

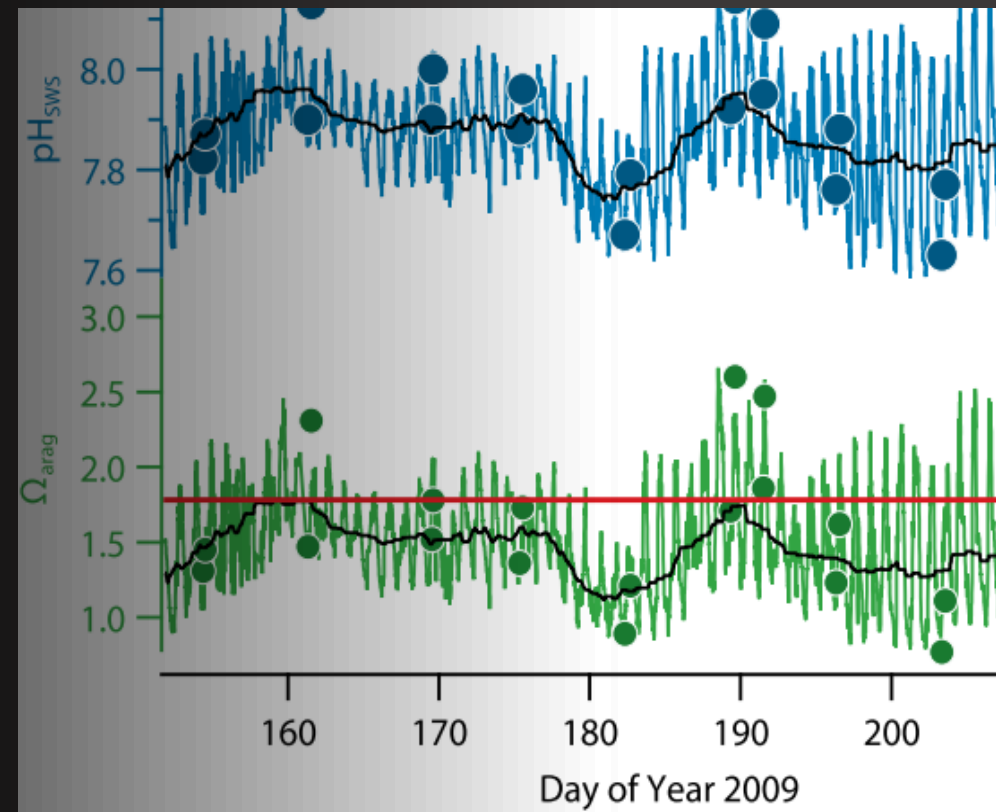
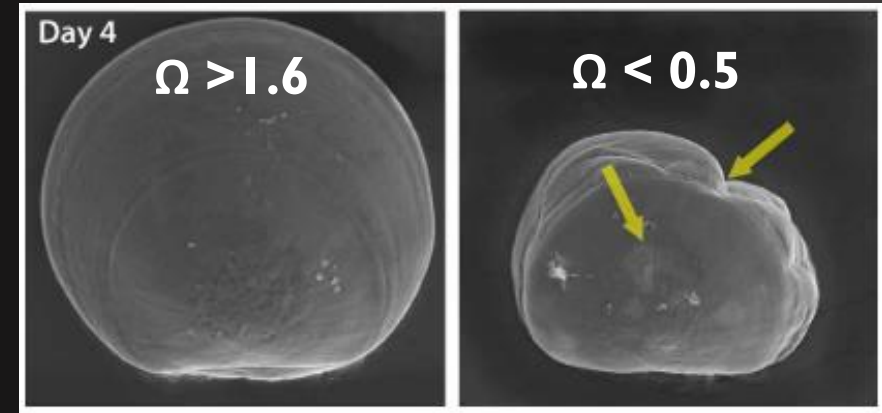


‘ENVIRONMENTAL LEARNING’ IN A TOLERANT COMMERCIAL CLAM; INSIGHTS FROM PHENOTYPIC AND SUBCELLULAR ADJUSTMENTS TO HYPERCAPNIC SEAWATER

Samuel J. Gurr*, Shelly A. Trigg, Brent Vadopalas, Steven B. Roberts, Hollie M. Putnam

12-minute talk

Problem:
“Pacific Northwest
seedstock crisis”



OA Remediation: The Seawater

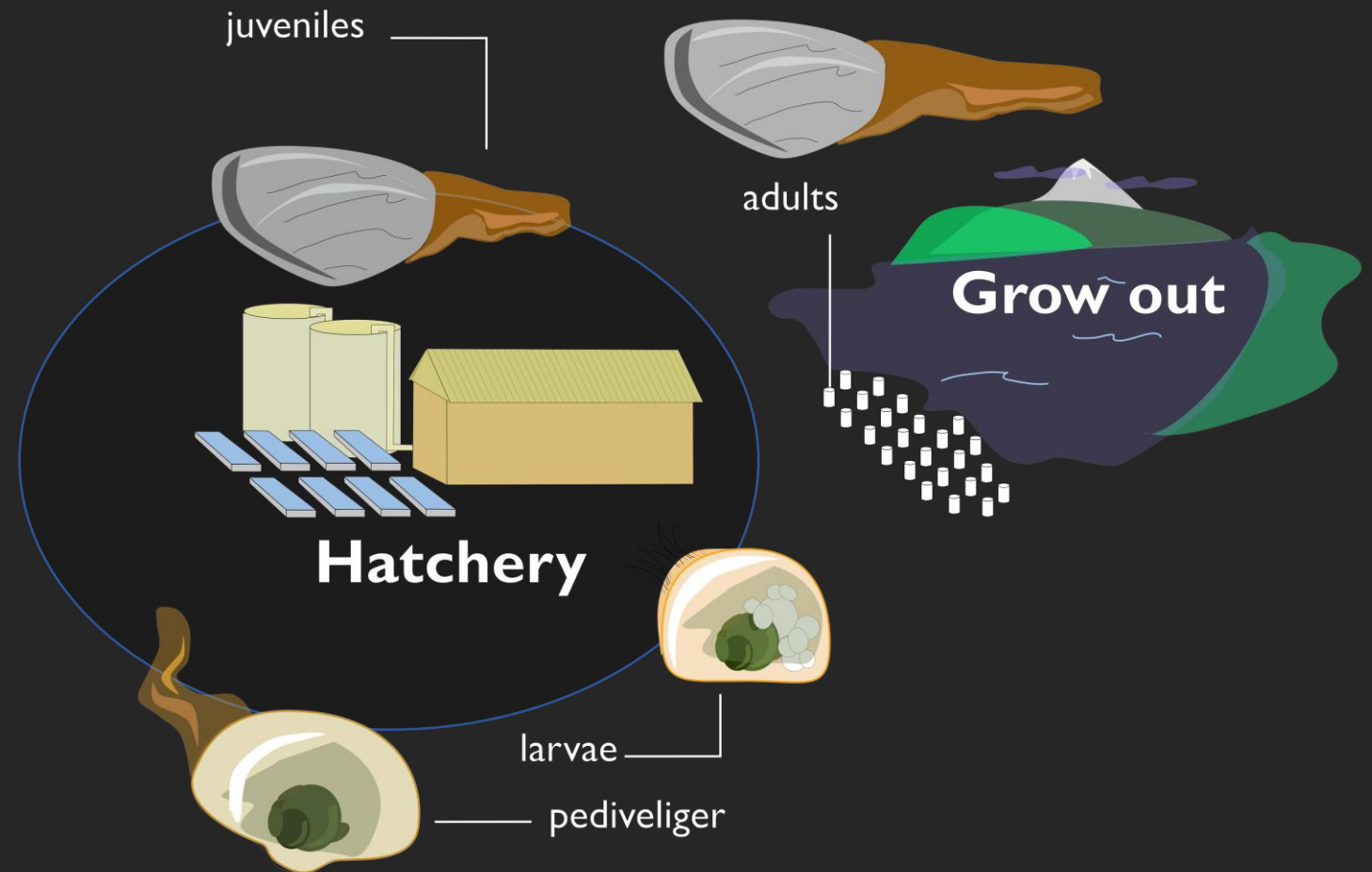
Chemical buffering (i.e. sodium bicarbonate)

Pros

- common in hatchery practice
- increases production 30-50%

Cons

- beneficial in the **short-term**
- expensive/labor intensive



Barton *et al.* 2012 & 2015

Washington State Blue Ribbon Panel on Ocean Acidification, 2012

OA Remediation: The Seawater

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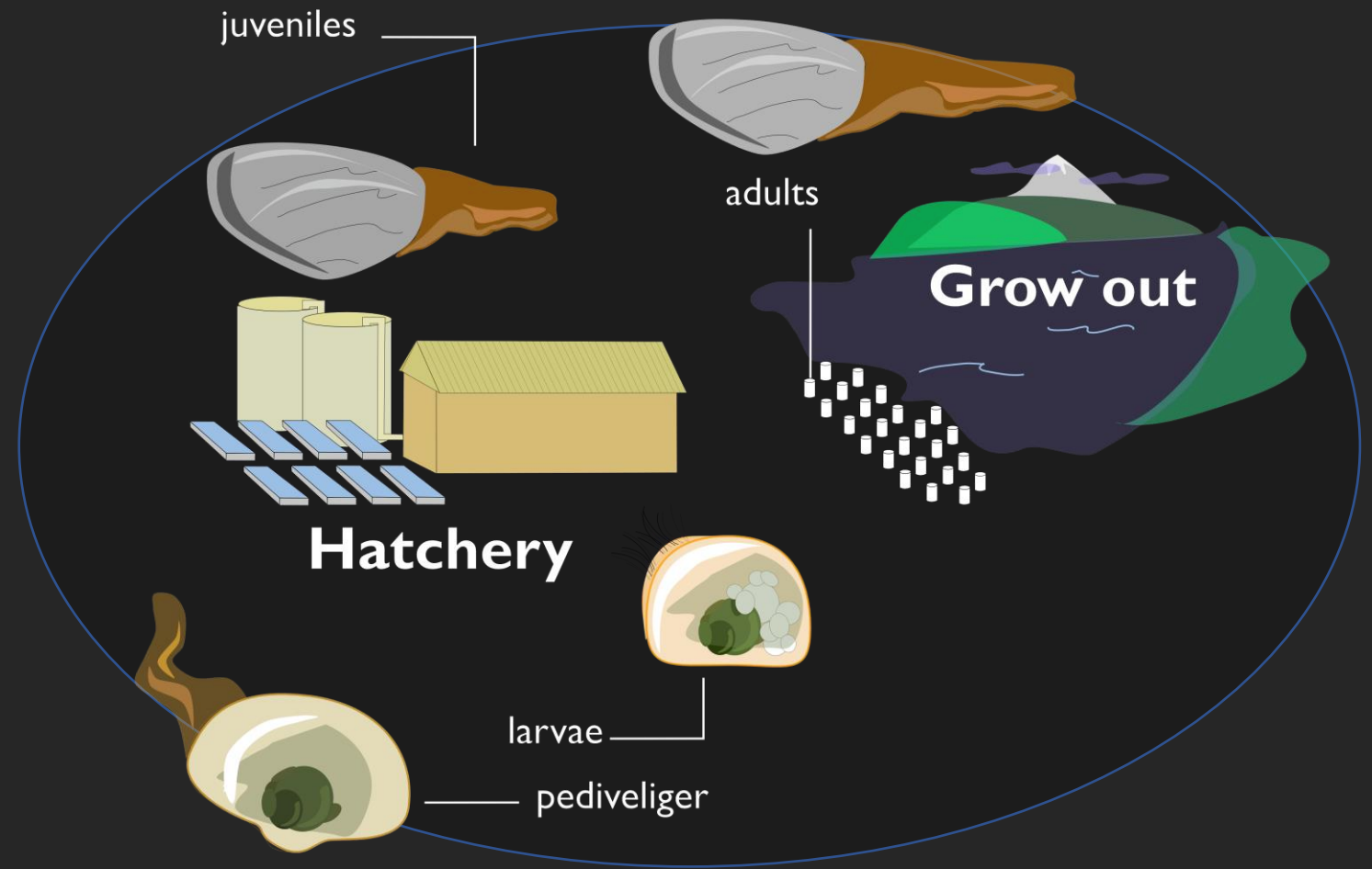


OA Remediation: The Animals

Adaptive potential

Stress conditioning

Priming with sub-lethal exposure(s) to increase stress-resilience and performance under a **subsequent encounter**



Adaptive potential: **Hormetic priming**

Adaptive potential

Stress conditioning

Priming with sub-lethal exposure(s) to increase stress-resilience and performance under a **subsequent encounter**



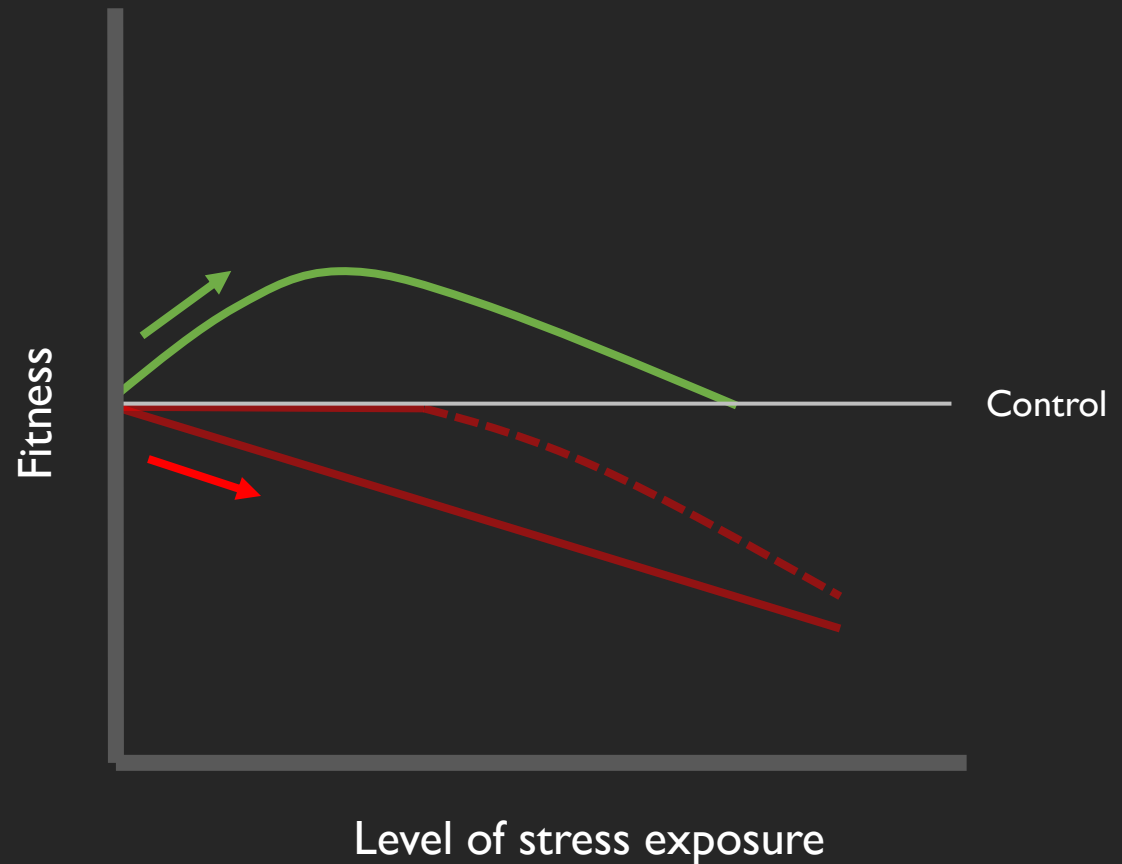
Adaptive potential: **Hormetic priming**

Adaptive potential

Stress conditioning

Priming with sub-lethal exposure(s) to increase stress-resilience and performance under a **subsequent encounter**

Initial stress encounter



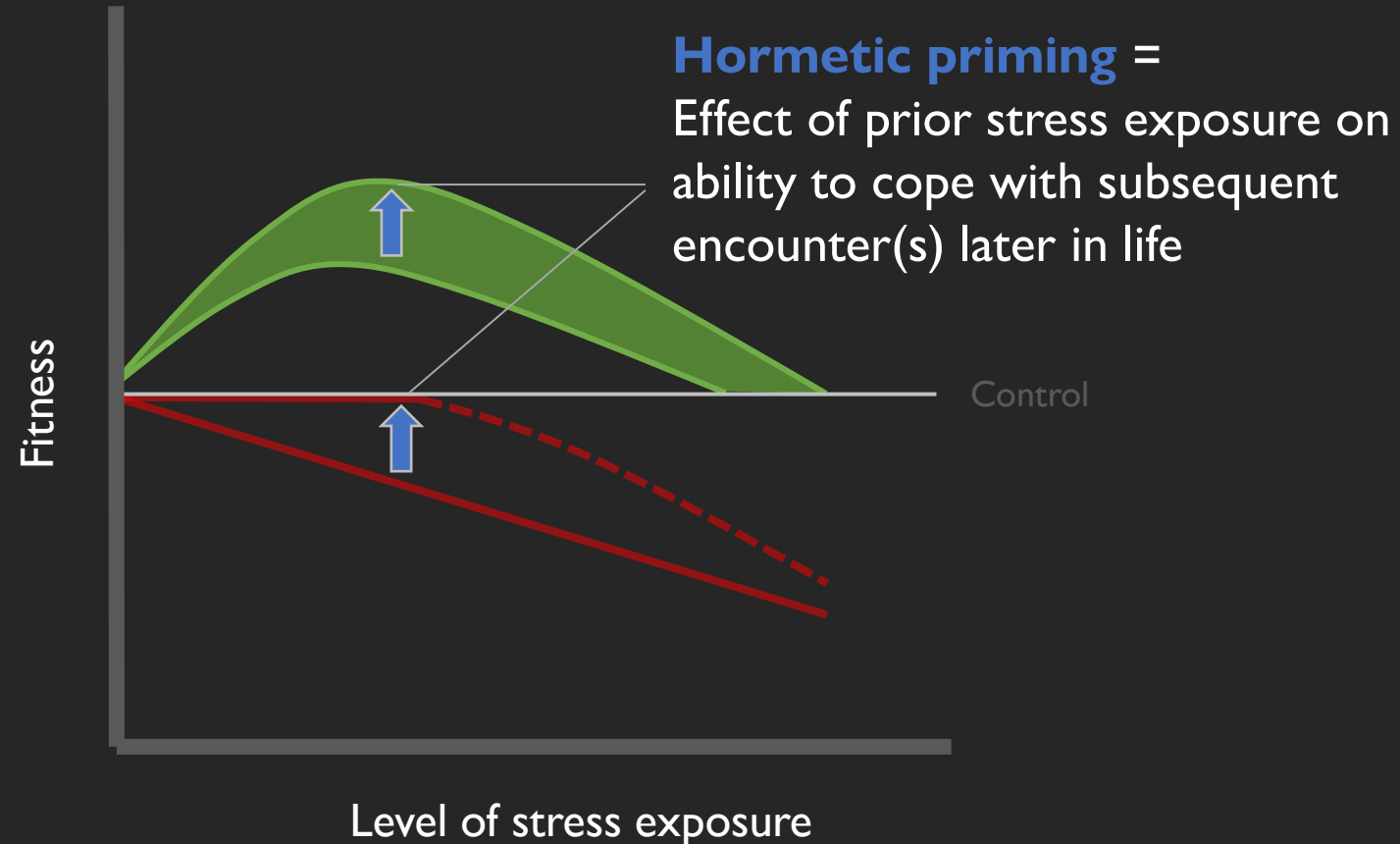
Adaptive potential: **Hormetic priming**

