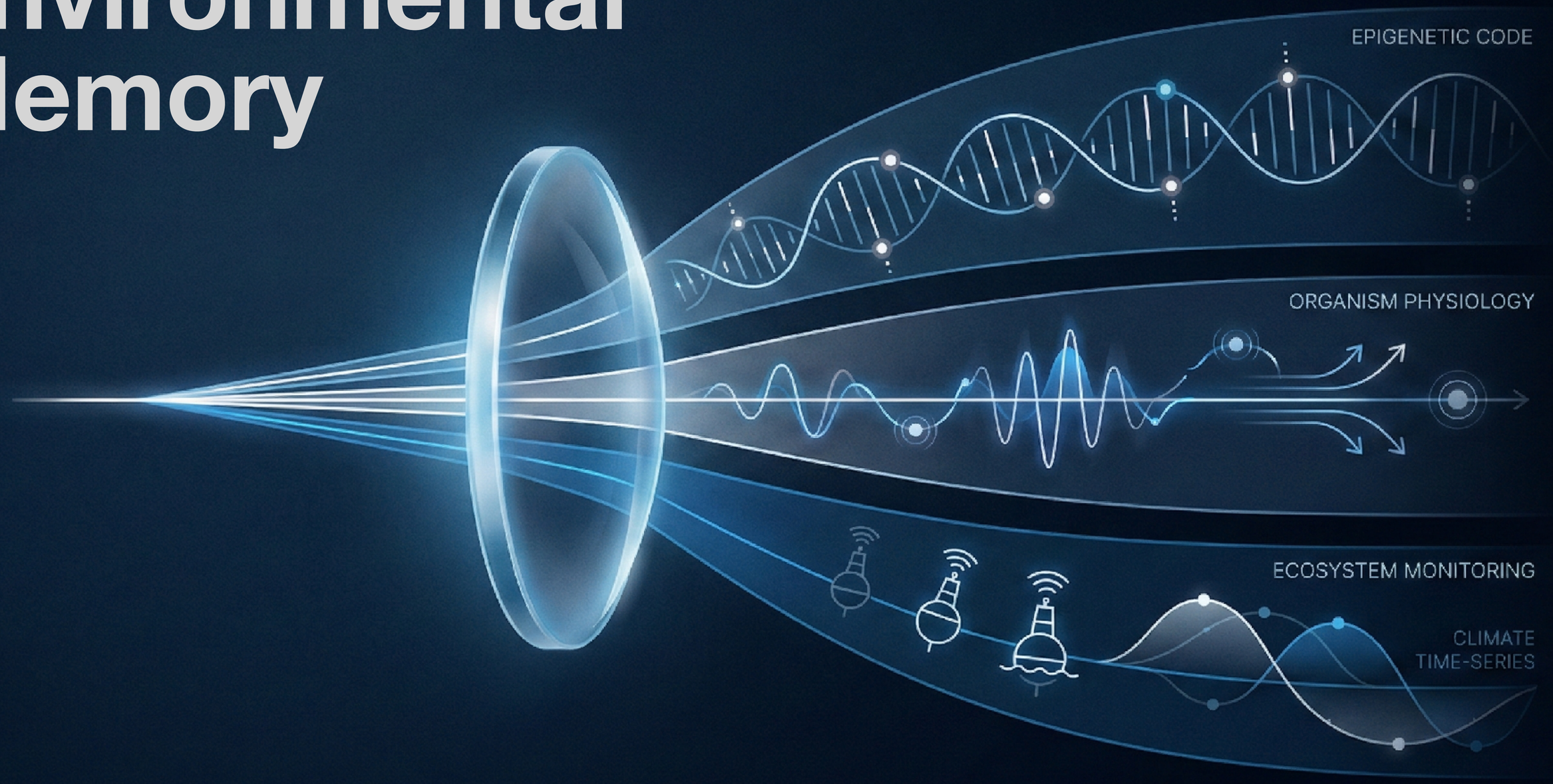
Environmental Memory

The Missing State Variable in Marine Biology

Steven Roberts
University of Washington
robertslab.info

github.com/sr320/talk-UNCW-2026

Environmental Memory



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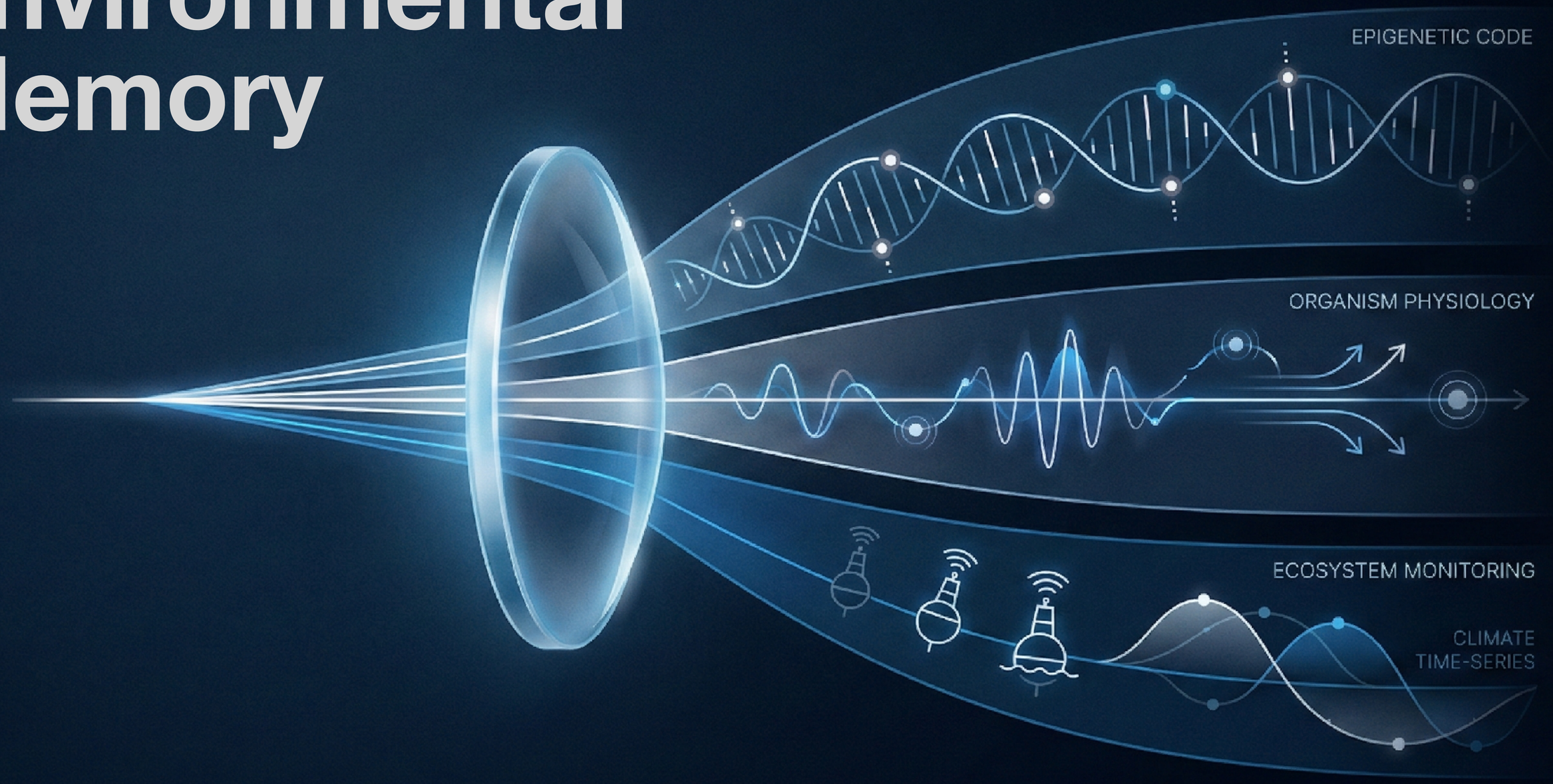

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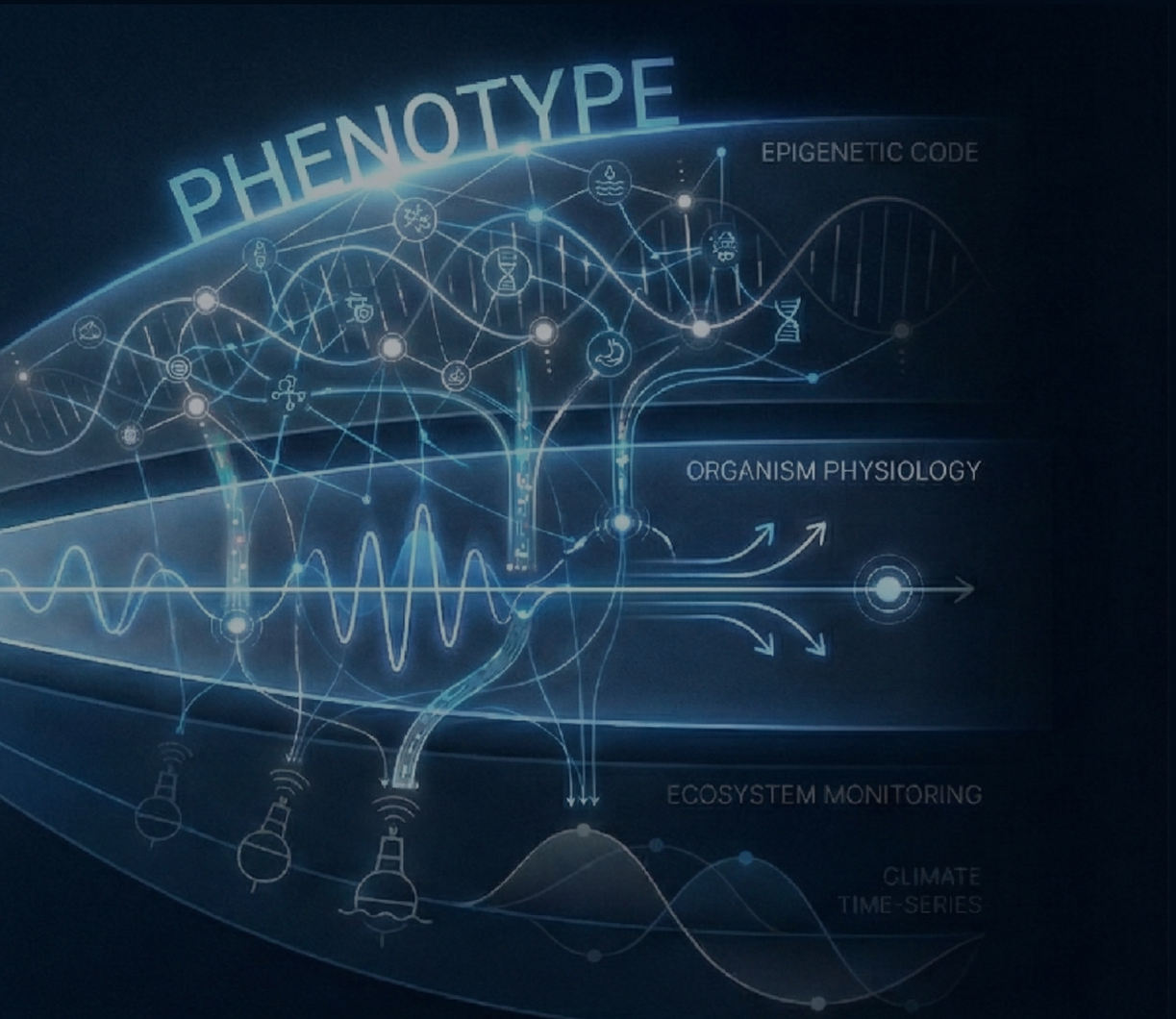

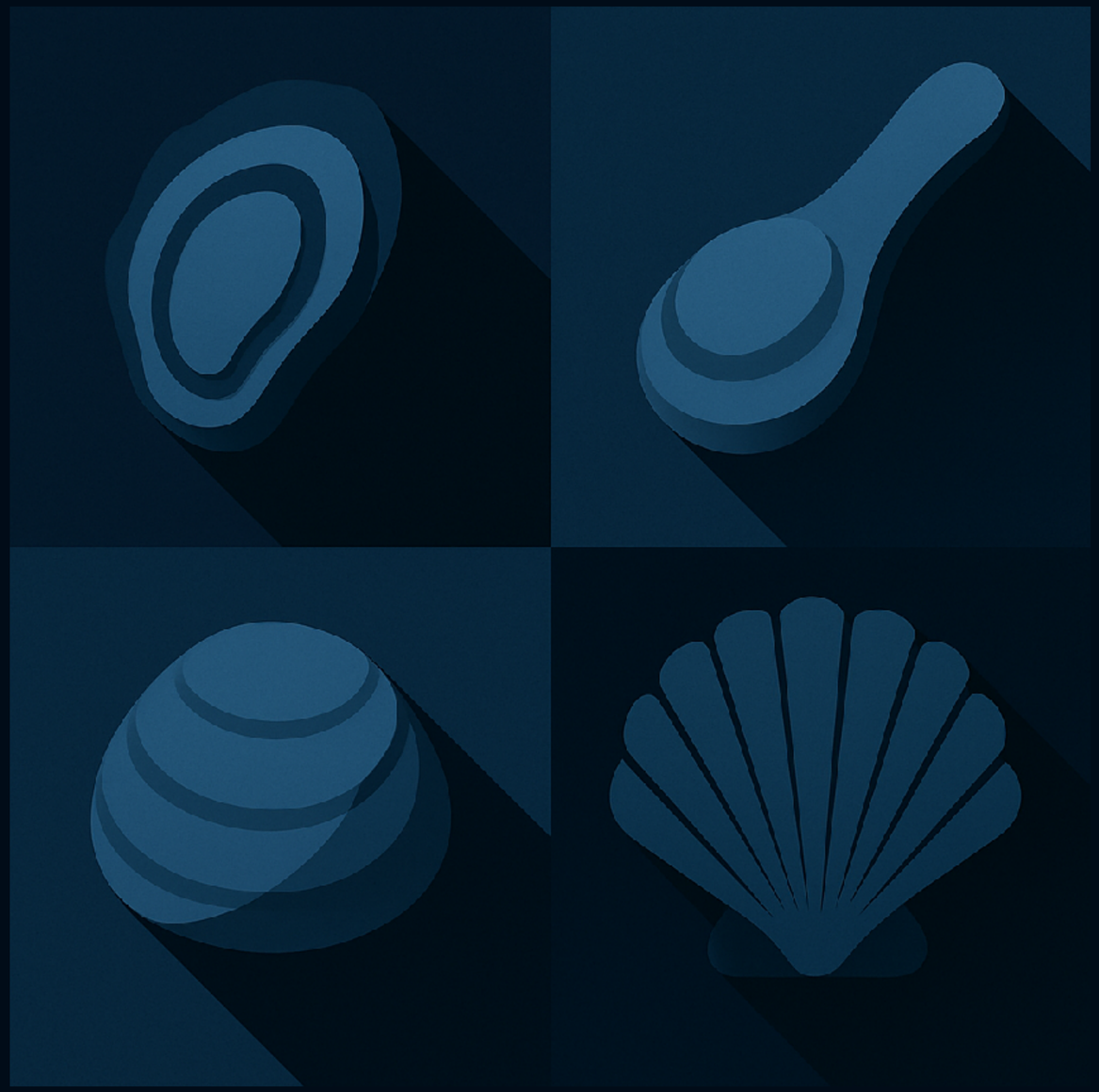

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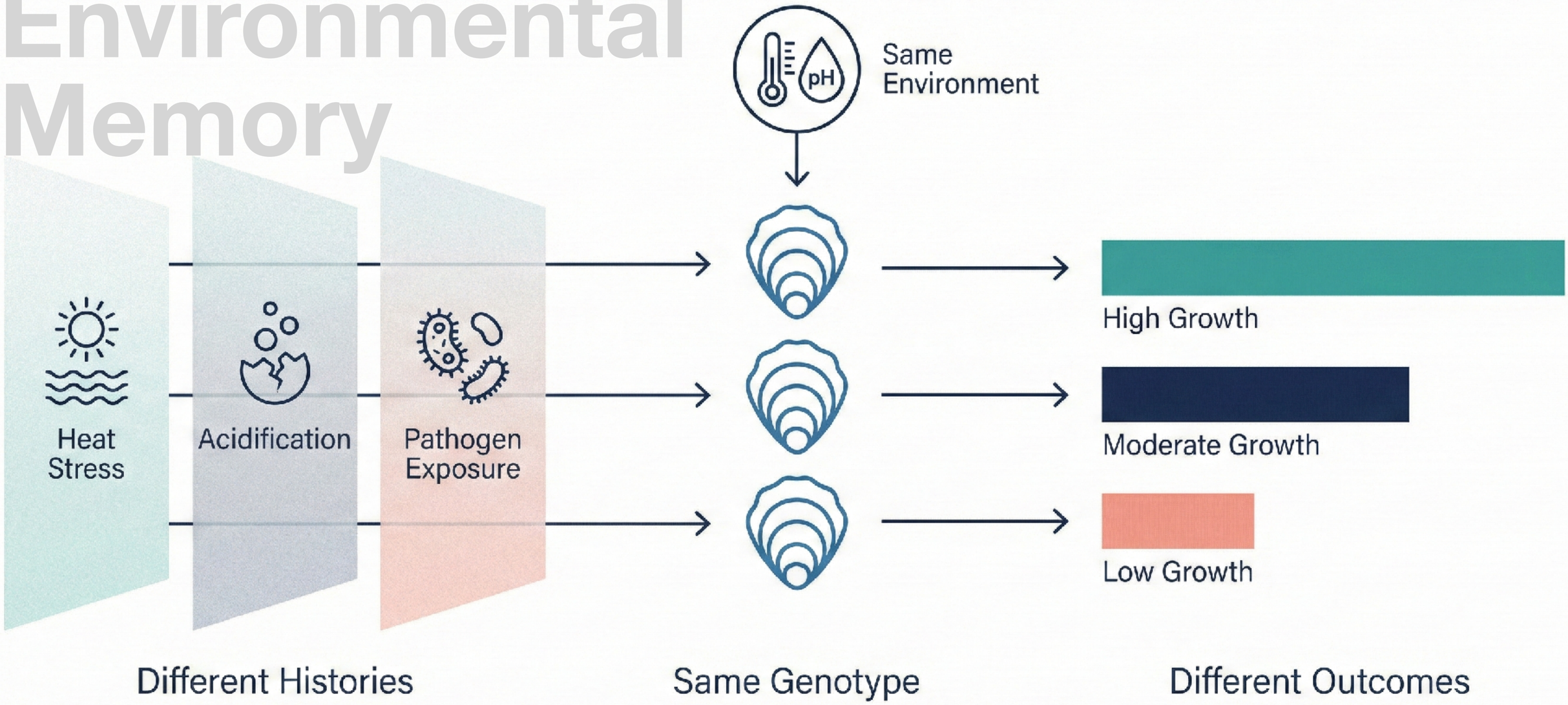
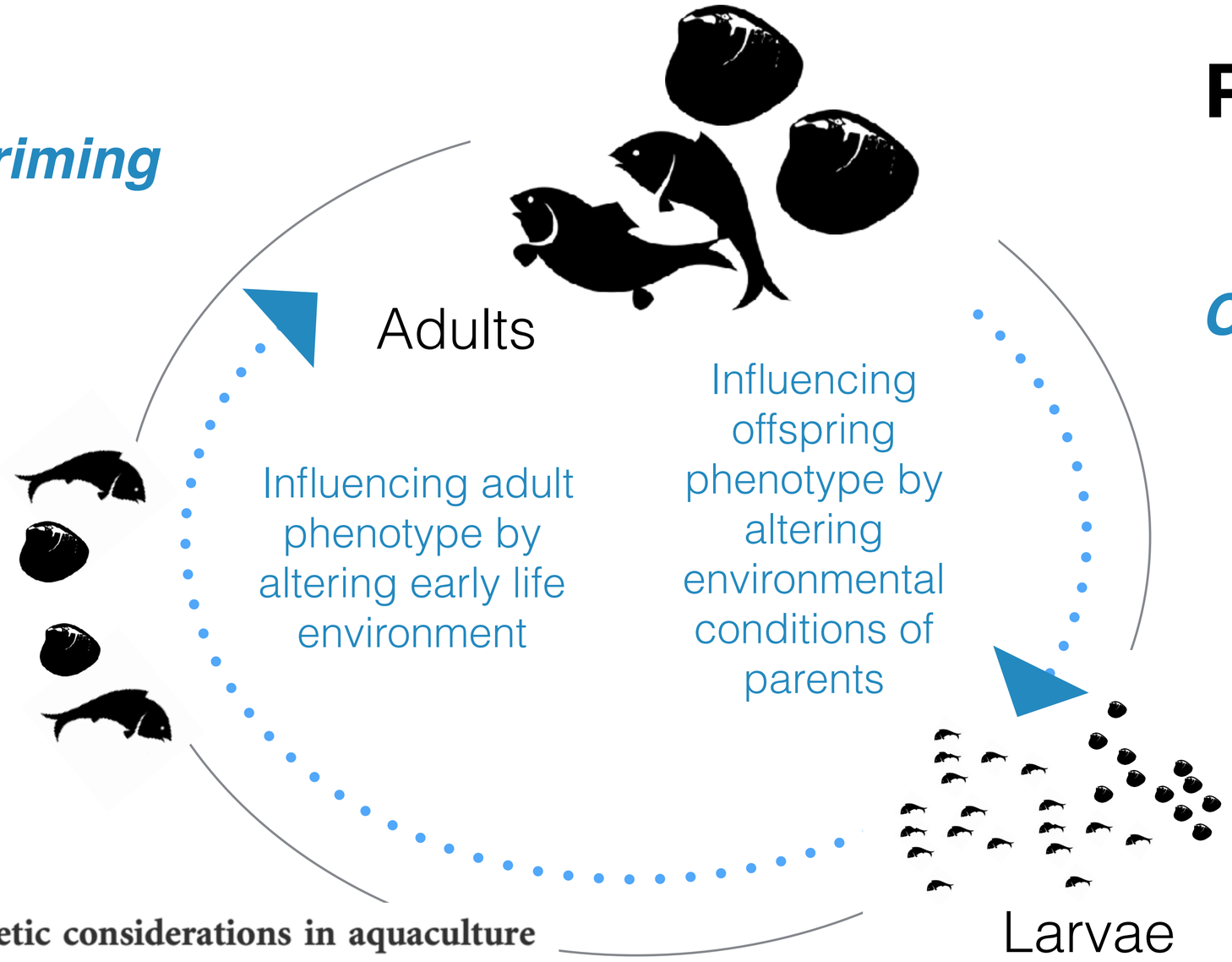


Environmental history is not noise. It's a state variable.

