Diversity in animal response to environmental change

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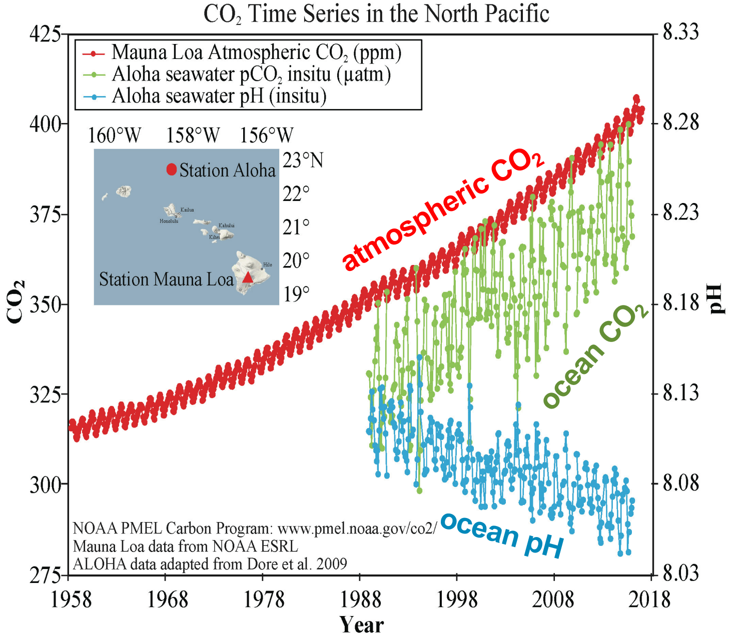
Outline

I. Background on environmental change and omics
II. Exposure experiments and omics analyses in different marine animals
III. Summary of the diversity in animal responses
IV. Future directions

Global ocean change is happening

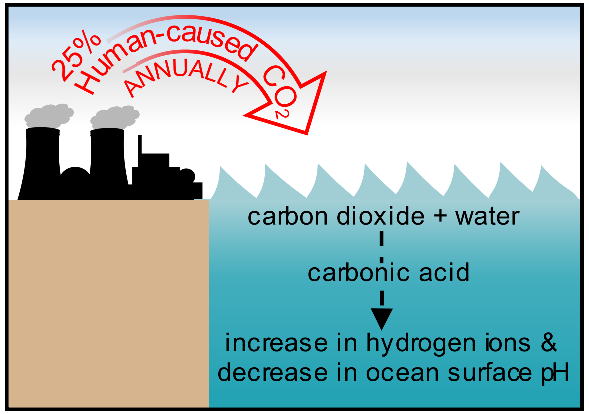
1958-2018 Carbon Emissions



Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/products/HOT_surface_CO2.txt)
Ref: J.E. Dore et al, 2009. Physical and biogeochemical modulation of ocean acidification in the central North Pacific. *Proc Natl Acad Sci USA* **106**:12235-12240.

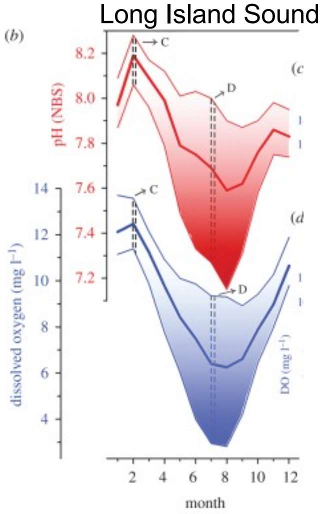
Ocean Acidification

Since 1850s,
global average ocean surface water has:
– 0.11 in pH
+ 30% in H^+ ions



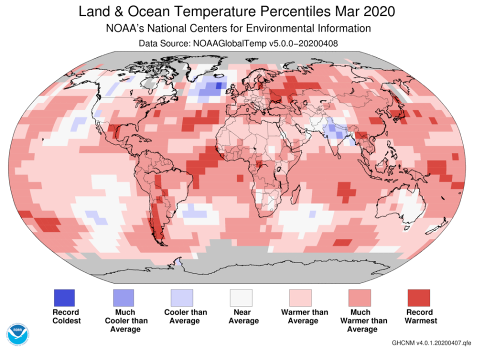
Ocean deoxygenation: pH and O_2 co-vary

Long Island Sound



Gobler and Baumann (2016)
Biology Letters

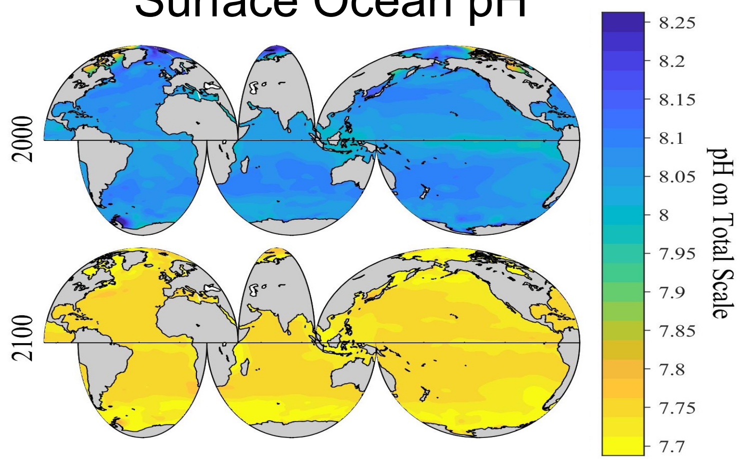
Ocean warming:



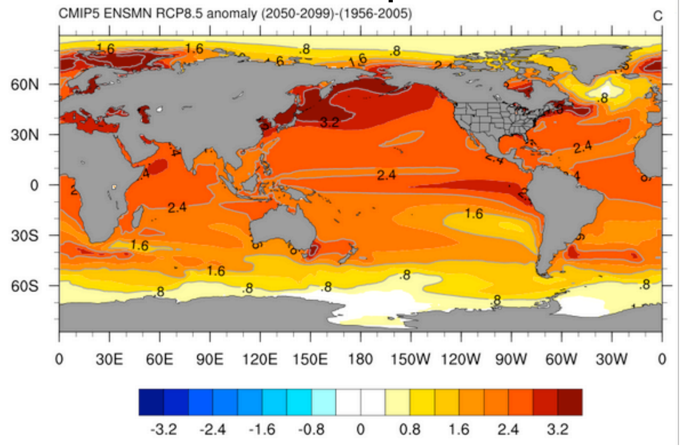
Ocean salinity variation

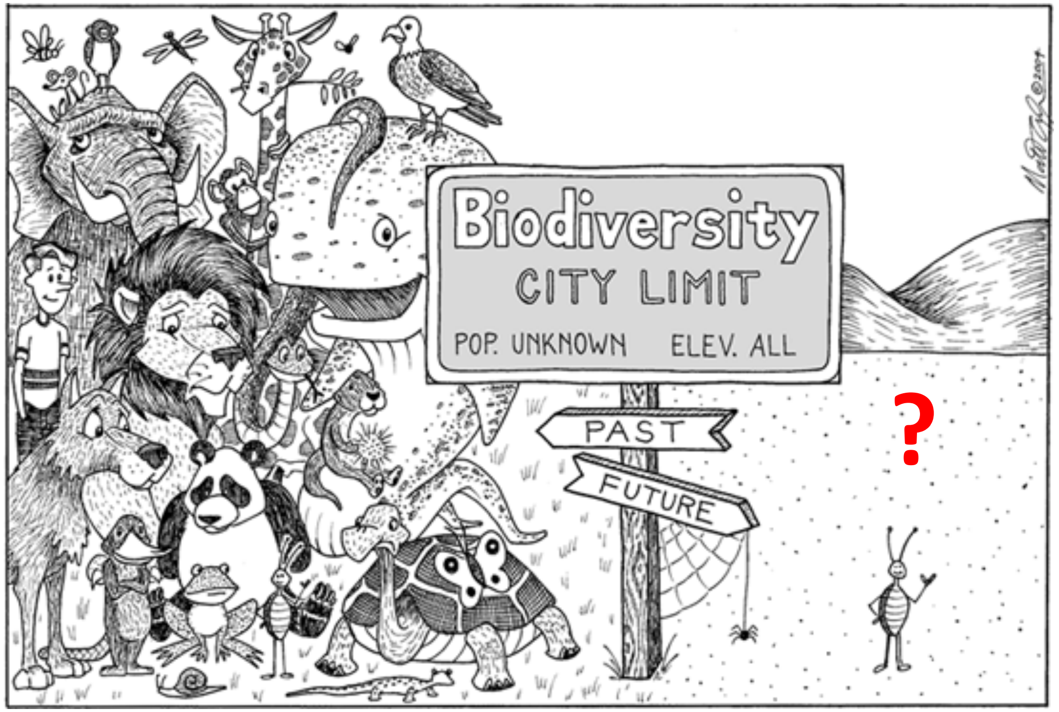
How will climate and ocean change affect different animals?

