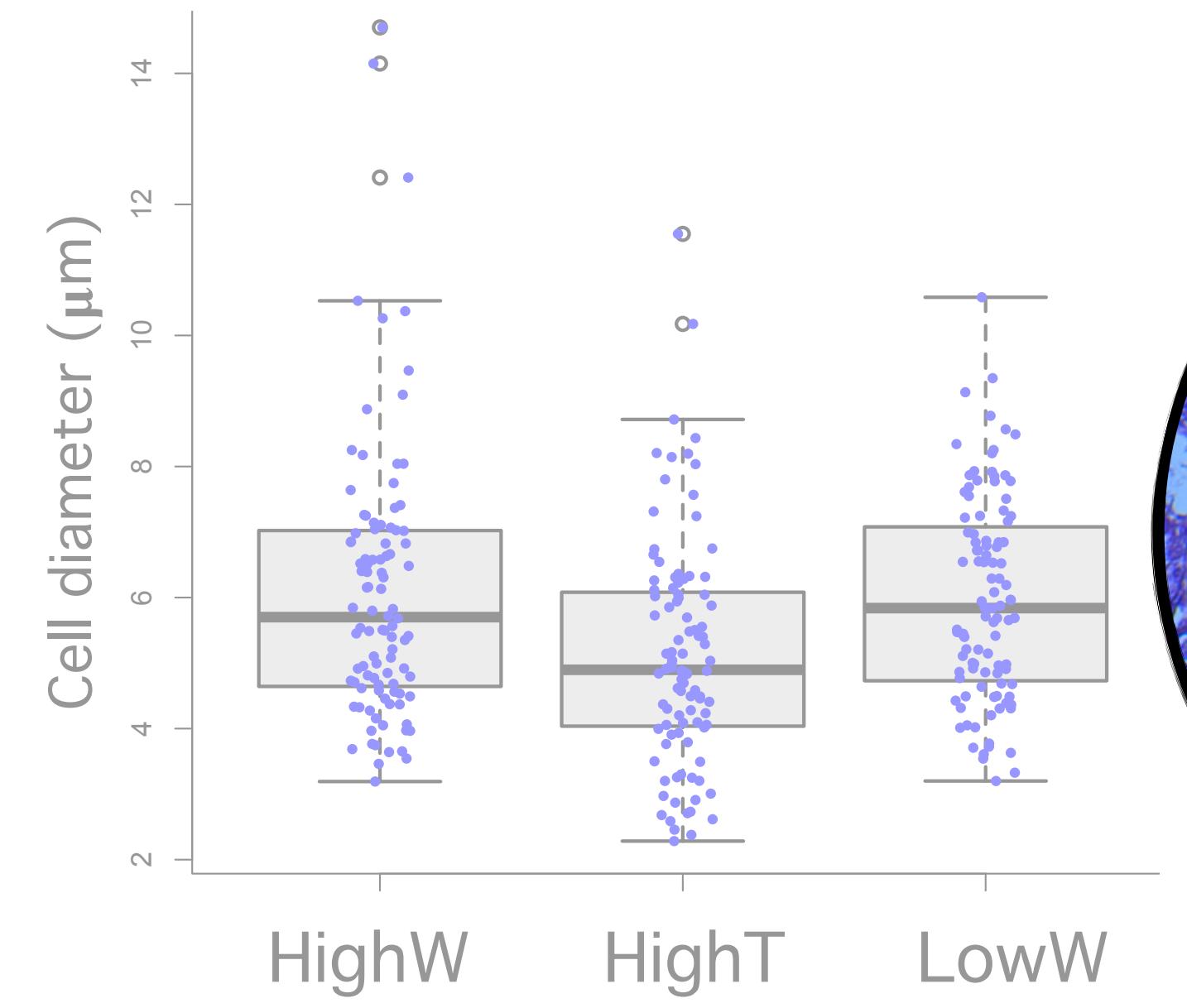
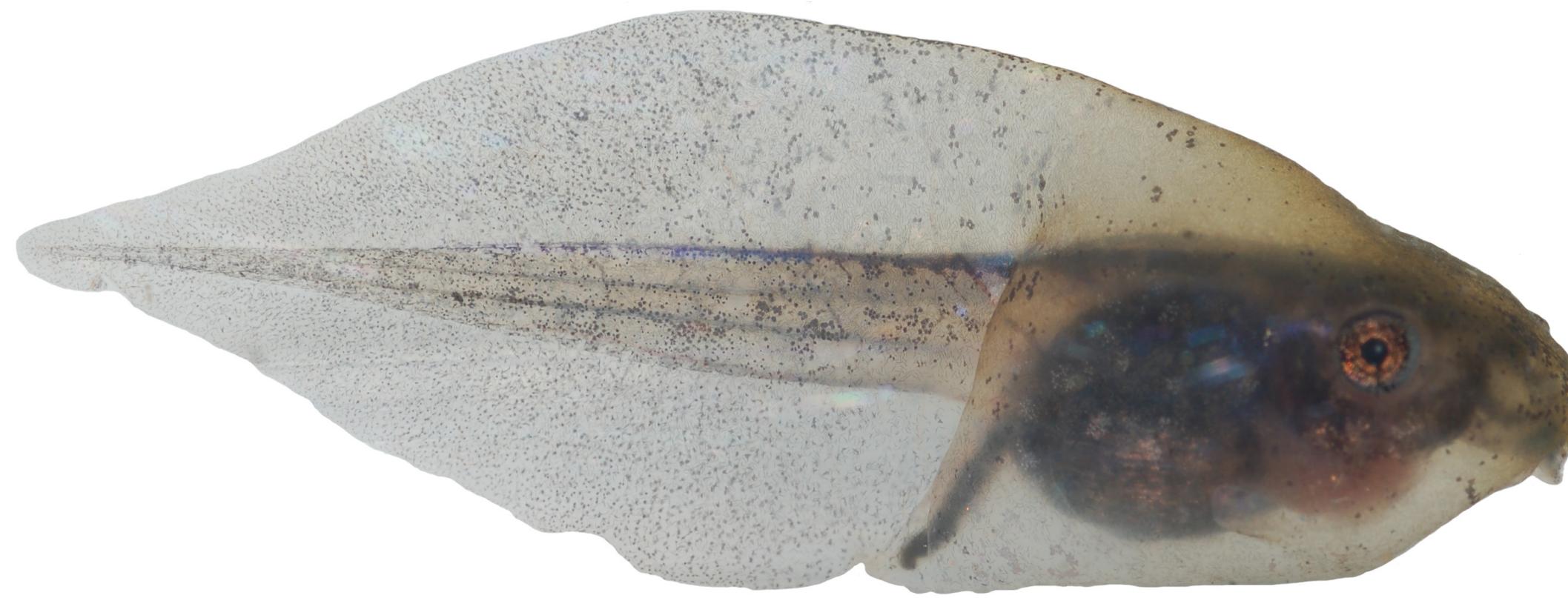
Gut