Adaptive potential

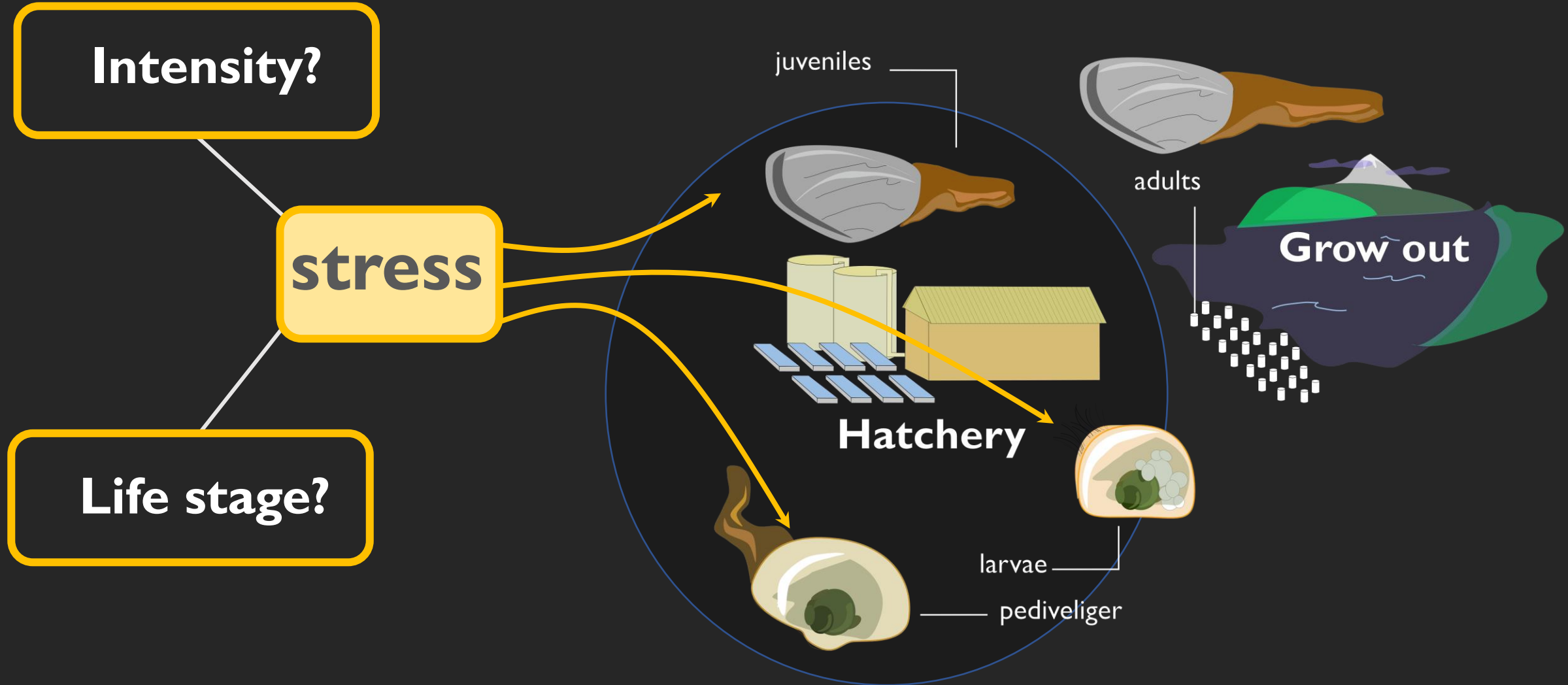
Stress conditioning

Priming with sub-lethal exposure(s) to increase stress-resilience and performance under a **subsequent encounter**

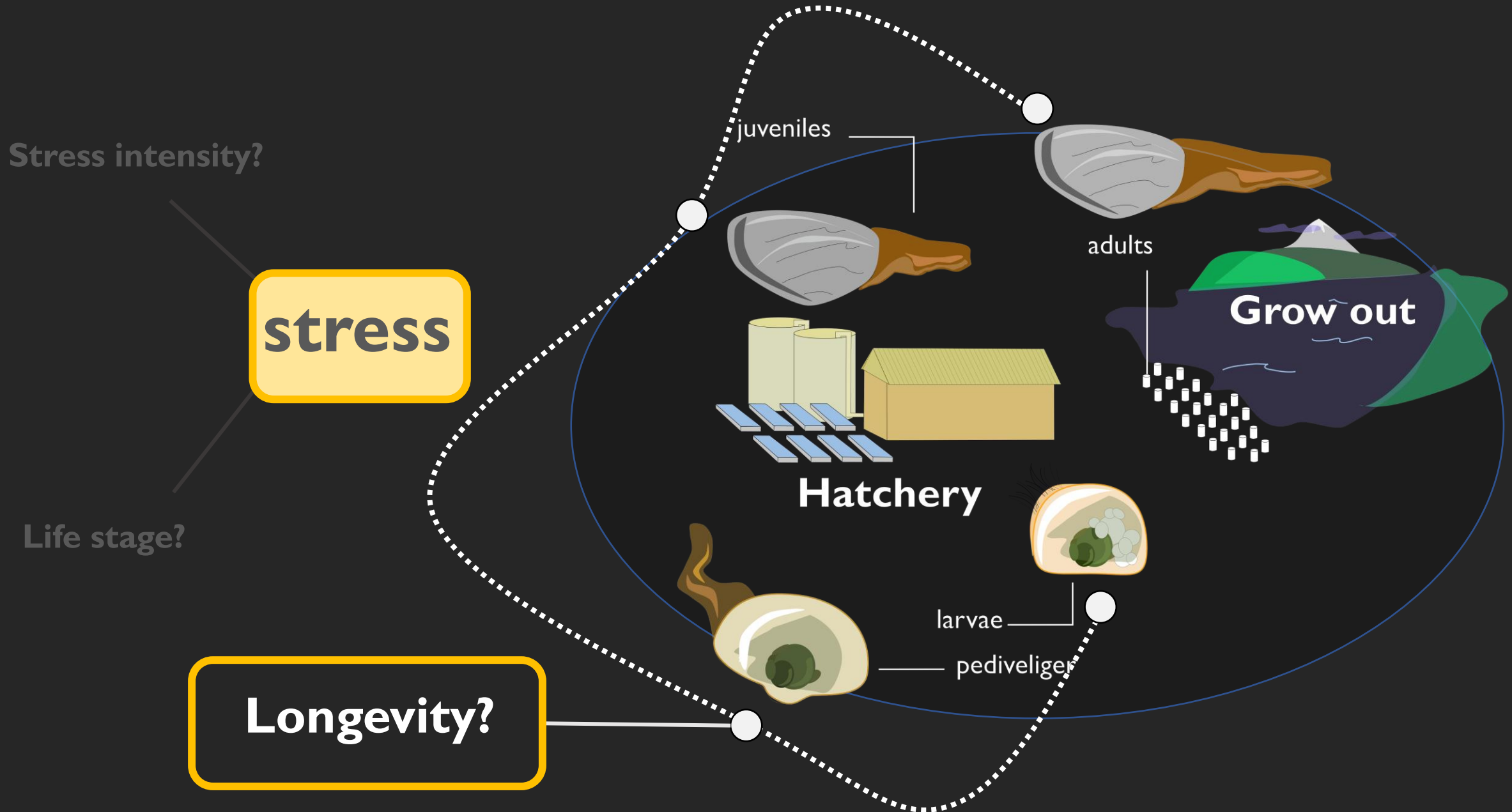
Subsequent stress encounter



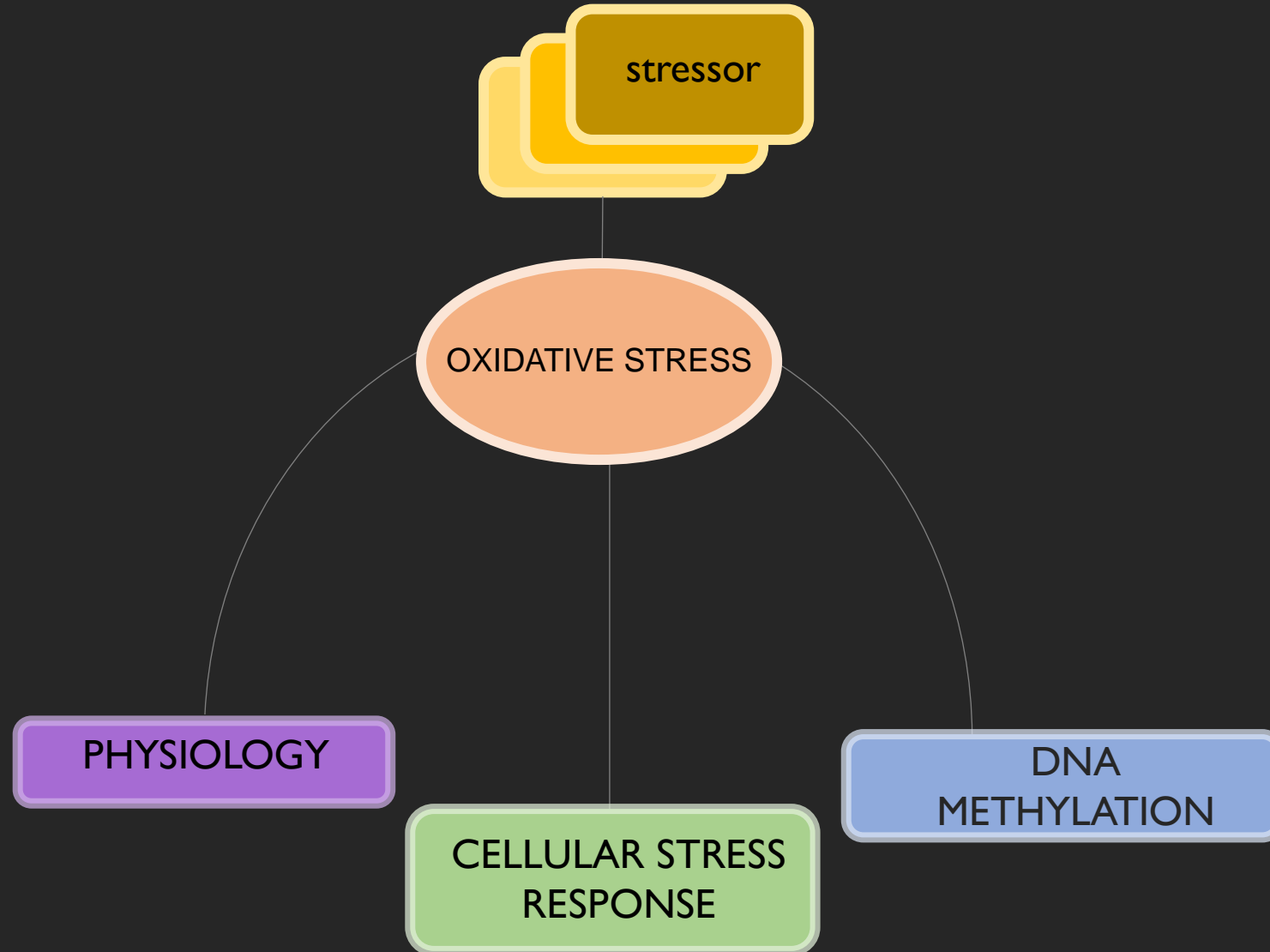
Applied in geoduck aquaculture



Applied in geoduck aquaculture



Nodes to investigate 'learning'...



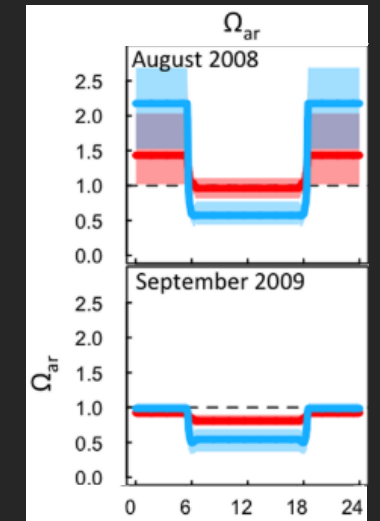
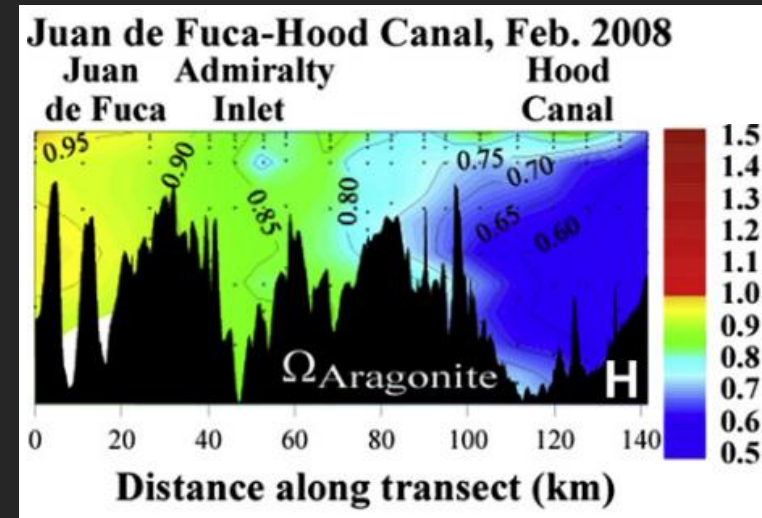
Nodes to investigate 'learning'...