Surface Ocean pH



Surface Ocean temperature change





Systems Biology: A bird's eye view

Individual parts view

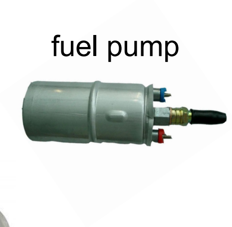
System-wide view

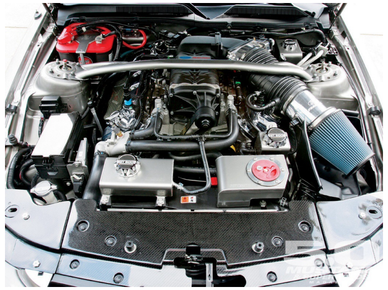
Auto mechanics

air intake

starter

fuel pump





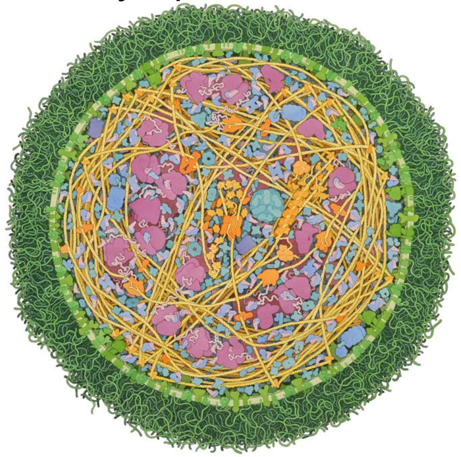
Biology

ribosome

chaparonin

receptor

Mycoplasma cell

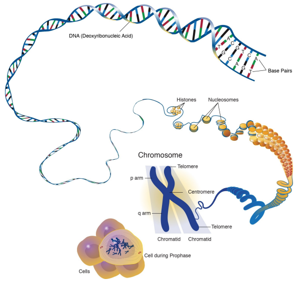


David Goodsell, TSRI

Why it's important

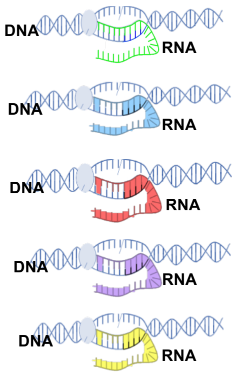
- Complex systems = many interconnected parts
- Compare across different animals
  - All animals have these basic parts

‘omics’ is the study of collections of biological components



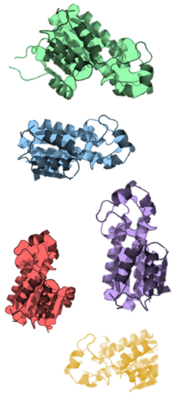
Genome
all genes or genetic material

→



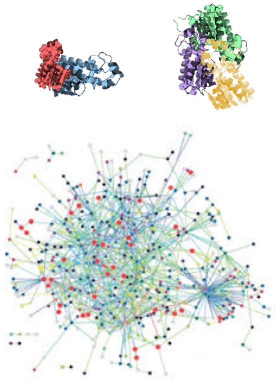
Transcriptome
all RNA strands transcribed from DNA

→



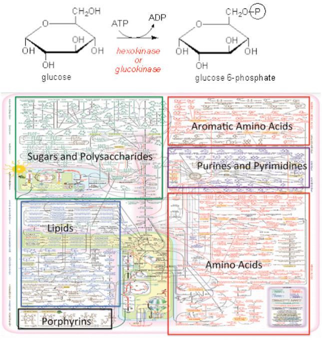
Proteome
all proteins

→



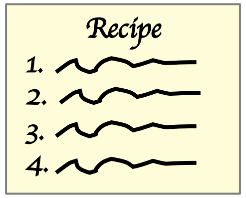
Interactome
all interactions between proteins

→



Metabolome
all small molecule byproducts of biochemical reactions (metabolites)

Meal prep analogy



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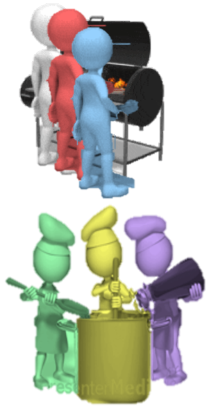

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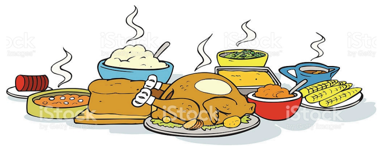

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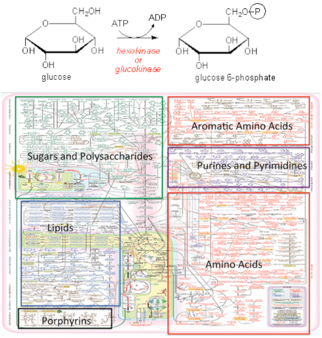
Metabolome response to ocean acidification



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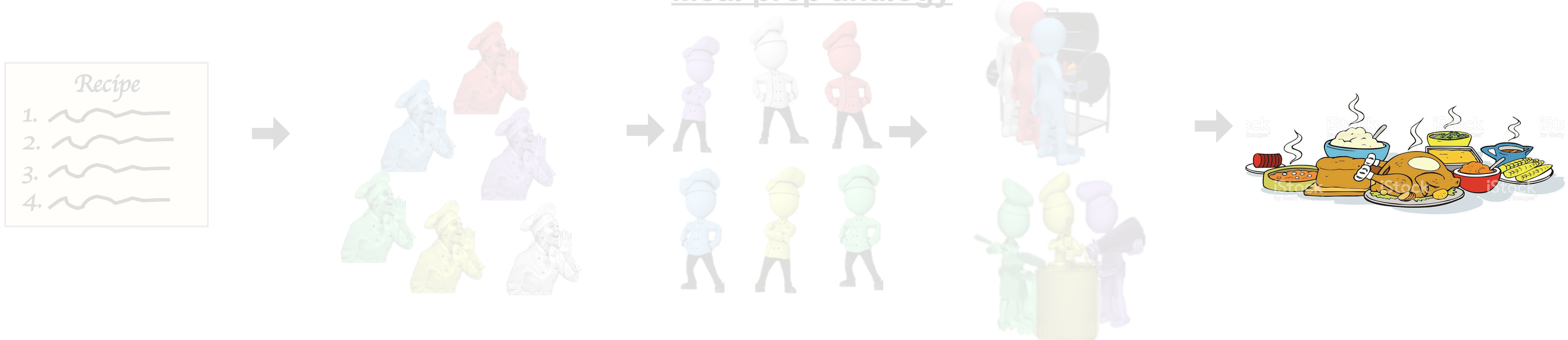
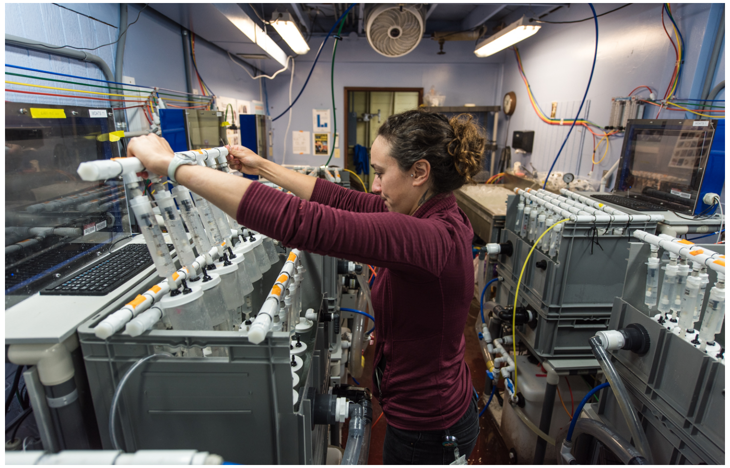


How do young crabs tolerate ocean acidification conditions?