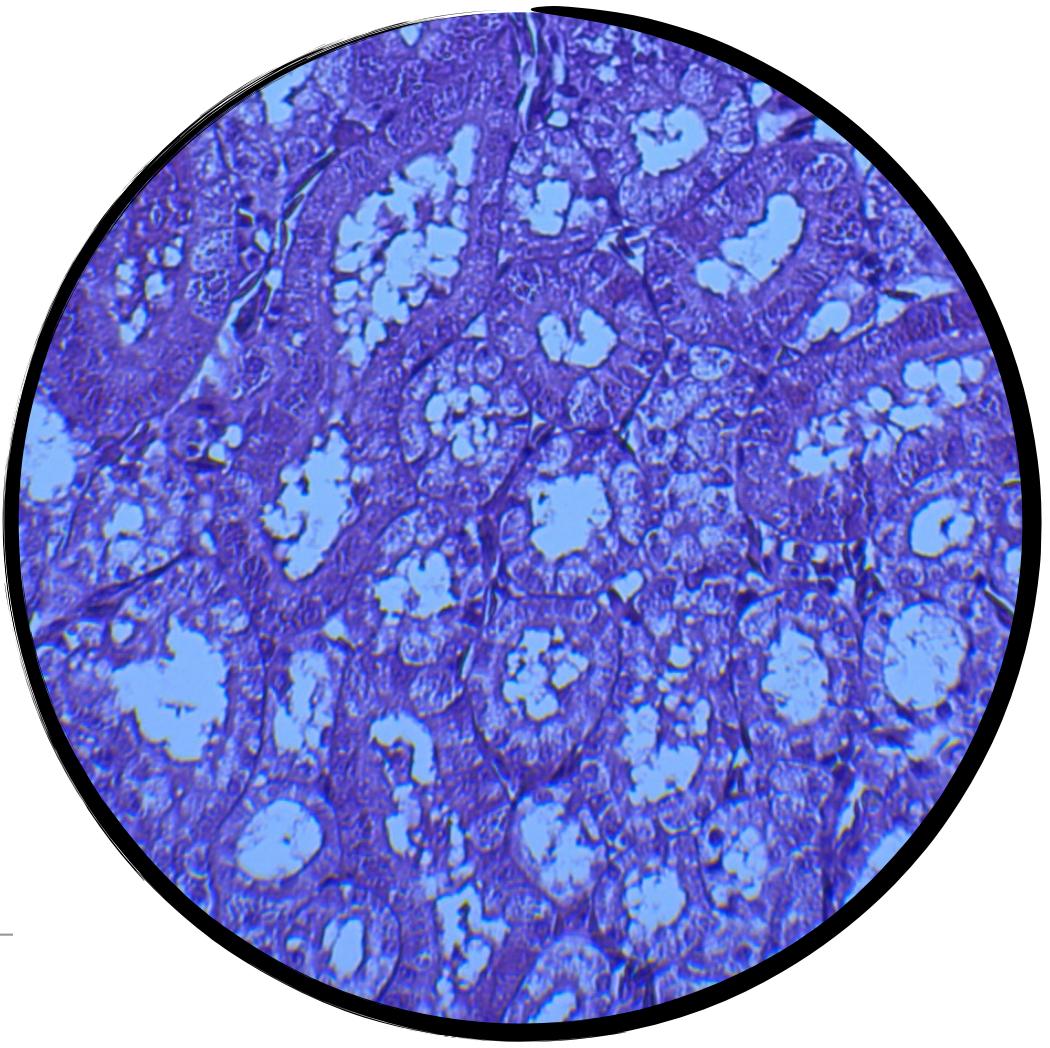
Liver



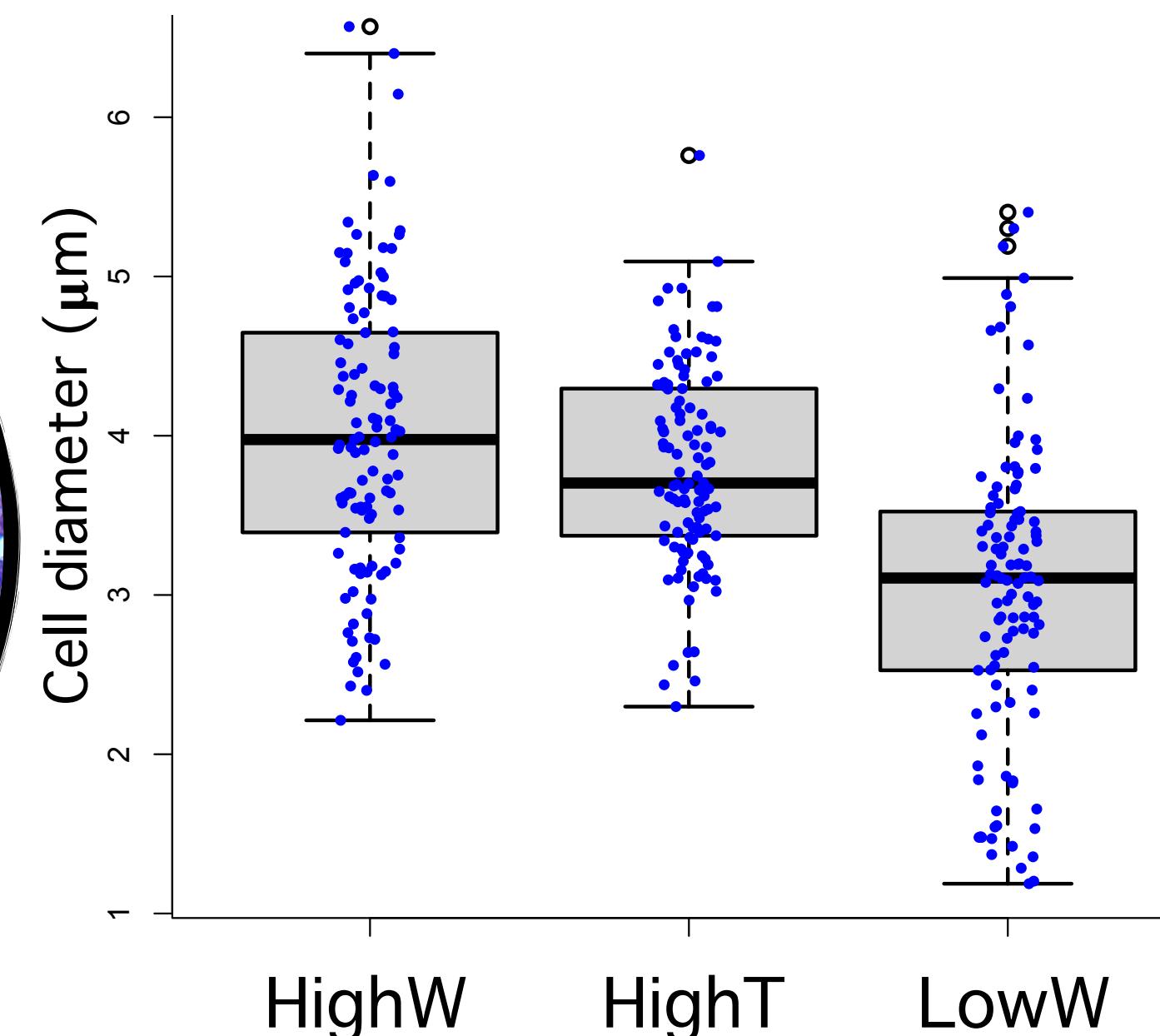
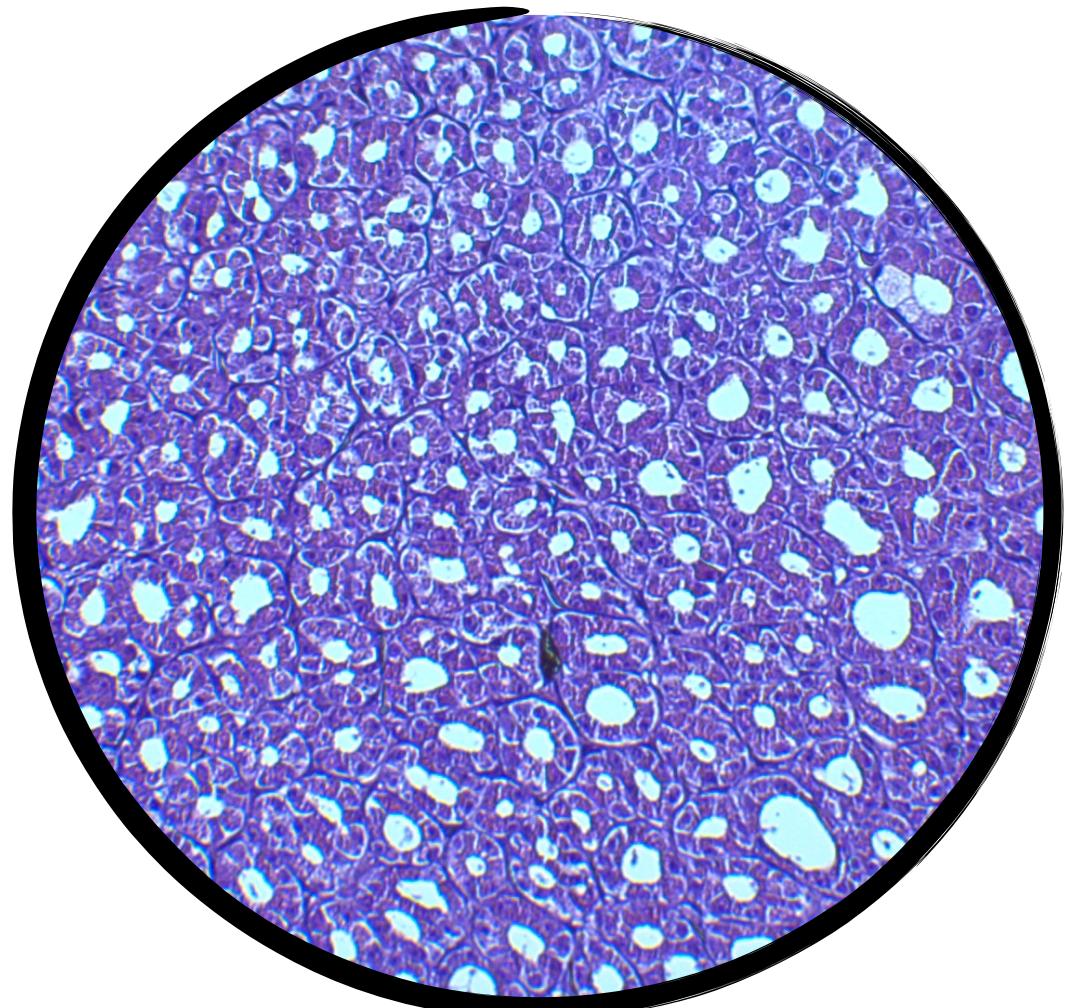
Only in the gut