stressor

- magnitude
- duration
- frequency

“Matched” stress can **elicit acclimation**

Relevance to dynamic environmental conditions

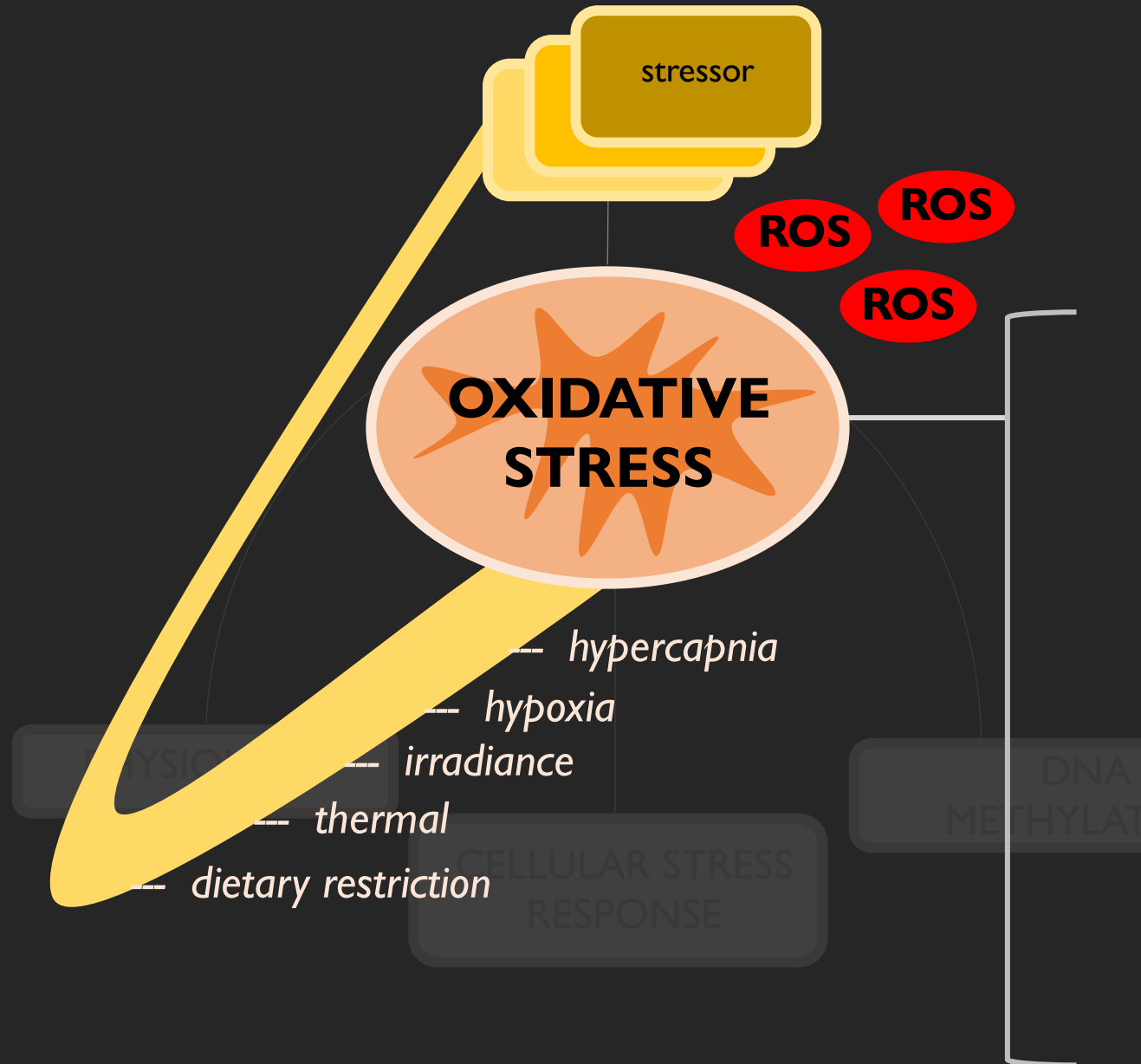


PHYSIOLOGY

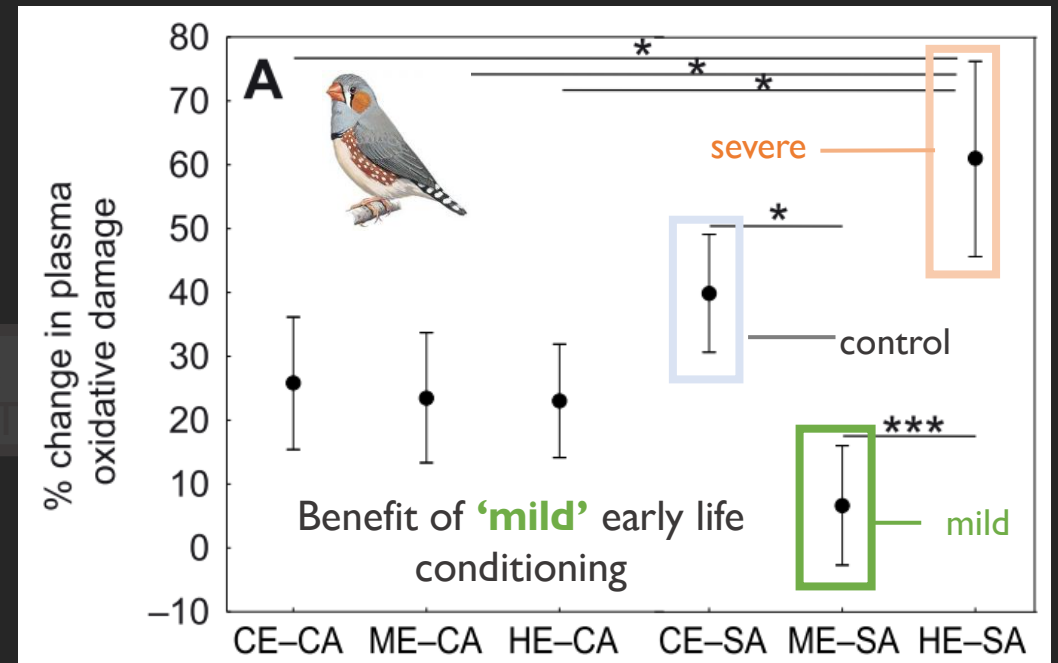
CELLULAR STRESS
RESPONSE

DNA
METHYLATION

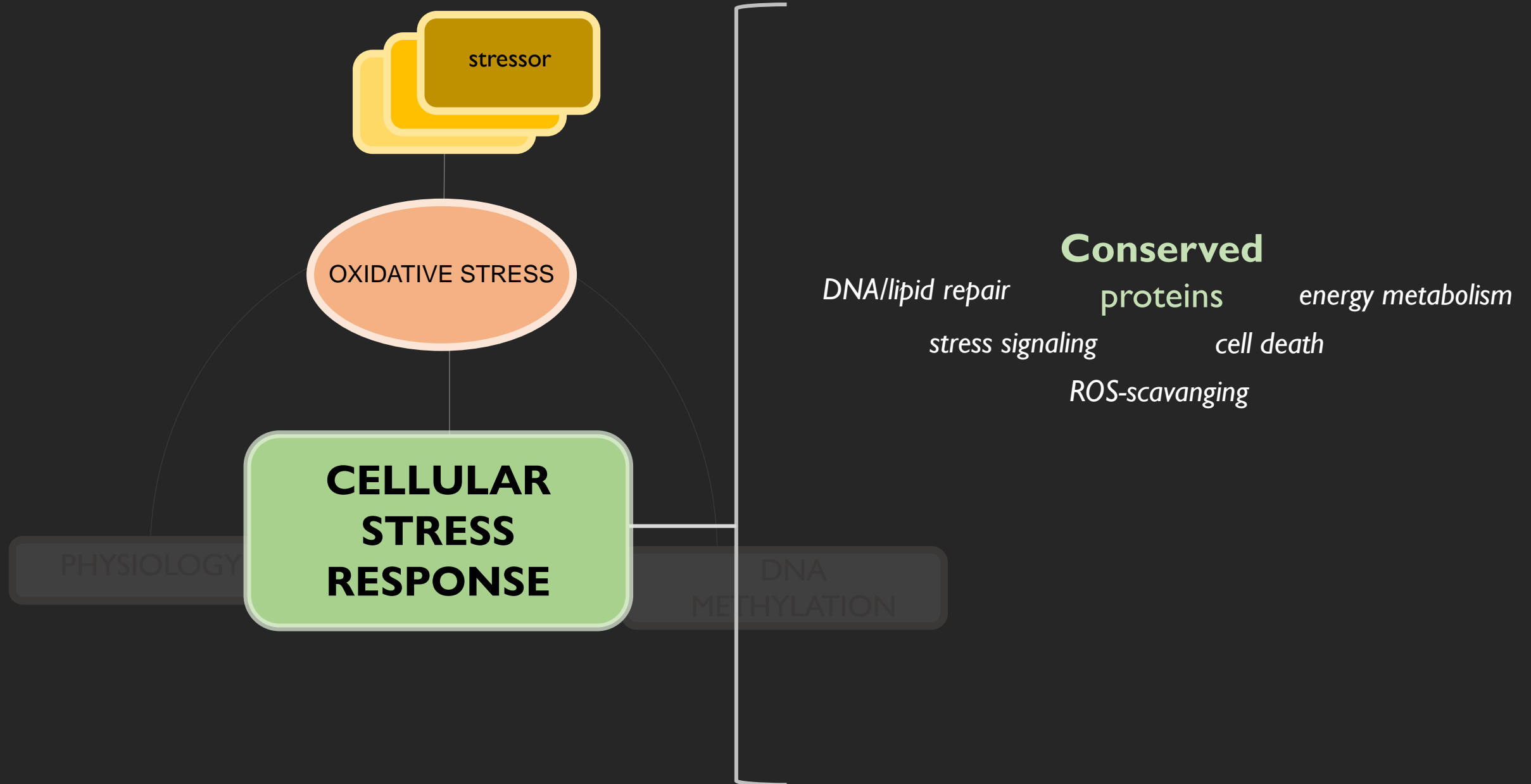
Nodes to investigate 'learning'...



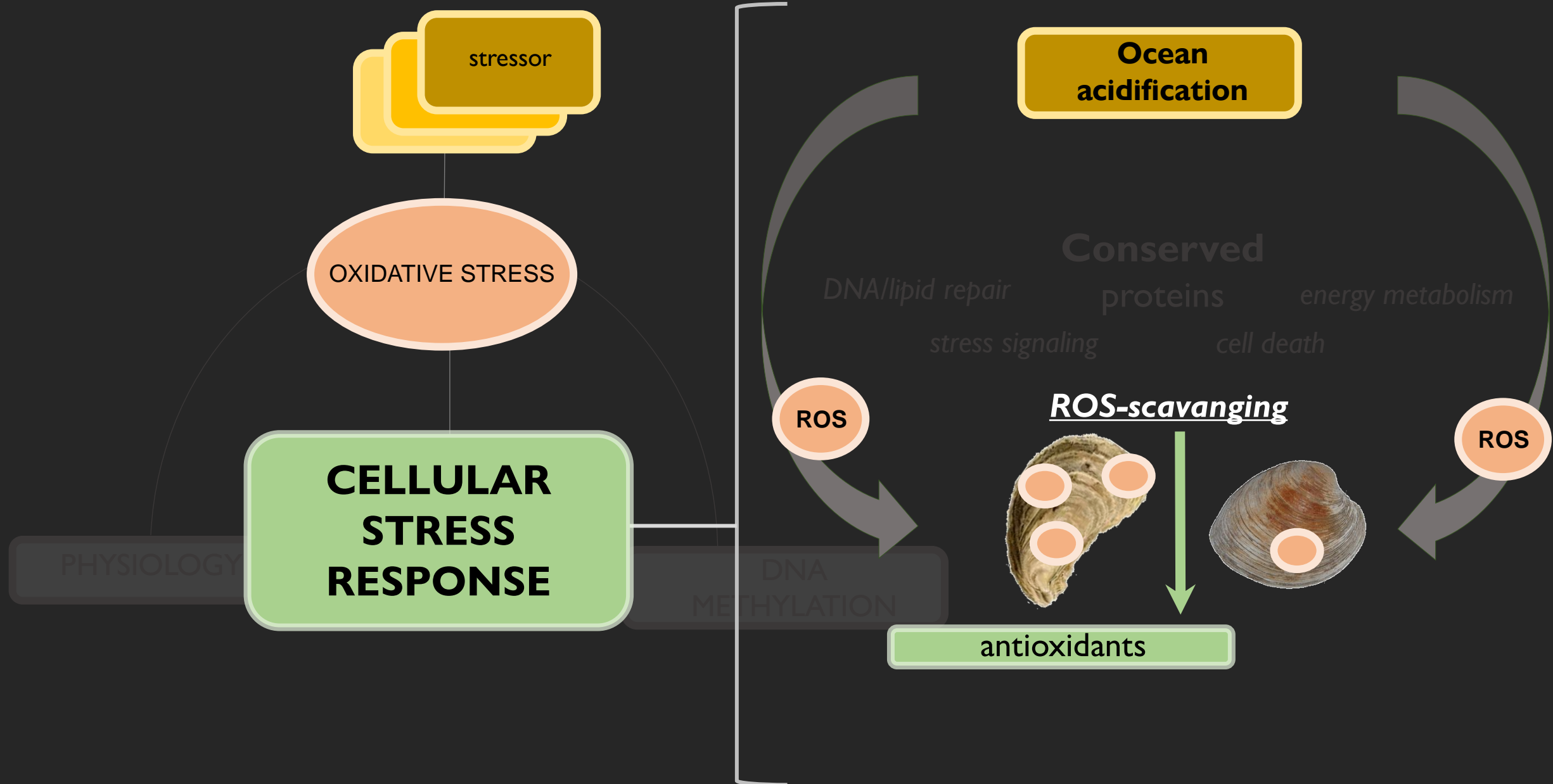
Driver of hormetic priming
Can be **beneficial** in **moderate** doses



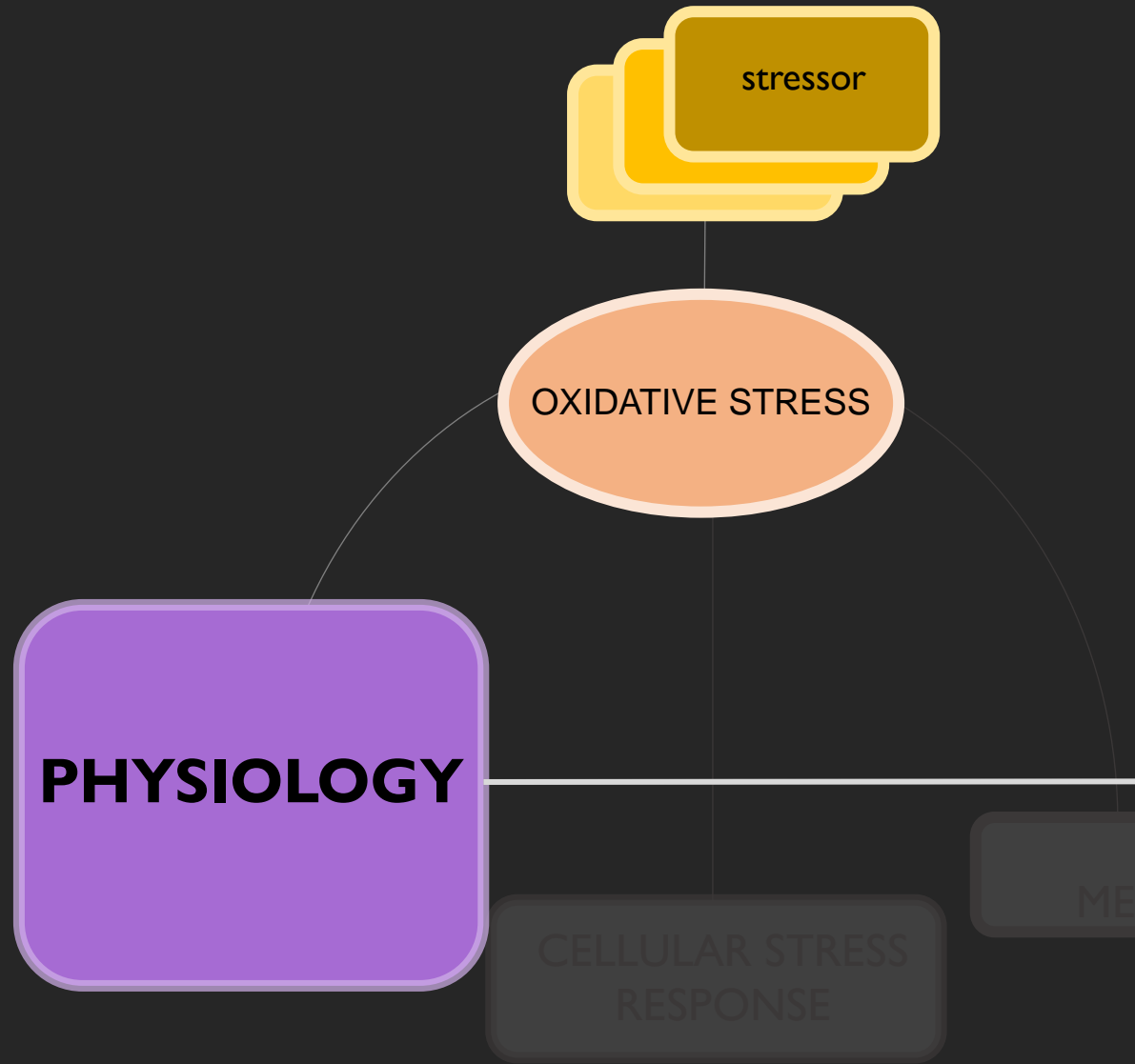
Nodes to investigate 'learning'...



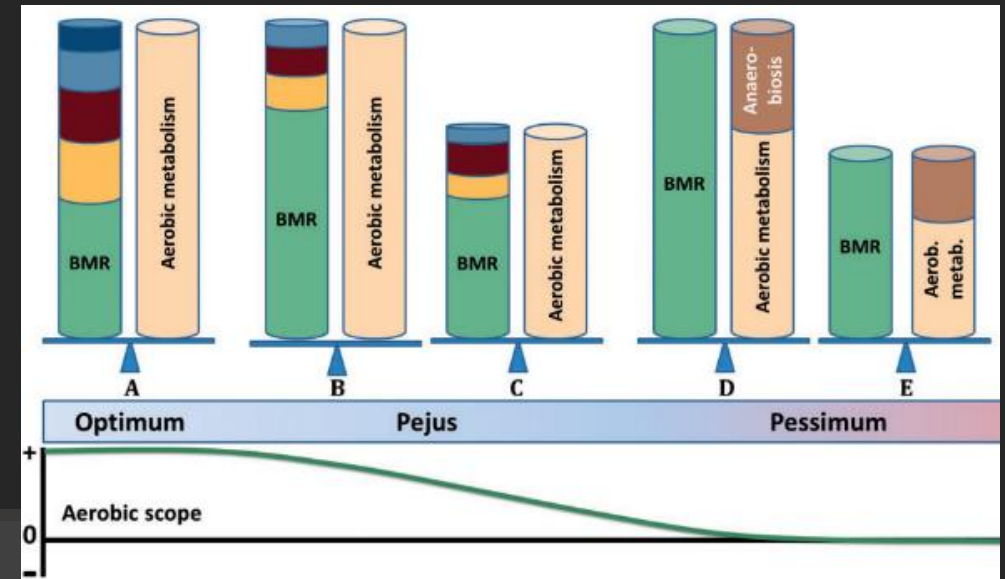
Nodes to investigate 'learning'...



Nodes to investigate 'learning'...

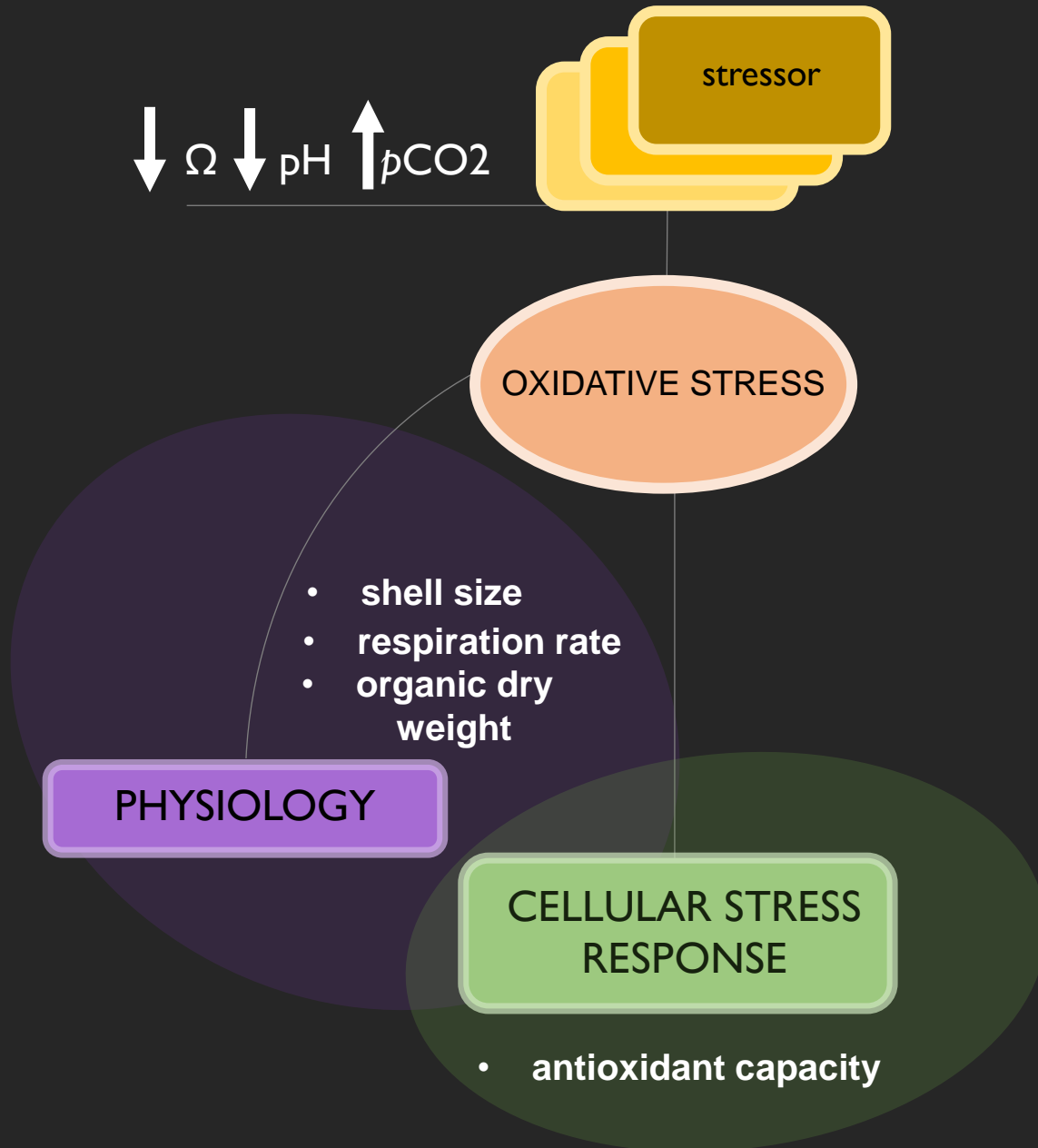


Integrative metrics
for energy partitioning & performance



Representative of **stress limitations**

Nodes to investigate 'learning'...