Phenotypes

Early-life Priming

Carry-over effects

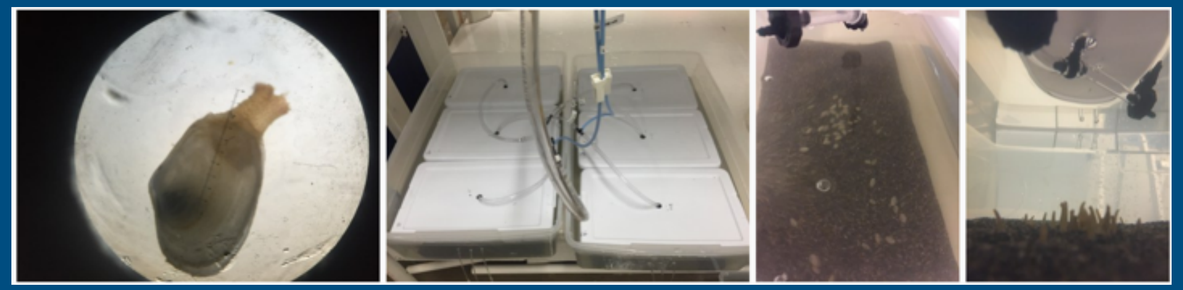


Epigenetic considerations in aquaculture

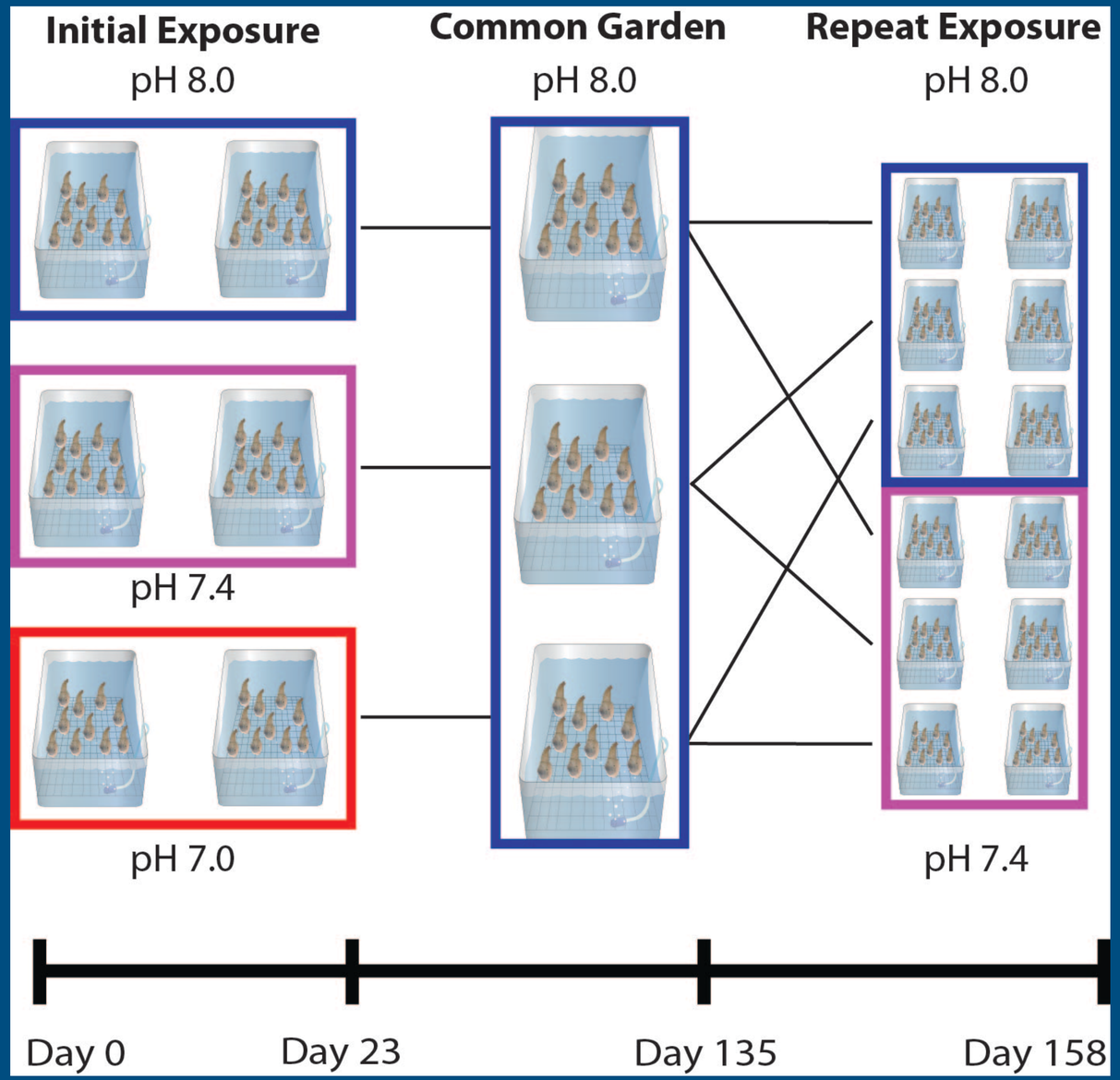
Mackenzie R. Gavery and Steven B. Roberts
School of Aquatic & Fishery Sciences, University of Washington, Seattle, WA, USA

PeerJ

GEODUCKS CLAMS



- Does conditioning to low pH confer tolerance within a generation?



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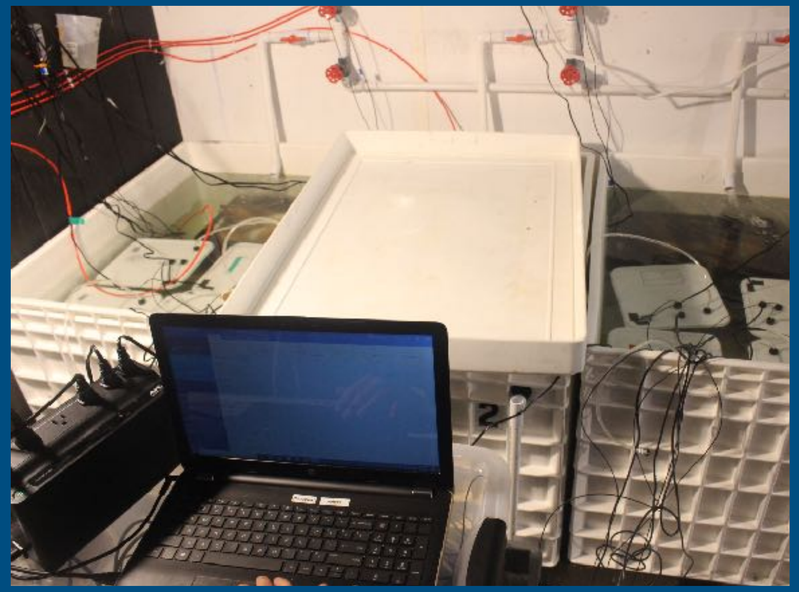

GEODUCKS CLAMS

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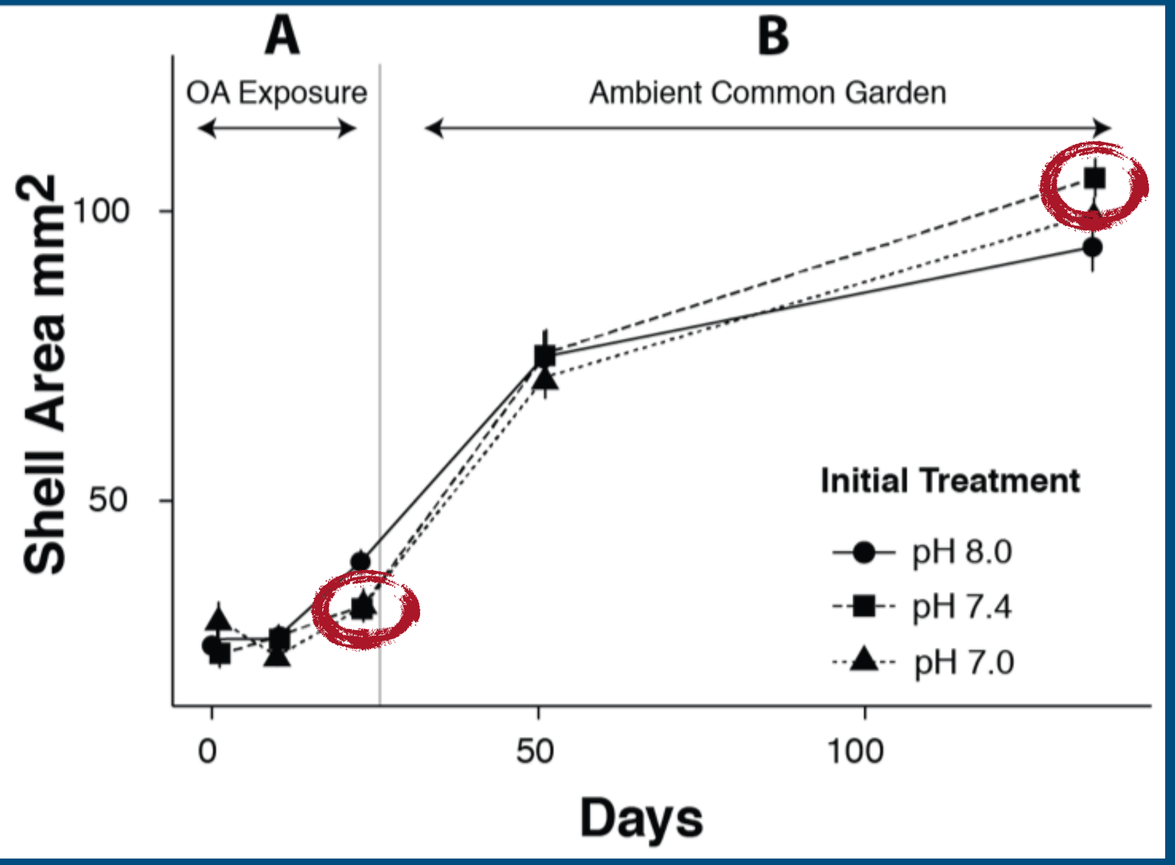


Heat-Priming Pacific Oysters: Field Performance vs. Lab Stress Tolerance

Results from an 18-month Sea Grant experiment at Westcott Bay Shellfish

Project Leads: Emily Carrington & Steven Roberts

Research Team: Grace Leuchtenberger & Ariana Huffmyer

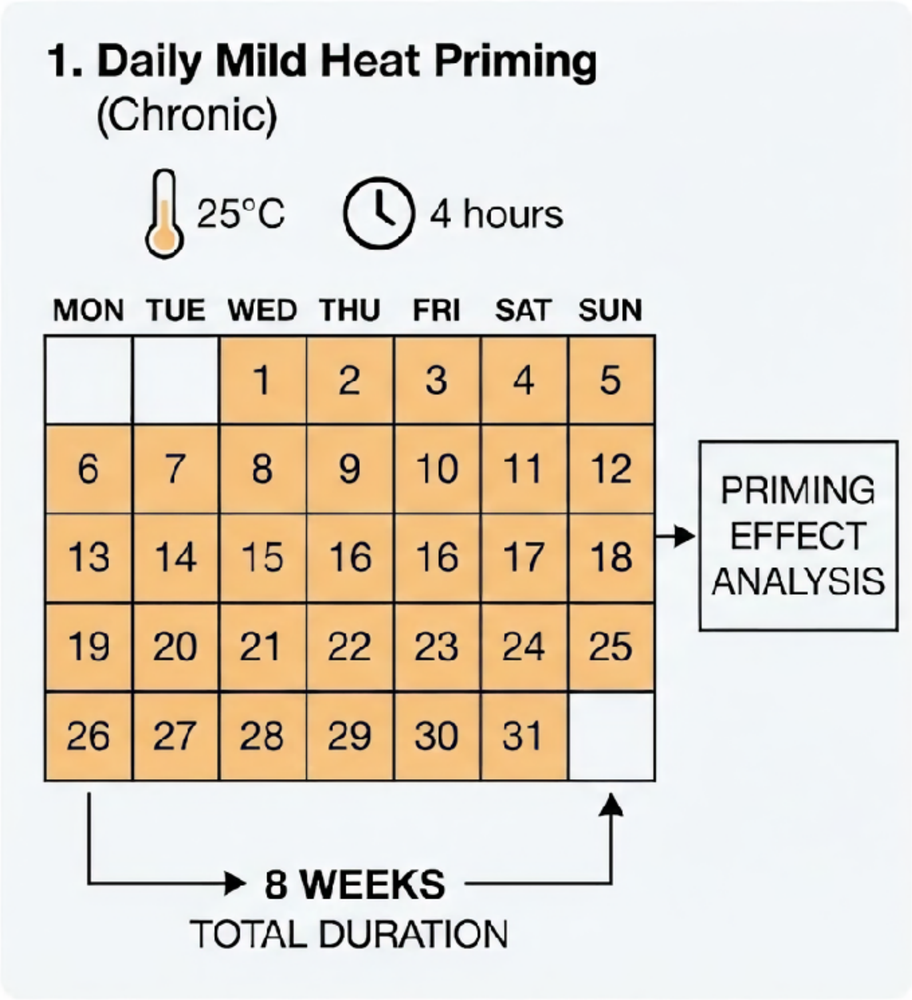
UNIVERSITY of WASHINGTON

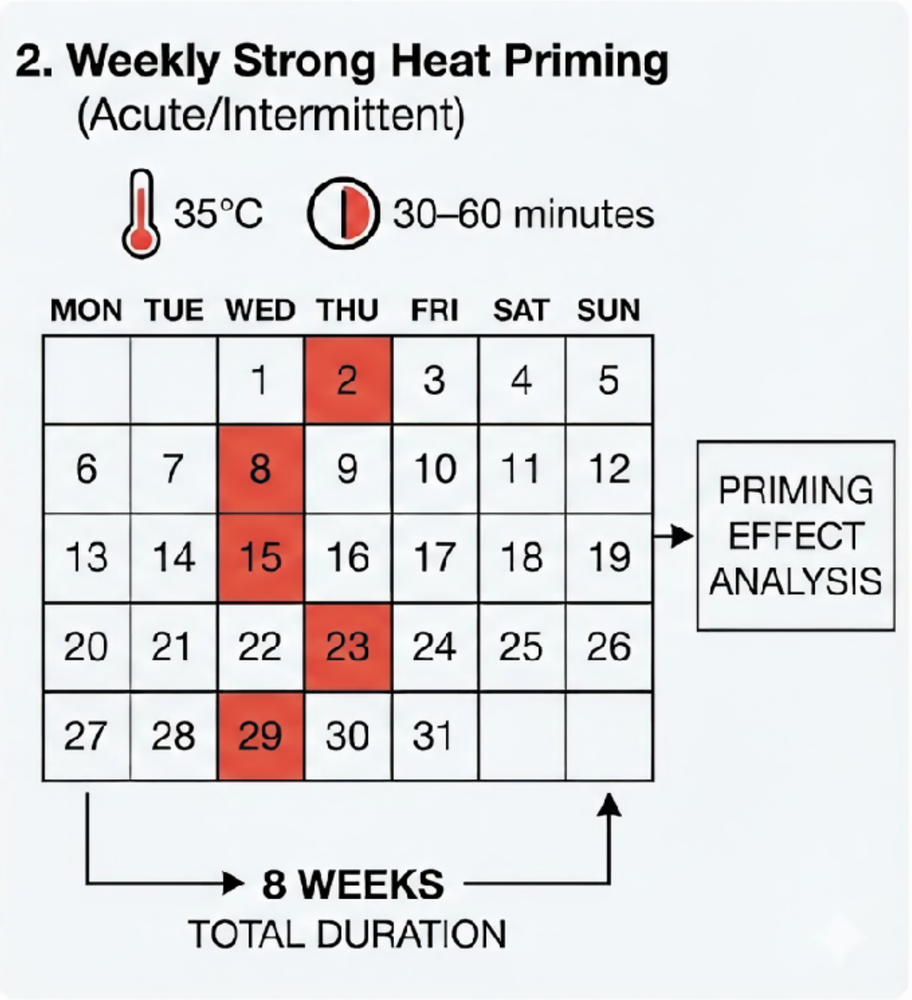
Sea Grant

WESTCOTT BAY SHELLFISH

NotebookLM

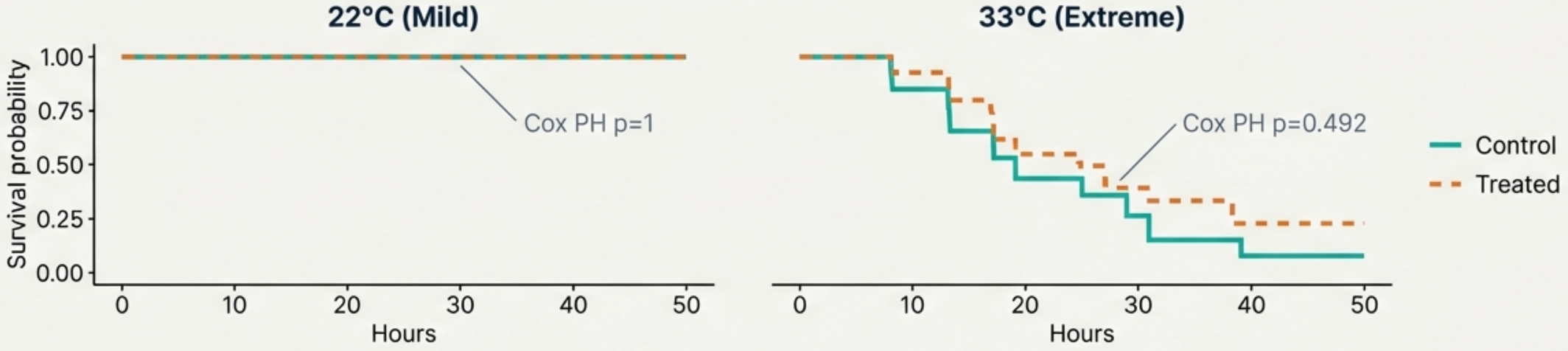
Early life (seed) heat priming



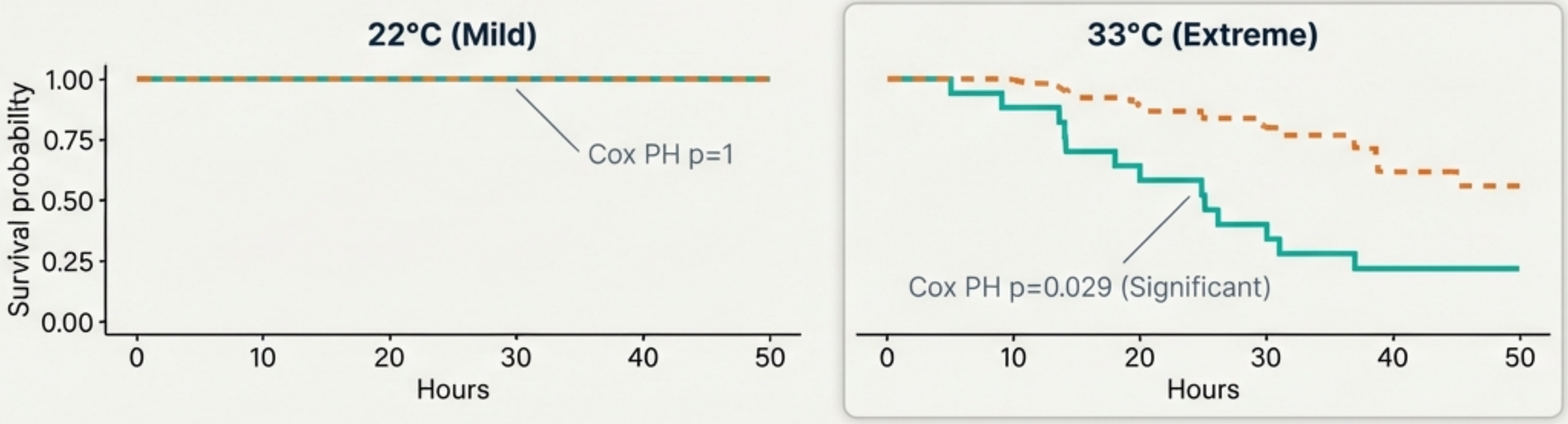


Hardening worked—but only revealed itself under extreme acute stress.