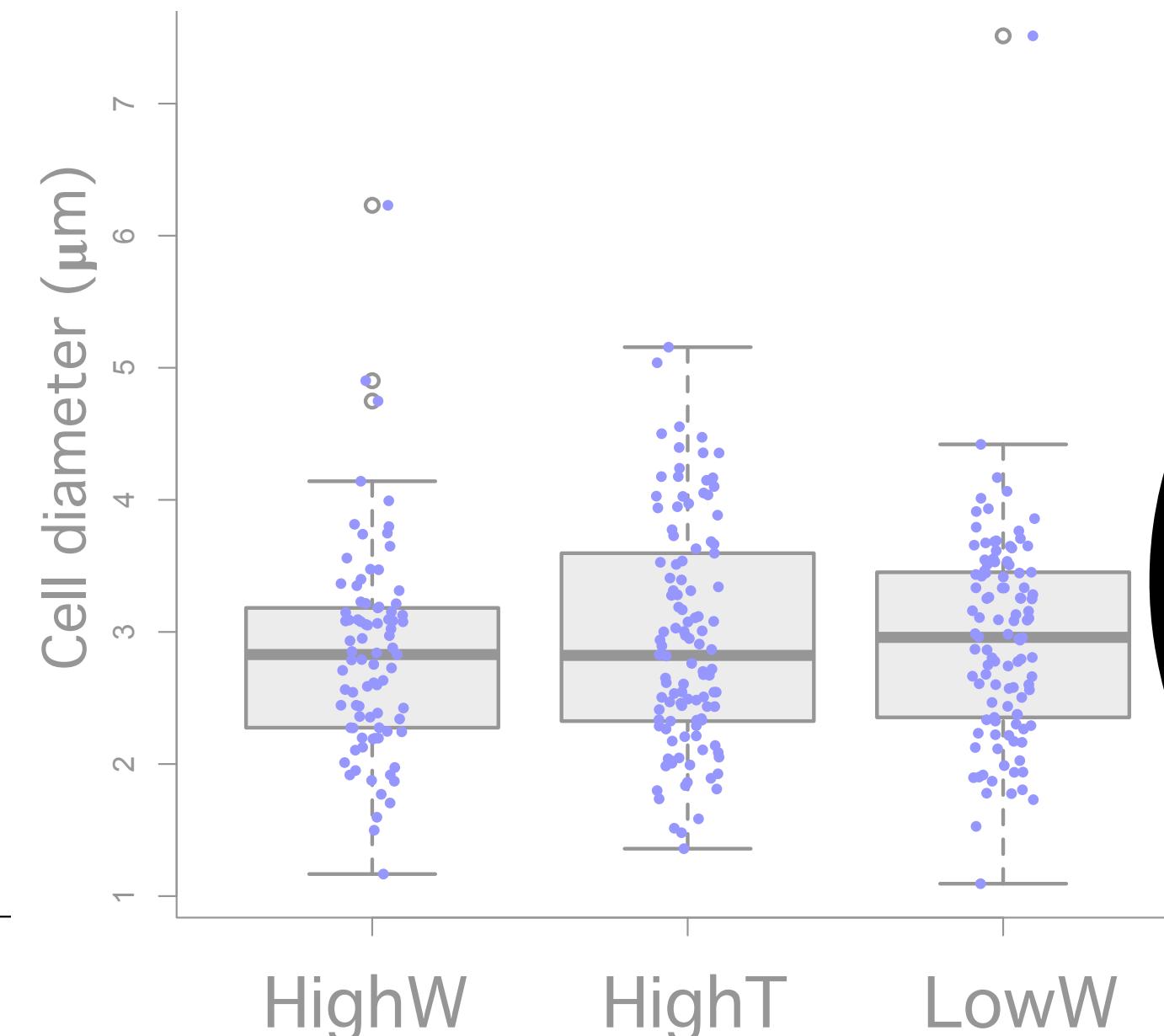
Kidney

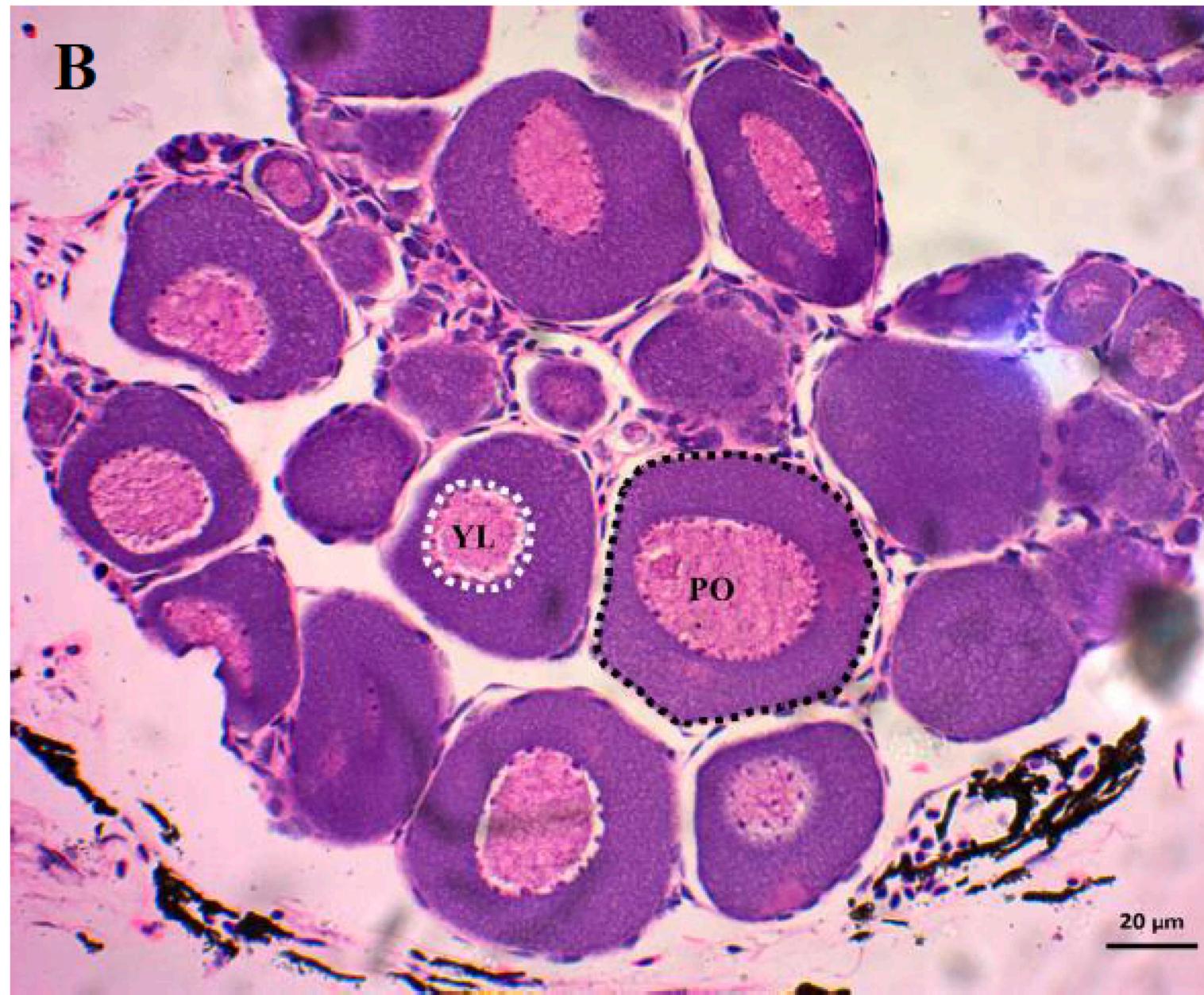
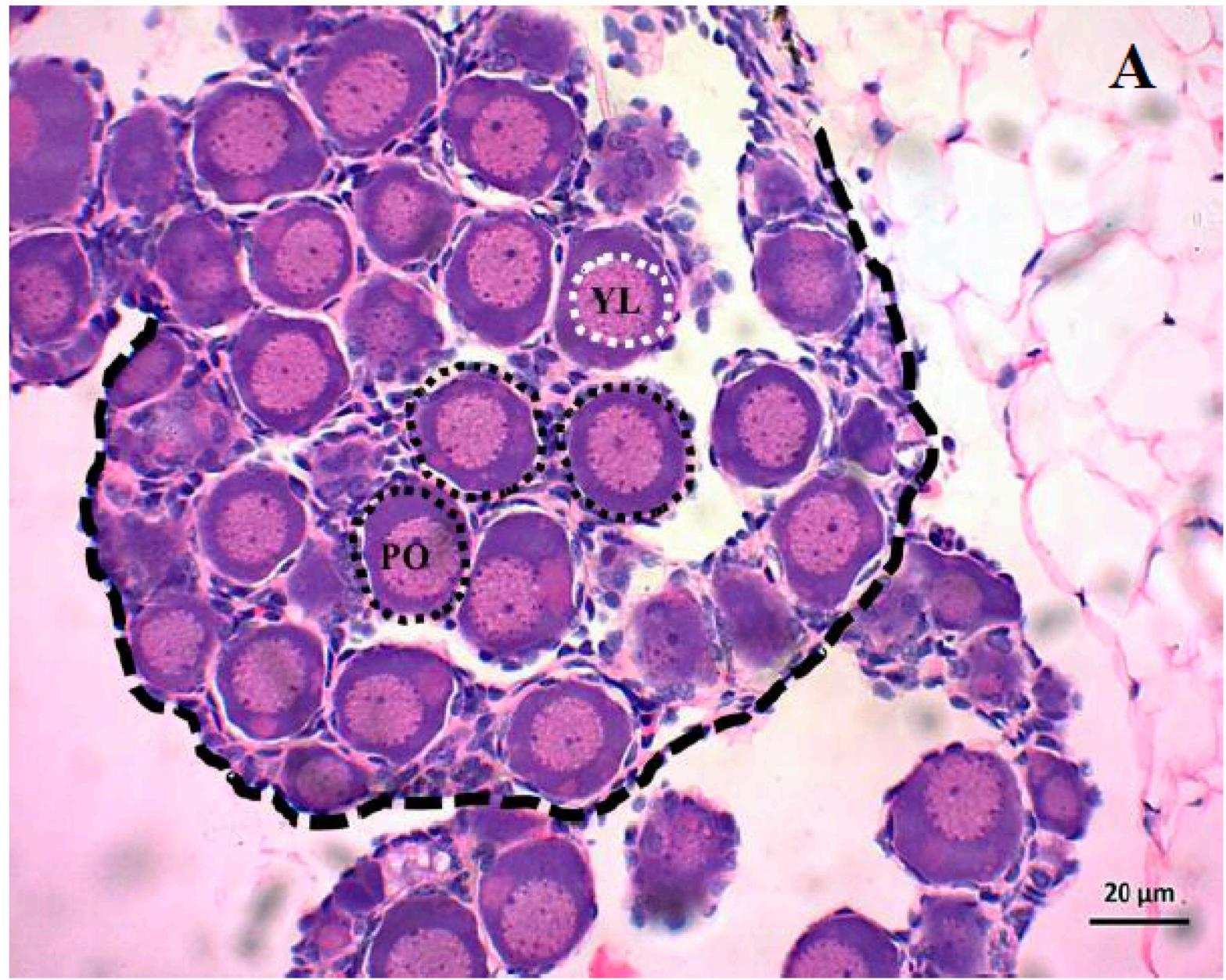