Questions:

Can **repeated stress** encounters **affect phenotype?**

What is the **timing** and **stress intensity** to elicit environmental learning?

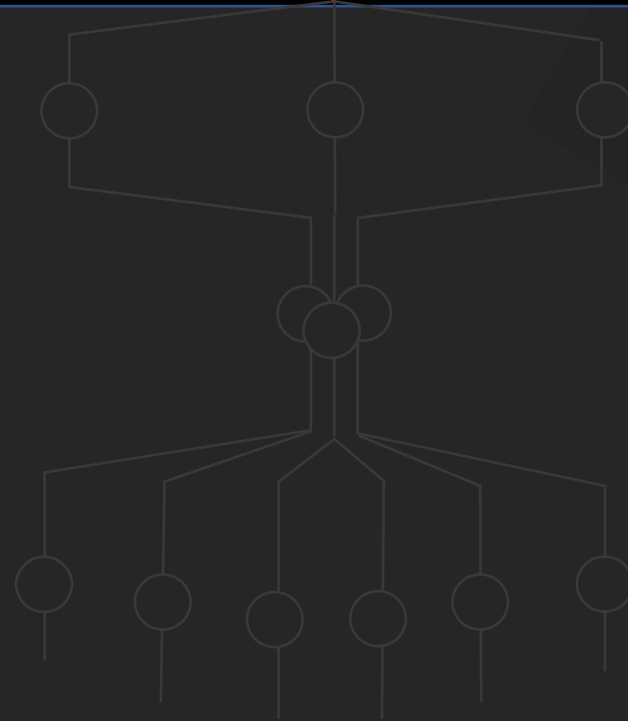
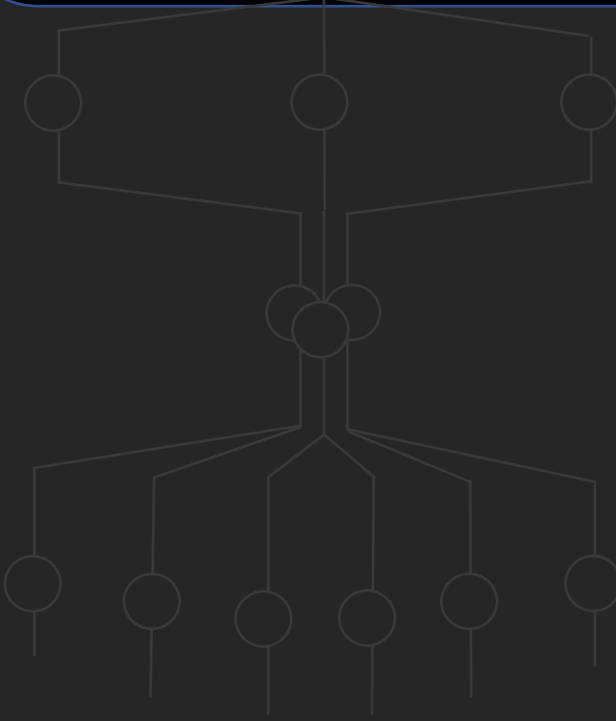
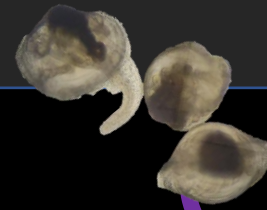


stressor
OA

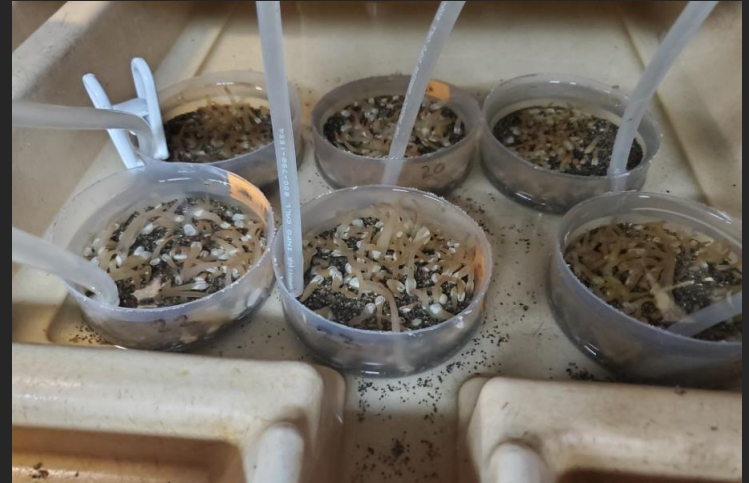
ambient
 $\Omega > 1$

moderate
 $\Omega 0.4$

**Primary
exposure**
110 days



stressor
OA



Second exposure
7 days

ambient
 $\Omega > 1$

moderate
 $\Omega 0.4$

severe
 $\Omega 0.1$

stressor
OA

Ambient recovery
7 days

stressor
OA



ambient

$\Omega > 1$

moderate

$\Omega 0.4$

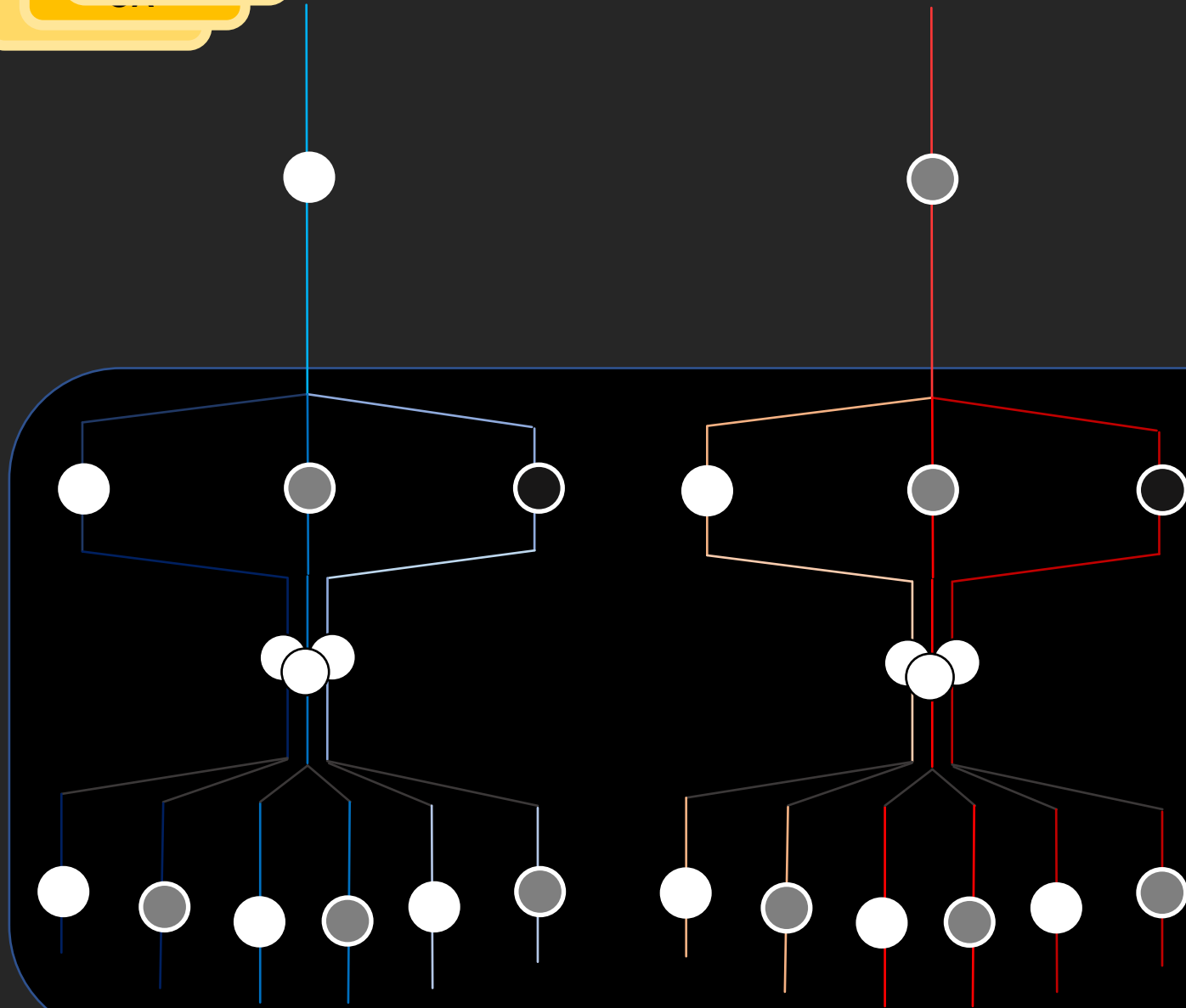
Third exposure
7 days

stressor
OA

21-d exposure period

RESPIRATION RATE
SHELL LENGTH
TISSUE BIOMASS

TOTAL
ANTIOXIDANT
CAPACITY

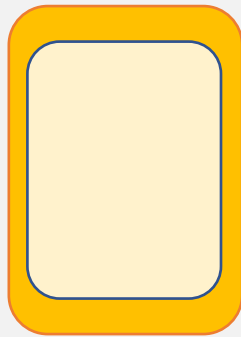


RESULTS

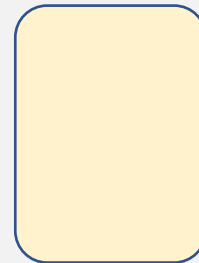
Schematic

Data

significant
effects

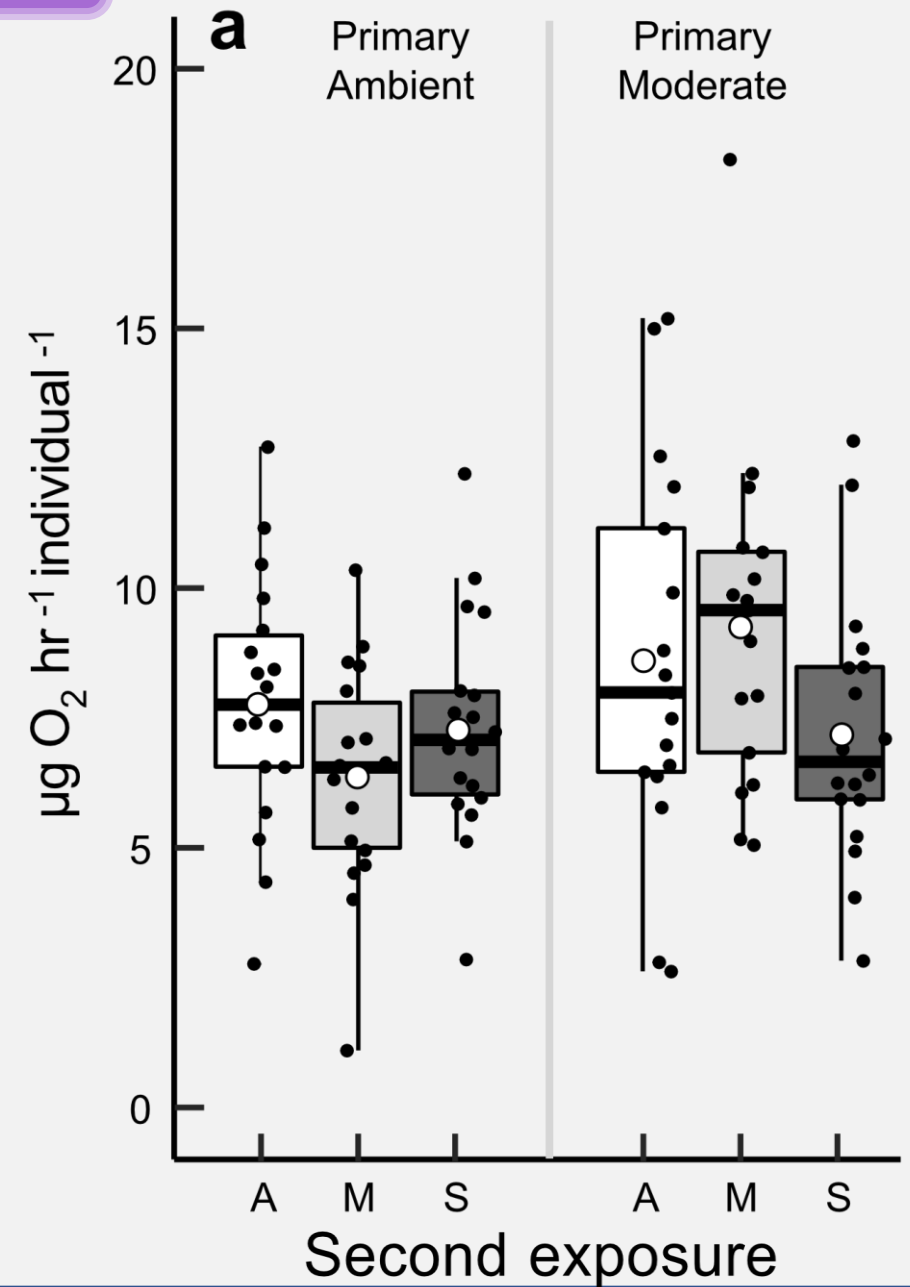


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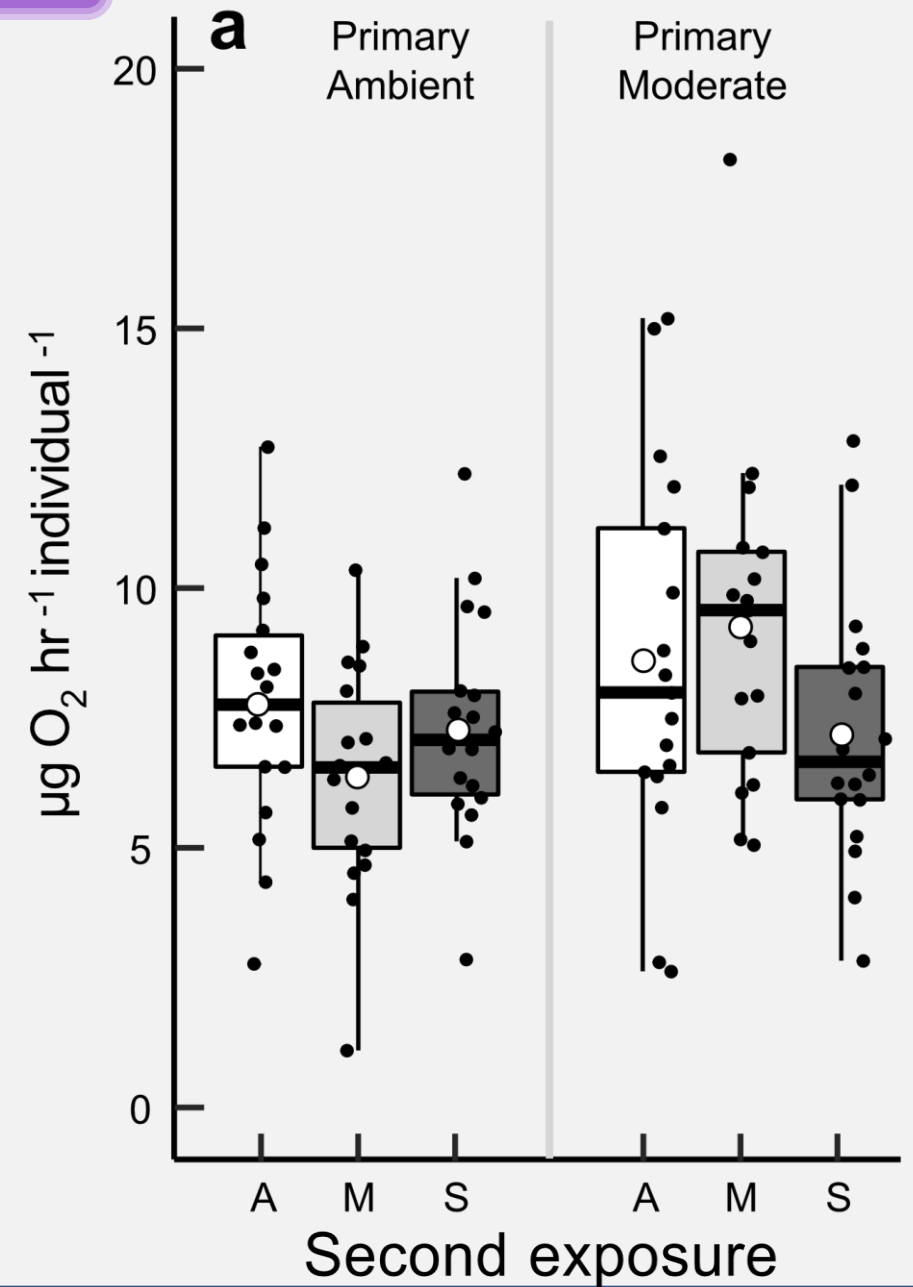
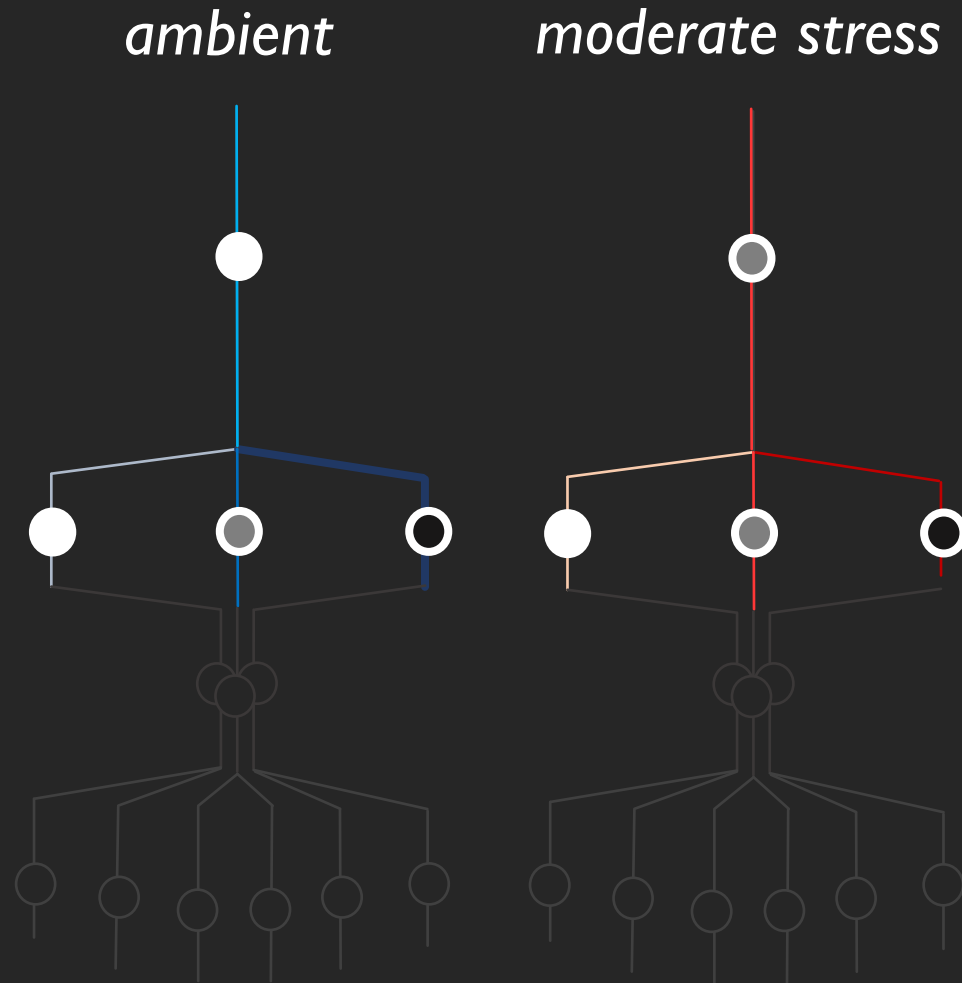
PHYSIOLOGY