Daily Hardening

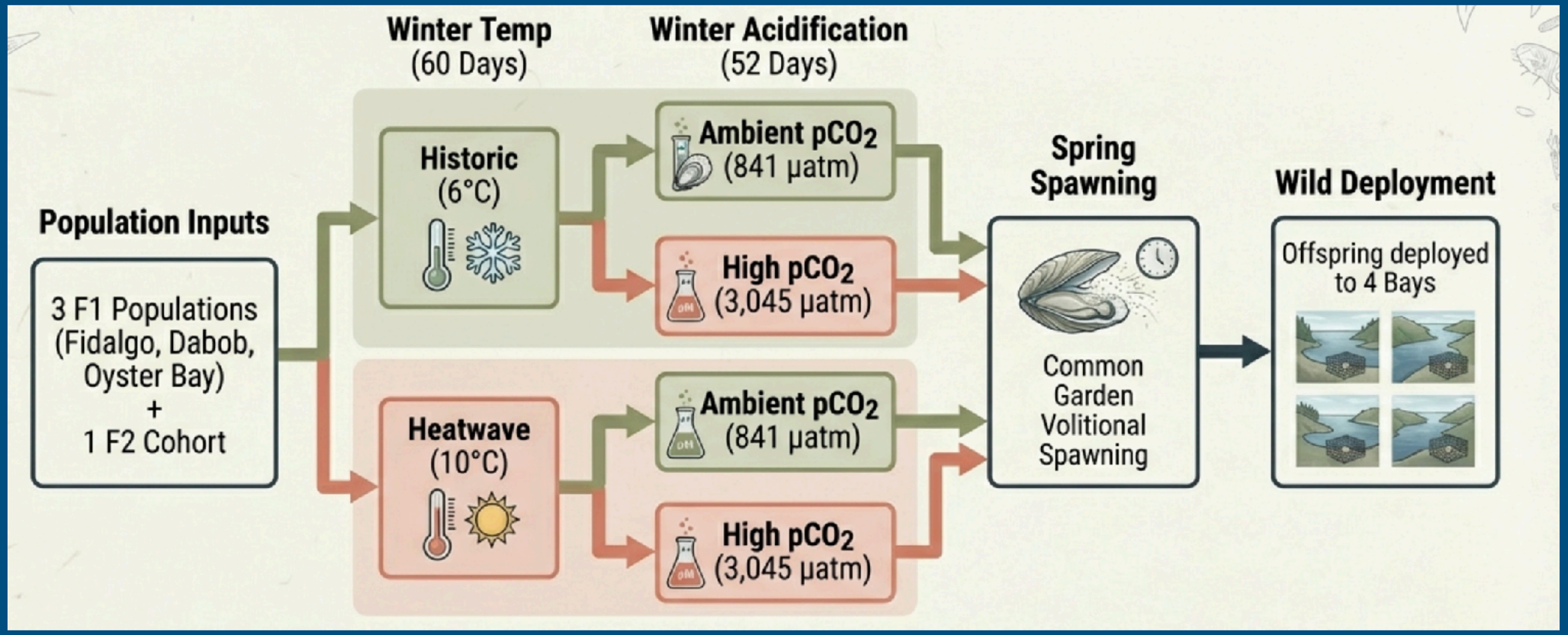


Weekly Hardening



SUCCESS:
Weekly primed oysters showed significantly higher survival during a simulated heat wave.

EFFECTS OF TEMPERATURE AND OA IN OLYMPIA OYSTER POPULATIONS



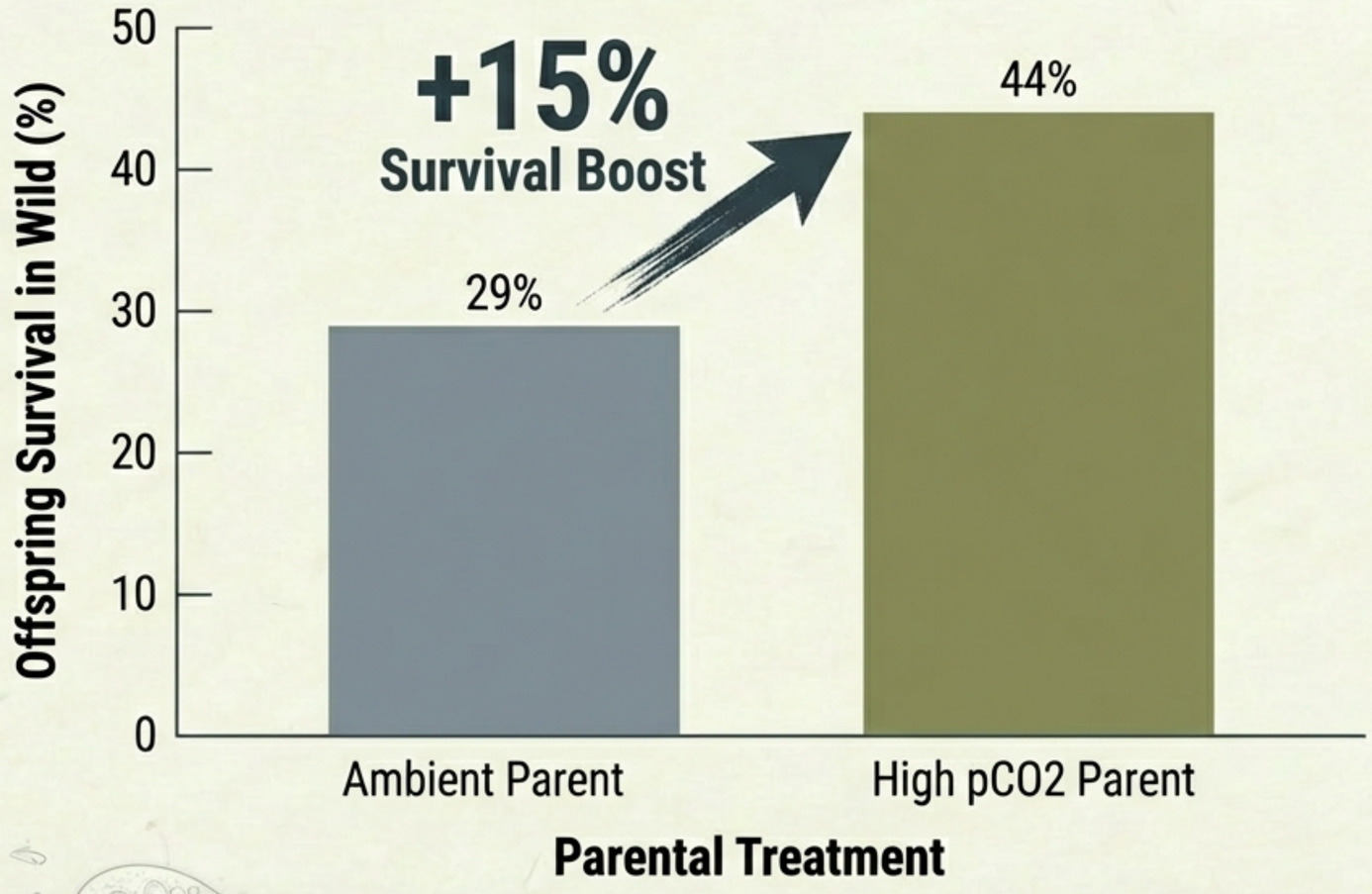
Carryover effects of temperature and pCO_2 across multiple Olympia oyster populations

Laura H. Spencer,[1] Yaamini R. Venkataraman,[1] Ryan Crim,[2] Stuart Ryan,[2] Micah J. Horwith,[3] and Steven B. Roberts[1,4]

LAURA SPENCER

EFFECTS OF TEMPERATURE AND OA IN OLYMPIA OYSTER POPULATIONS

Stress as Preparation: The Beneficial Carryover



- **Finding:** Offspring of parents exposed to High pCO2 had significantly higher survival rates.
- **Interpretation:** Intergenerational Plasticity. The parents "primed" the offspring for a tough environment.

Resilience is Context-Dependent

Significant Survival Boost.
(Low pH / High Salinity Bays)

Significant Survival Boost.

Matching Stressful Environment

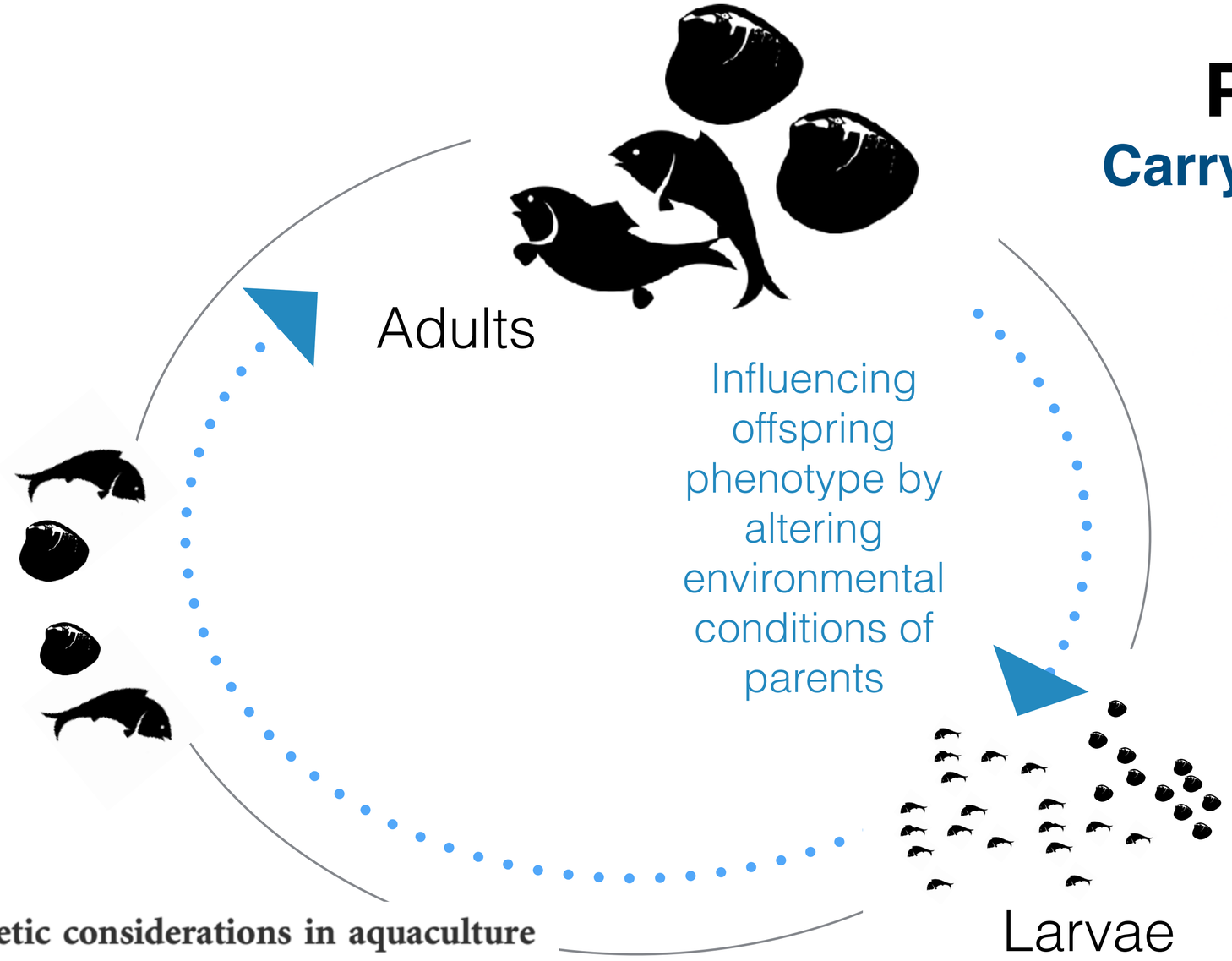
No Significant Benefit.

Mismatch

The benefit wasn't universal. The "preparation" provided by parents is most useful when offspring face a matching stressful environment.

Phenotypes

Carry-over effects



OLYMPIA OYSTER

Epigenetic considerations in aquaculture

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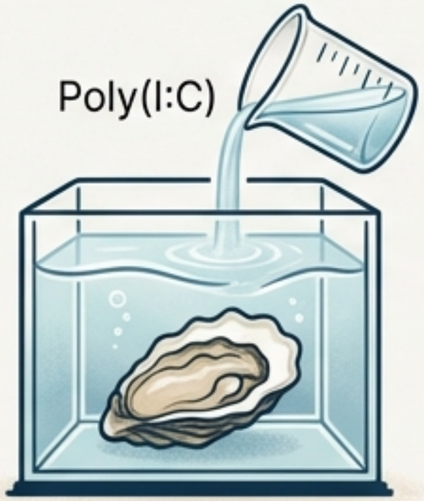
School of Aquatic & Fishery Sciences, University of Washington, Seattle, WA, USA

PeerJ

Pacific Oyster Across Generation Memory

Broodstock Exposure

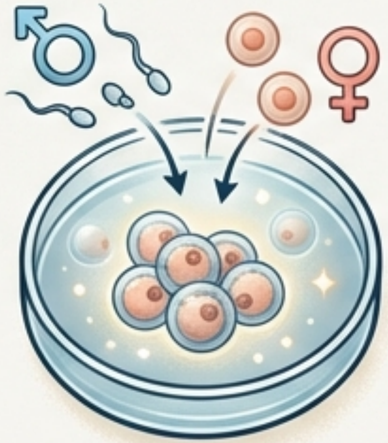
Oct 2024



Adults immersed in Poly(I:C) vs. Control.

Spawning

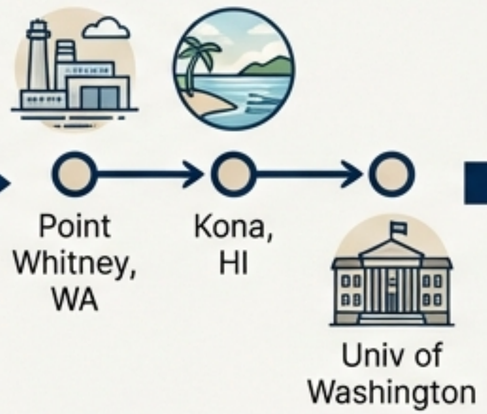
Immediate



Strip spawning following exposure.

Larval Rearing

Oct - Feb



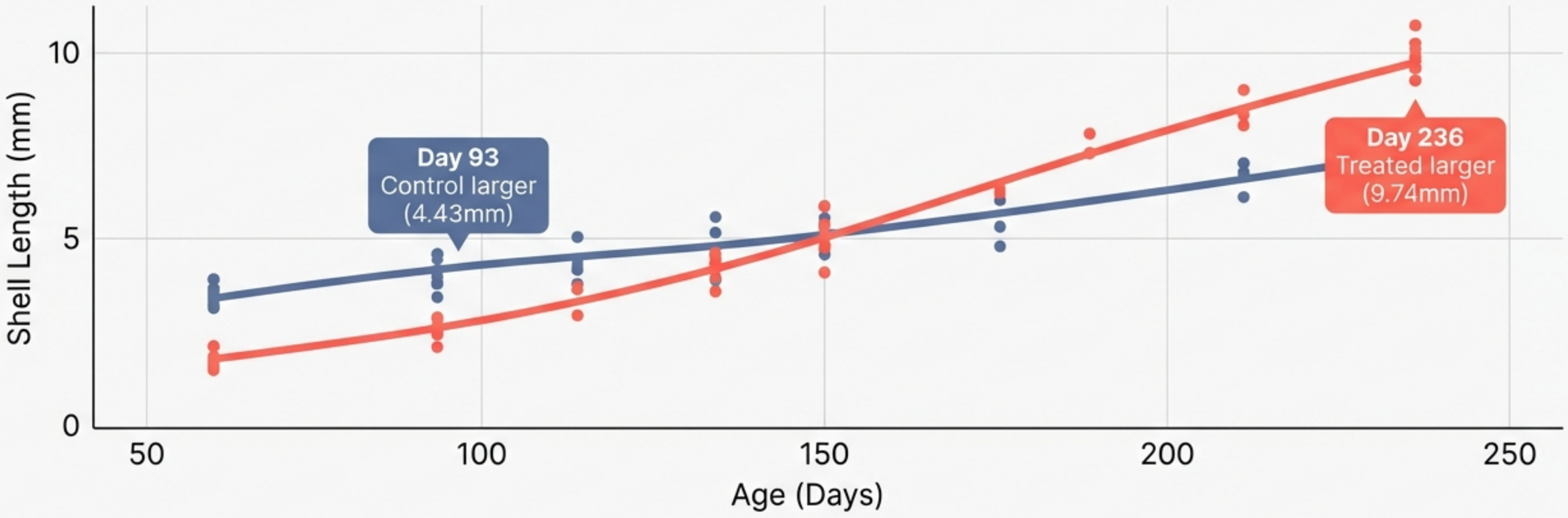
7+ months of development tracked.

The Stress Test

Feb - Mar 2025

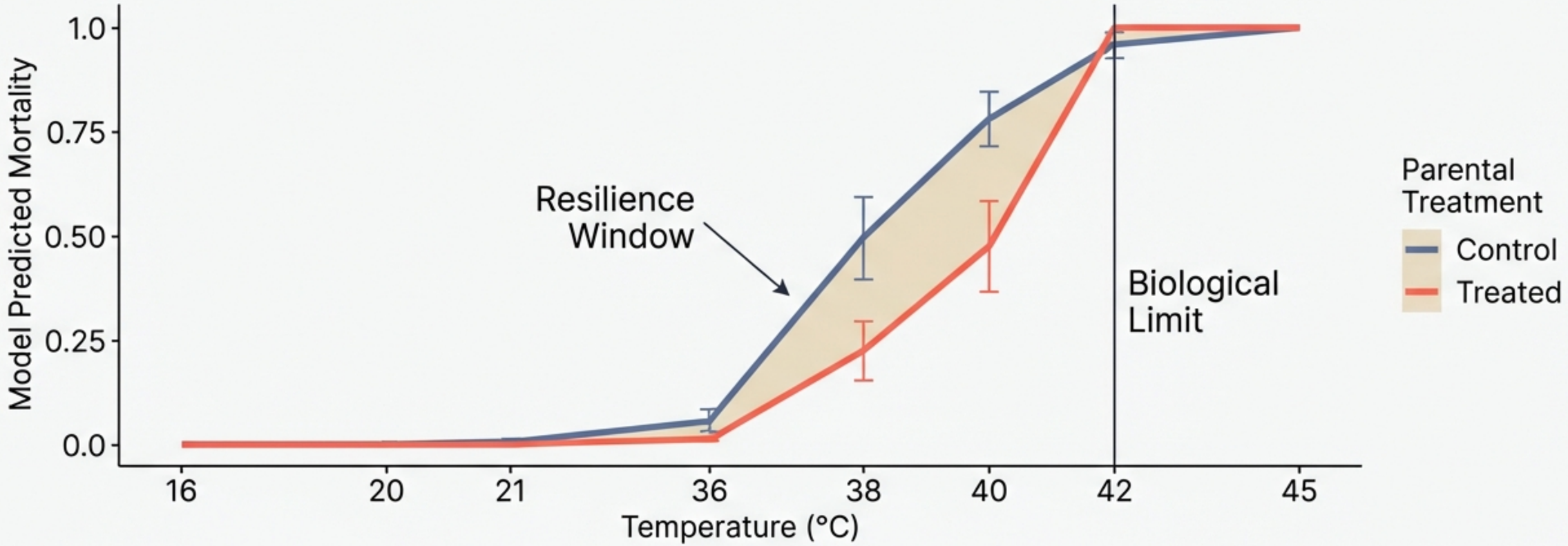
Offspring subjected to extreme thermal stress.