NOAA FISHERIES
Northwest Fisheries SCIENCE CENTER

catching larvae in Puget Sound

transferring larvae to individual aquaria



Ocean Acidification Treatment Systems

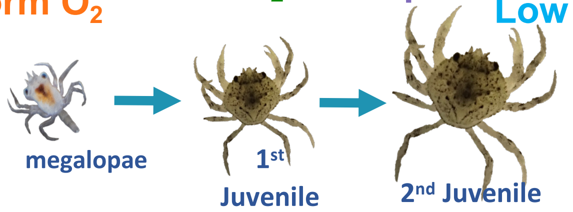
30-day treatment:

Norm pH
Norm O_2

Low O_2

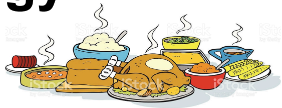
Low pH

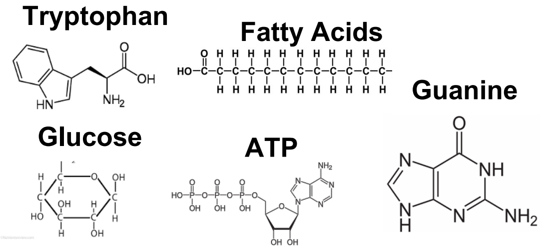
Low pH
Low O_2



No effect on survival

Metabolomics to measure physiology





Infer activity of pathways

LIPID METABOLISM

ENERGY METABOLISM

NUCLEIC ACID METABOLISM

Multi-statistical approach reveals molecular tolerance markers

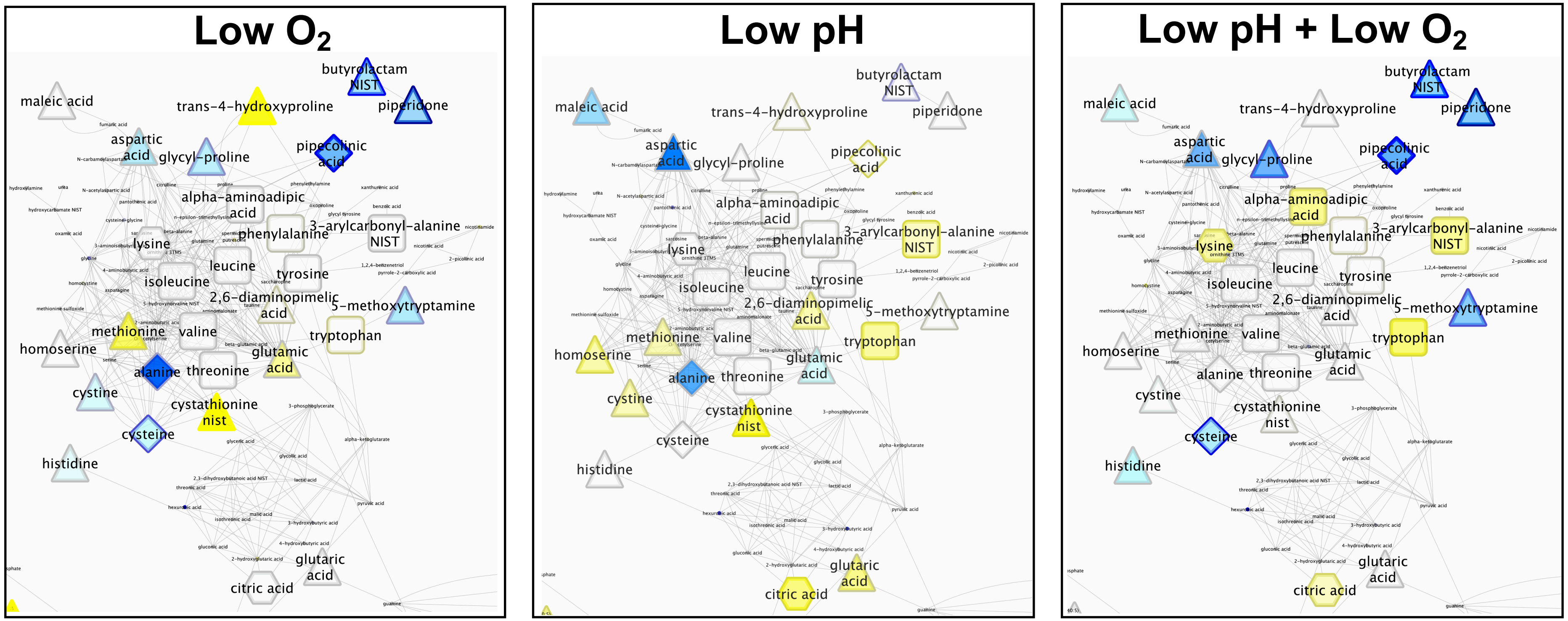
Abundance relative to ambient

decreased increased no change

Large shapes = significantly affected

shape

- ANOVA
- PLS-DA
- Random Forest and ANOVA
- PLS-DA and ANOVA
- Not important by PLS-DA, ANOVA, or random forest



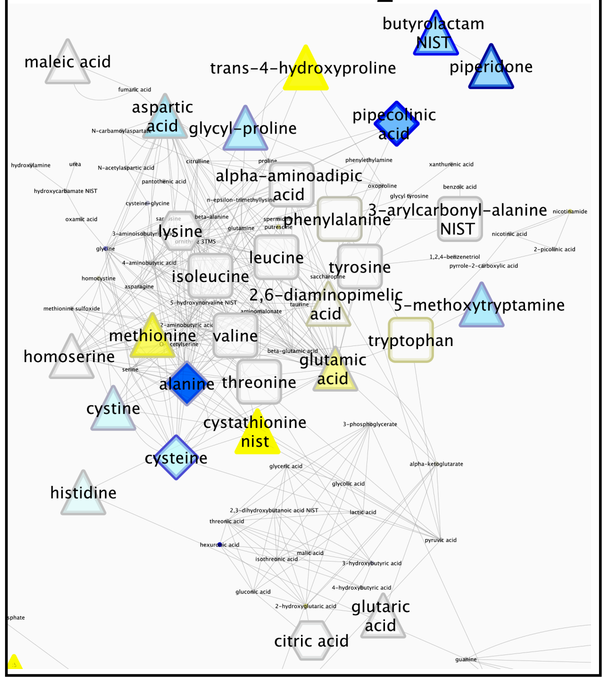
SA Trigg *et al.* (2019) *Scientific Reports*

Multi-statistical approach reveals molecular tolerance markers

ENERGY CONSERVATION

Conserved hypoxia responses
(e.g. cysteine degradation up, glutathione synthesis down, lysine degradation down)

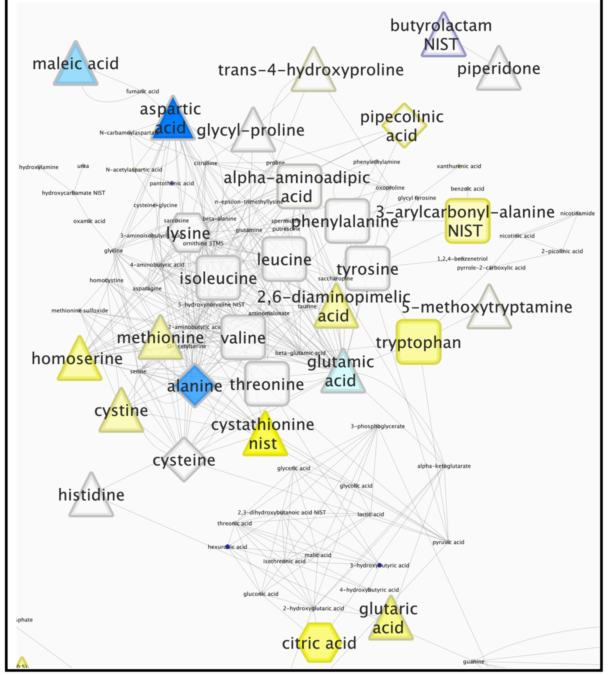
Low O_2



ENERGY GENERATION

(e.g. aspartic and maleic acid down citric acid cycle up)