Gut



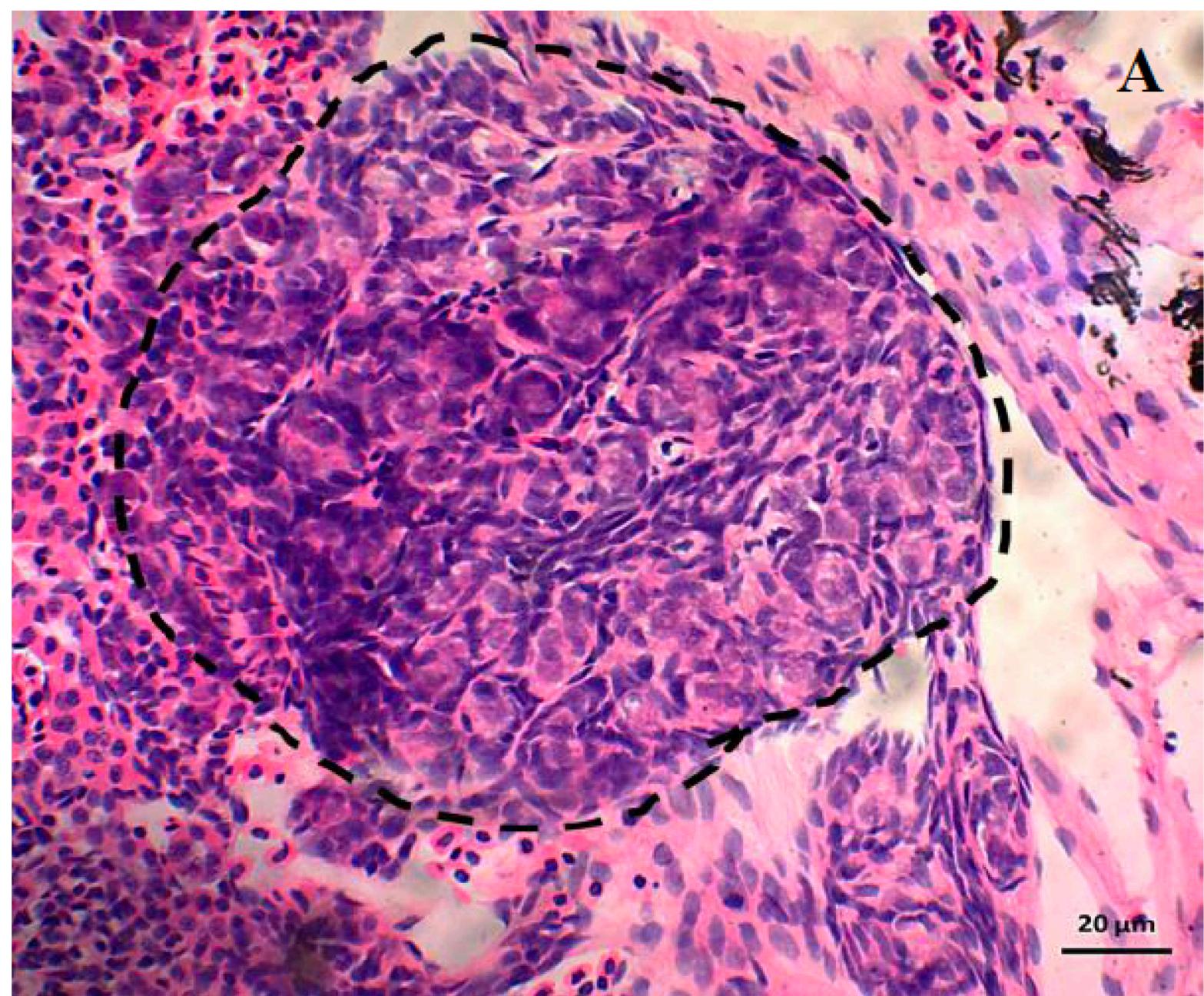
Liver





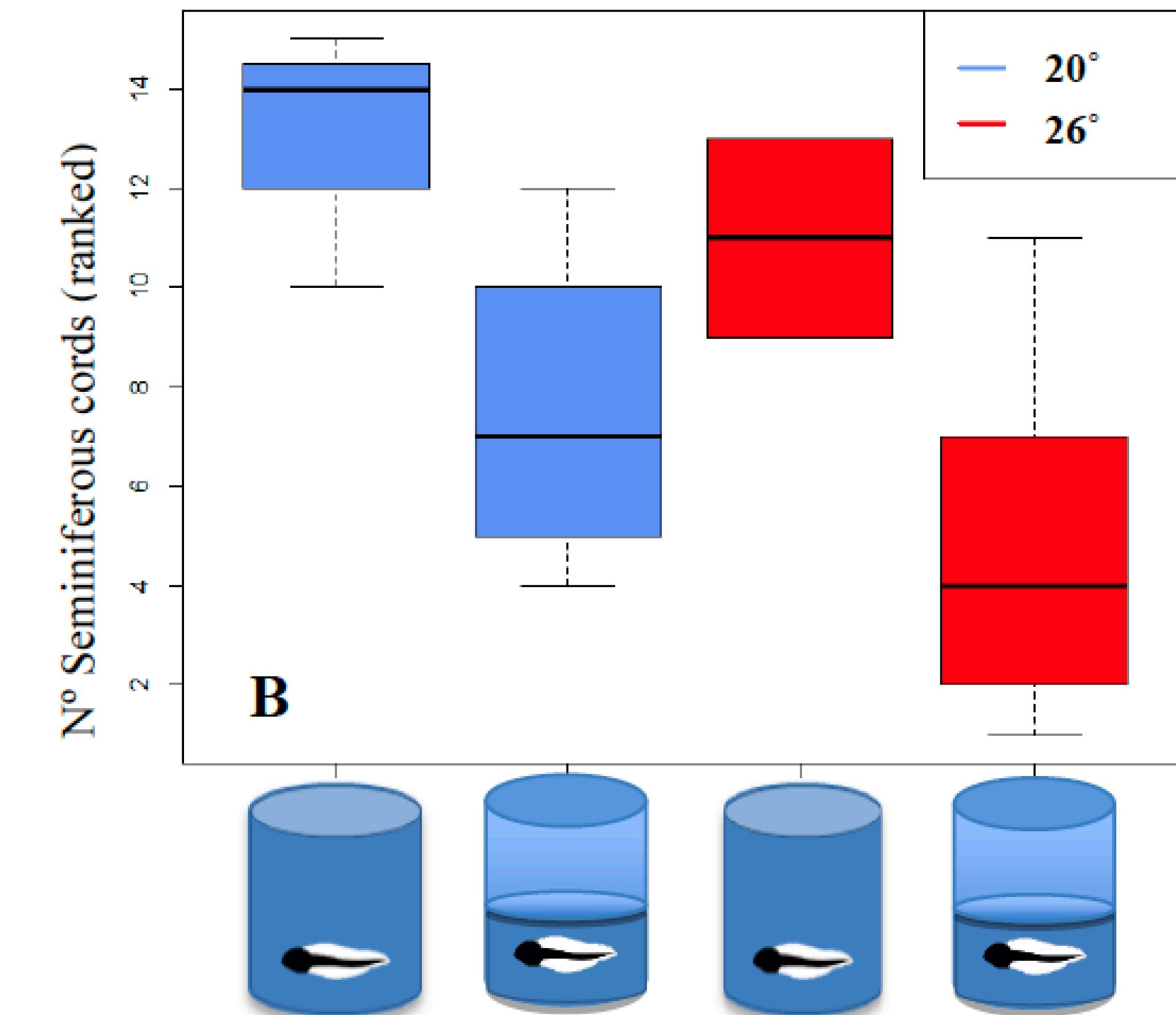
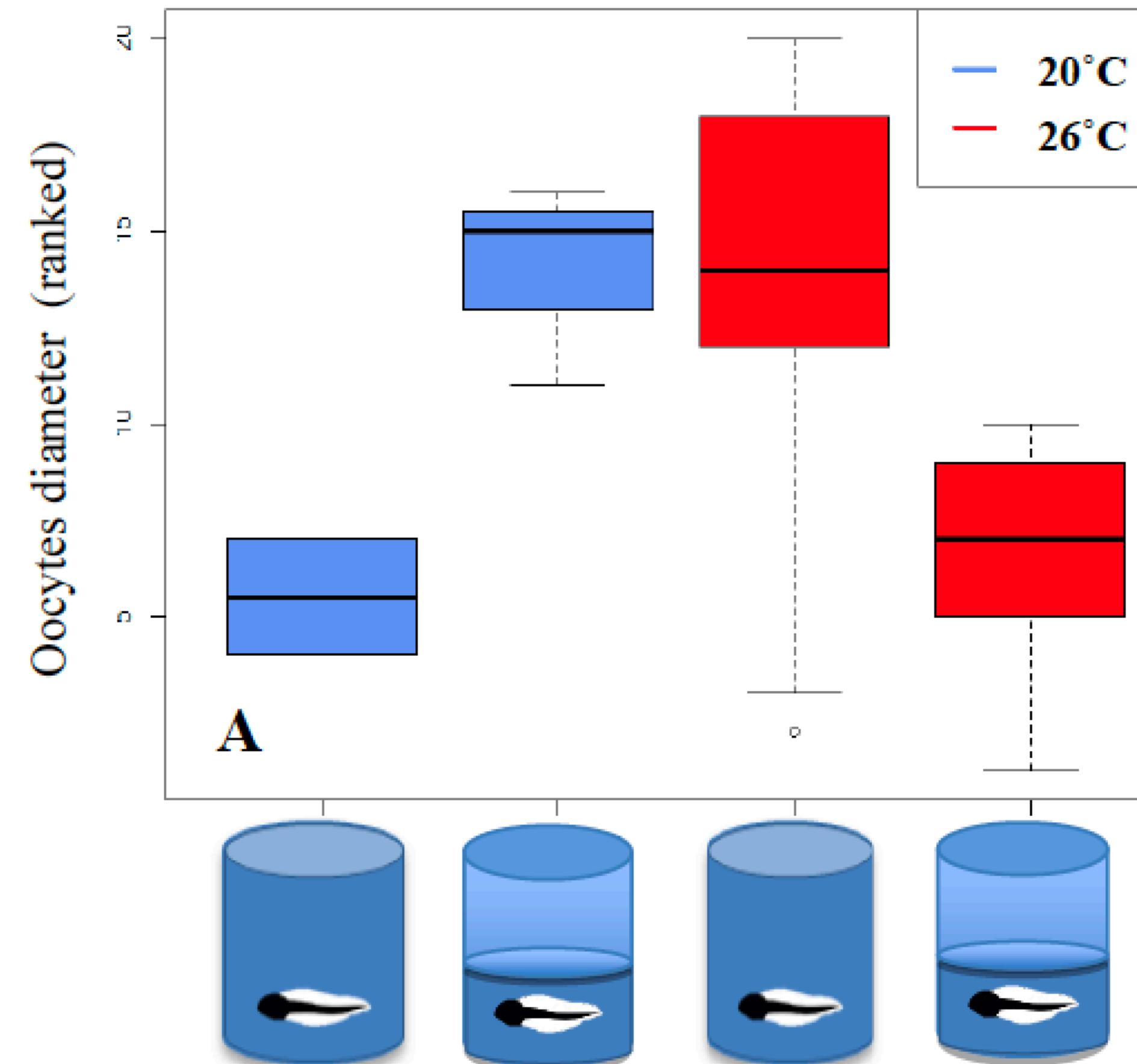
Ovaries

Temp x Water level

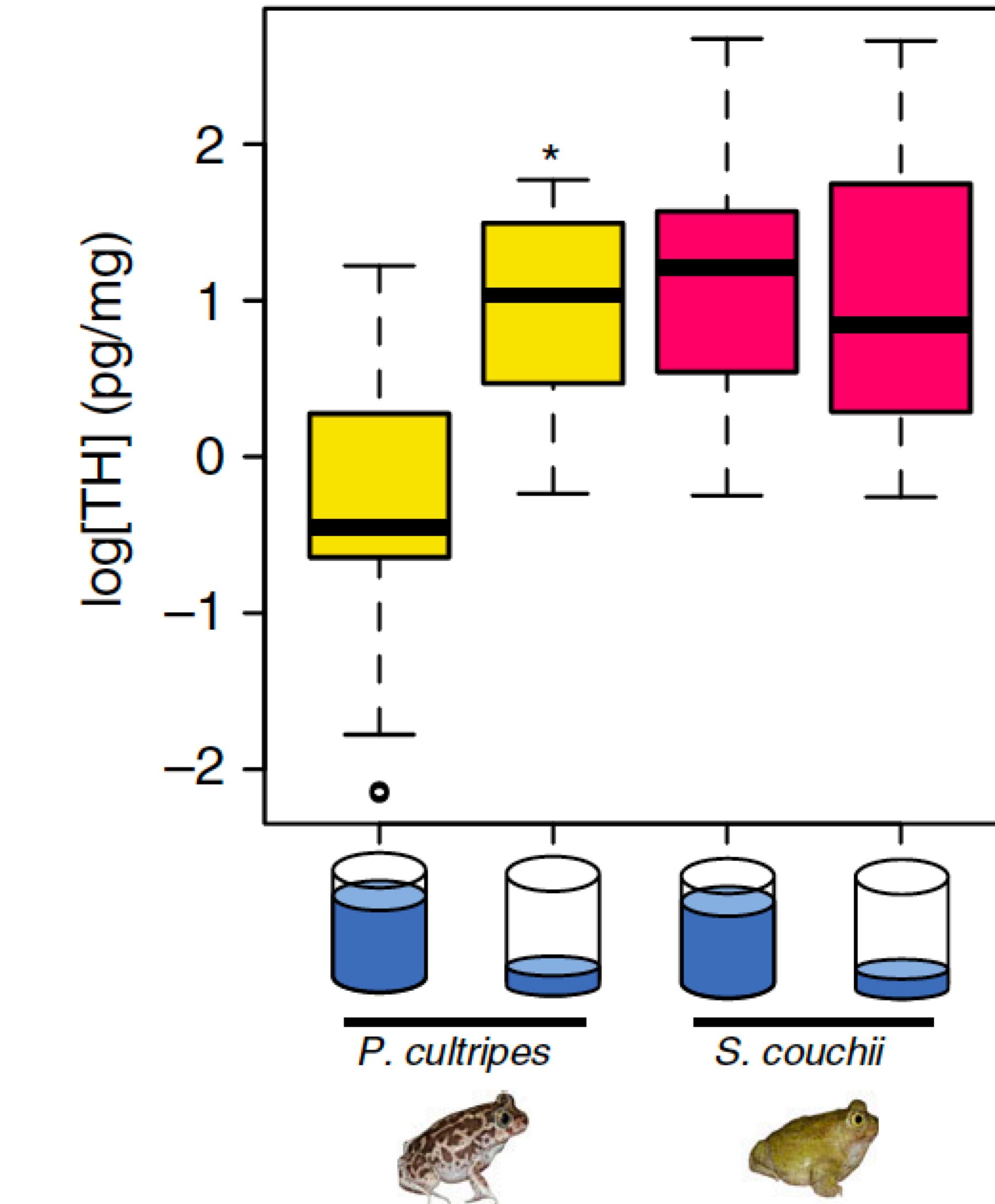
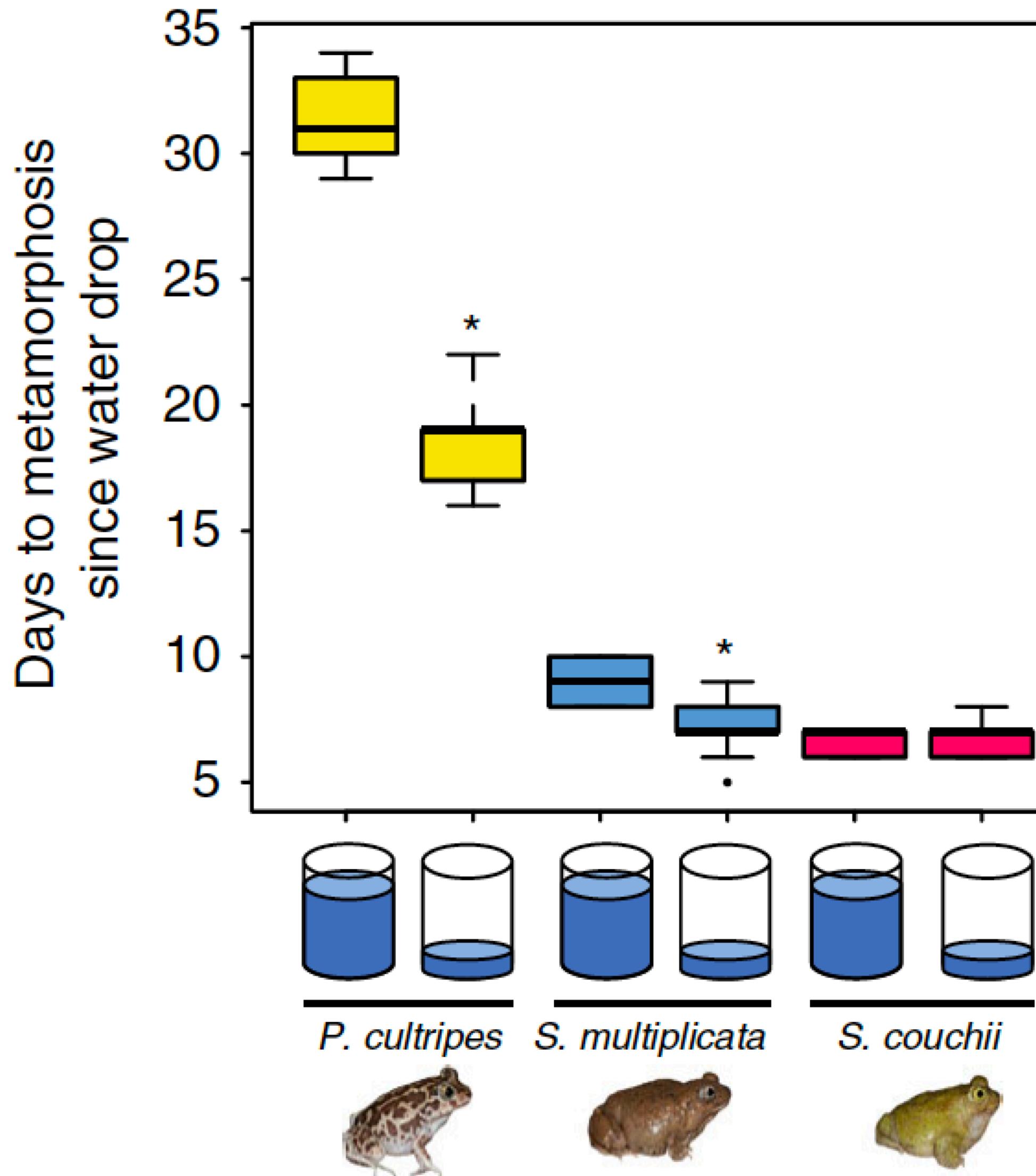