Growth Dynamics: The ‘Catch-Up’ Phenomenon



Insight: Treated offspring started slower—likely investing energy in immune defense—but **accelerated later** to become significantly larger.

Thermal Tolerance: The Resilience Window

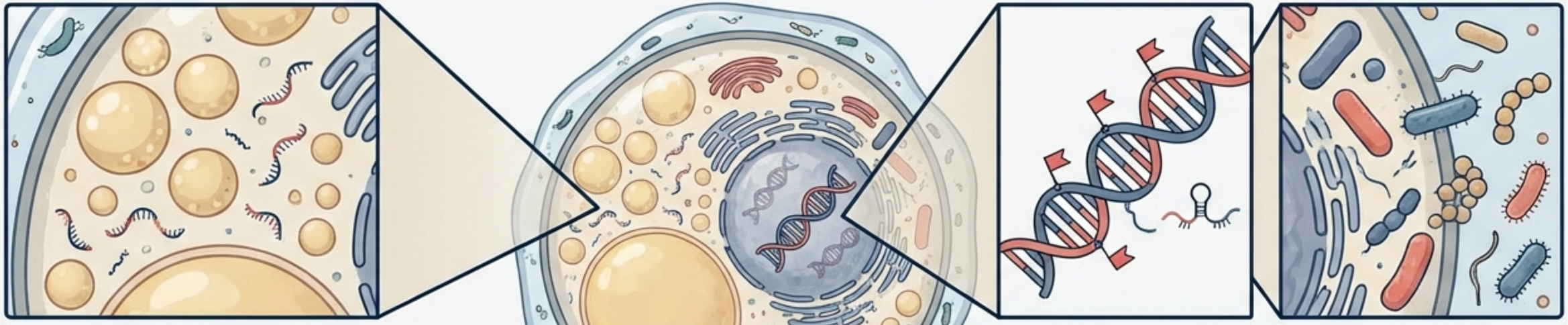


Insight: Priming widens the survival window up to 40°C, creating a ‘buffer zone’ for heatwaves. However, this defense mechanism has a biological breaking point at 42°C.

Cross-Protection: Immune Inputs, Thermal Outputs

The Surprise: Parents were treated with a viral mimic, yet offspring showed heat tolerance. Why? The ‘fire drill’ prepared the cellular machinery for both fire (heat) and intruders (virus).

How is the Message Passed?



Maternal Provisioning

Investment of Lipids & mRNA

A survival 'starter pack'.

Oyster Egg Cell

Epigenetics

DNA Methylation & Non-coding RNAs.

Switches that turn stress genes On/Off.

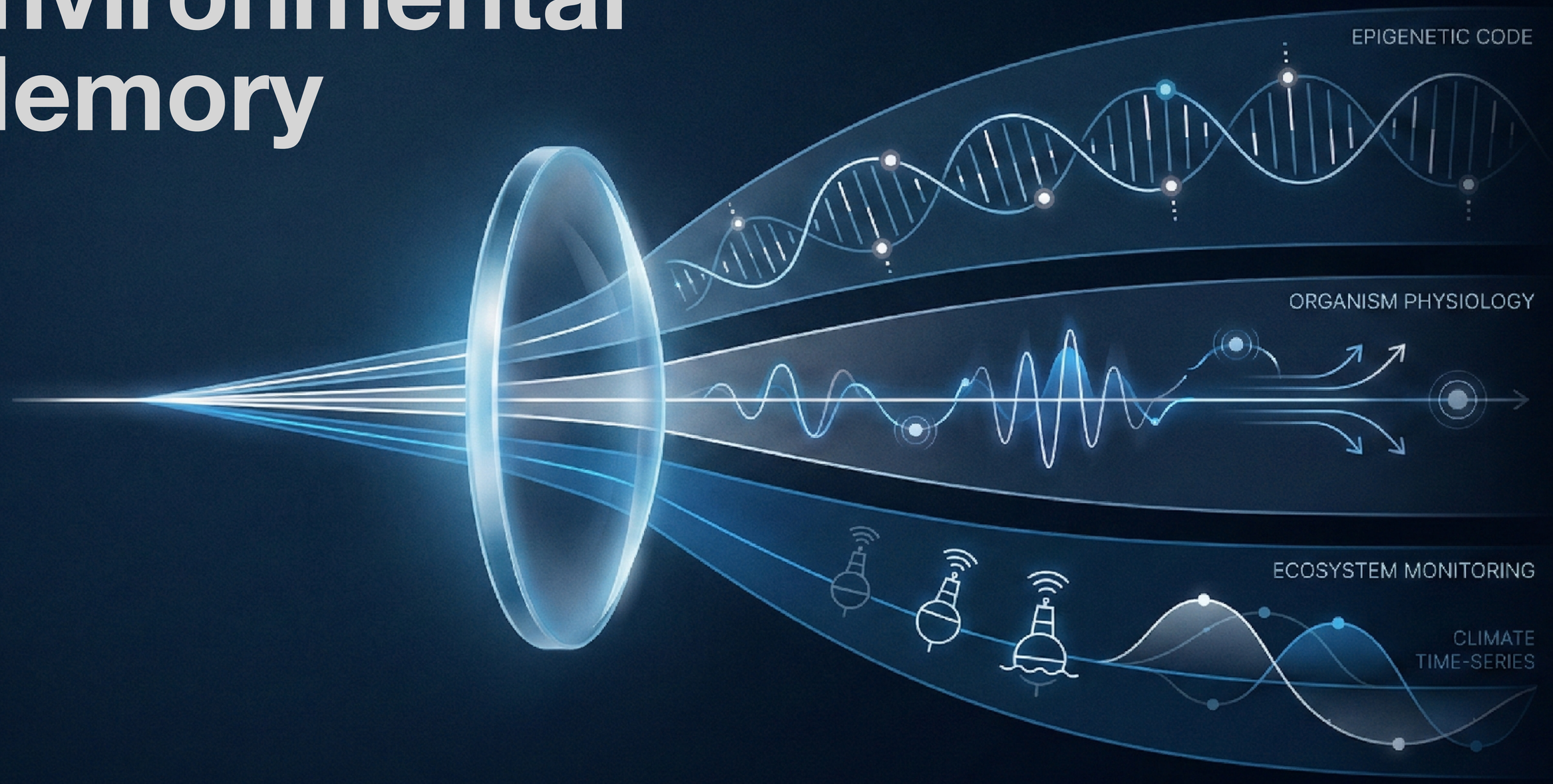
Microbiome

Microbial Transfer

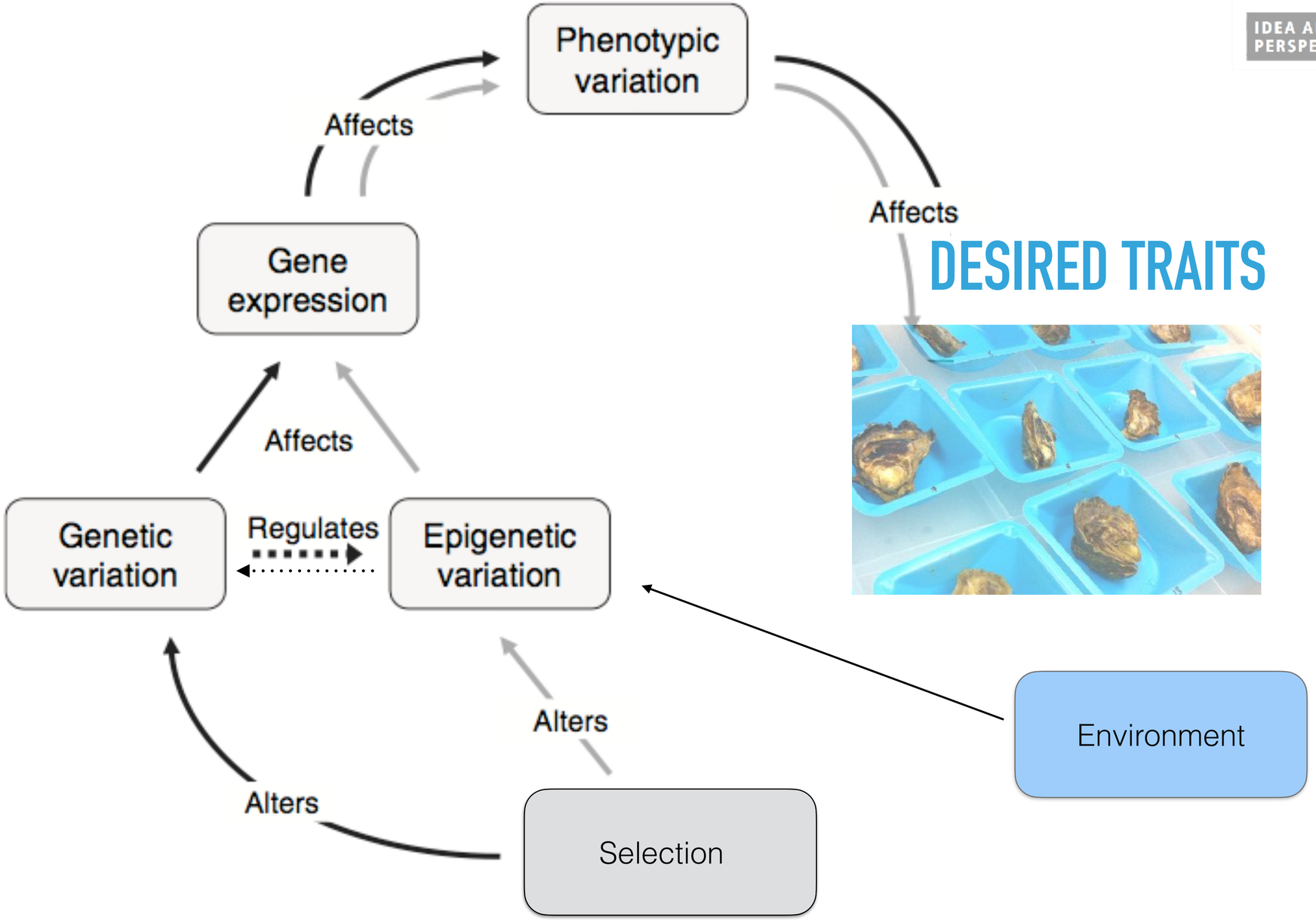
Shifts in bacterial community passed to seed.

Status: Observed effects persisted >7 months, strongly suggesting epigenetic mechanisms beyond simple energy provisioning.

Environmental Memory



ECOLOGICAL EPIGENETICS



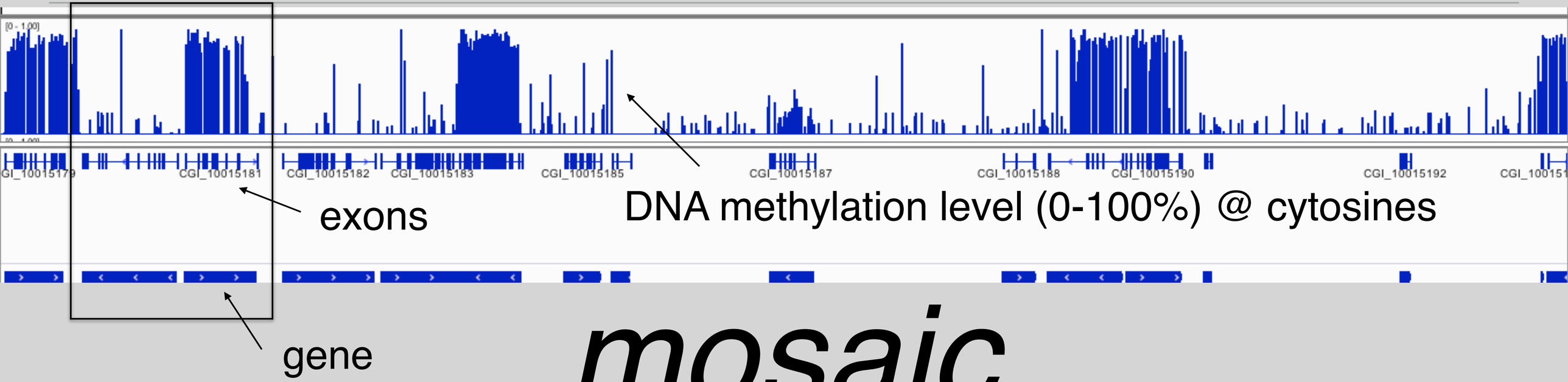
Ecology Letters, (2008) 11: 106–115 doi: 10.1111/j.1461-0248.2007.01130.x

IDEA AND PERSPECTIVE

Epigenetics for ecologists

Affects

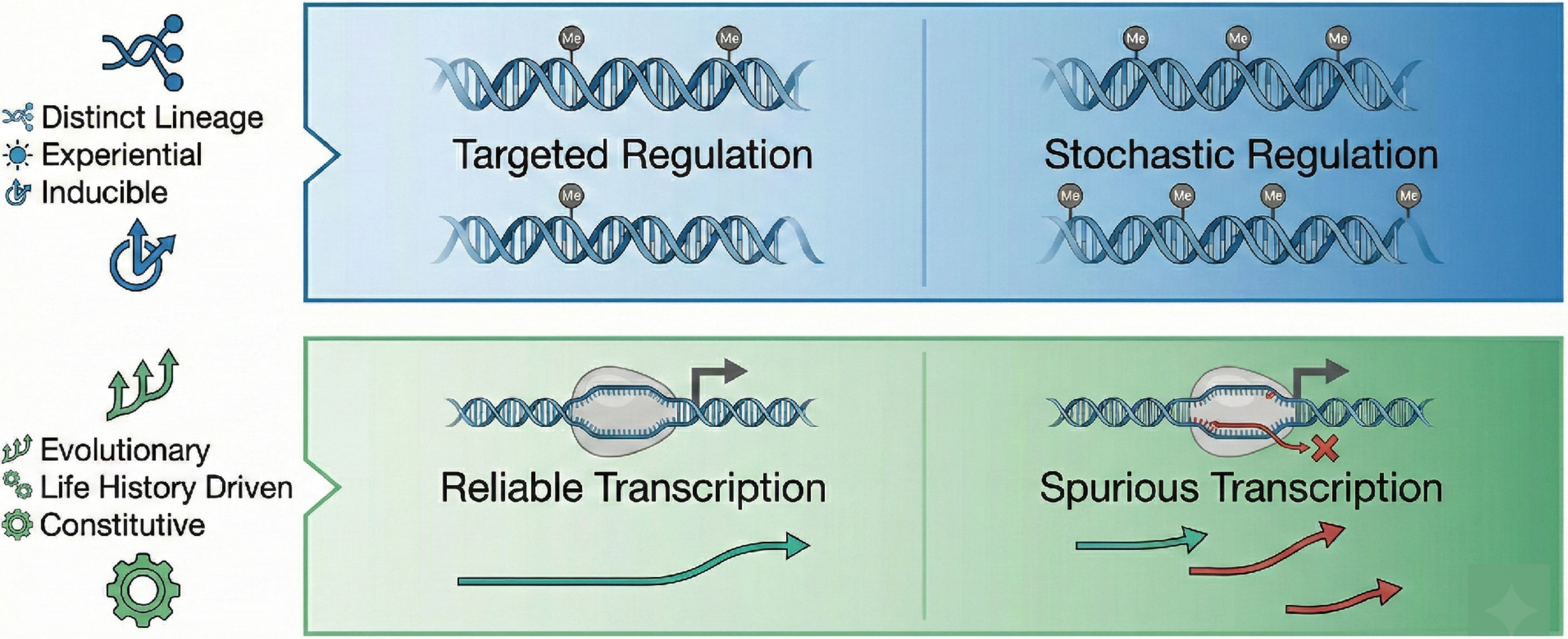
DESIRED TRAITS



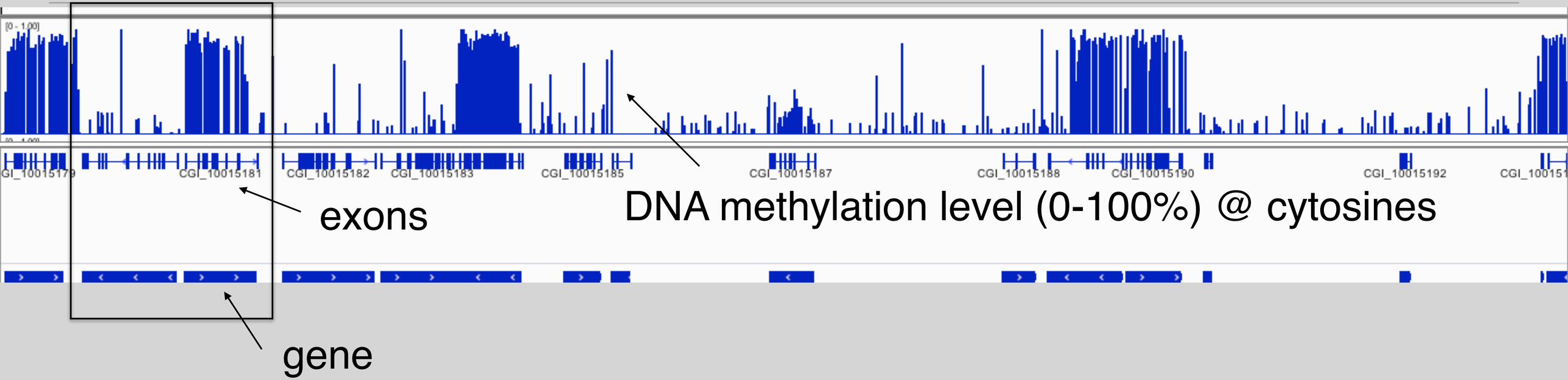
mosaic

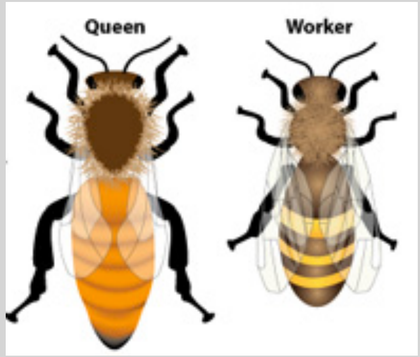
associated with gene bodies

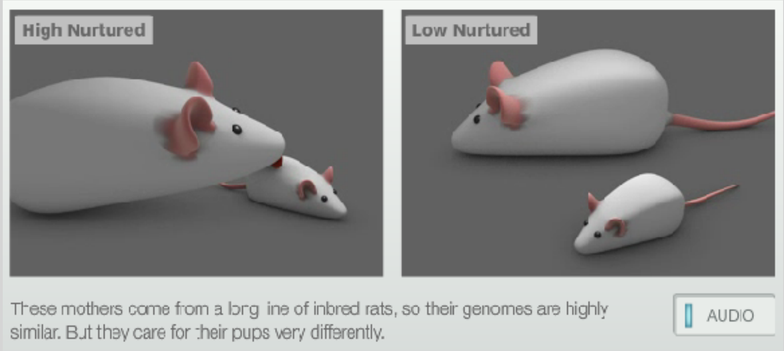
DNA Methylation Dynamics in Marine Invertebrates:
Four Dimensionalities