Respiration rate



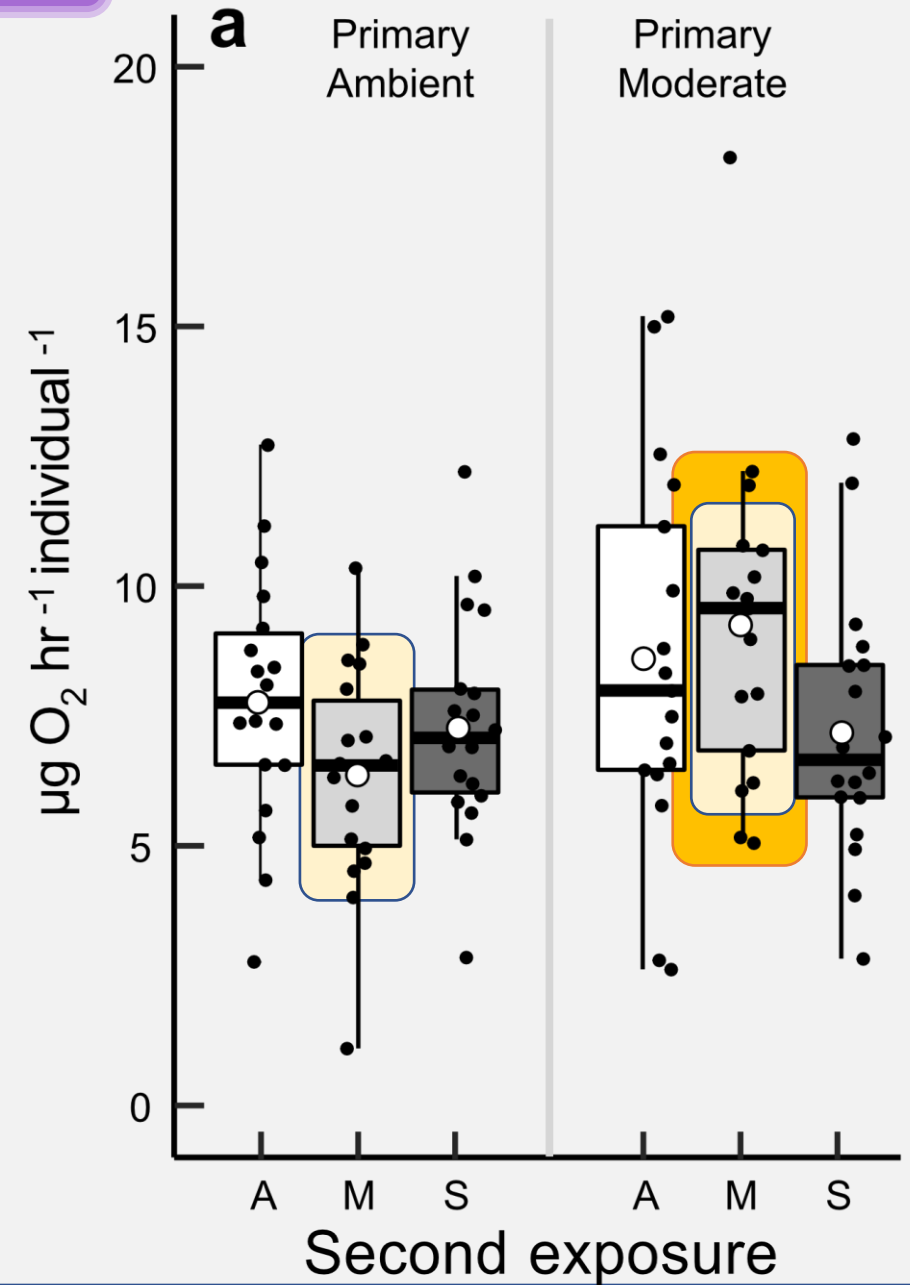
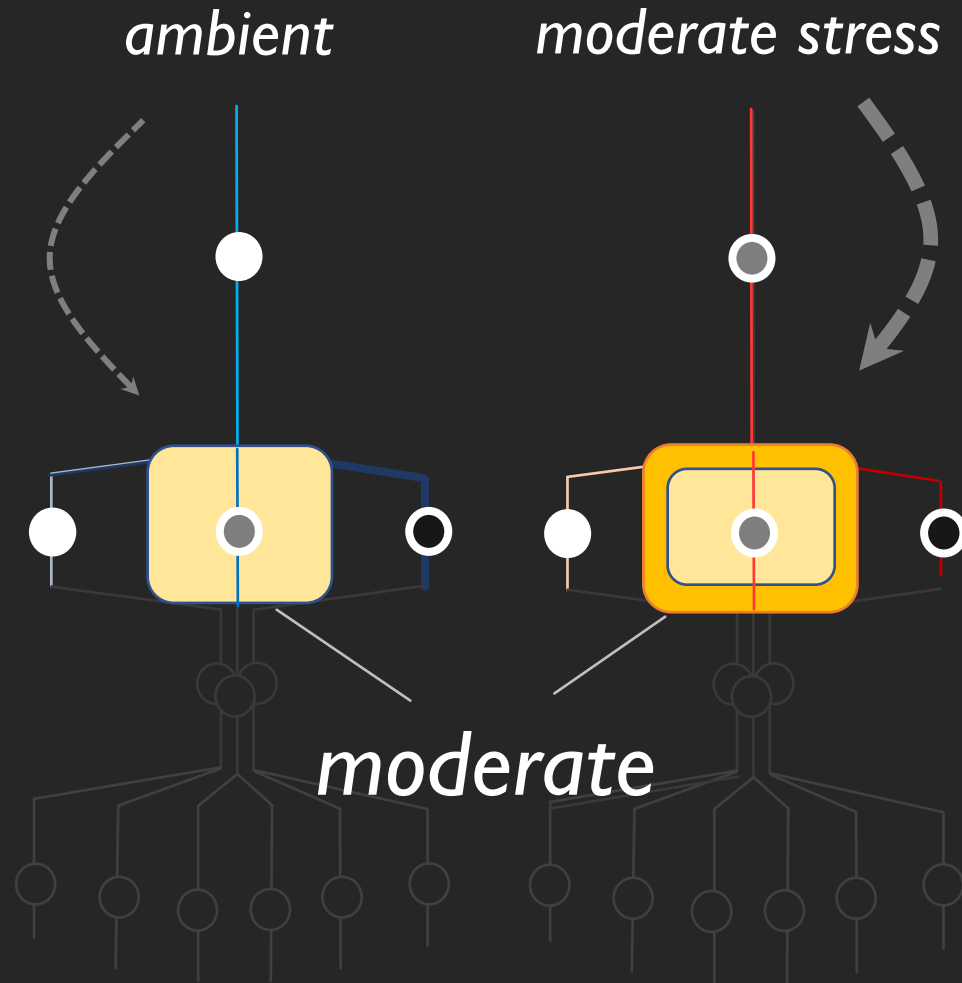
PHYSIOLOGY