Testes

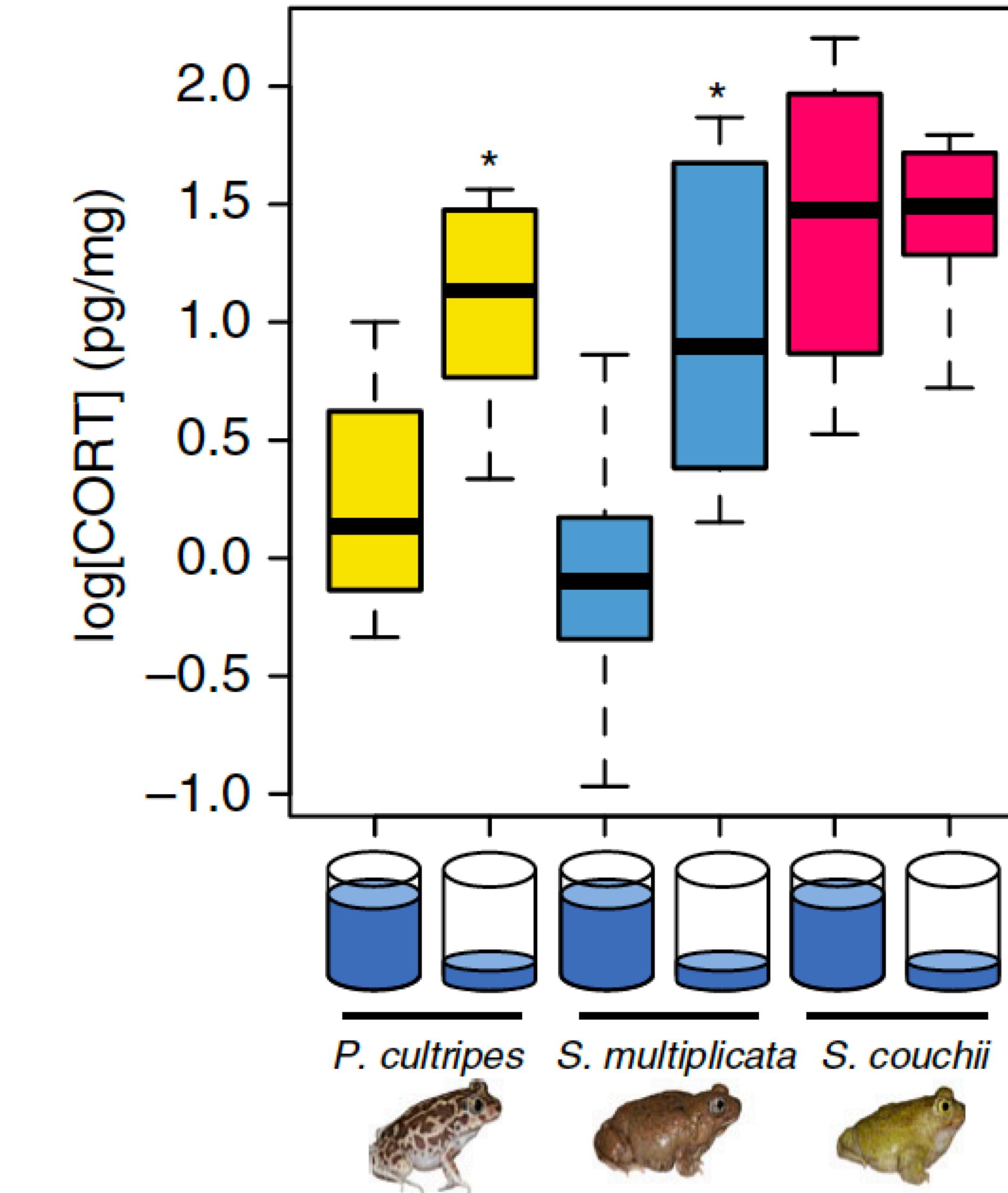
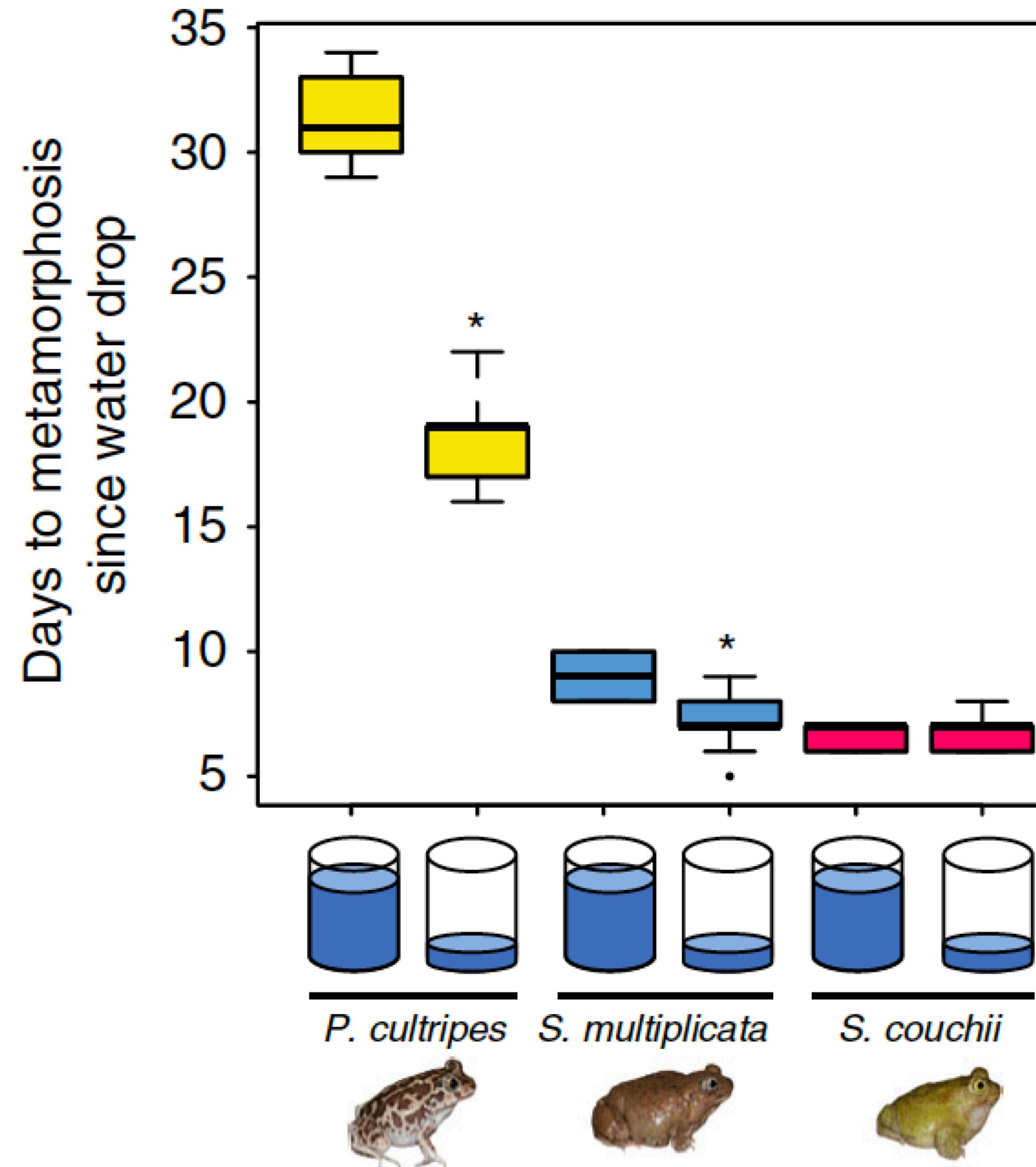
# Water level and temperature affect gonadal maturation