METHYLATION LANDSCAPE IN MARINE INVERTEBRATES







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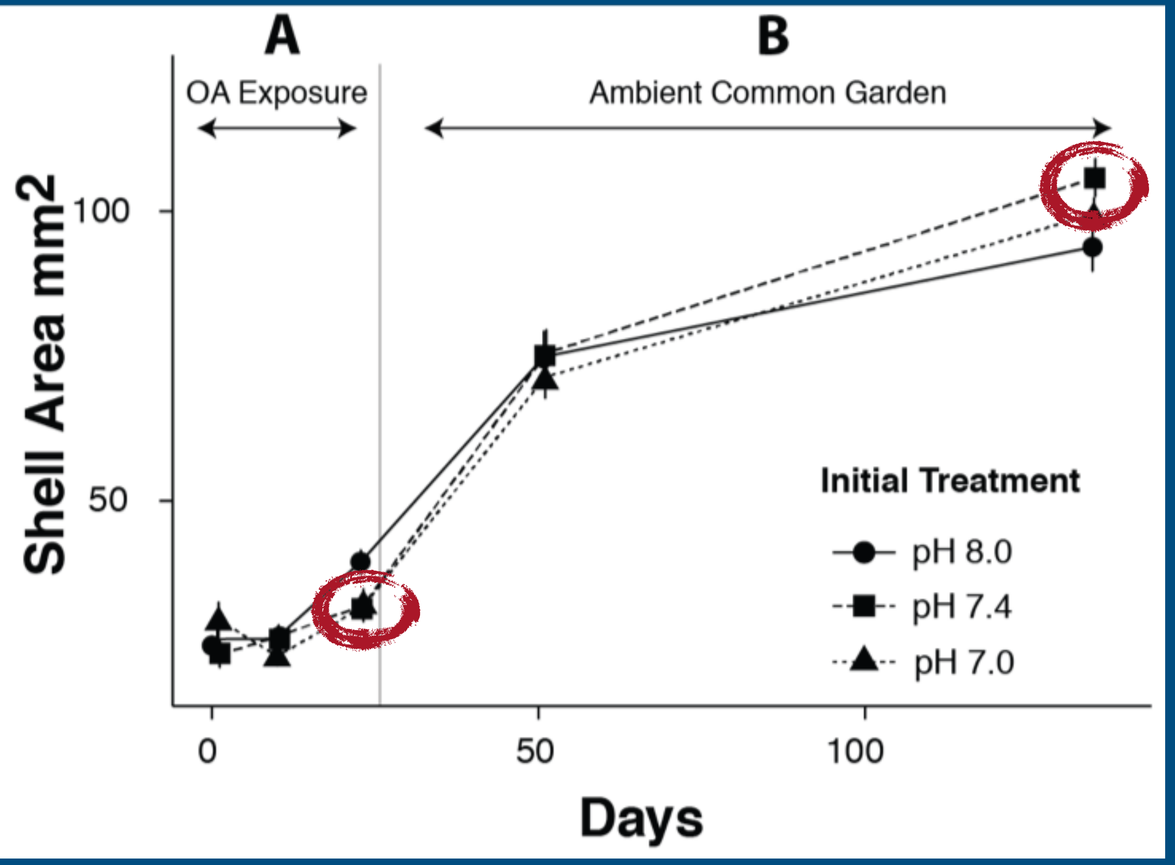
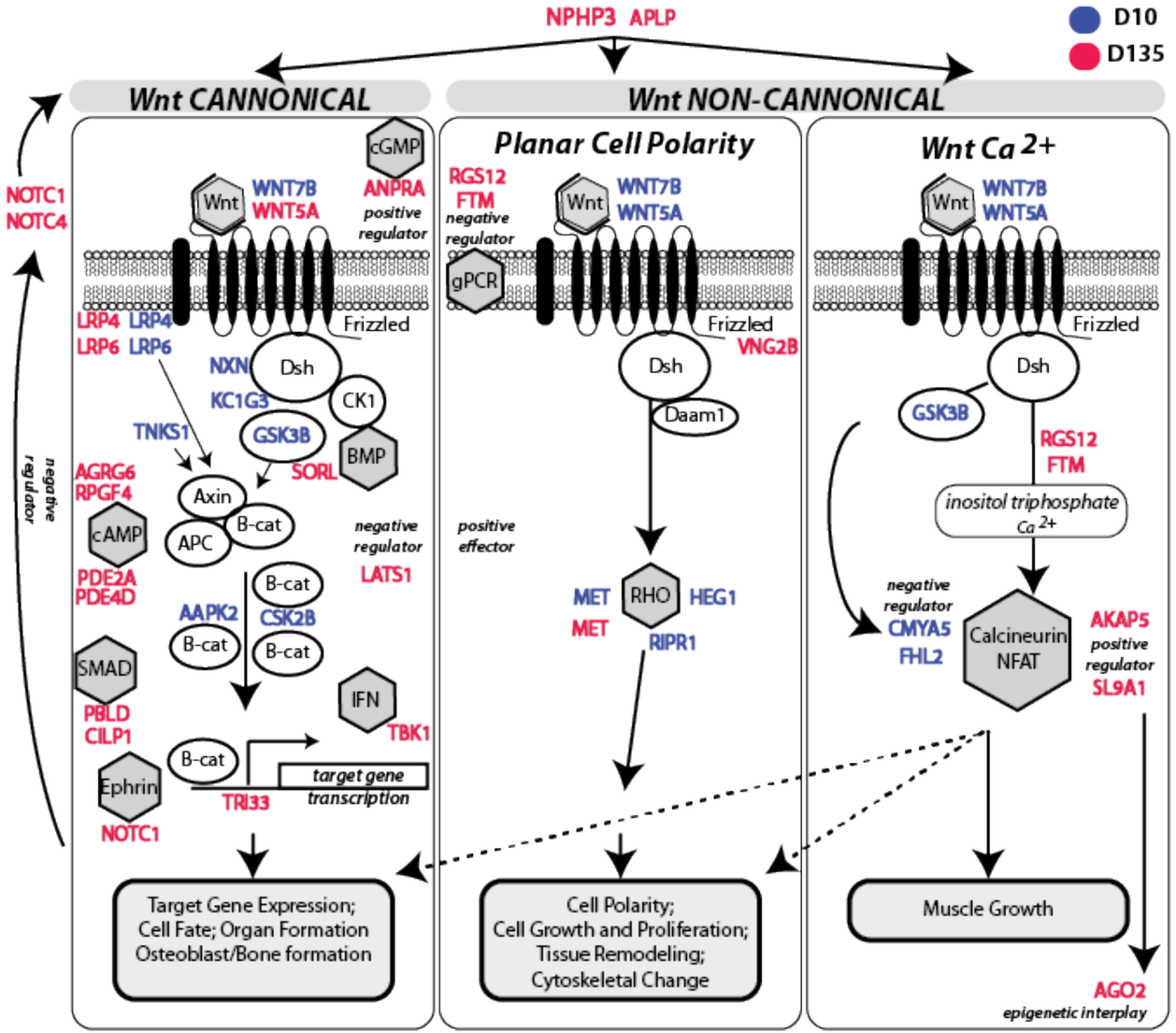
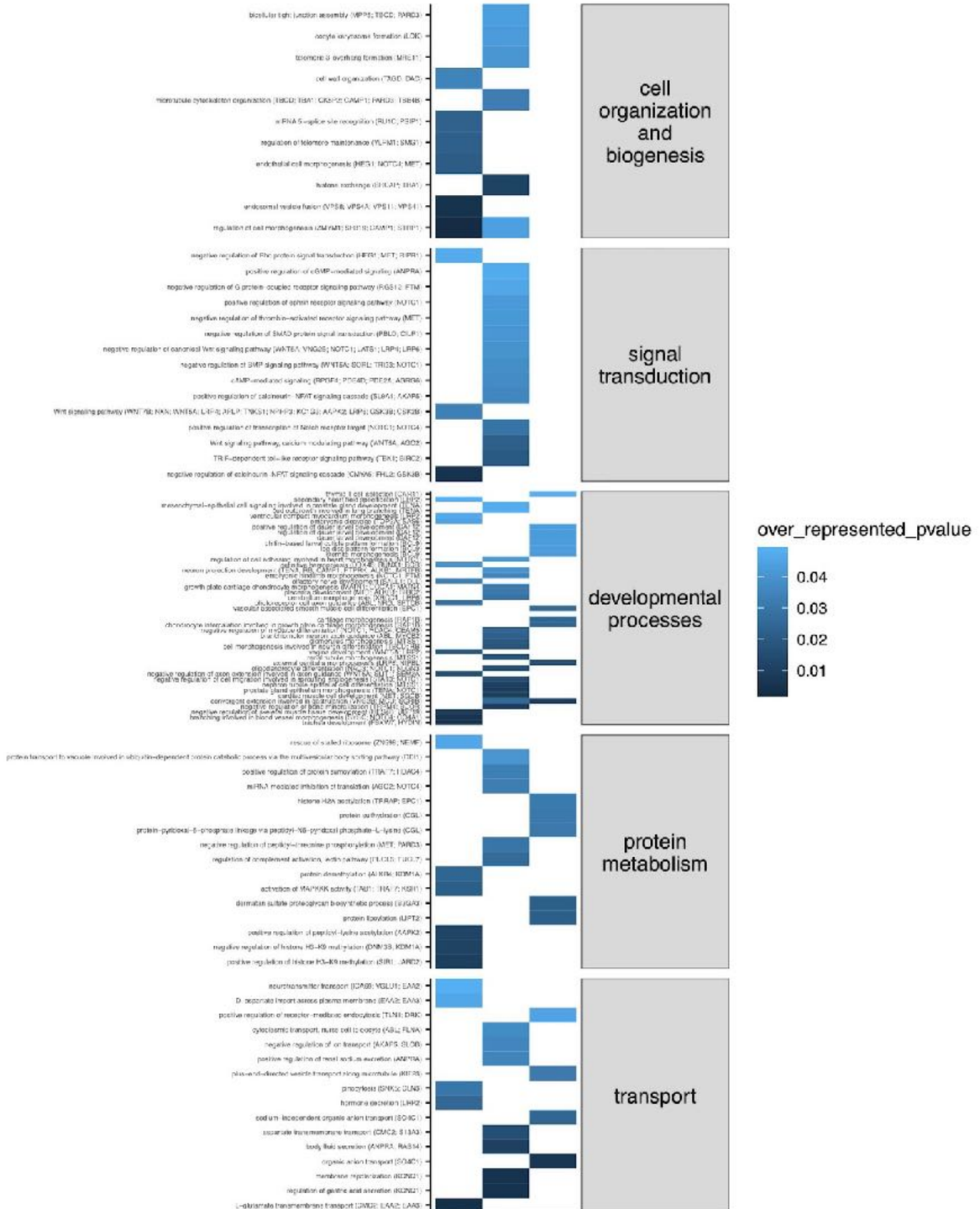


GEODUCKS AND OA





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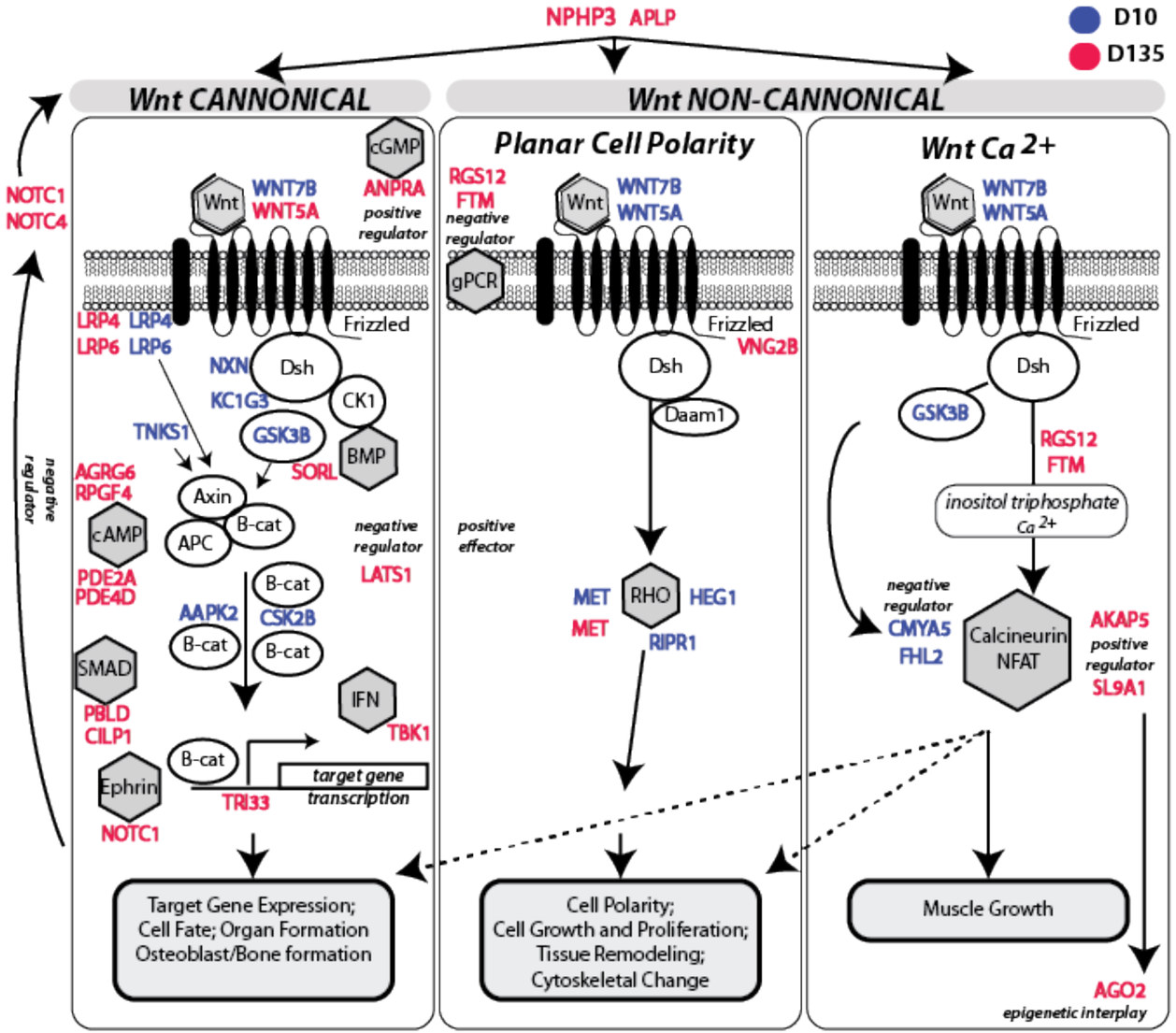


New Results

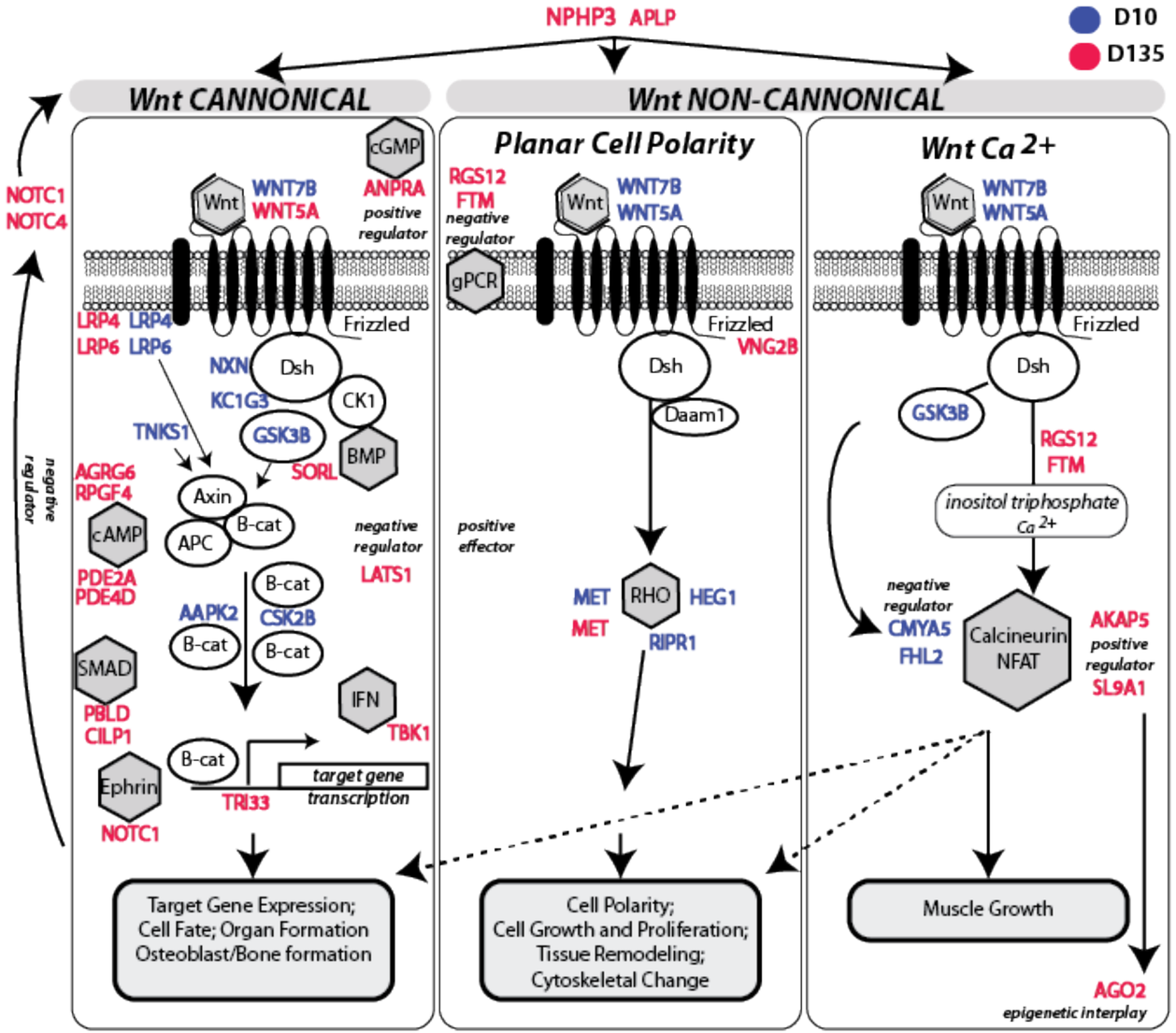
Follow this preprint

Dynamic DNA methylation contributes to carryover effects and beneficial acclimatization in geoduck clams

Hollie M. Putnam, Shelly A. Trigg, Samuel J. White, Laura H. Spencer, Brent Vadopalas, Aparna Natarajan, Jonathan Hetzel, Erich Jaeger, Jonathan Soohoo, Cristian Gallardo-Escárate, Frederick W. Goetz, Steven B. Roberts

doi: https://doi.org/10.1101/2022.06.24.497506

GEODUCKS AND OA



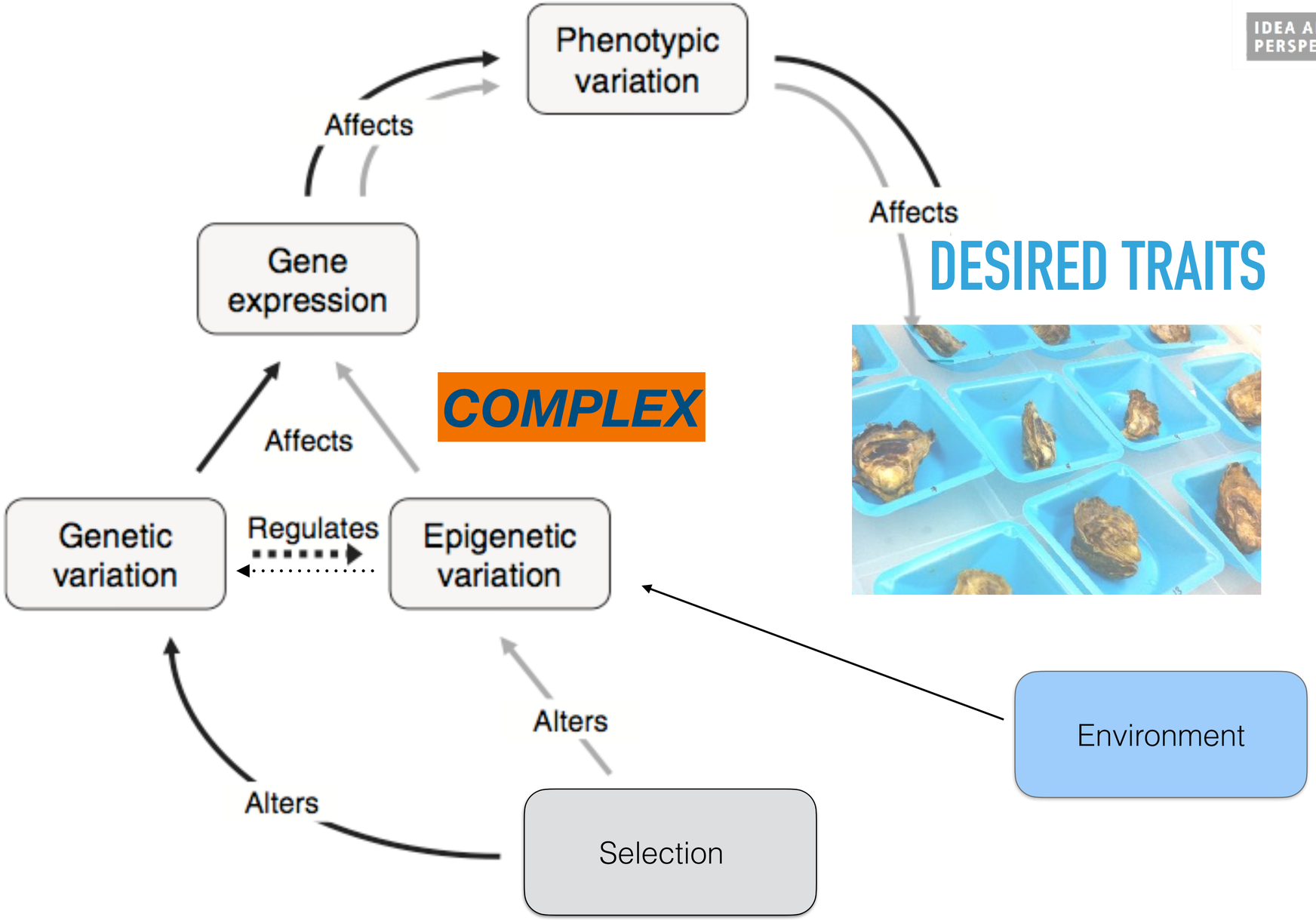
Following four months of ambient common-garden conditions, **juveniles initially exposed to low pH compensatorily grew larger**, with DNA methylation indicative of these phenotypic differences, demonstrating epigenetic carryover effects persisted months after initial exposure.