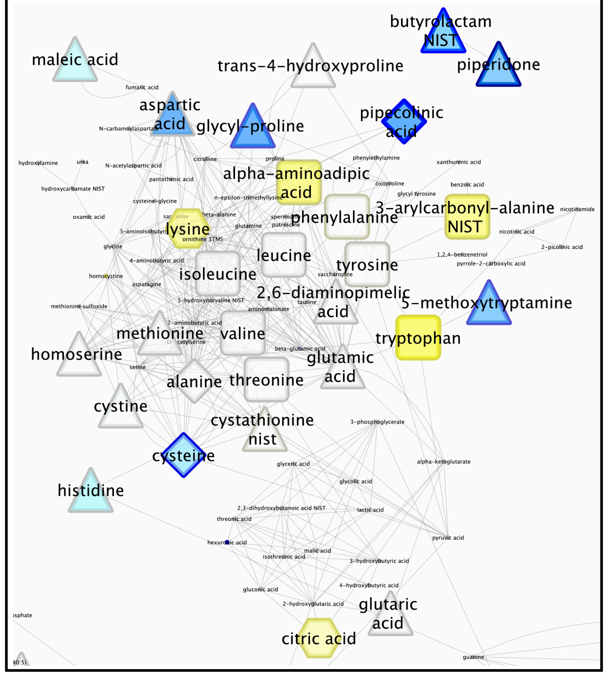
Low pH



ENERGY CONSERVATION

Conserved hypoxia responses
(e.g. synergistic effects on lysine degradation, synergistic effects on aromatic amino acid metabolism)

Low pH + Low O_2

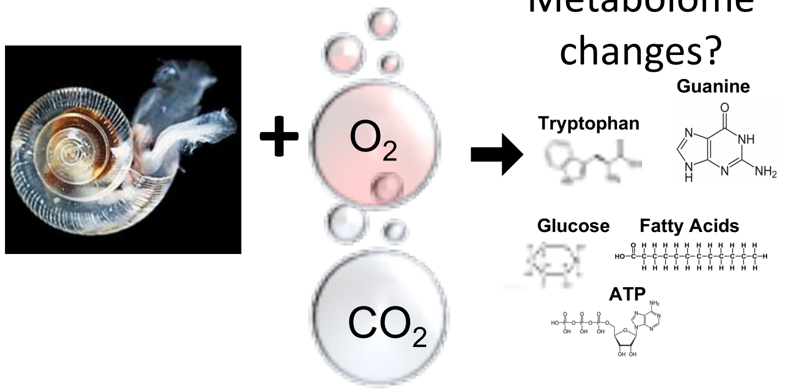


SA Trigg *et al.* (2019) *Scientific Reports*

Pteropod metabolomic response to ocean acidification conditions

9-day treatment:

Norm pH Norm O_2 **Low O_2** **Low pH** **Low pH Low O_2**



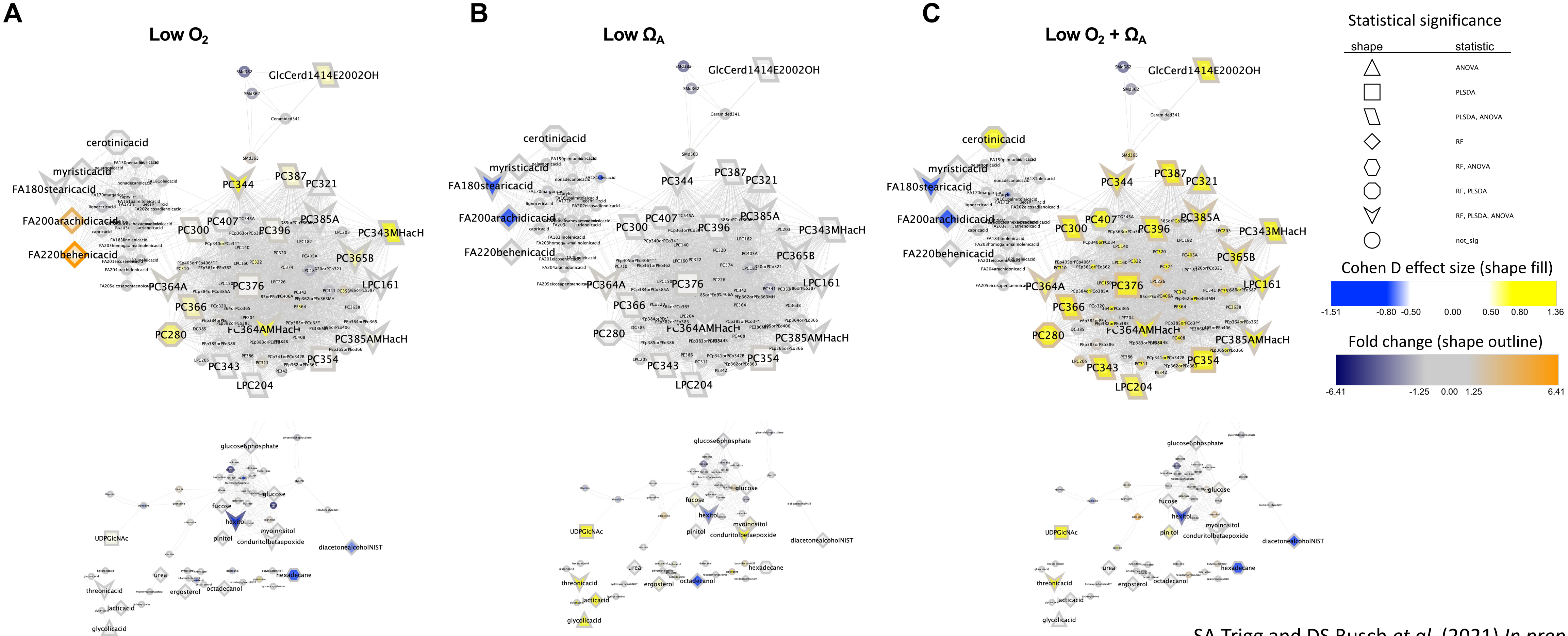
No effect on survival

Multi-statistical approach reveals molecular tolerance markers

- Lipid metabolism broadly altered by low O_2
- Sugar metabolism affected by low pH
- Low O_2 induces stronger metabolome changes than low pH