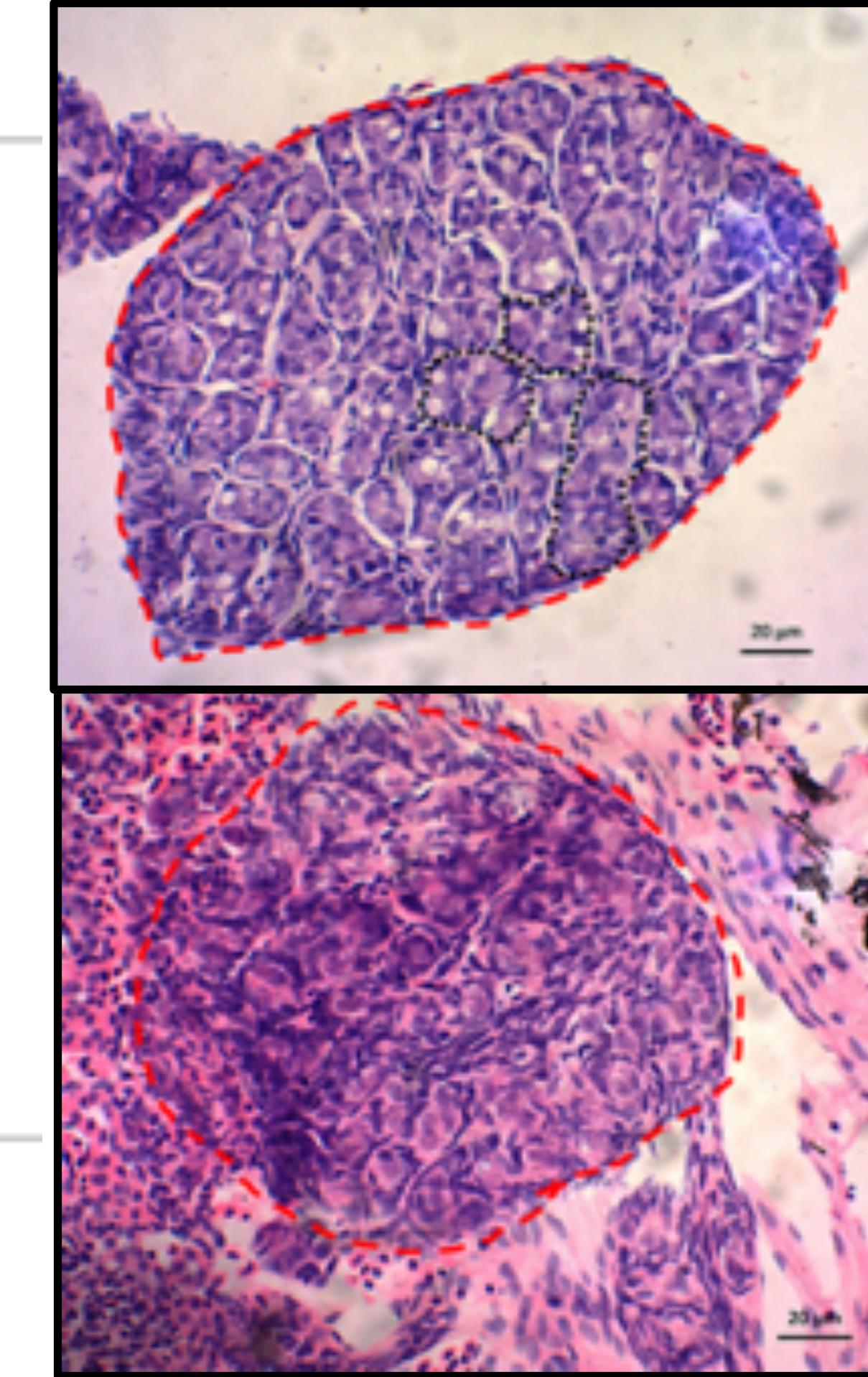
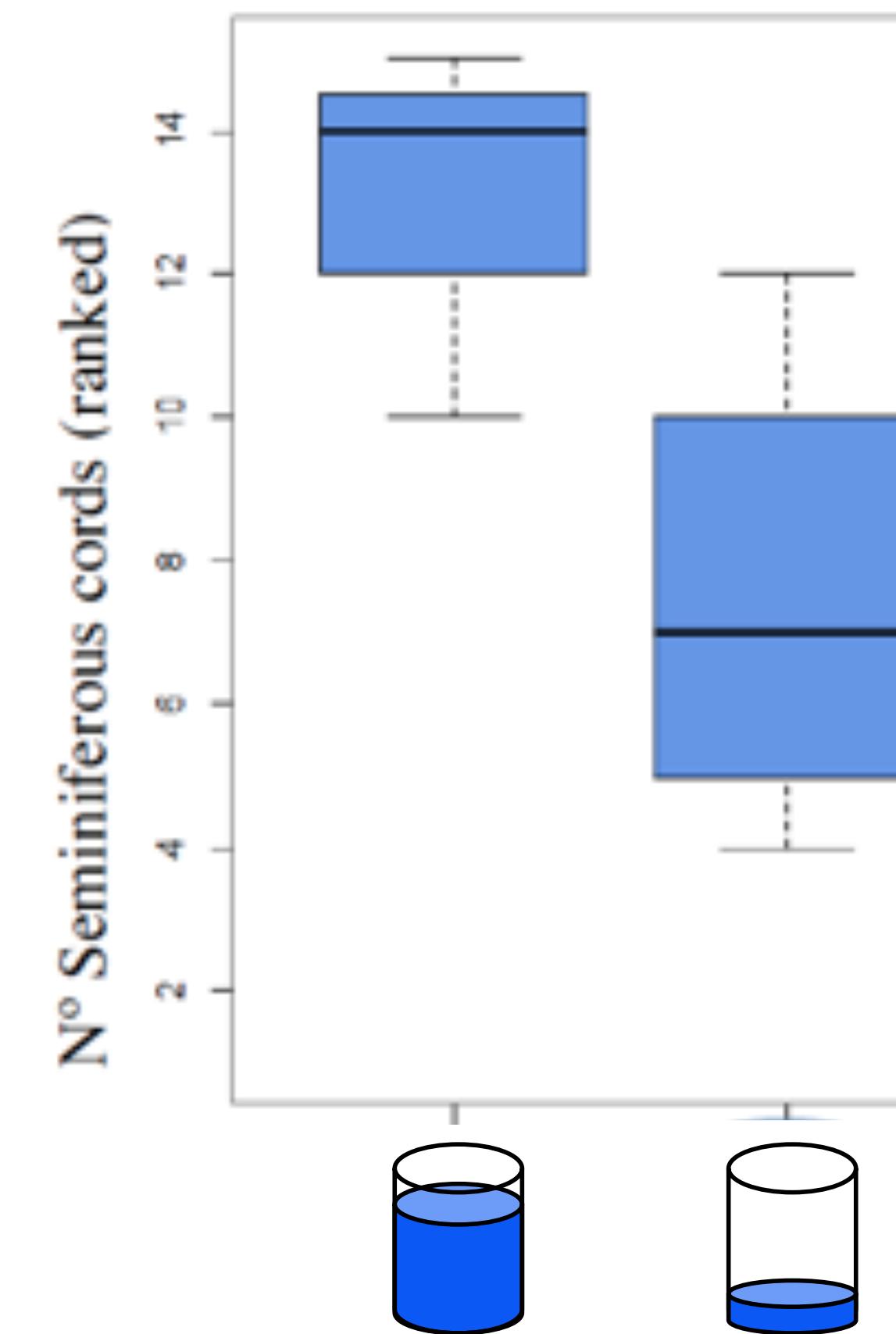
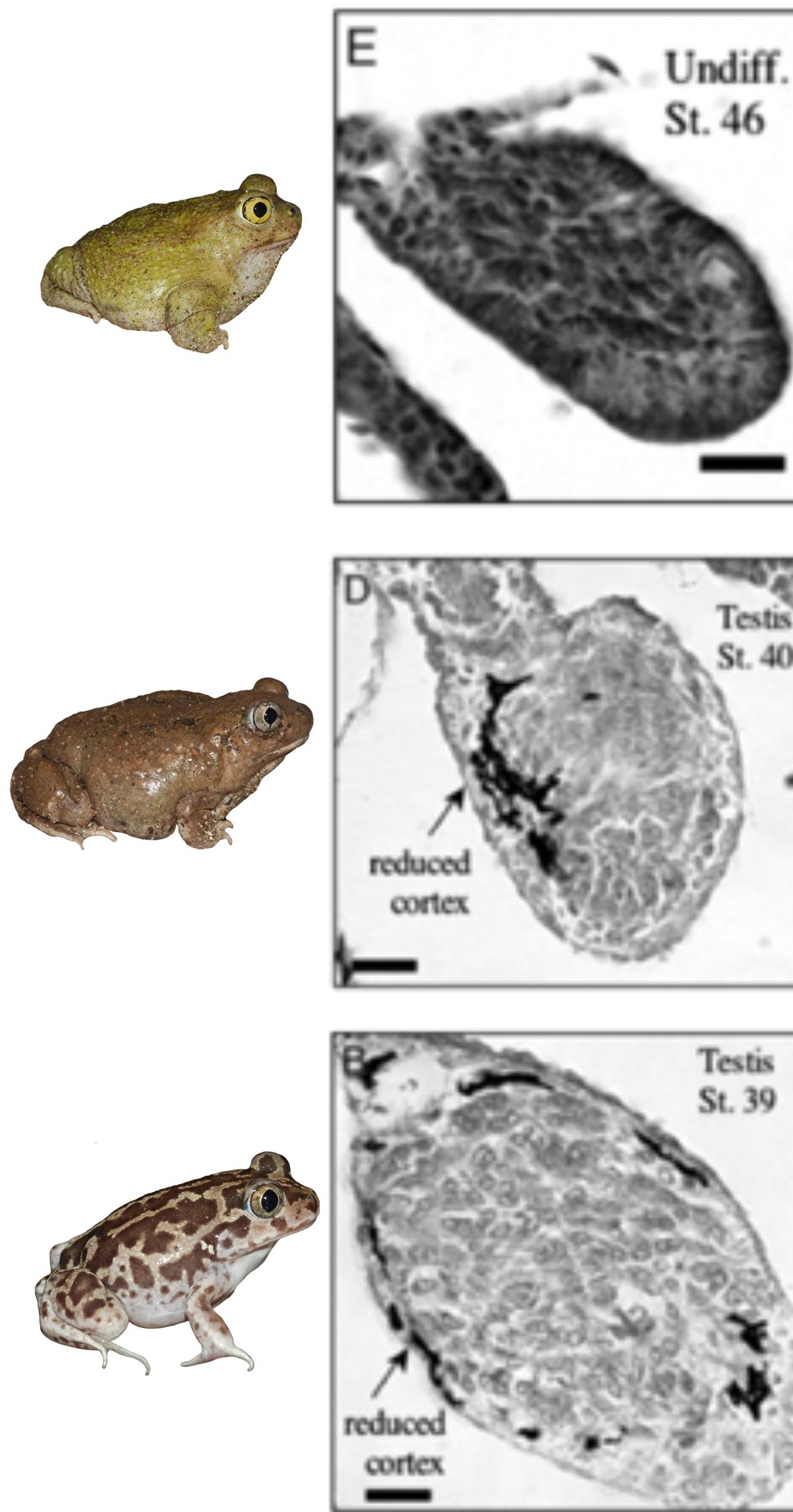
# Within-species plasticity mirrors among-species differences