ECOLOGICAL EPIGENETICS

Ecology Letters, (2008) 11: 106–115 doi: 10.1111/j.1461-0248.2007.01130.x

IDEA AND PERSPECTIVE

Epigenetics for ecologists



COMPLEX

DESIRED TRAITS

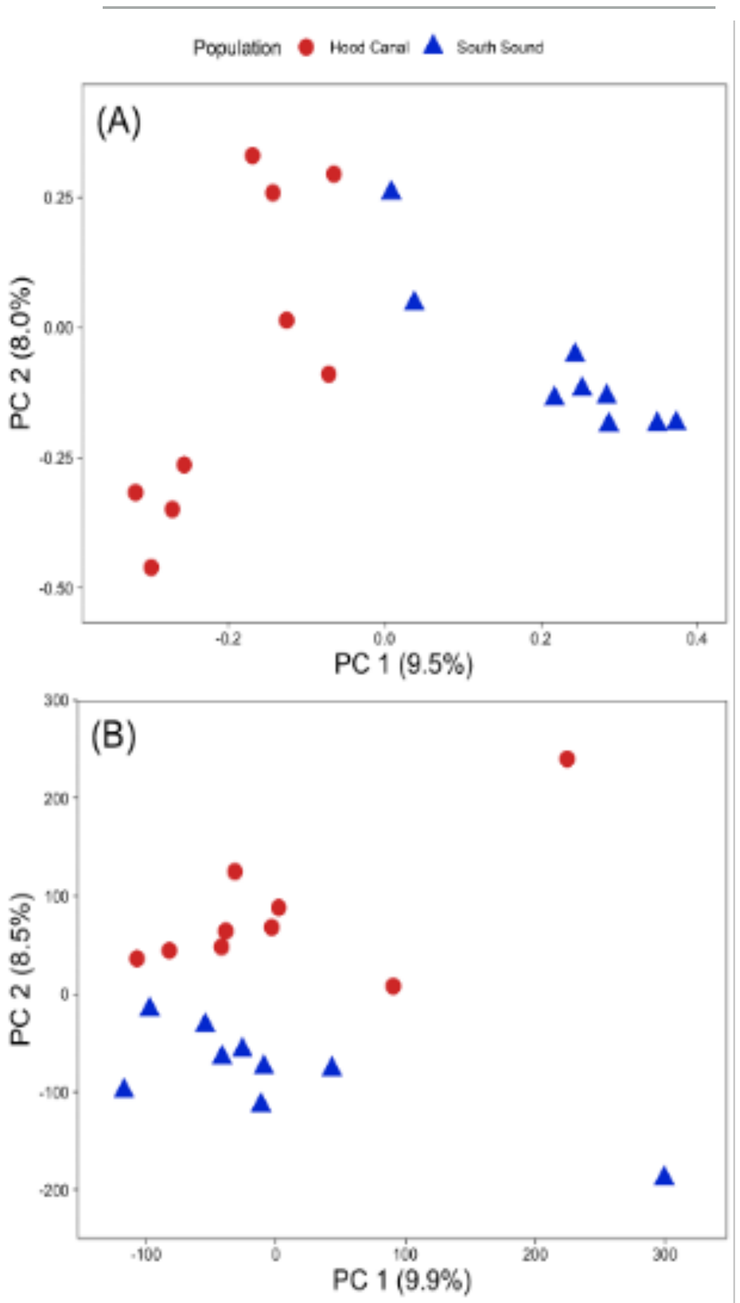
Epigenetic and Genetic Population Structure is Coupled in a Marine Invertebrate

Katherine Silliman [1,†], Laura H. Spencer [2,†], Samuel J. White[2], and Steven B. Roberts [2,*]

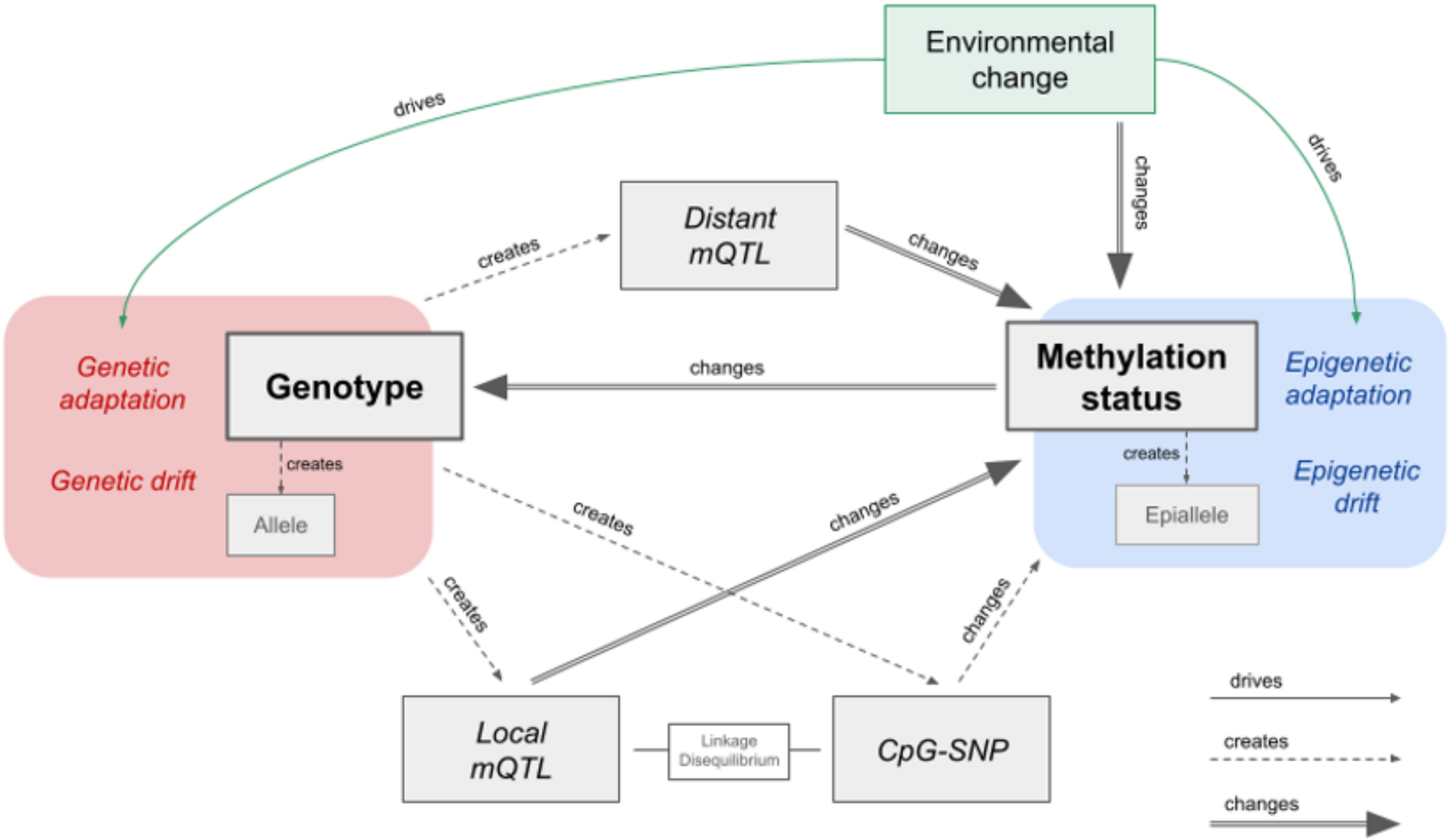
First characterization of genome-wide DNA methylation patterns in the oyster genus *Ostrea*

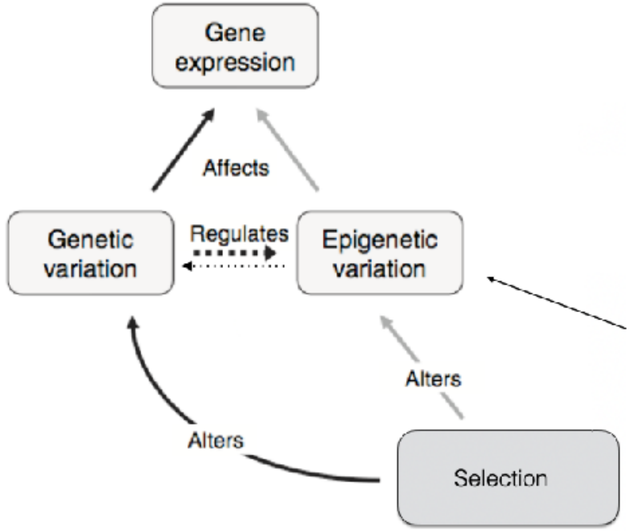
Identified 3,963 differentially methylated loci between populations. Clear coupling between genetic and epigenetic patterns of variation, **with 27% of variation in inter-individual methylation differences explained by genotype**.

Underlying this association are both direct genetic changes in CpGs (CpG-SNPs) and genetic variation with indirect influence on methylation (mQTLs).



EPIGENETIC AND GENETIC POPULATION STRUCTURE





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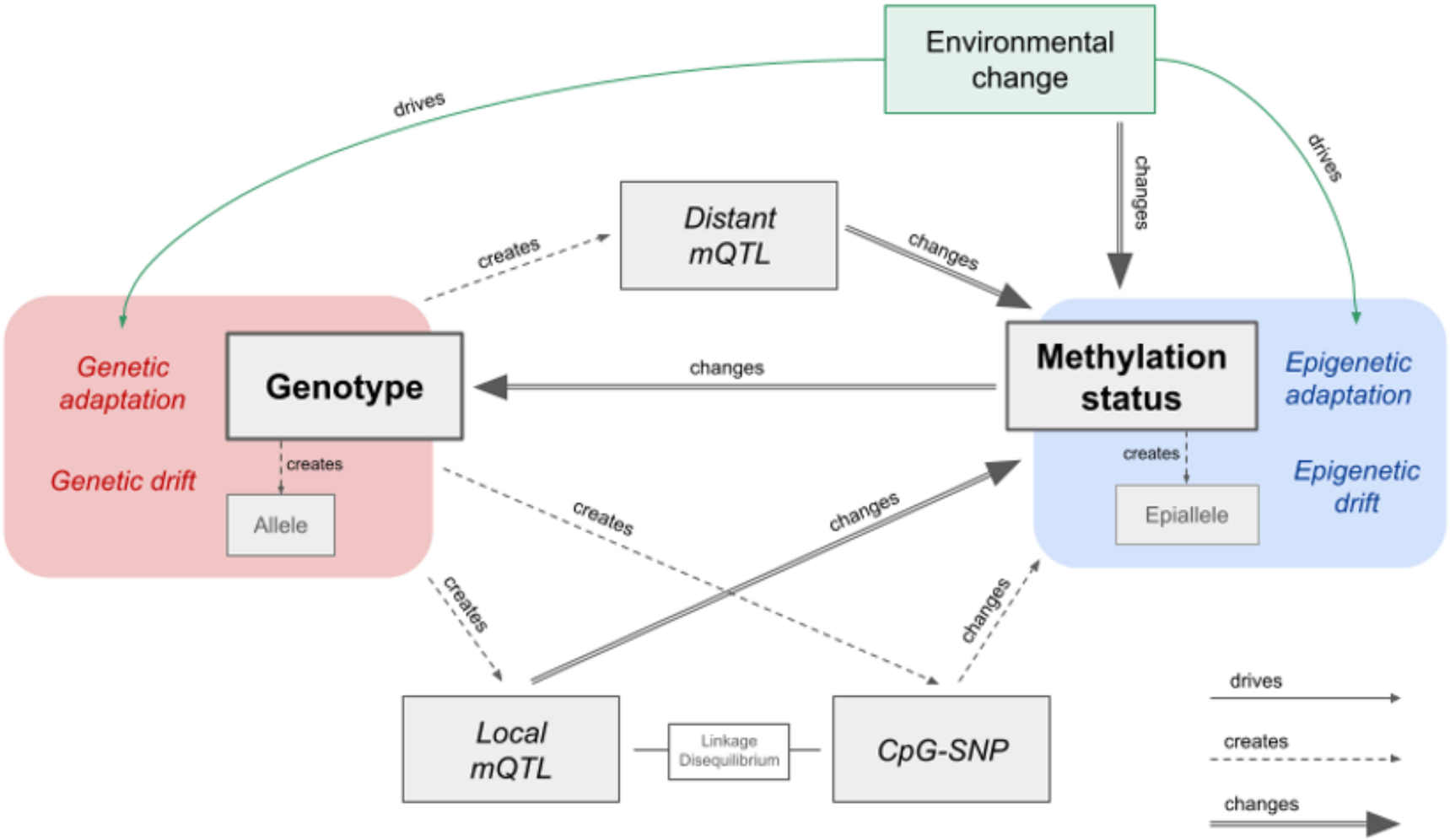
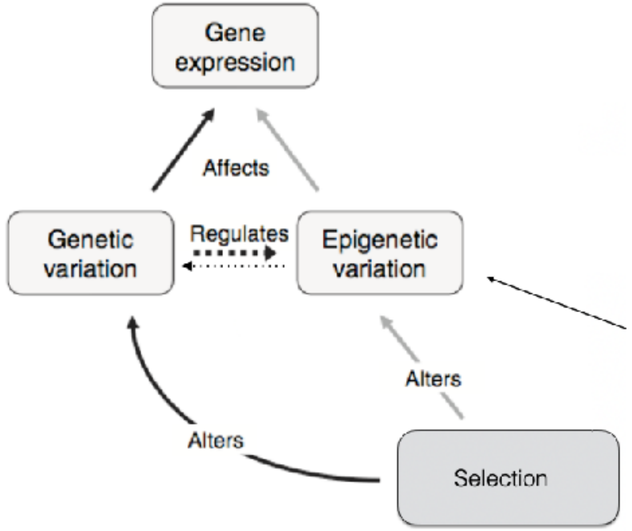


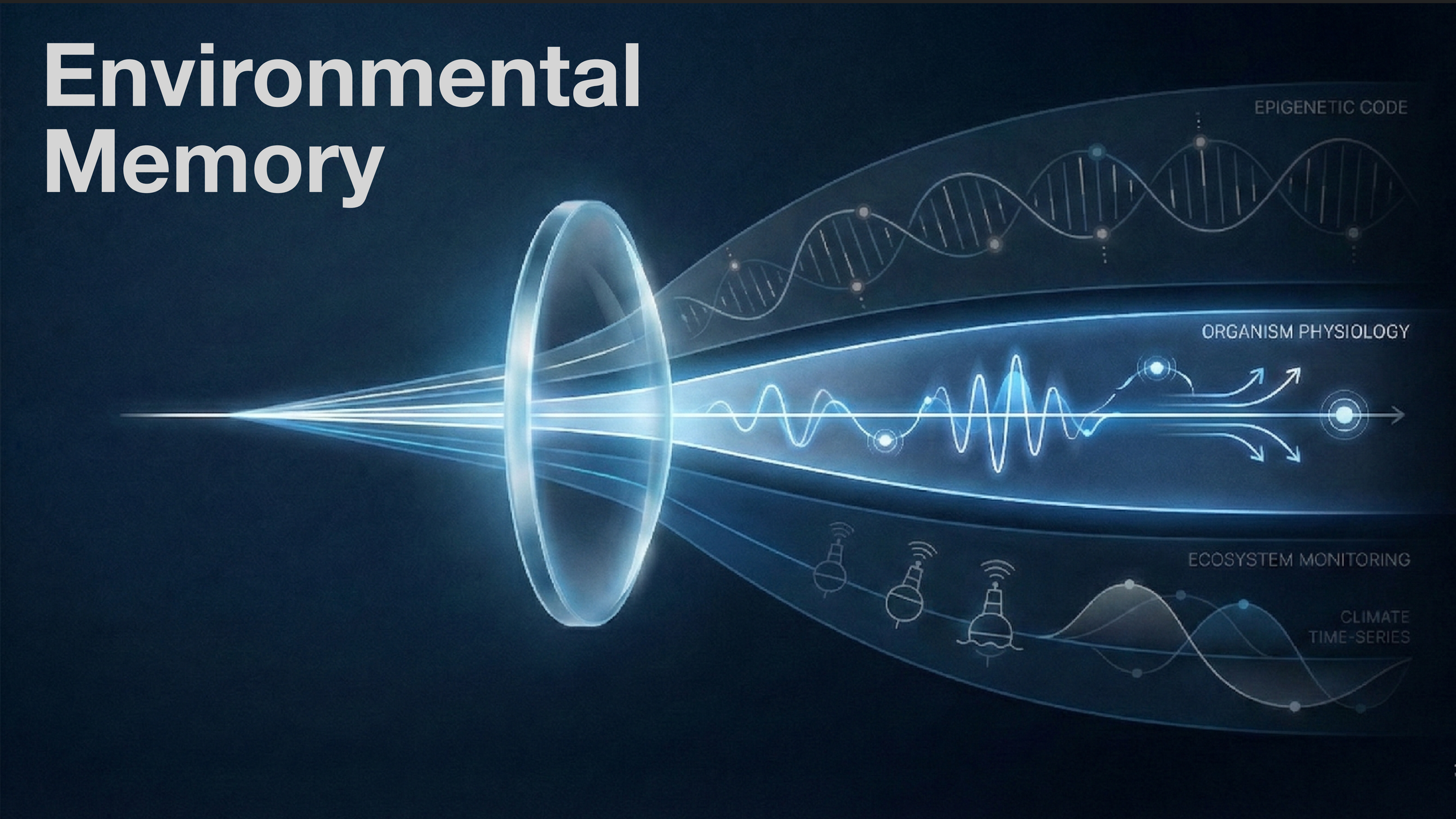


MEMORY AT DIFFERENT SCALES

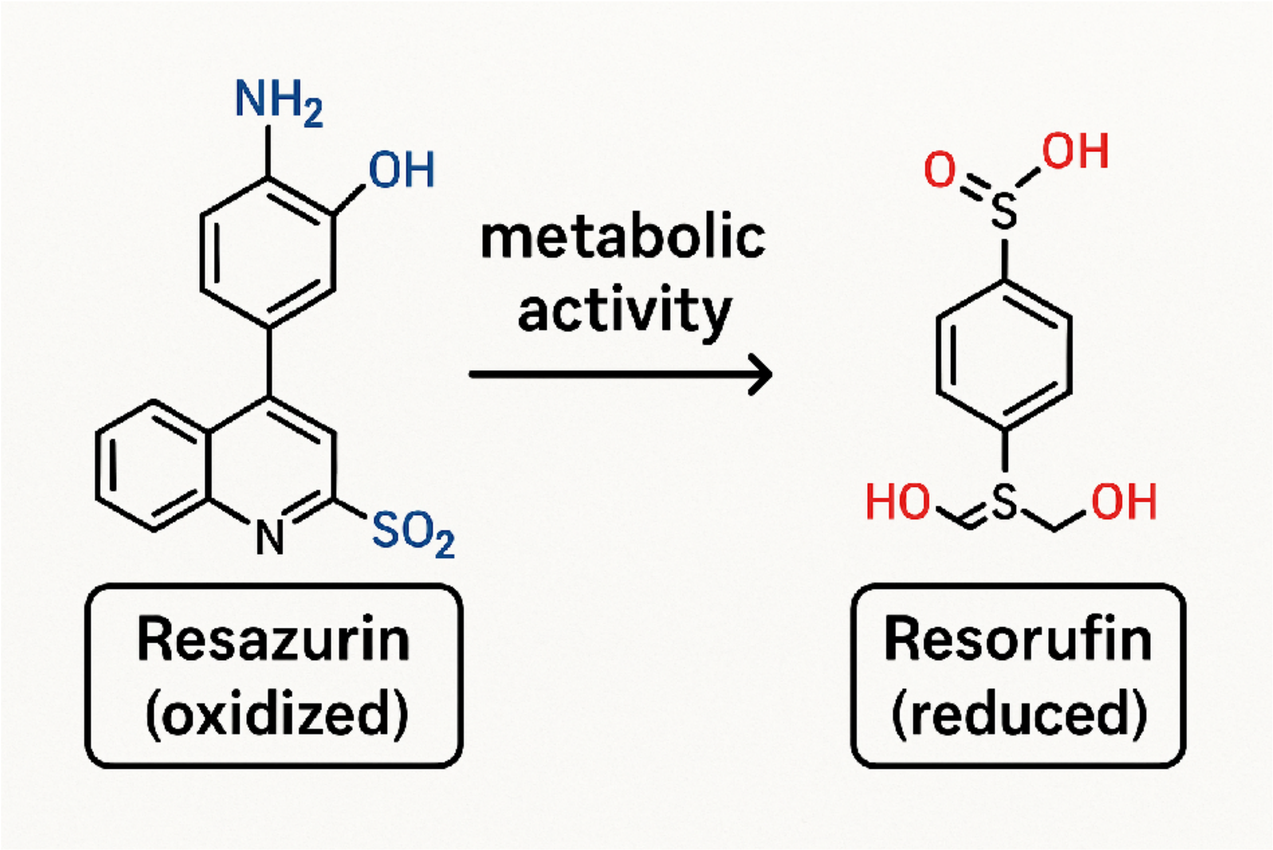
-

KEY STATES IN PREDICTION

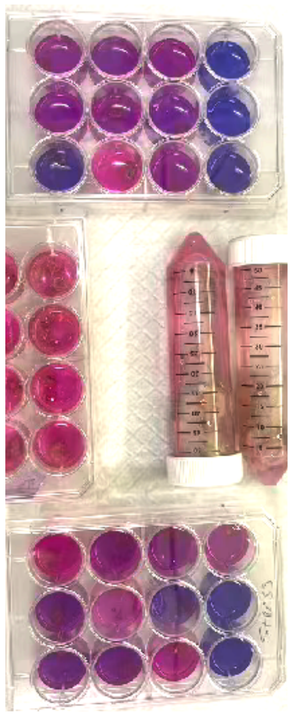
Environmental Memory



Understanding Memory - Predicting Performance



Resazurin



Is metabolic activity associated with a stress event different when oyster had previously experienced a stress? Is there evidence for functional priming?