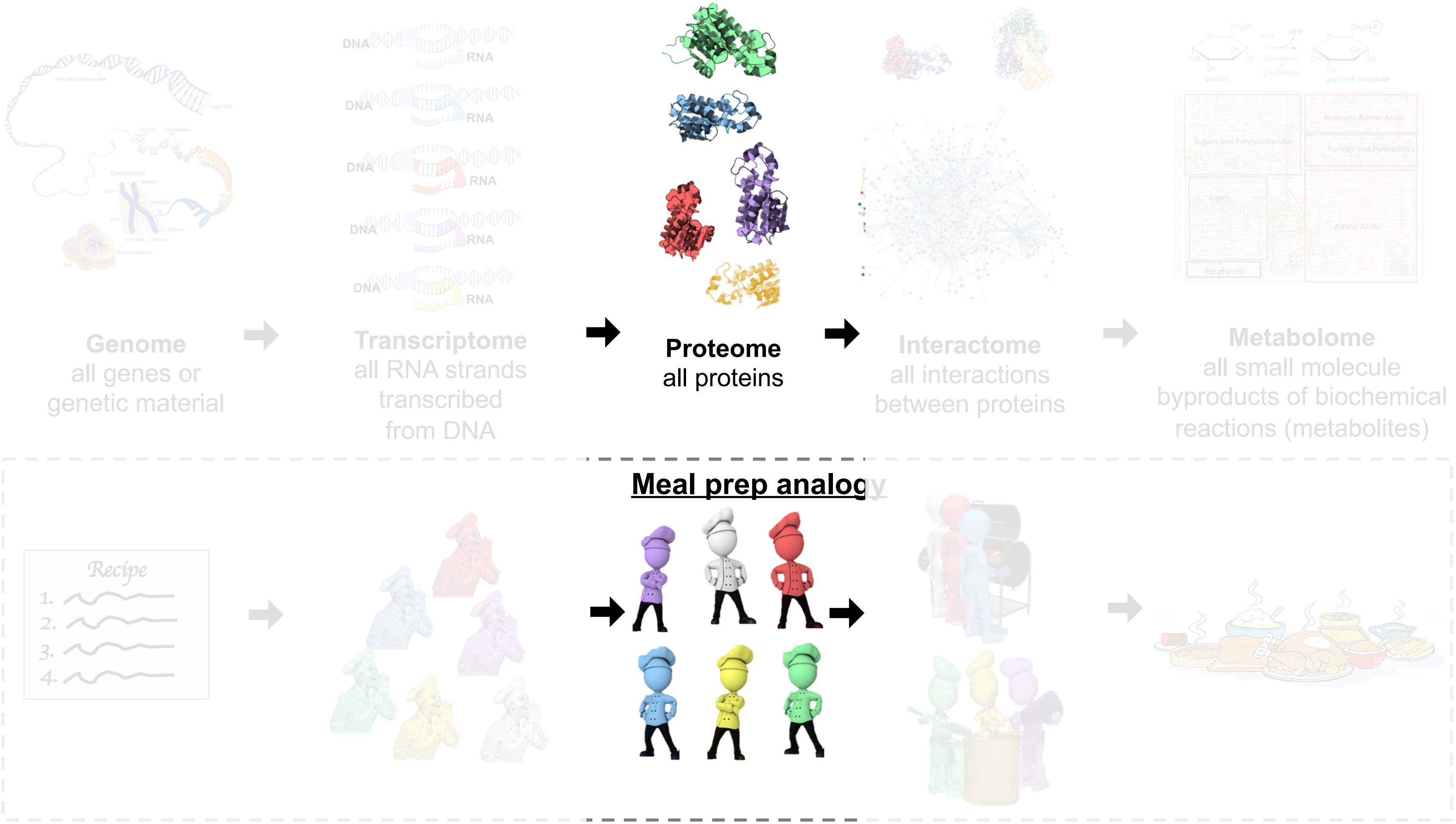
Lipids

Sugars

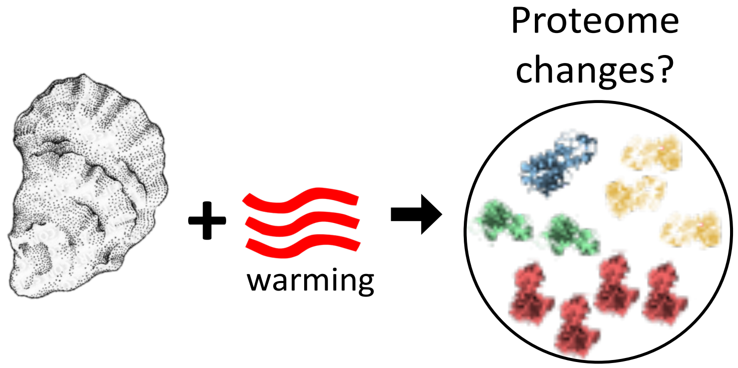


SA Trigg and DS Busch *et al.* (2021) *In prep.*

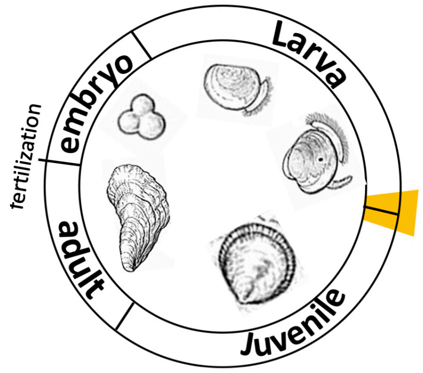
Proteome response to warming

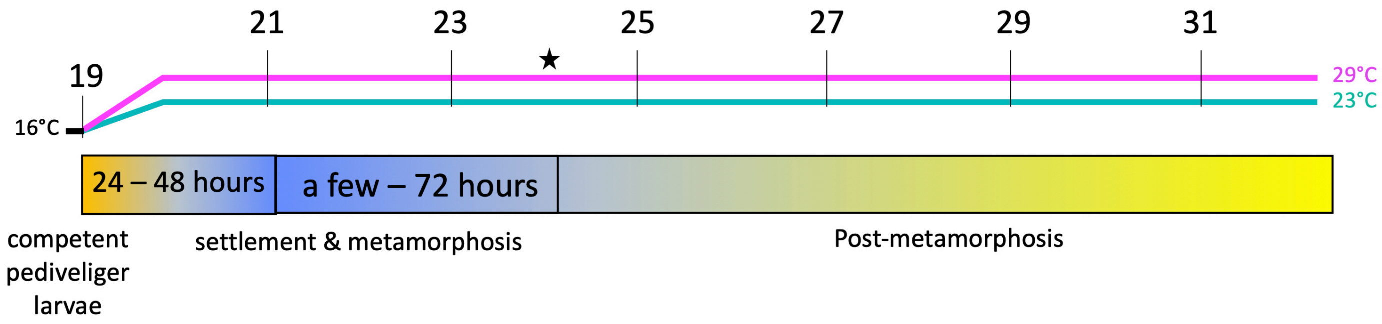


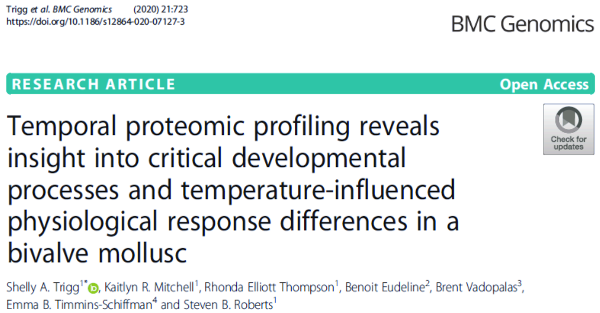
Oyster response to warm temperature



Rhonda Elliot







Trigg et al. BMC Genomics (2020) 21:723
https://doi.org/10.1186/s12864-020-07127-3

BMC Genomics

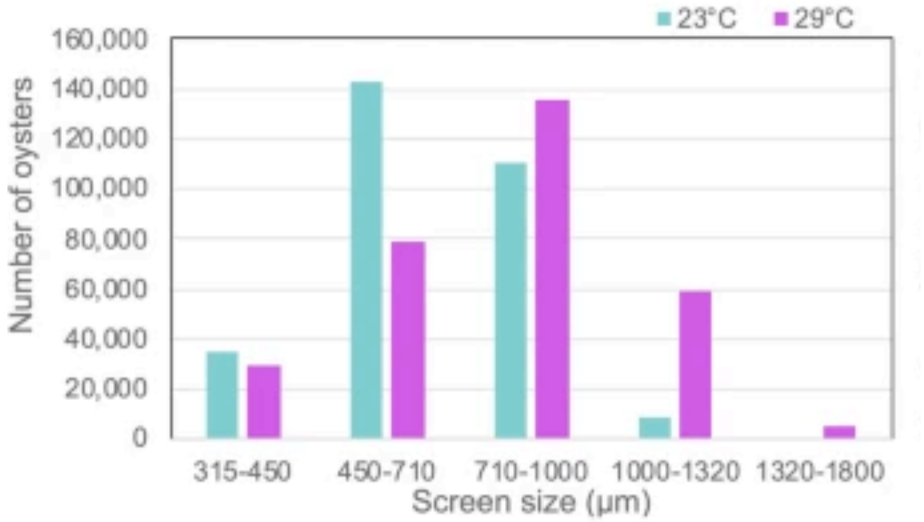
RESEARCH ARTICLE Open Access

Temporal proteomic profiling reveals insight into critical developmental processes and temperature-influenced physiological response differences in a bivalve mollusc

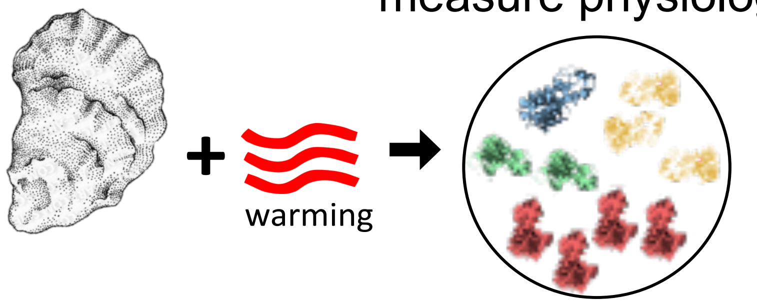
Shelly A. Trigg[1*], Kaitlyn R. Mitchell[1], Rhonda Elliott Thompson[1], Benoit Eudeline[2], Brent Vadopalas[3], Emma B. Timmins-Schiffman[4] and Steven B. Roberts[1]