Respiration rate



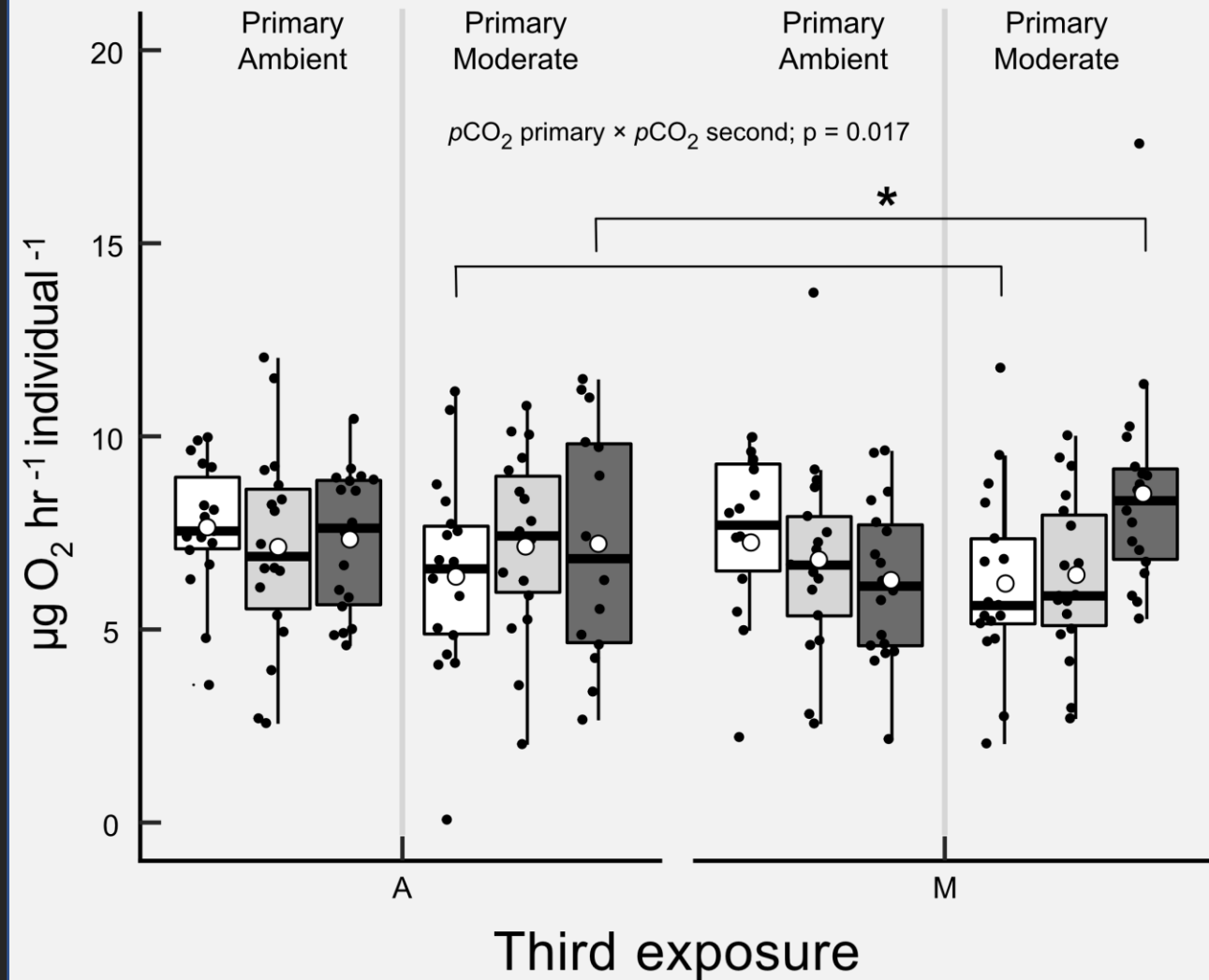
PHYSIOLOGY

Respiration rate



PHYSIOLOGY

Respiration rate



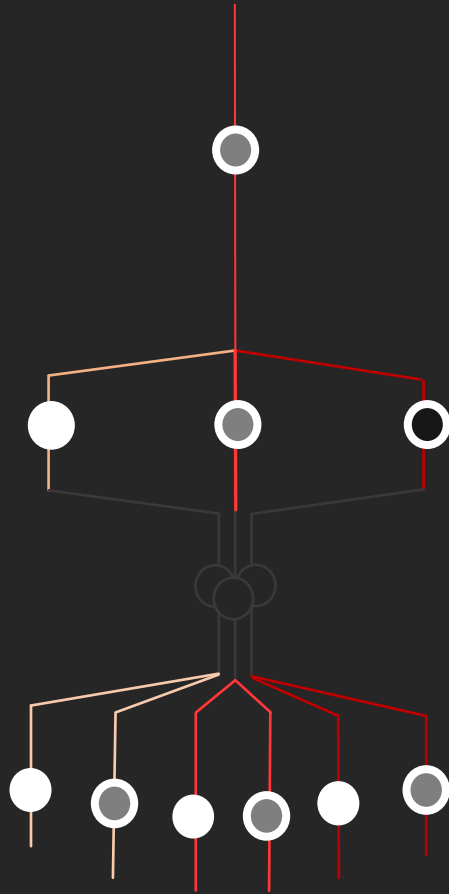
PHYSIOLOGY

moderate stress

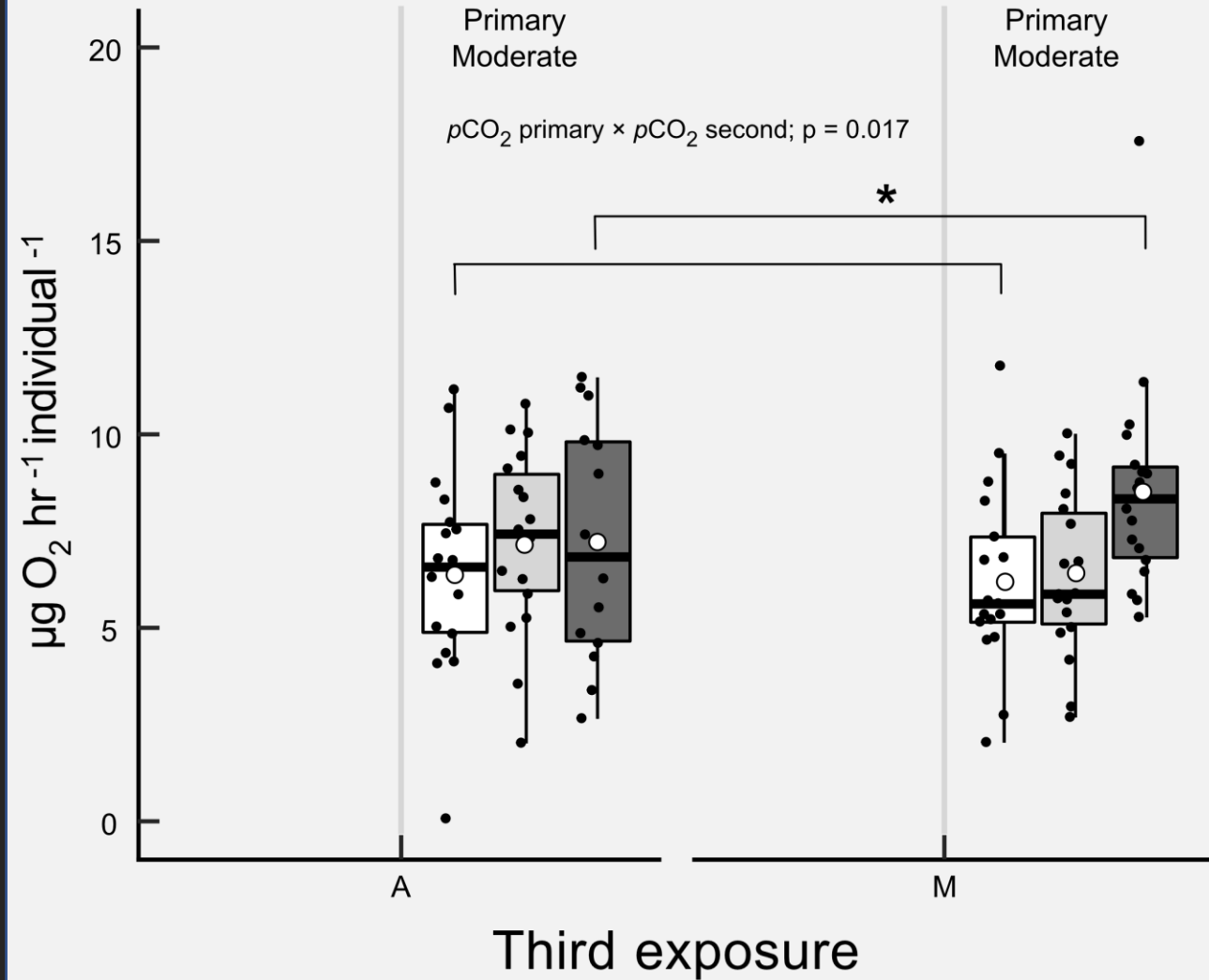
PRIMARY

2ND

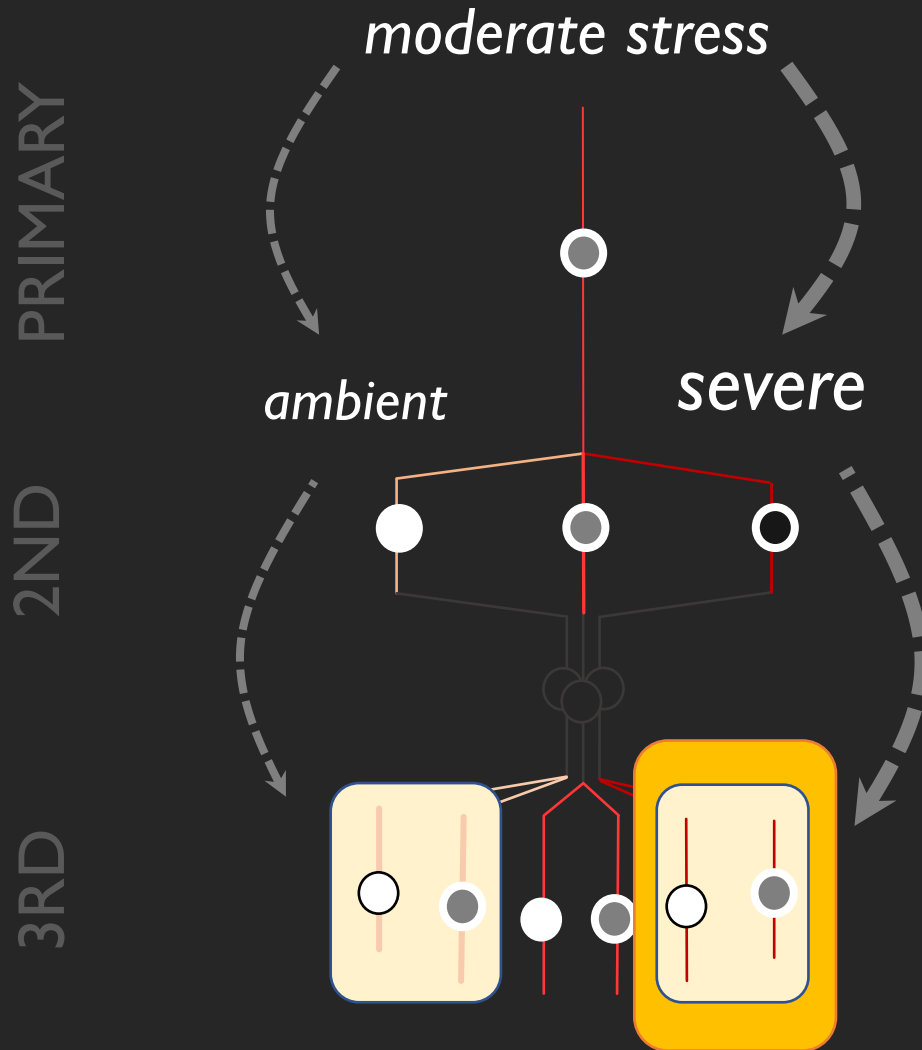
3RD



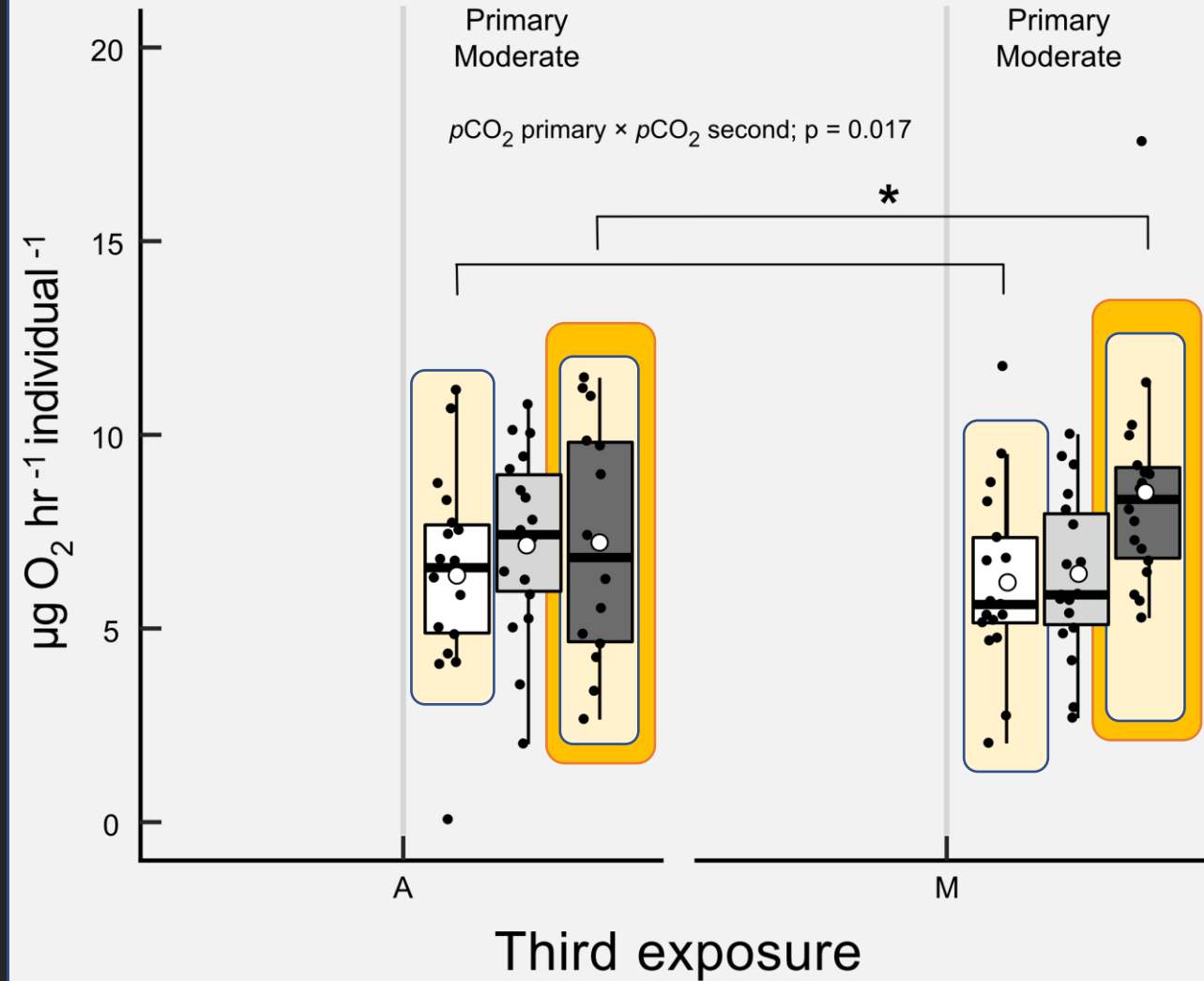
Respiration rate



PHYSIOLOGY



Respiration rate



PHYSIOLOGY

Respiration rate

moderate stress

20

Primary
Moderate

Primary
Moderate

$p\text{CO}_2 \text{ primary} \times p\text{CO}_2 \text{ second}; p = 0.017$

Postlarval stress acclimation and **repeated stress exposure**
to hypercapnic seawater **increases respiration rate**
in juvenile clams