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Results from an 18-month Sea Grant experiment at Westcott Bay Shellfish

Project Leads: Emily Carrington & Steven Roberts

Research Team: Grace Leuchtenberger & Ariana Huffmyer

UNIVERSITY of WASHINGTON

Sea Grant

WESTCOTT BAY SHELLFISH

NotebookLM

Ariana Huffmyer - UW

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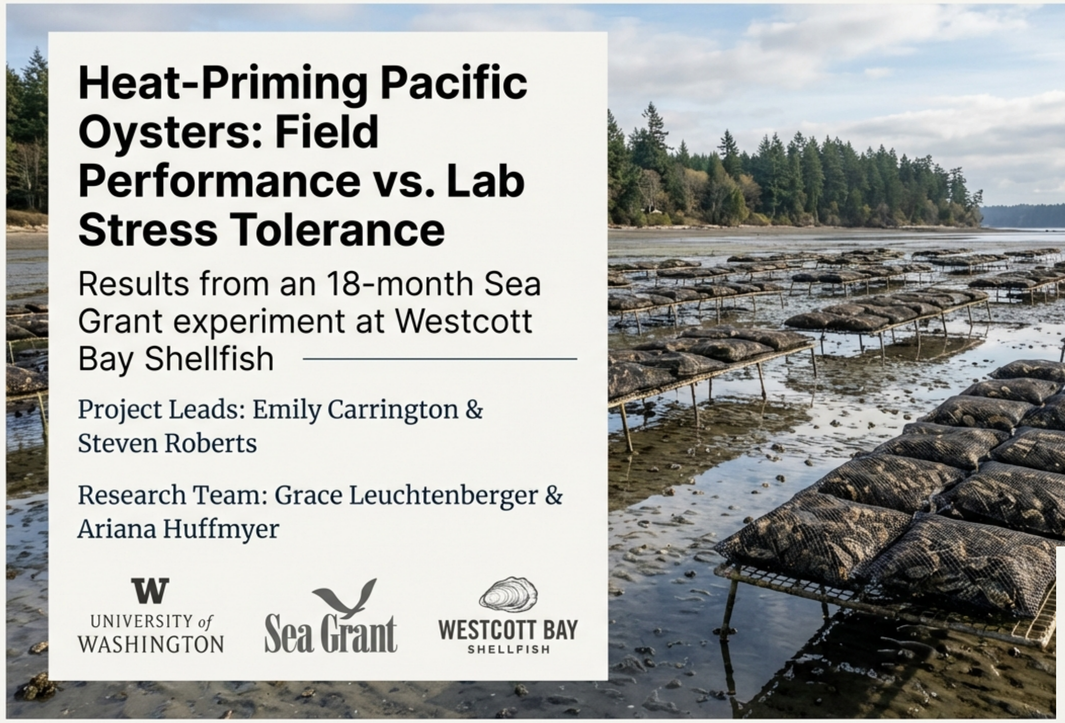
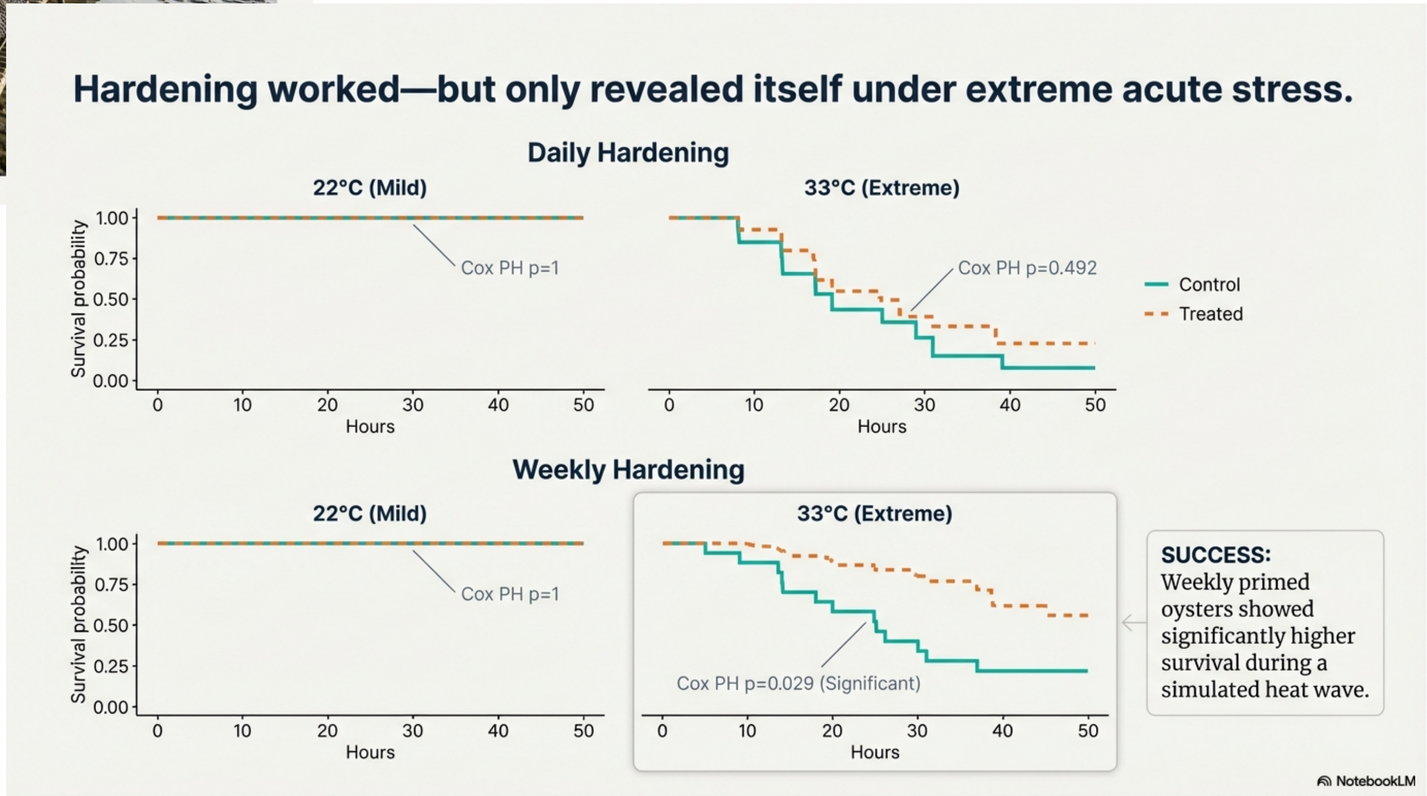
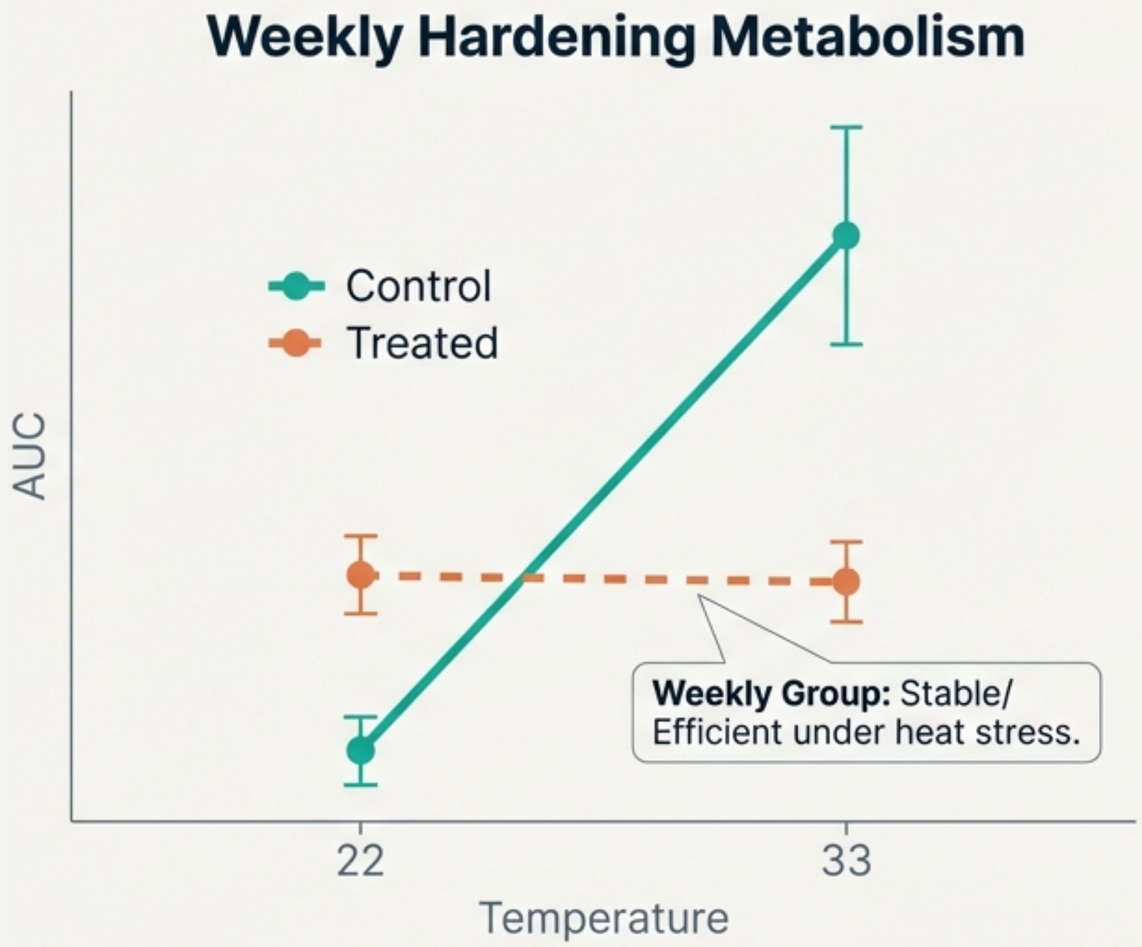


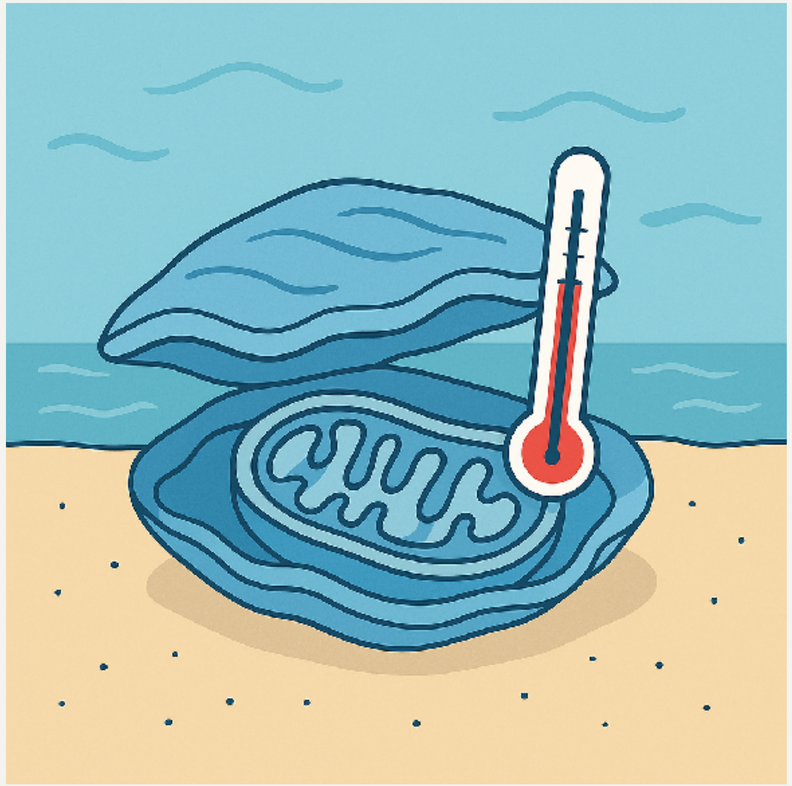


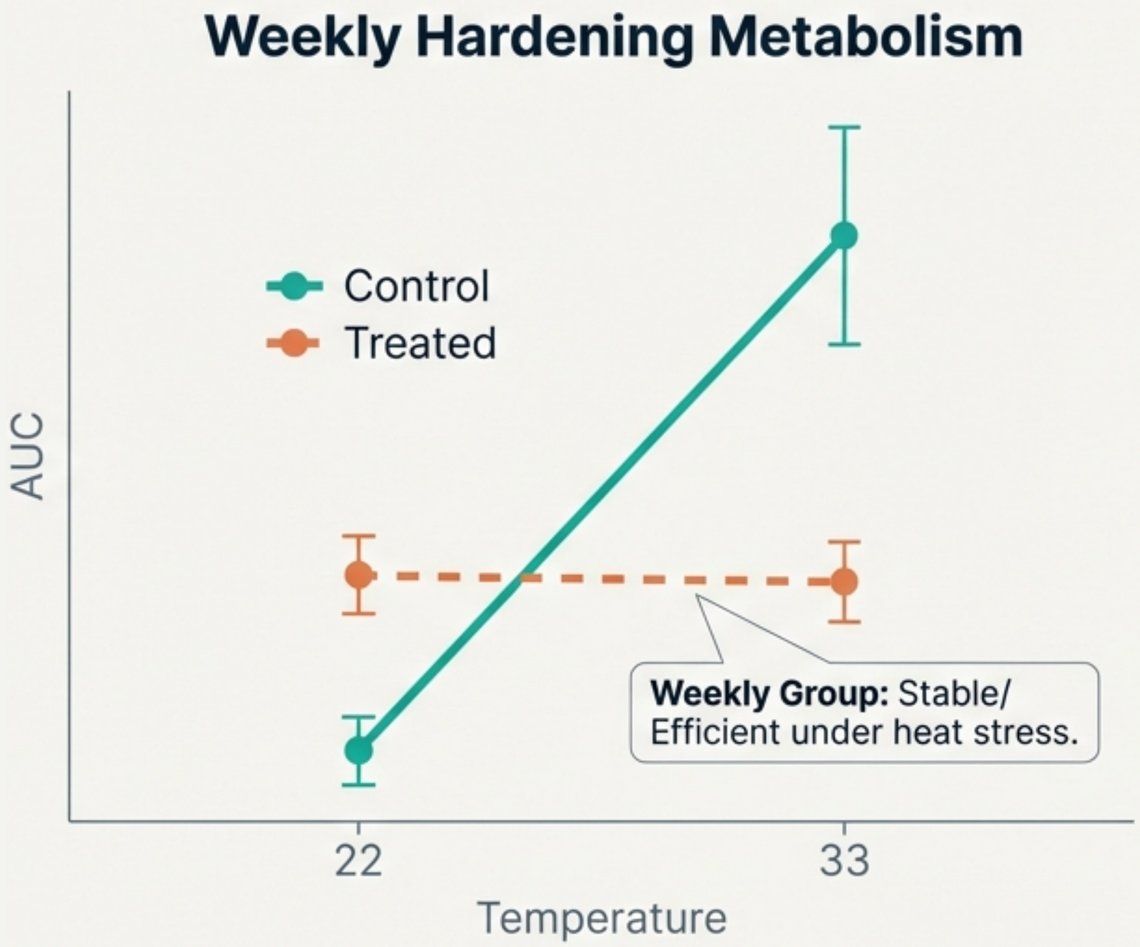
Priming fundamentally altered oyster metabolic strategies.



Conclusion: The hatchery treatments successfully programmed long-term changes in energy management.

Priming fundamentally altered oyster metabolic strategies.





Conclusion: The hatchery treatments successfully programmed long-term changes in energy management.

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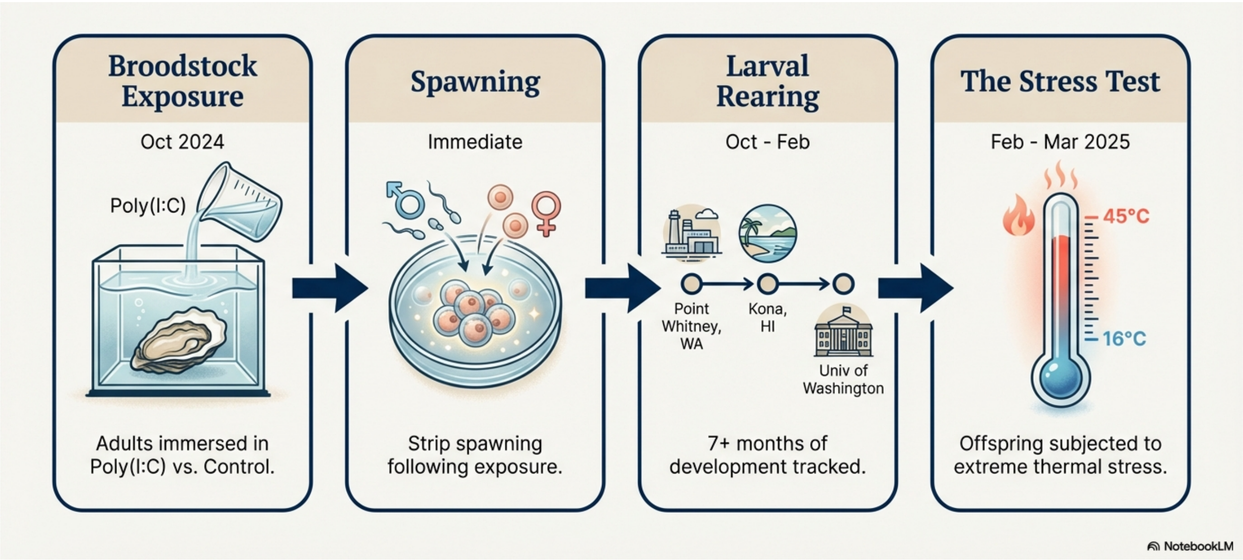

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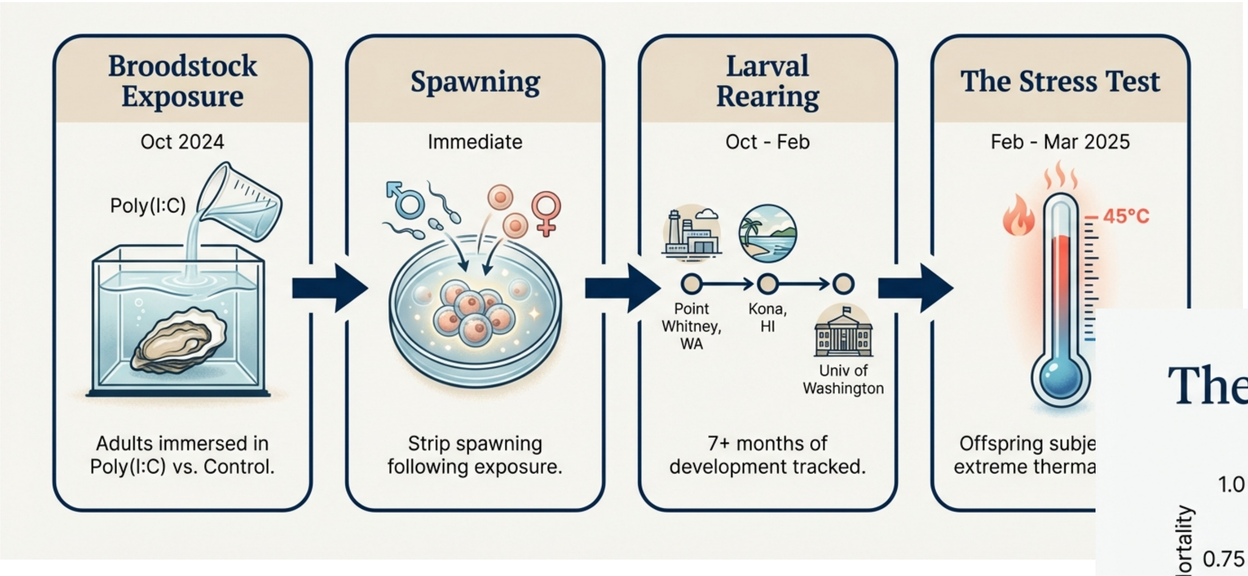