Oyster response to warm temperature

- No effect on survival
- oysters in warmer temperature are larger



Proteomics to measure physiology

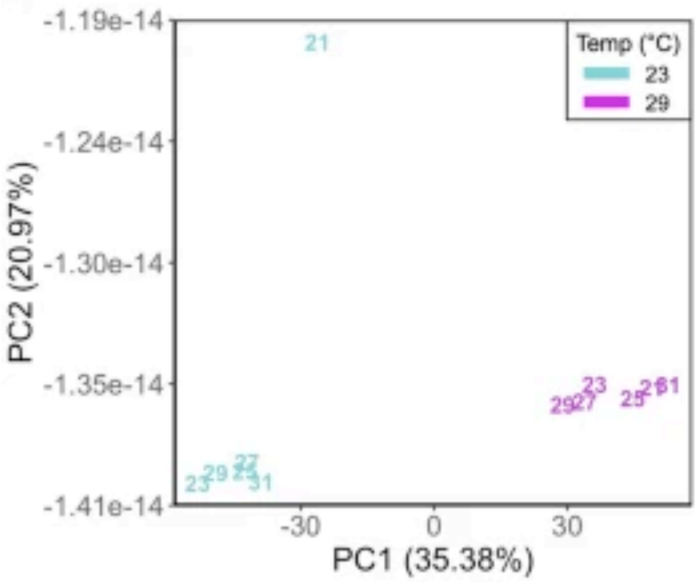


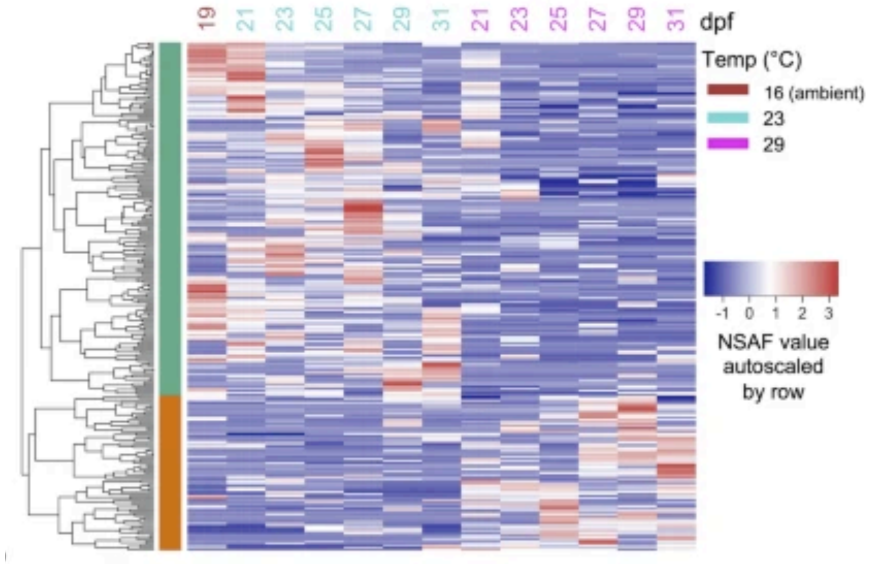
SA Trigg *et al.* (2020) *BMC Genomics*. https://doi.org/10.1186/s12864-020-07127-3

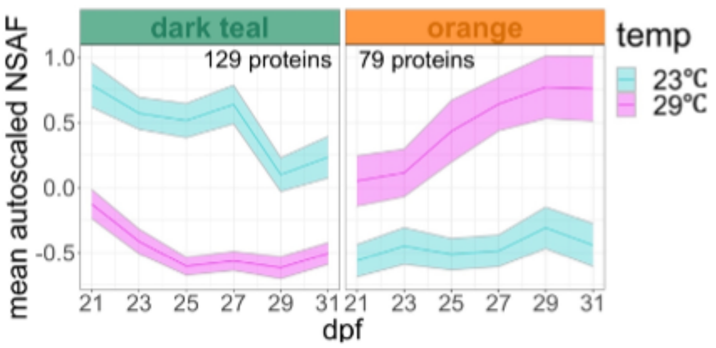
Multivariate statistical analyses reveal protein markers of improved performance

ANOVA-Simultaneous component analysis to tease apart effects from time and temperature

Temperature effect







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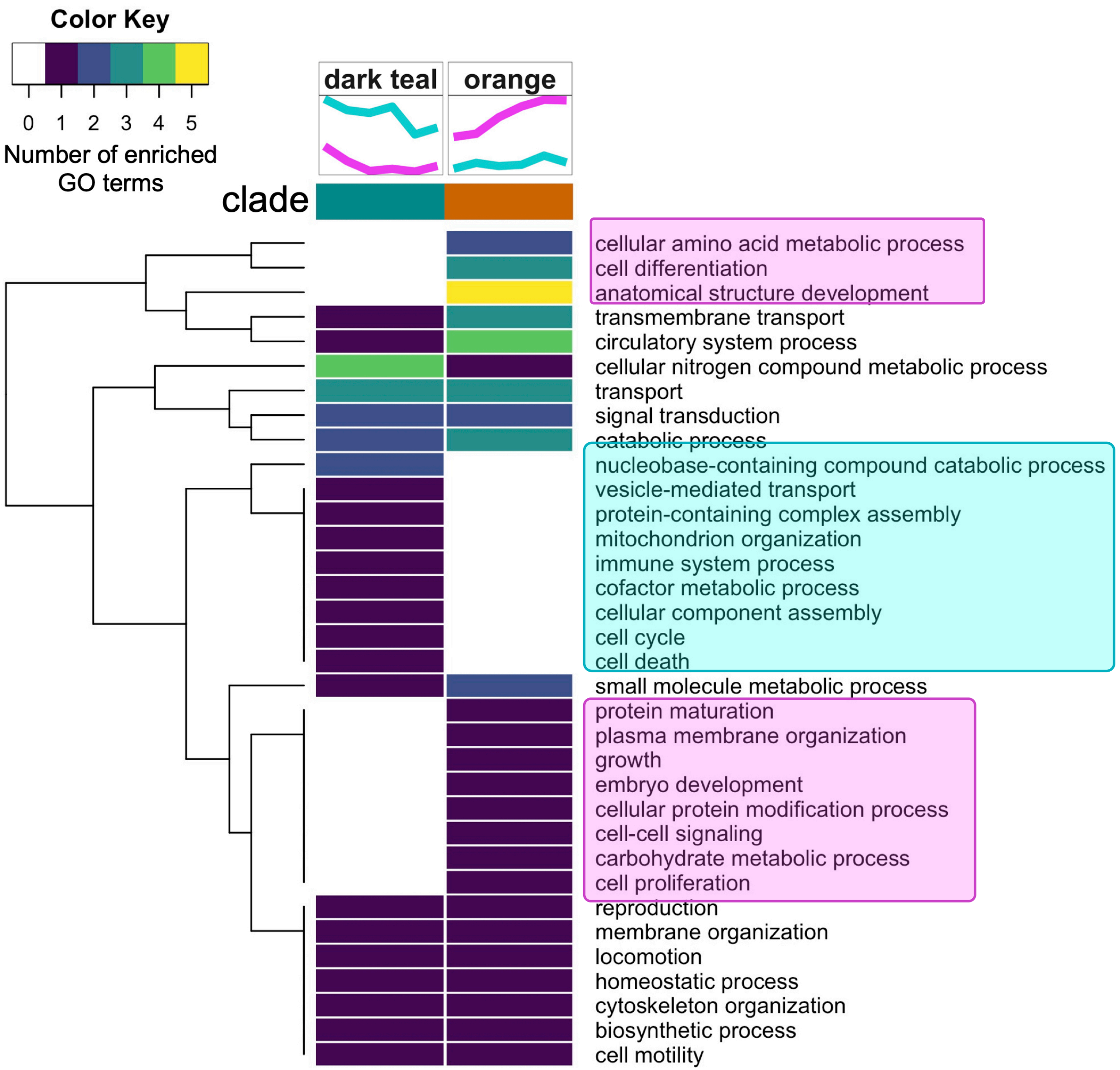
Protein markers of improved performance

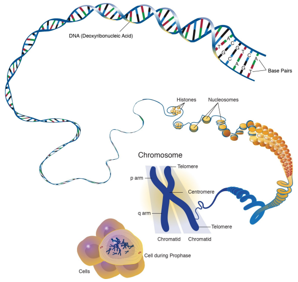


In metamorphosing oysters, warmer temperature led to:

- **larger size**
- **increased growth pathways**
- **decreased immune response pathways**

SA Trigg *et al.* (2020) *BMC Genomics*. https://doi.org/10.1186/s12864-020-07127-3

Methylome response to environmental change



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all genes or
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Transcriptome
all RNA strands
transcribed
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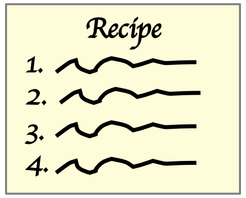
Proteome
all proteins

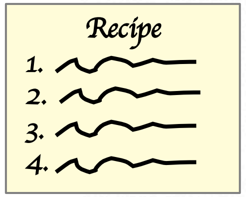
Interactome
all interactions
between proteins