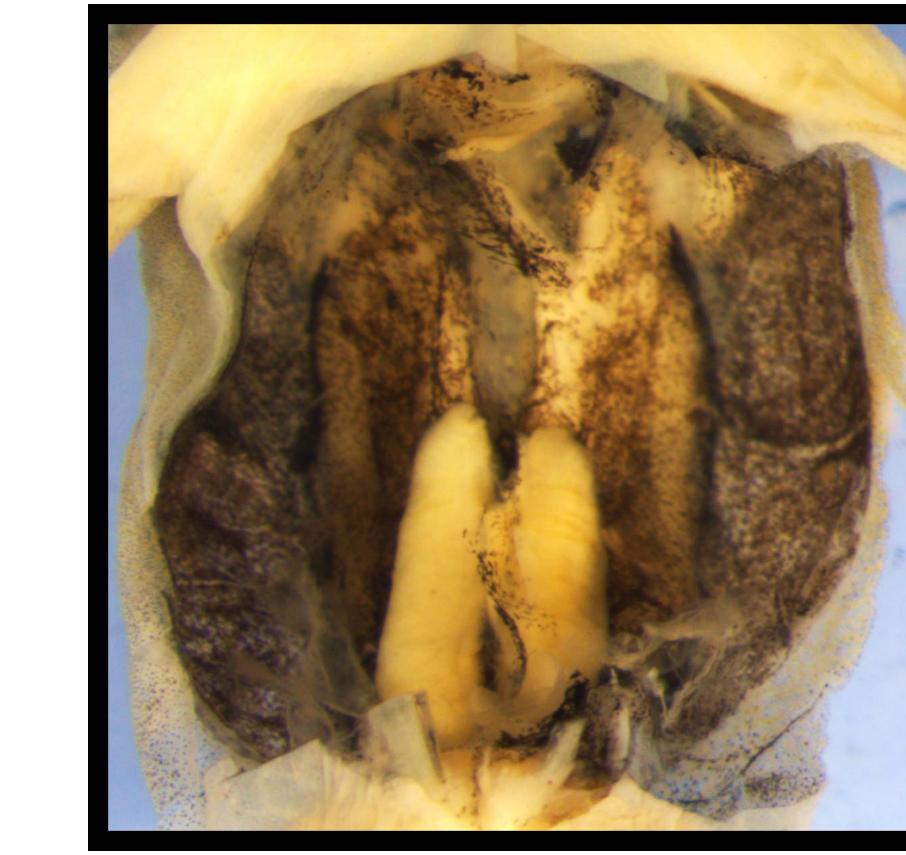
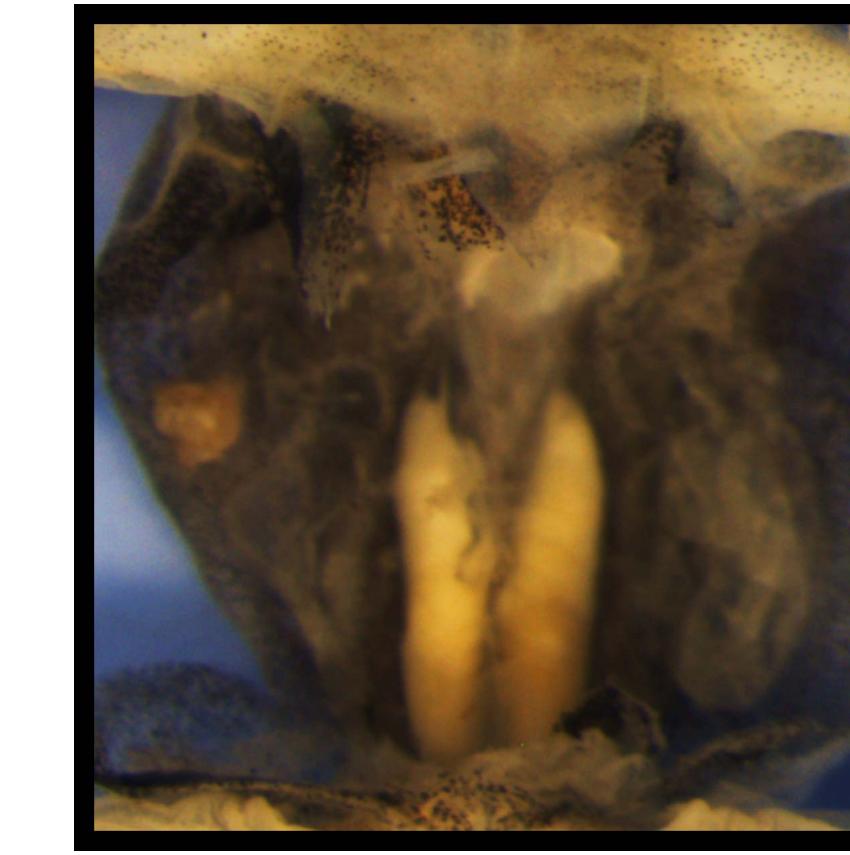
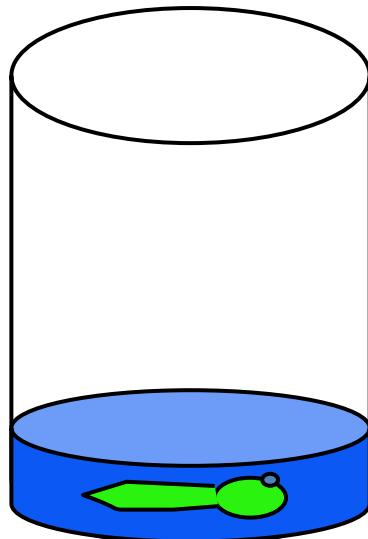
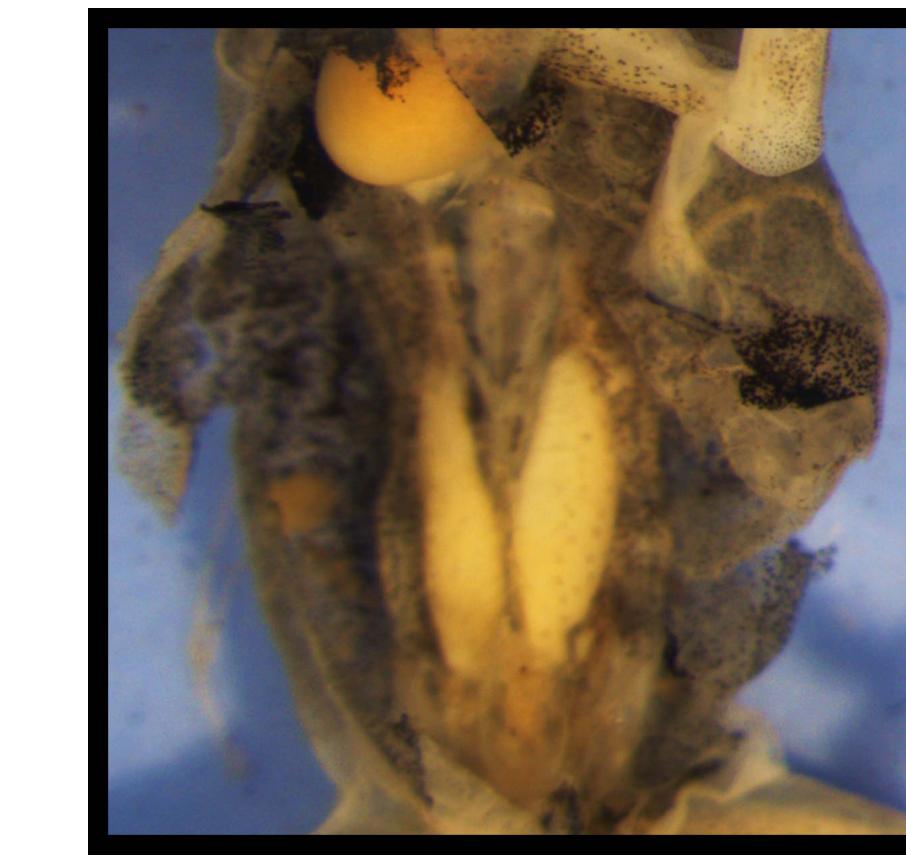
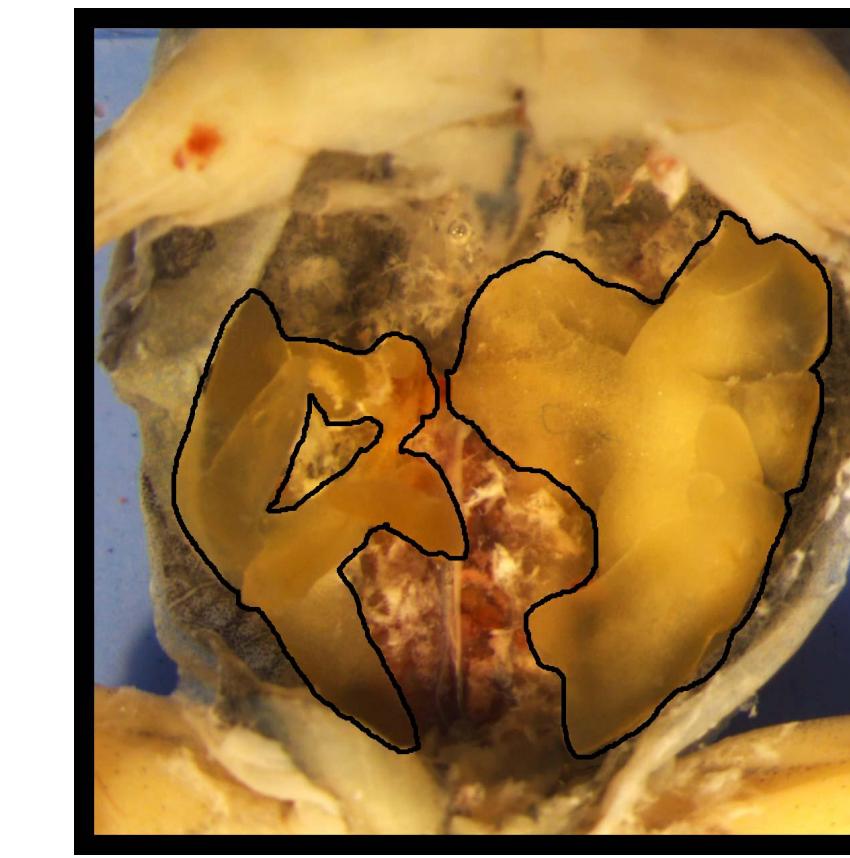
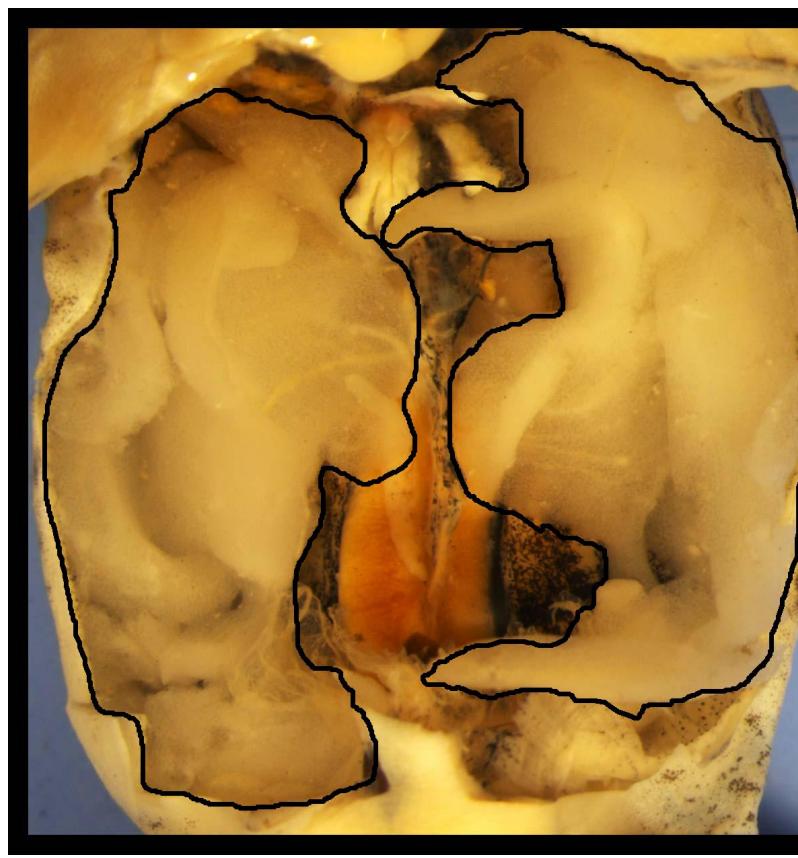
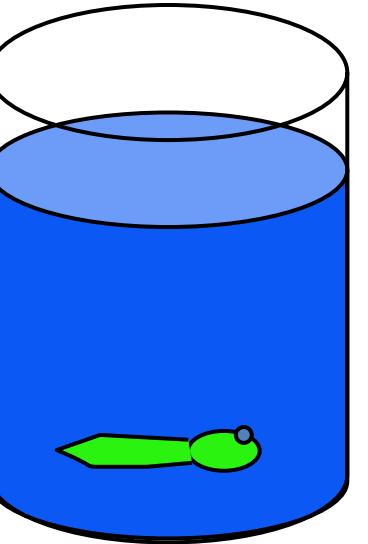
# Within-species plasticity mirrors among-species differences



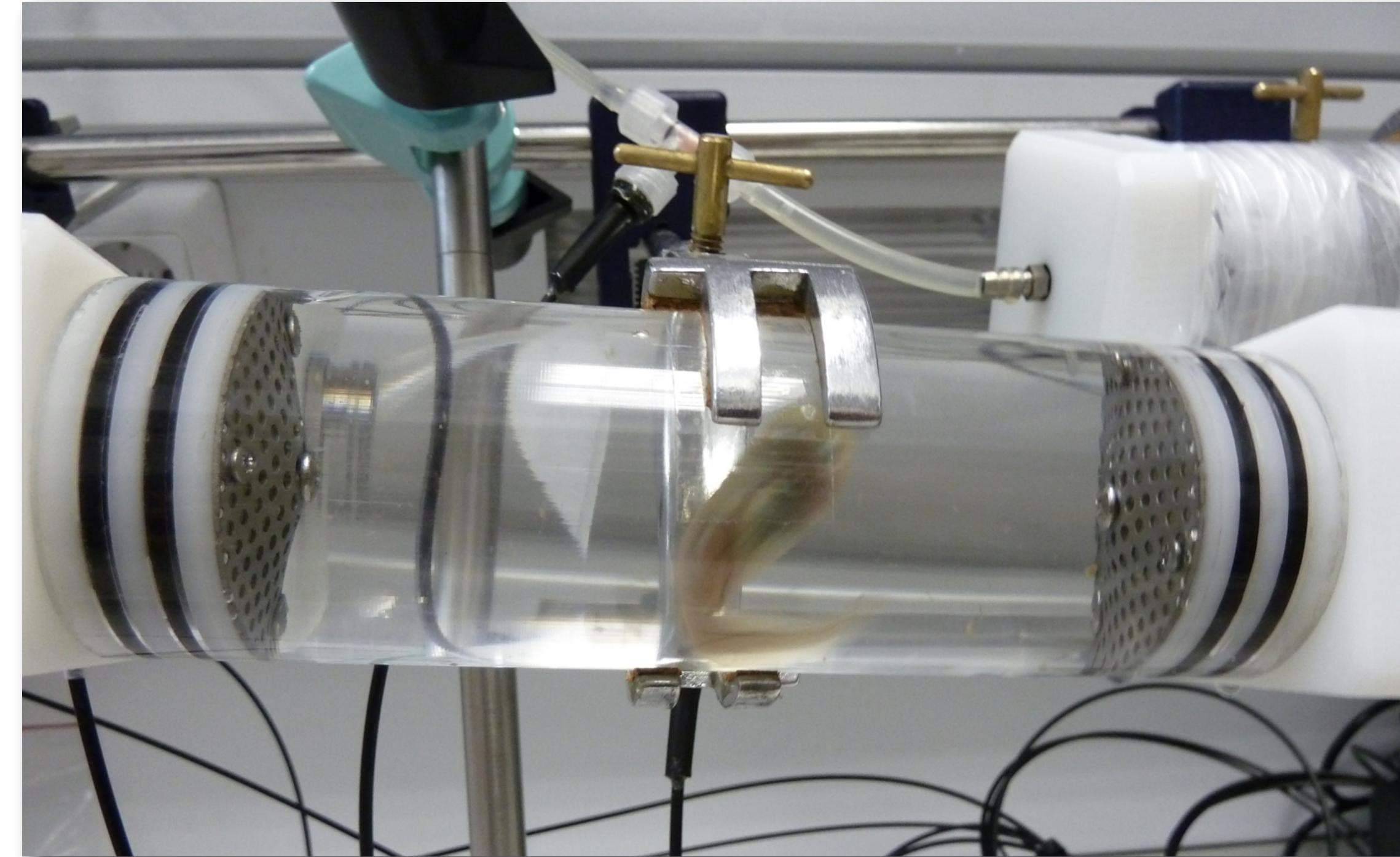
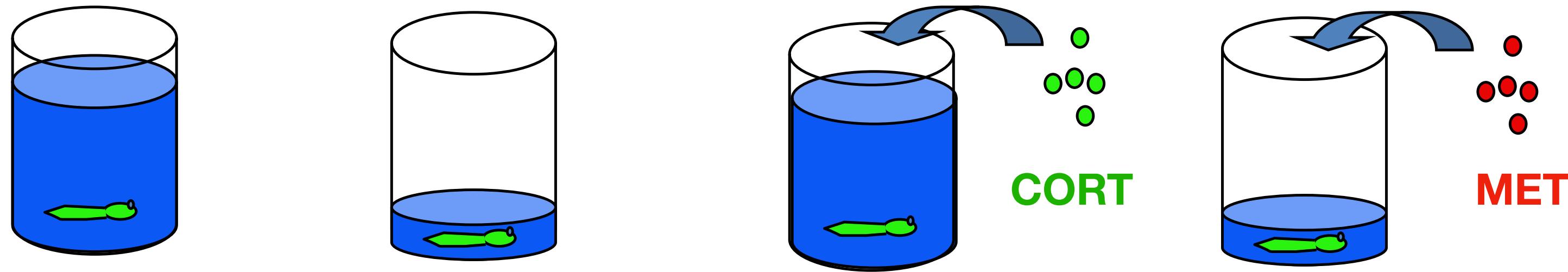
# Within-species plasticity mirrors among-species differences