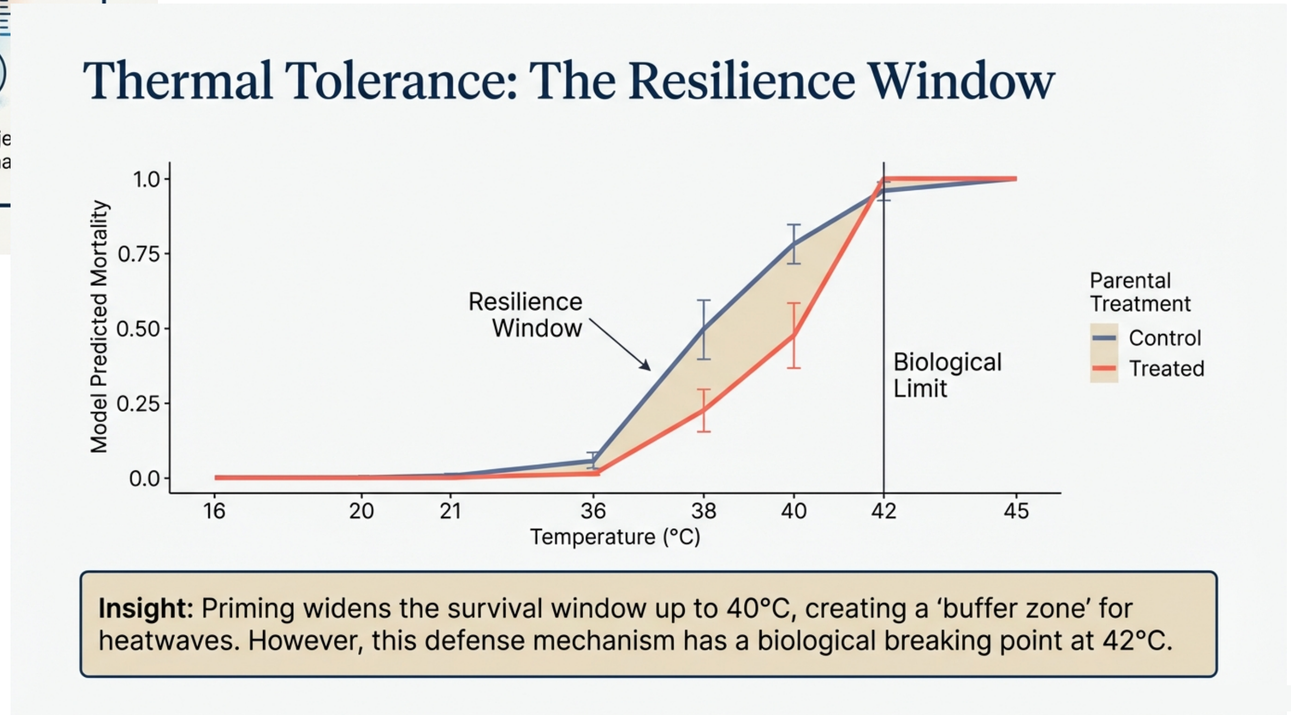

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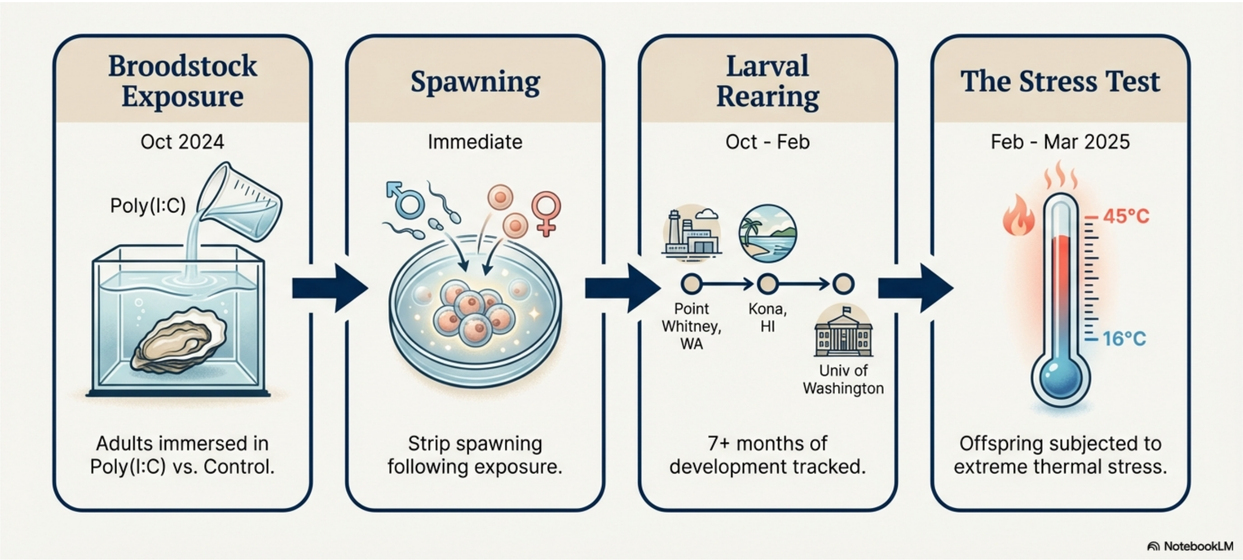
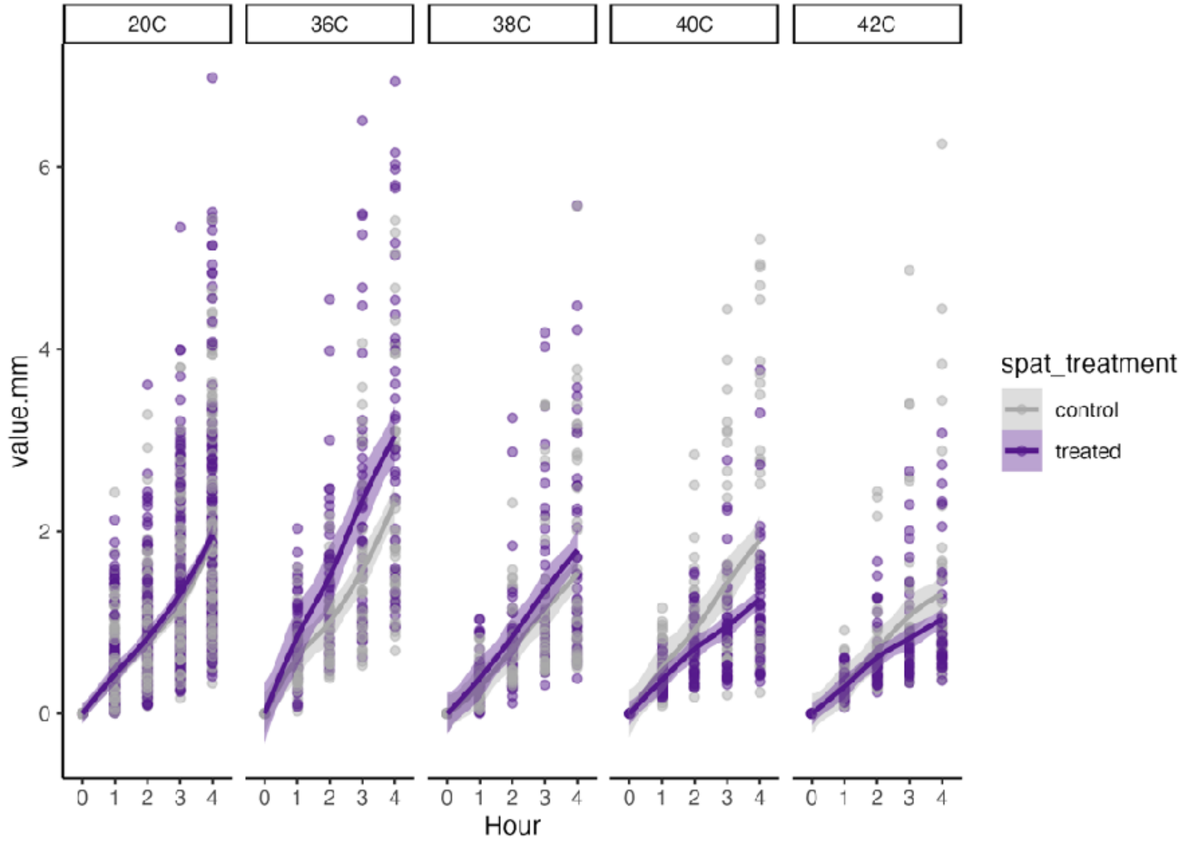
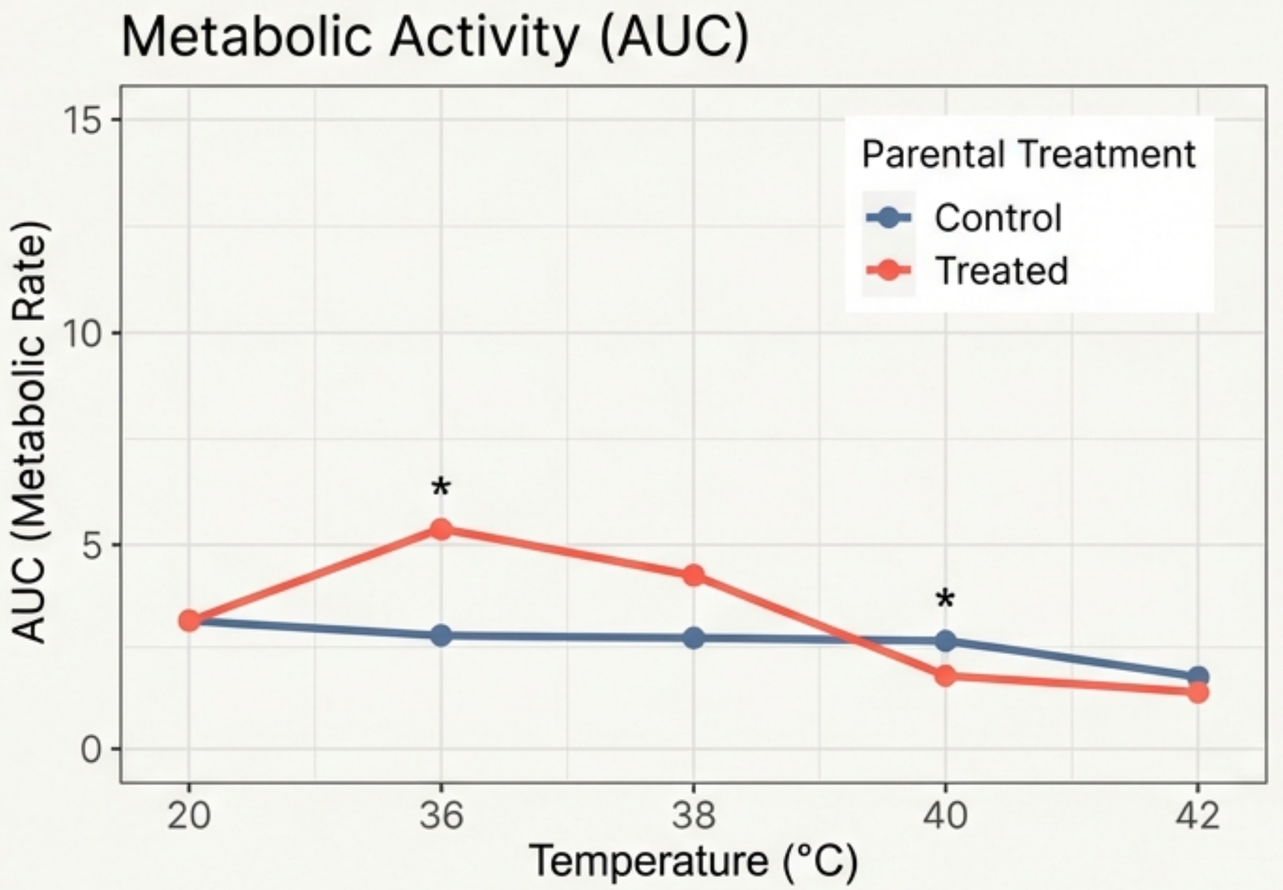


Offspring from immune-challenged parents exhibited ***greater metabolic flexibility***



The Hidden Mechanism: Metabolic Flexibility

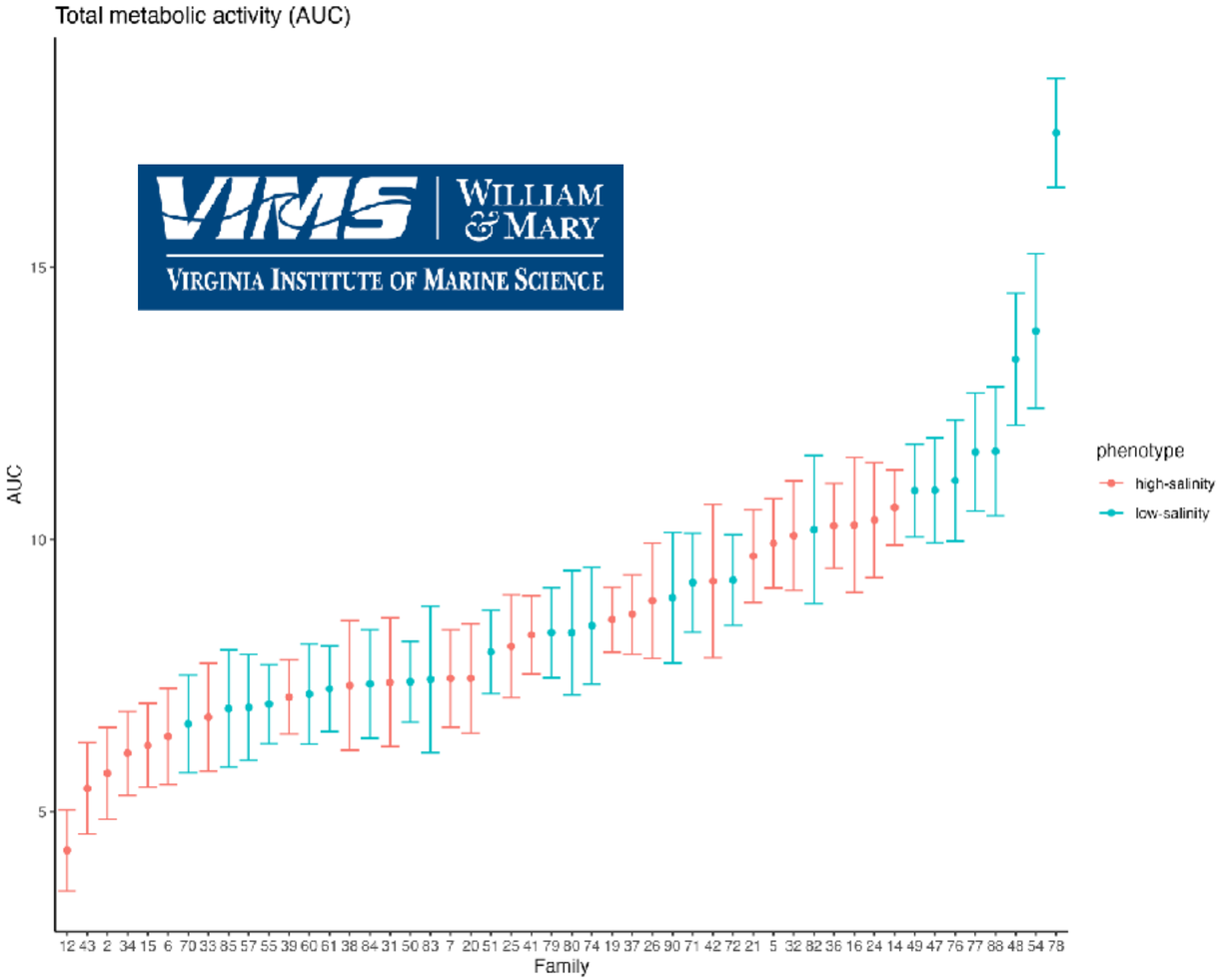


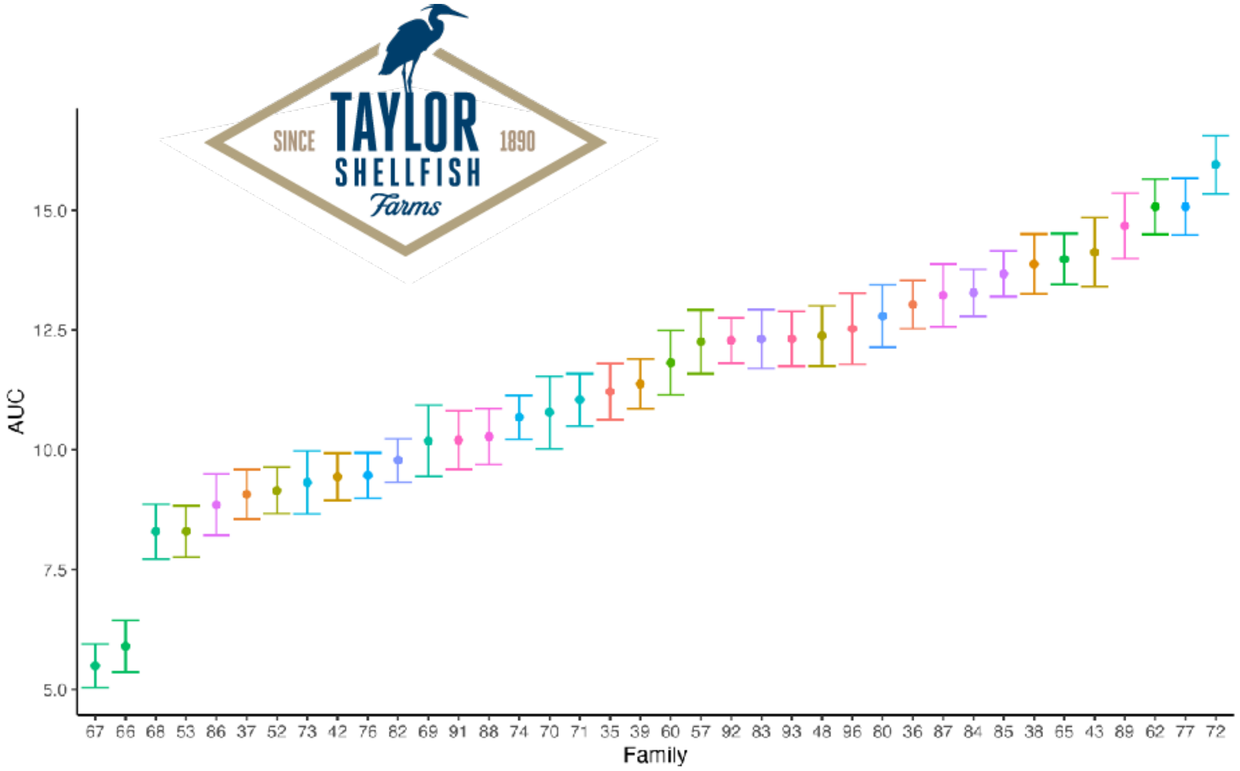
36°C: Ramping Up Defenses

Insight: Treated offspring were not just ‘tougher’; they were metabolically flexible. They revved up early to prepare, then idled down to survive the peak heat.

NotebookLM

Resazurin :: Predictive Phenotyping





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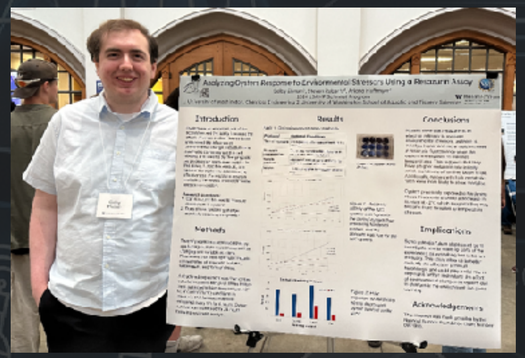

NSF FFAR NOAA USDA

github.com/sr320/talk-UNCW-2026