0

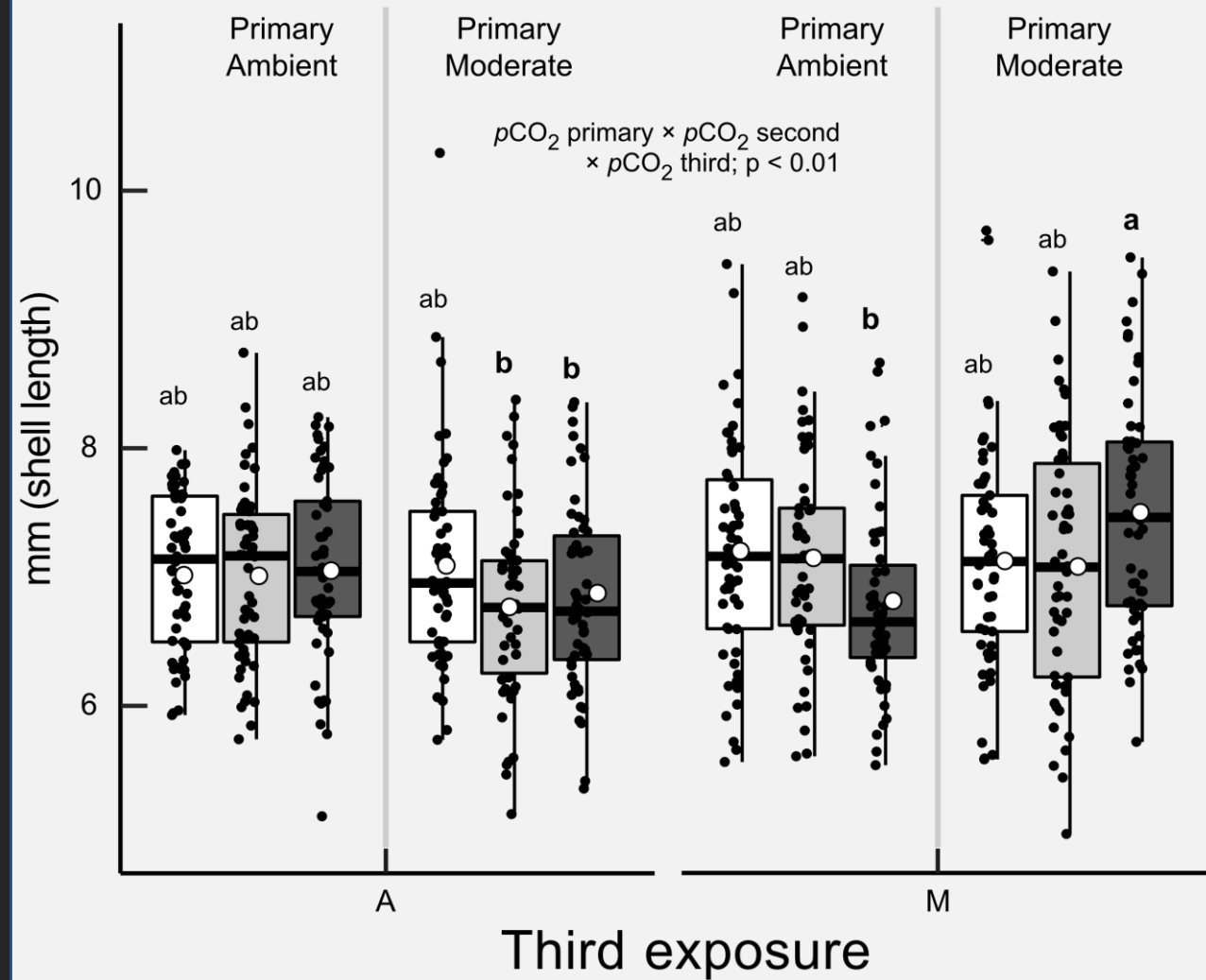
A

M

Third exposure

PHYSIOLOGY

Shell size



PHYSIOLOGY

PRIMARY

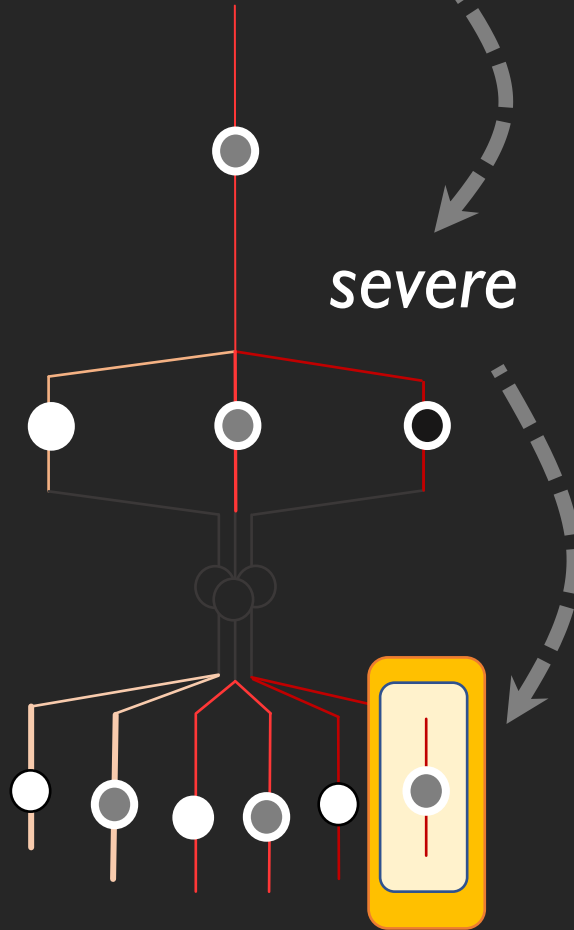
2ND

3RD

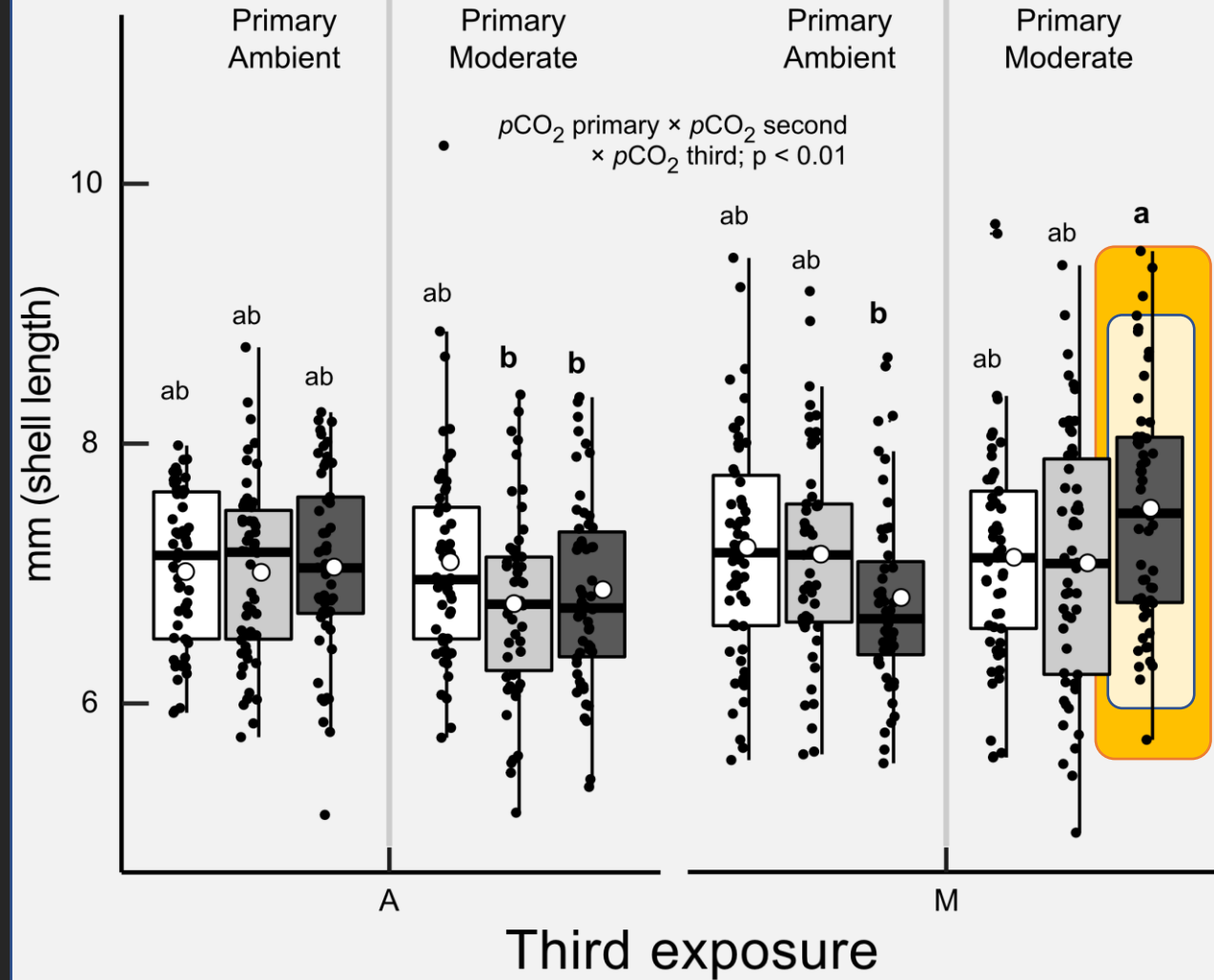
moderate stress

severe

moderate

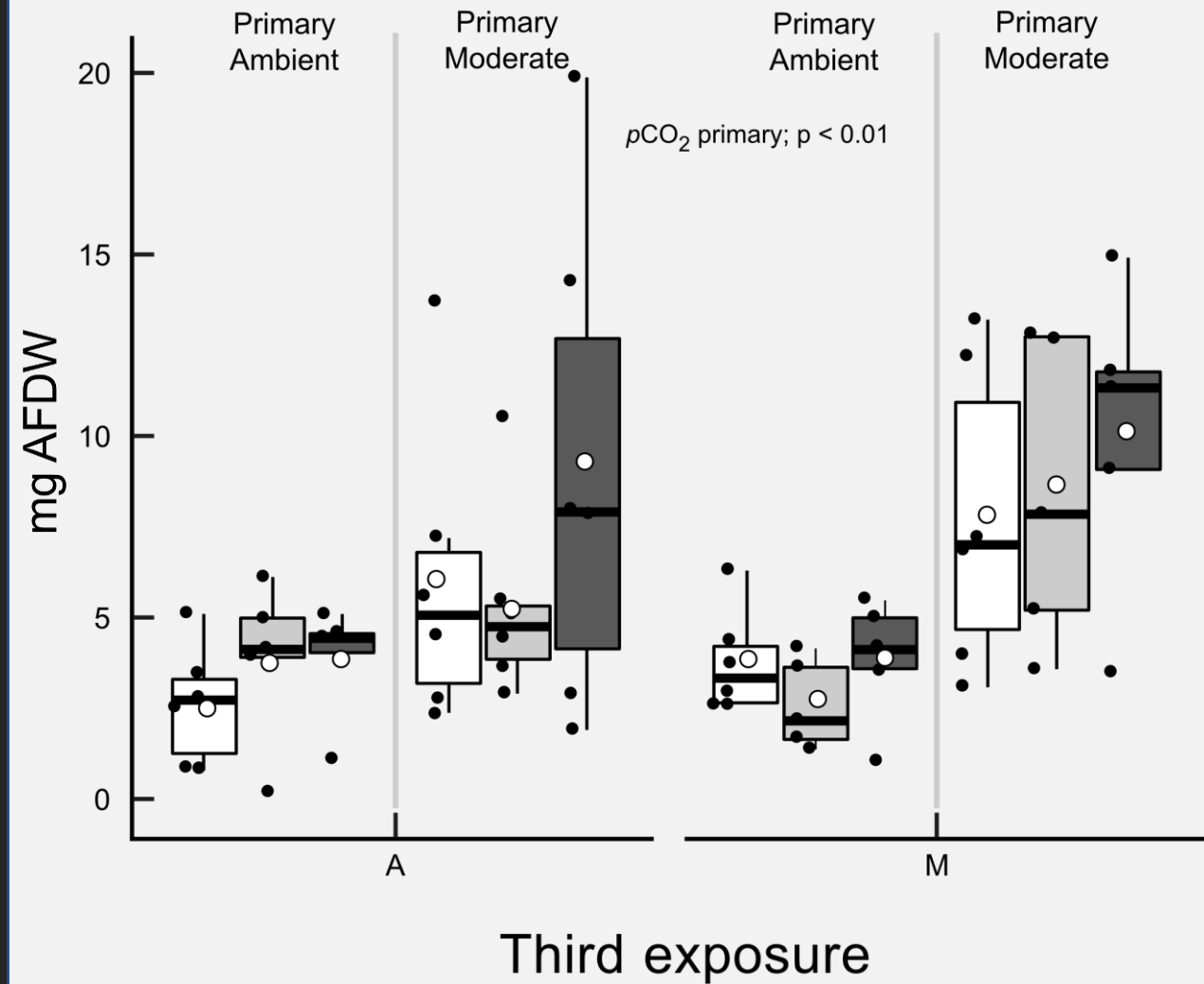


Shell size



PHYSIOLOGY

Organic biomass

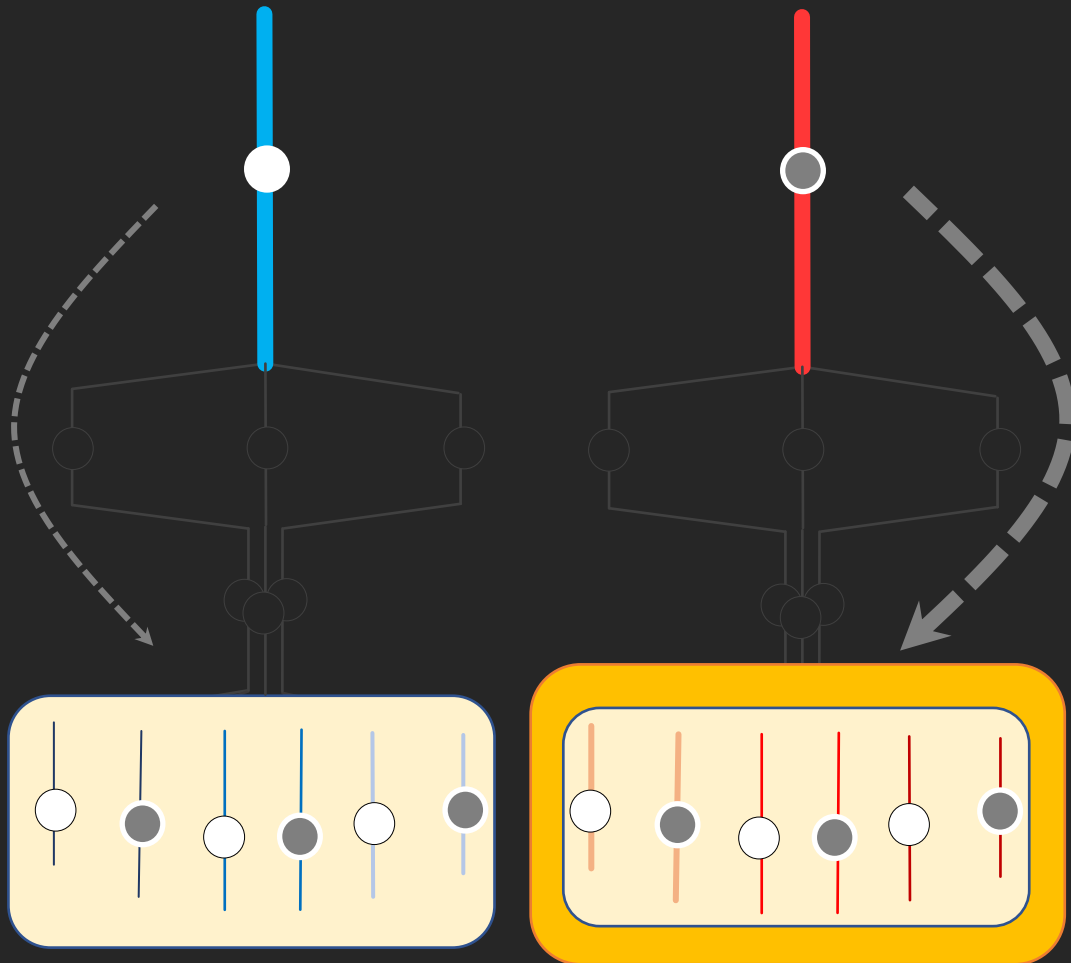


PHYSIOLOGY

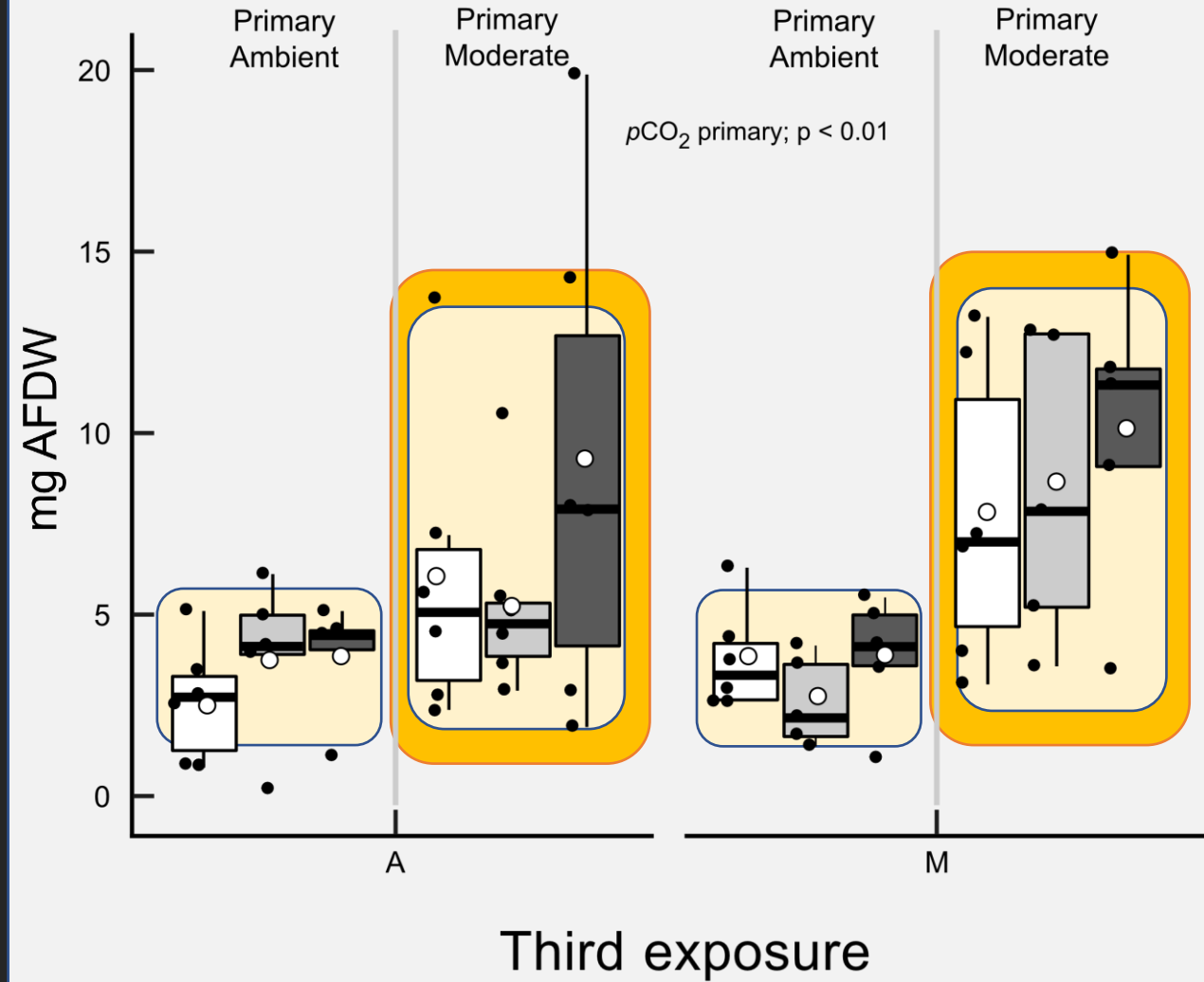
PRIMARY
2ND
3RD

ambient

moderate stress



Organic biomass



PHYSIOLOGY

Organic biomass

ambient

moderate stress

20

Primary
Ambient

Primary
Moderate

Primary
Ambient

Primary
Moderate

**Postlarval stress acclimation and matched stress exposure
to hypercapnic seawater **increases size**
(shell & biomass) of juvenile clams**