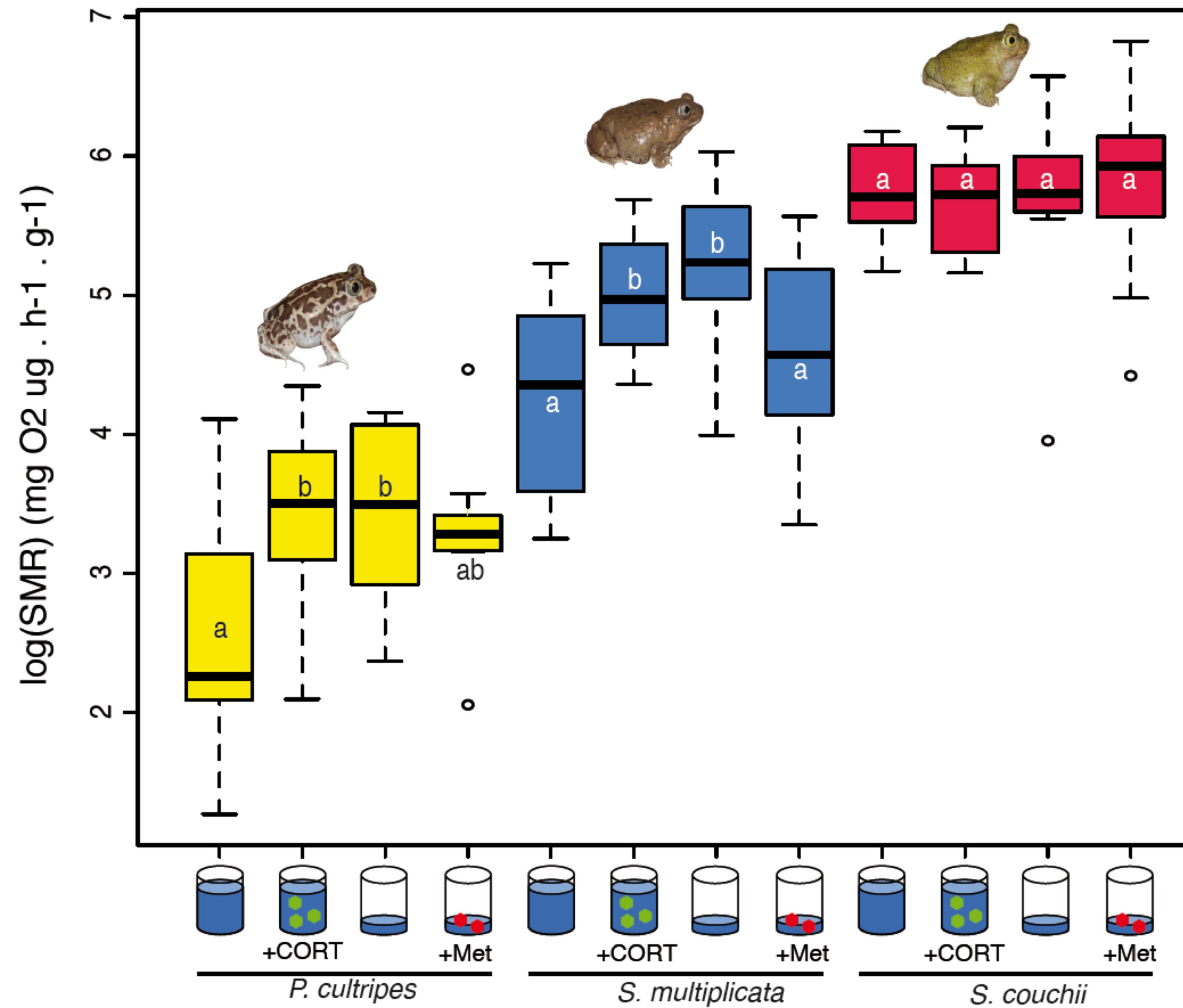
# Within-species plasticity mirrors among-species differences



# How does metabolic rate vary within and among species?



# How does metabolic rate vary within and among species?

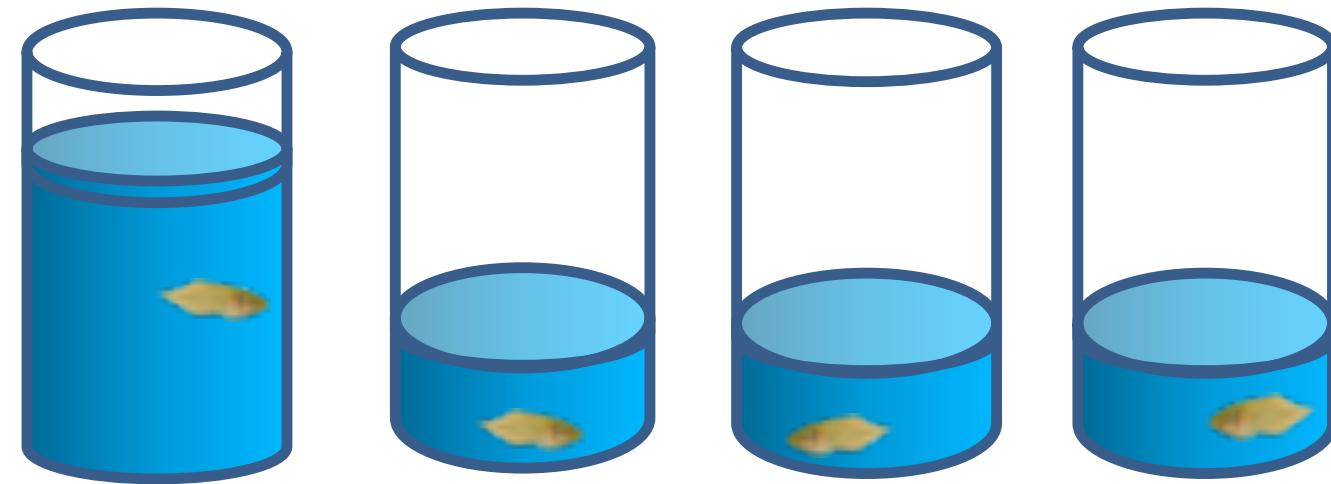


# How does gene expression vary in response to water level?

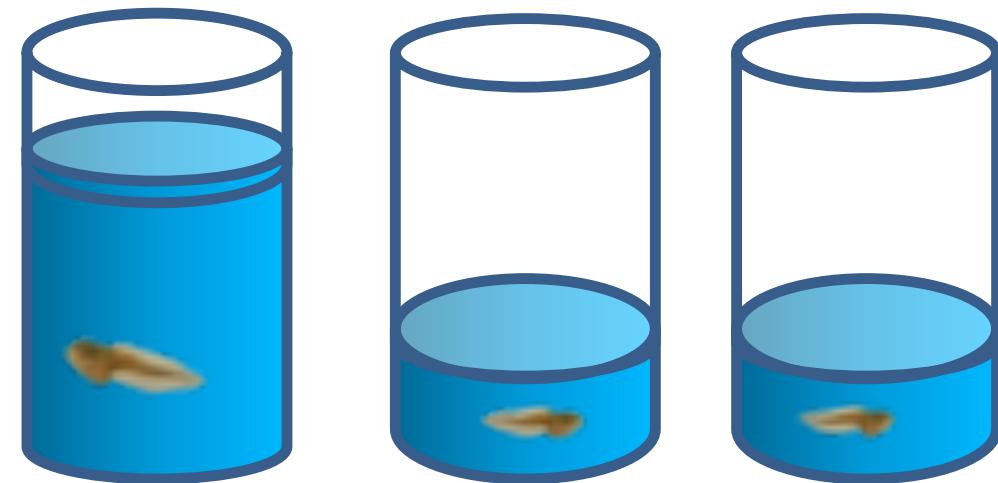
control 24h 48h 72h



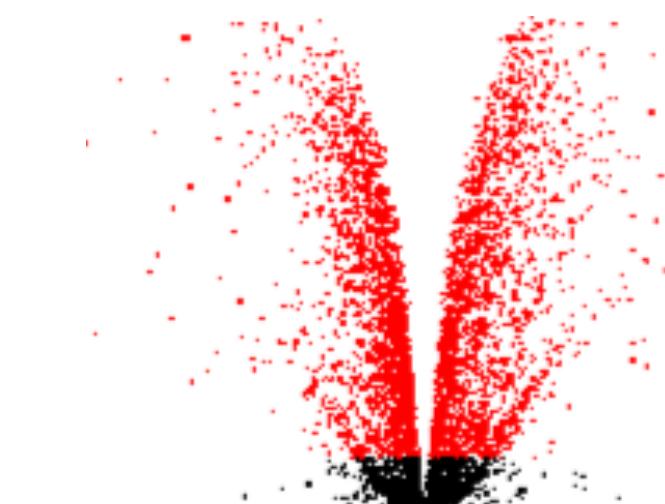
**Pelobates**



**Scaphiopus**



- ✖ Standardized conditions
- ✖ Control + 2 or 3 treatments
- ✖ 3 biological replicates
  
- ✖ Total RNA extraction from whole body
- ✖ Illumina (HiSeq2000) ~30 mil. reads per sample
  
- ✖ *De novo* transcriptome assembly and annotation using Trinity + Trinotate
- ✖ Differential expression analysis using Kallisto and EdgeR + GOseq



ARTICLES

<https://doi.org/10.1038/s41559-020-1202-x>

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# Nutrition-responsive gene expression and the developmental evolution of insect polyphenism

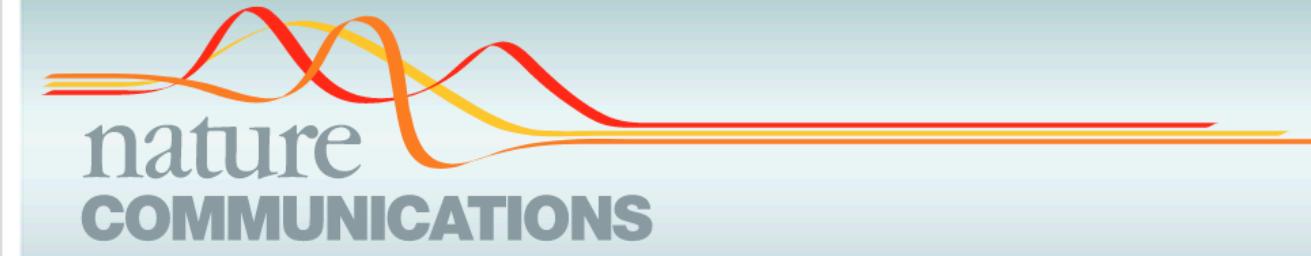
Sofia Casasa  <sup>1</sup>✉, Eduardo E. Zattara  <sup>1,2</sup>✉ and Armin P. Moczek  <sup>1</sup>

ORIGINAL ARTICLE

## Cross-species transcriptomics uncovers genes underlying genetic accommodation of developmental plasticity in spadefoot toads

Hans Christoph Liedtke<sup>1</sup> | Ewan Harney<sup>2</sup> | Ivan Gomez-Mestre<sup>1</sup> 

MOLECULAR ECOLOGY WILEY

  
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## ARTICLE

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## Transcriptomic and macroevolutionary evidence for phenotypic uncoupling between frog life history phases

Katharina C. Wollenberg Valero<sup>1,†</sup>, Joan Garcia-Porta<sup>2</sup>, Ariel Rodríguez<sup>3,†</sup>, Mónica Arias<sup>4,5,\*</sup>,  
<sup>1,4,6,\*</sup>, Roger Daniel Randrianaaina<sup>3,7,\*</sup>, Jason L. Brown<sup>8</sup>, Frank Glaw<sup>9</sup>,  
Sven Künzel<sup>11</sup>, Dirk Metzler<sup>4</sup>, Raphael D. Isokpehi<sup>1</sup> & Miguel Vences<sup>3</sup>