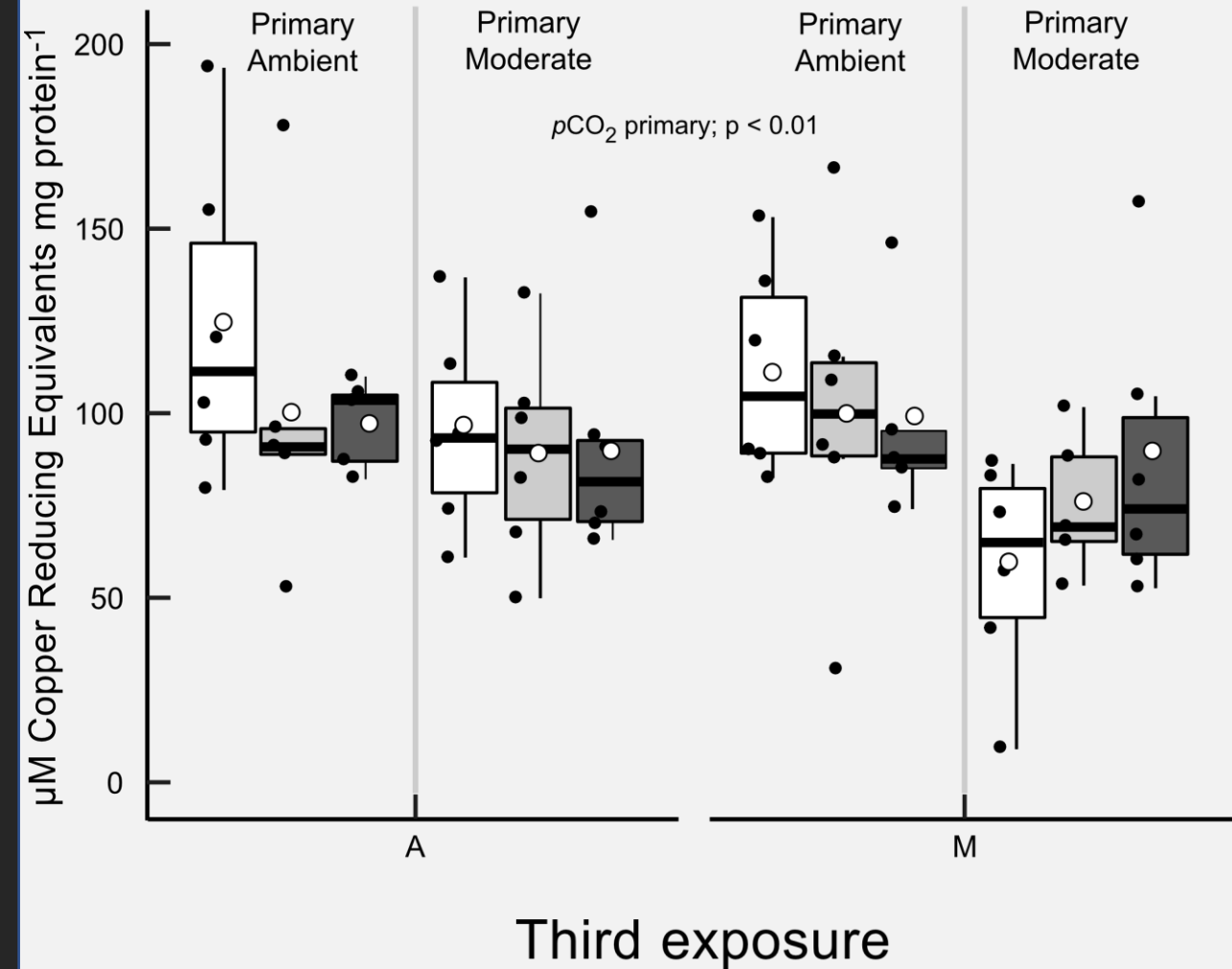
A

M

Third exposure

CELLULAR STRESS RESPONSE

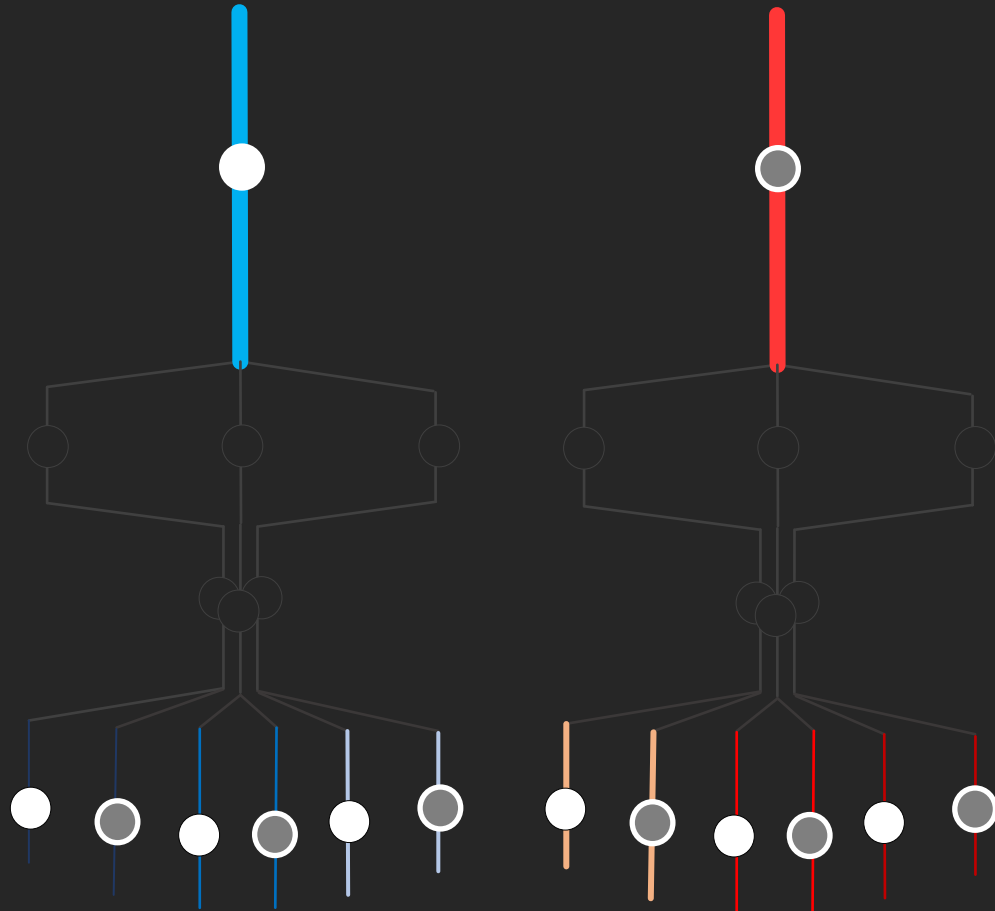
Total Antioxidant Capacity



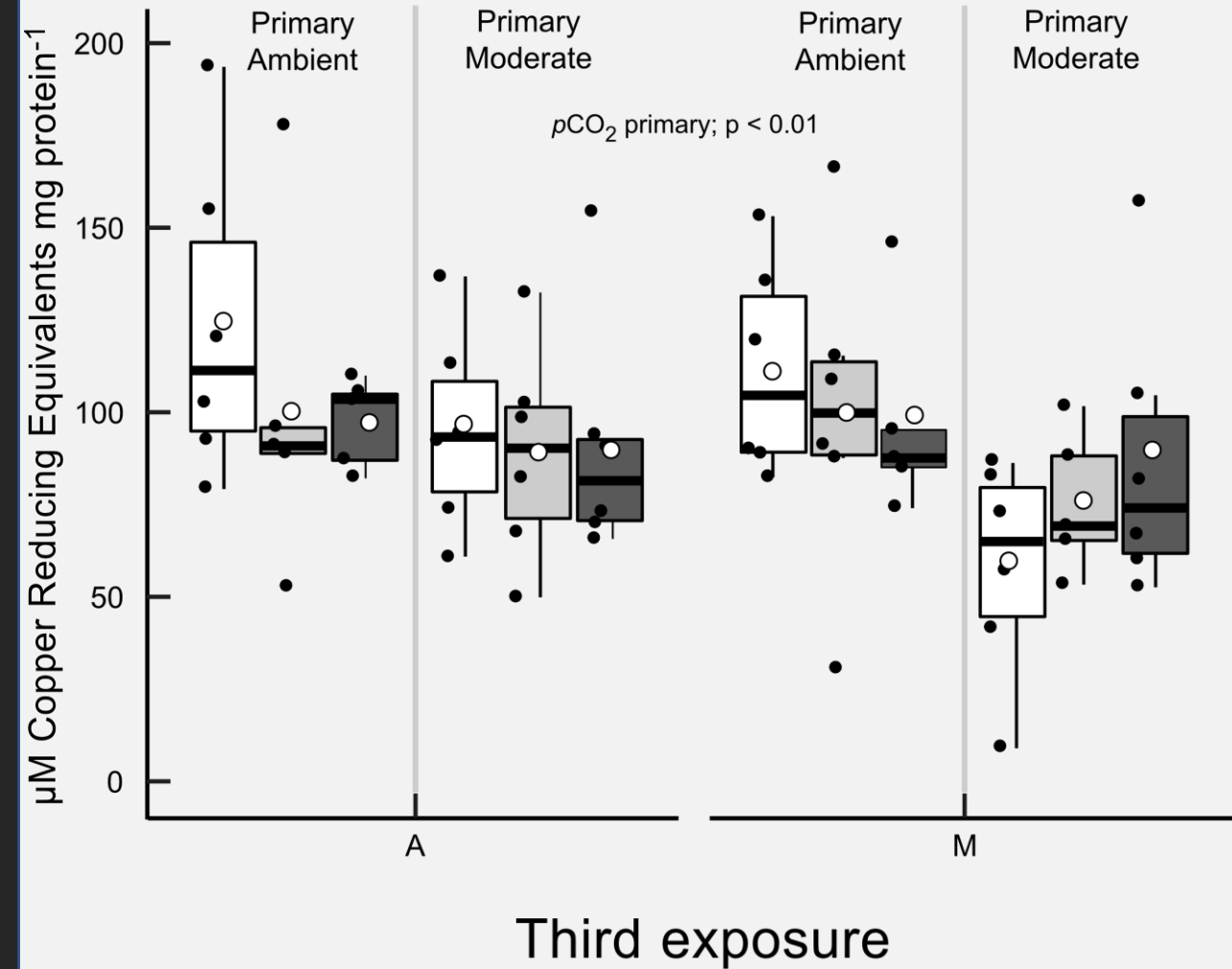
CELLULAR STRESS RESPONSE

ambient

moderate stress



Total Antioxidant Capacity

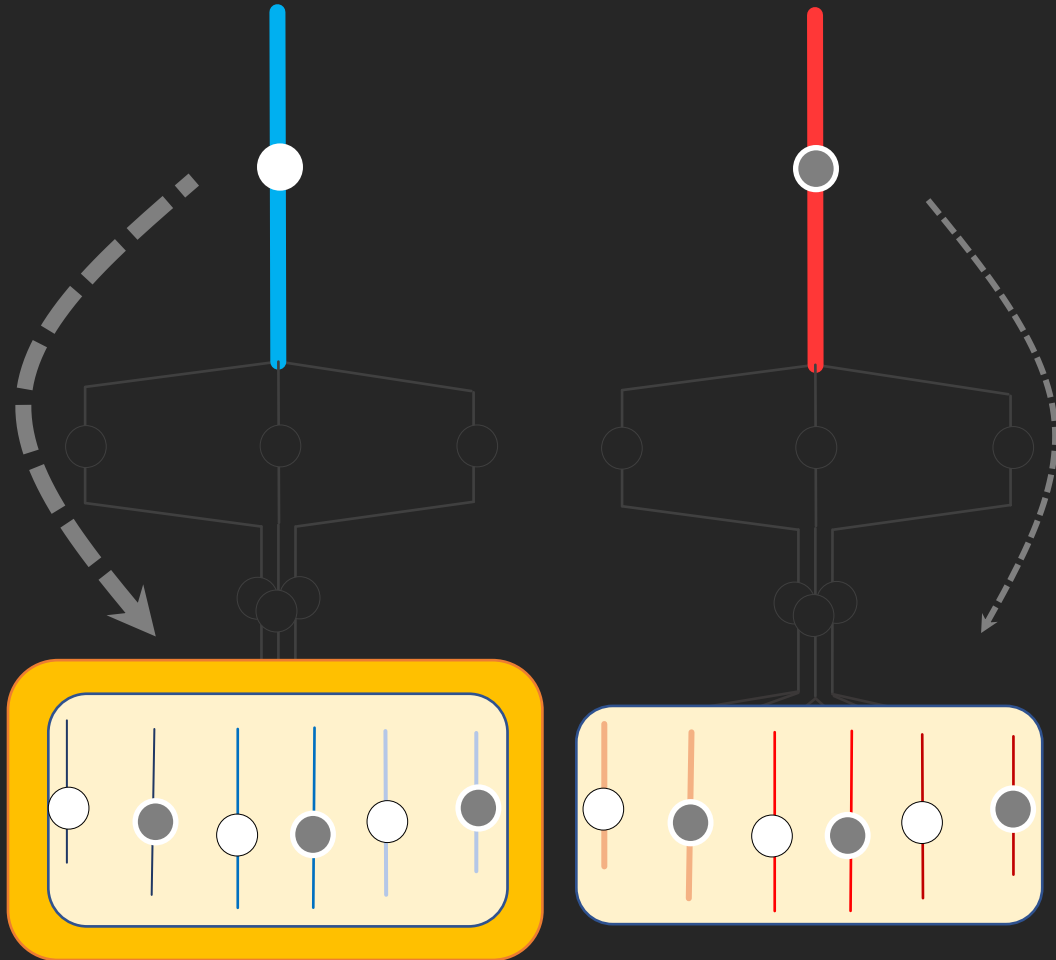


CELLULAR STRESS RESPONSE

PRIMARY
2ND
3RD

ambient

moderate stress



Total Antioxidant Capacity



CELLULAR STRESS RESPONSE

Total Antioxidant Capacity

ambient

moderate stress

ein⁻¹

200

Primary
Ambient

Primary
Moderate

Primary
Ambient

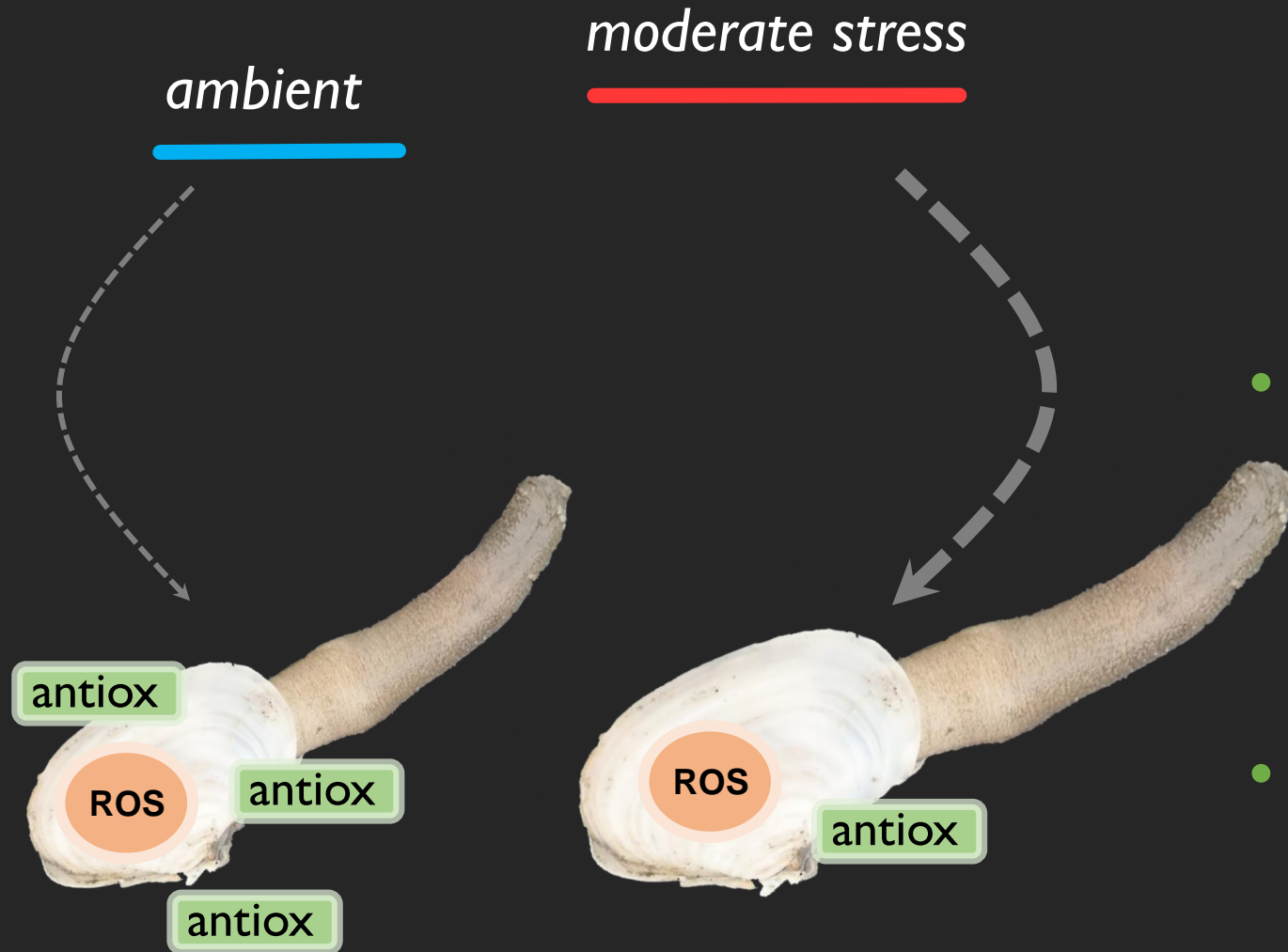
Primary
Moderate

**Postlarval stress acclimation to hypercapnic seawater
reduced antioxidant capacity in juvenile clams**

A

M

Third exposure



Can repeated stress encounters 'prime' phenotype?

- Early **moderate** stress acclimation elicited a **larger** phenotype associated with **lower CSR**
- Plasticity of bioenergetic and subcellular responses to OA

Takeaways

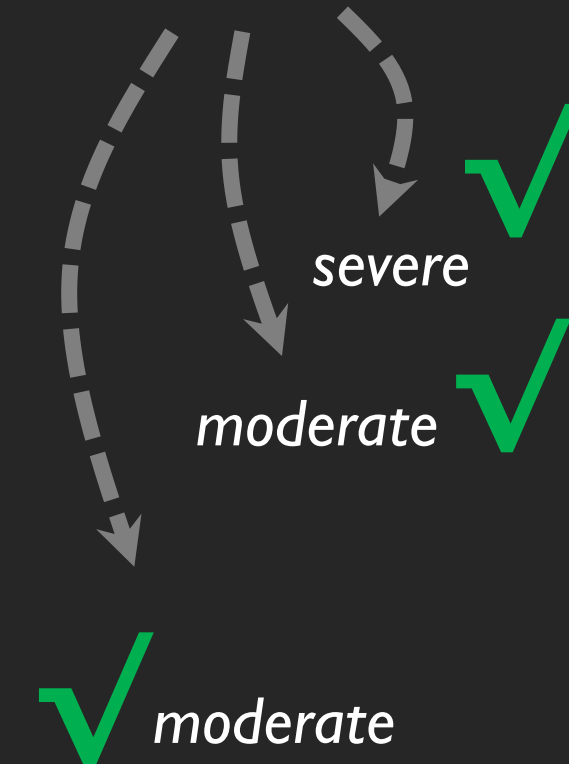
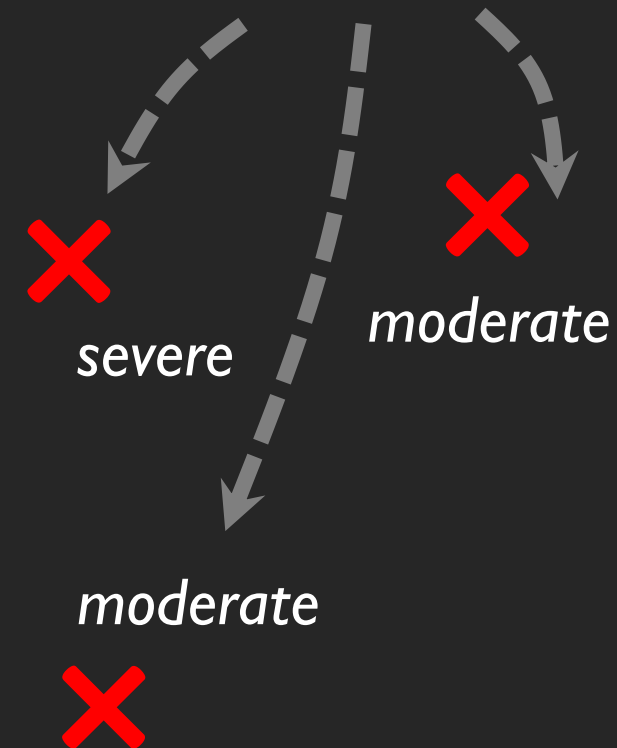
Mismatched

Matched

*Early-life
acclimation*

ambient

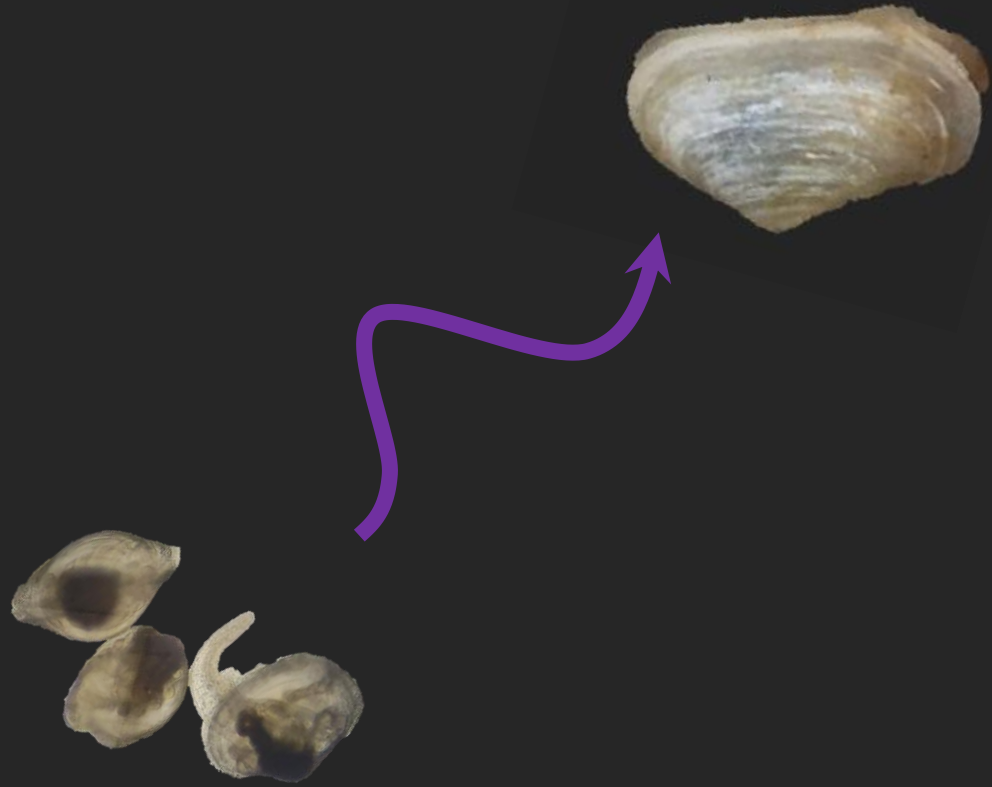
moderate stress



**Can repeated stress
encounters 'prime'
phenotype?**

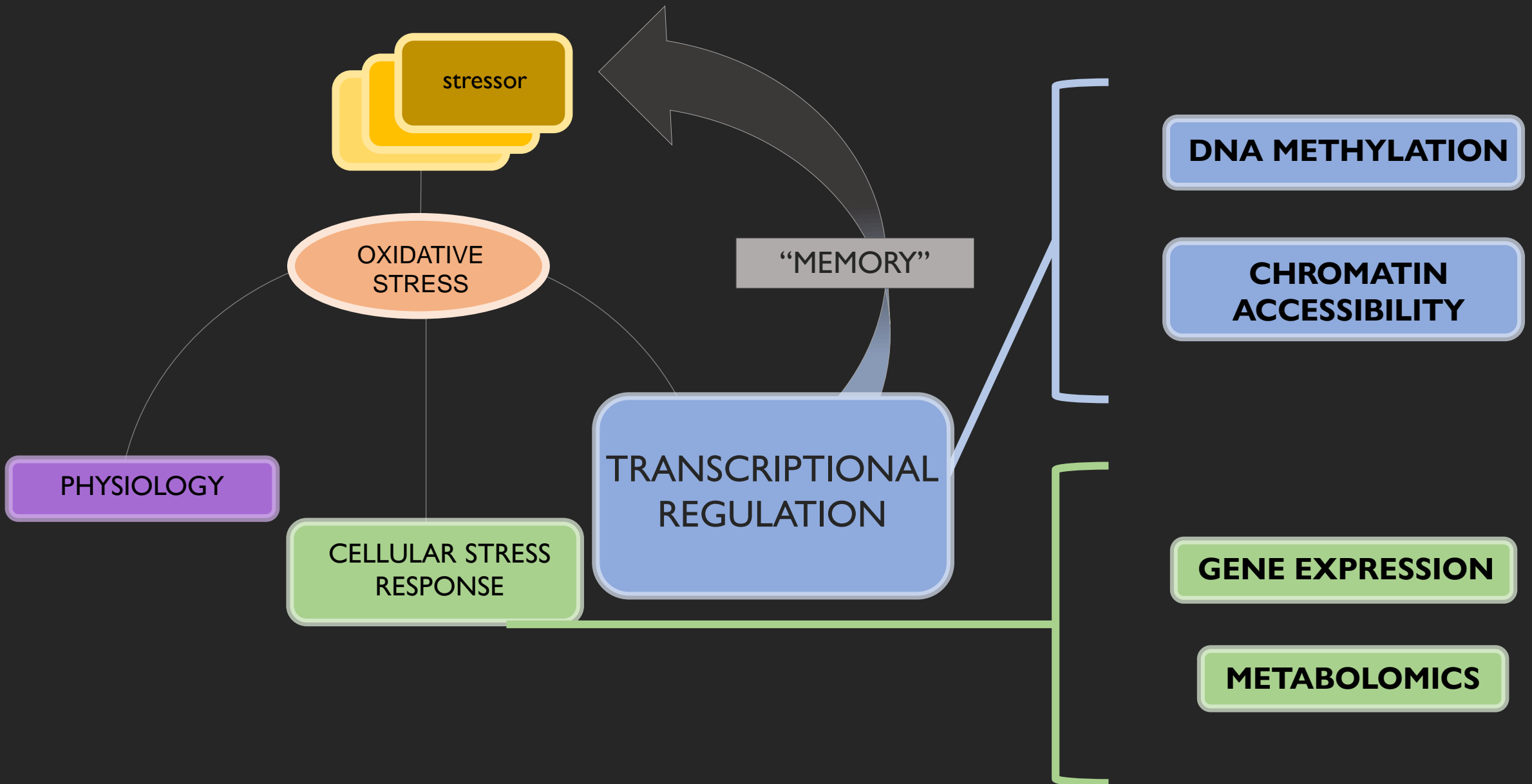
- Early **moderate** stress acclimation elicited a **larger** phenotype associated with **lower CSR**
- Plasticity of bioenergetic and subcellular responses to OA

What is the timing and stress intensity to elicit this reponses?



- Geoduck clams are relatively resilient to moderate and extreme $p\text{CO}_2$ levels
- Stress **post ‘settlement’** may elicit adaptive phenotypic variation

Future directions...



Acknowledgements

- Hollie Putnam
- Steven Roberts
- Brent Vadopalas
- Shelly Trigg

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- Matt Henderson
- Josh Valley
- Clara Duncan

Emma Strand,
Kevin Wong,
Kaitlyn Mitchell



JAMESTOWN
S'KLALLAM
TRIBE



FFAR



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