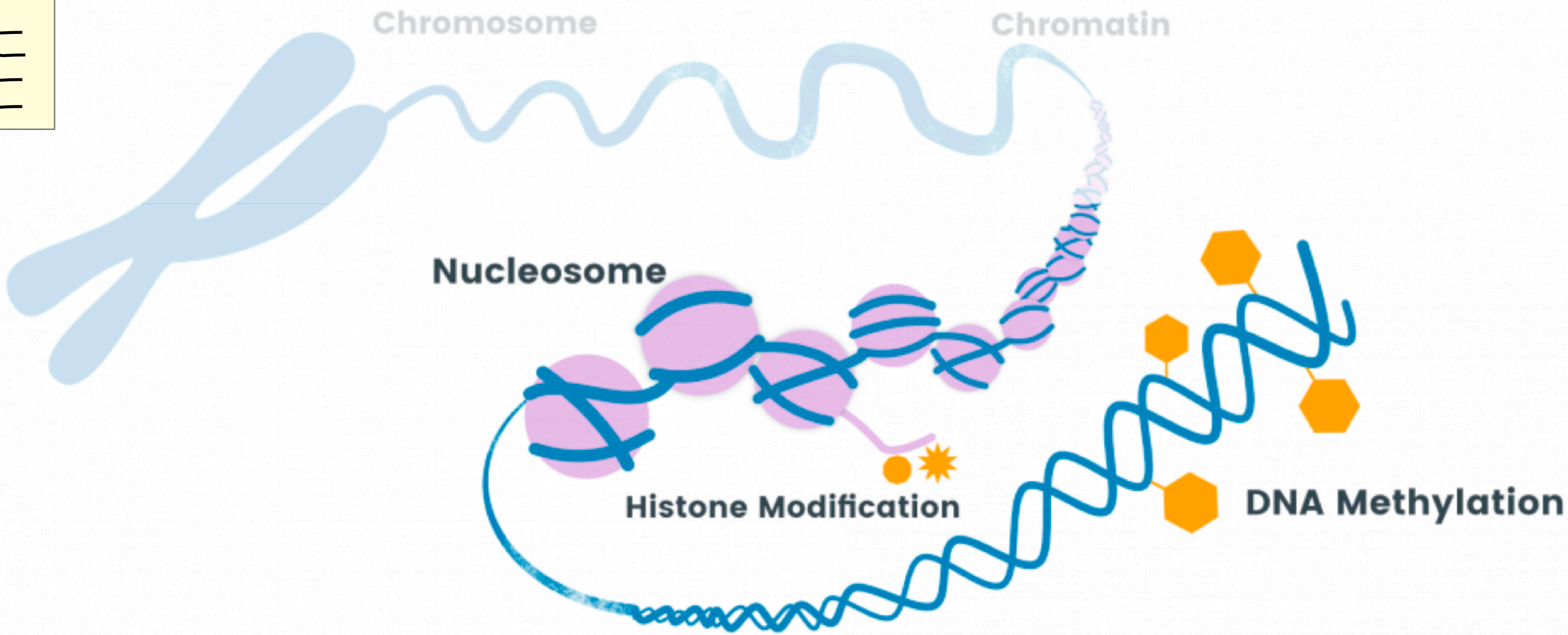
Metabolome
all small molecule
byproducts of biochemical
reactions (metabolites)

<u>Meal prep analogy</u>



ALTERS THE PHENOTYPE (WITHOUT CHANGING DNA CODE): HERITABLE



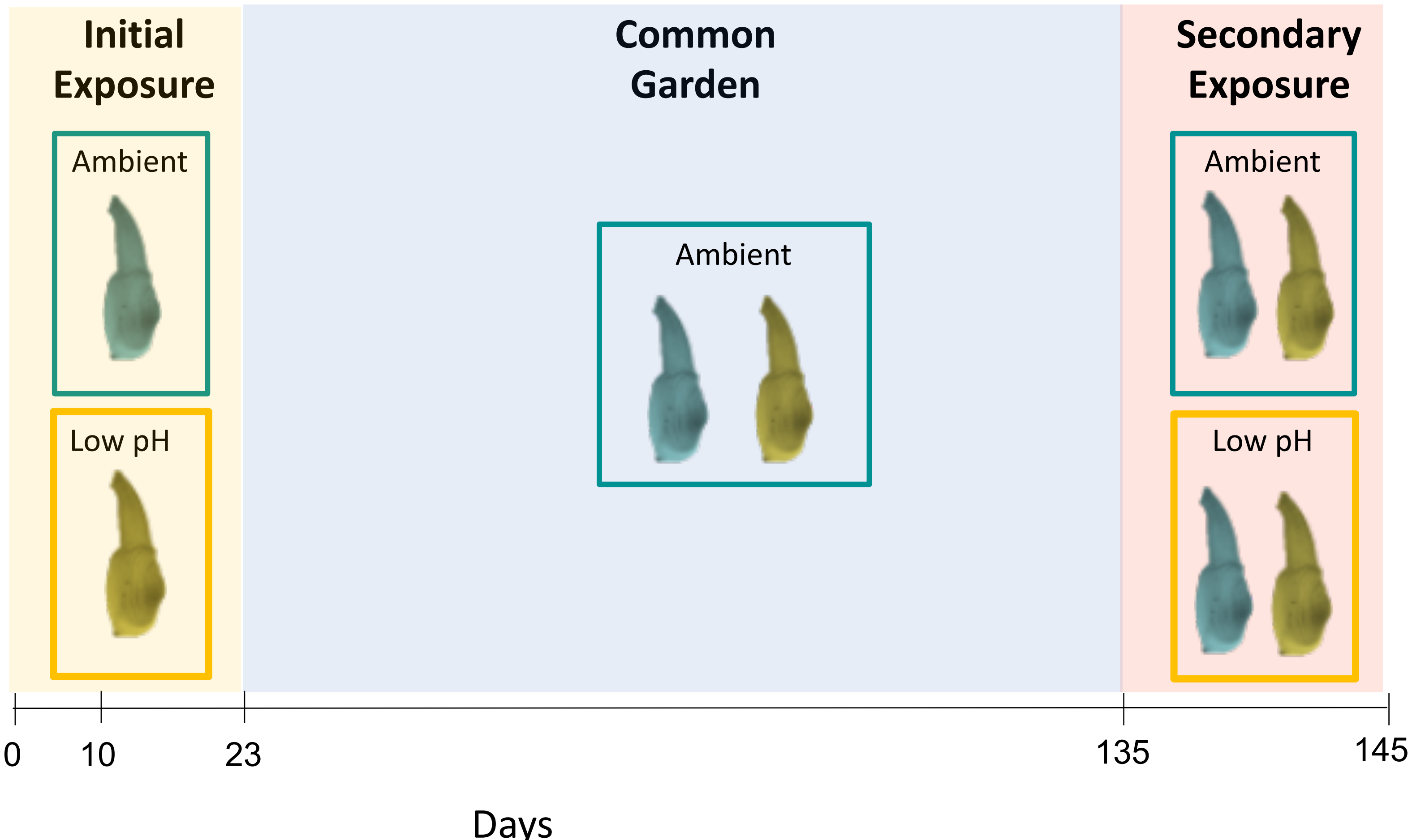


CAN BE INDUCED WITH ENVIRONMENTAL MANIPULATION

Pacific geoduck response to pH

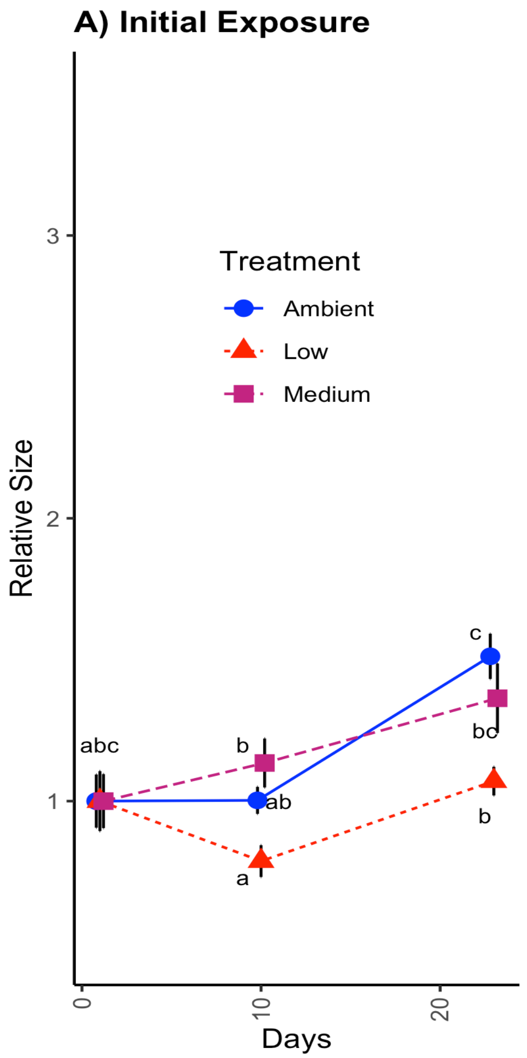
Geoduck are important:

- One of the most valuable farmed shellfish (>$20 M/year in WA)
- Biofilter and prey source
- Tribal sustenance



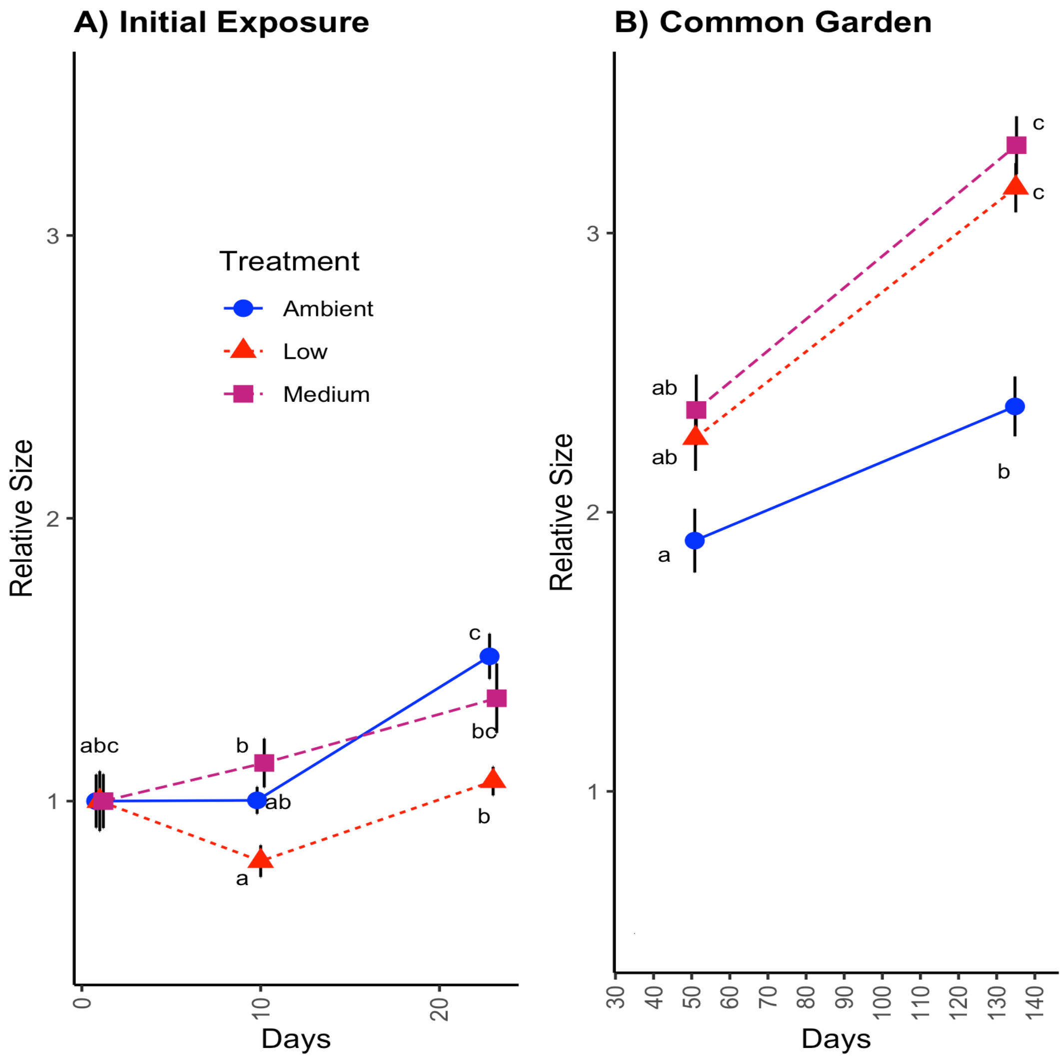
Static low pH initial exposure delays juvenile growth

3 month old juveniles



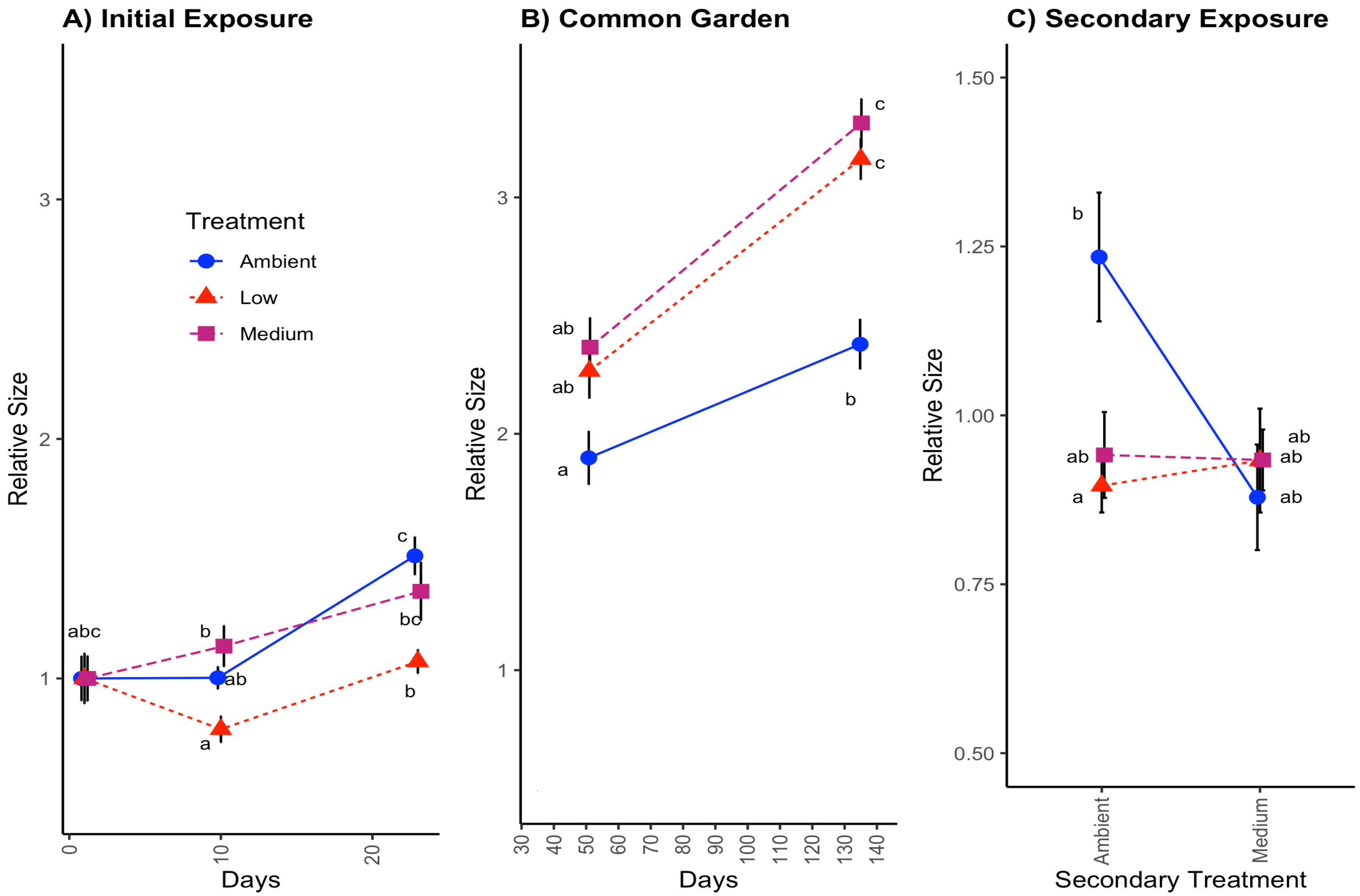
Dr. Hollie Putnam, URI

Static moderate and low pH initial exposure leads to accelerated growth after common garden



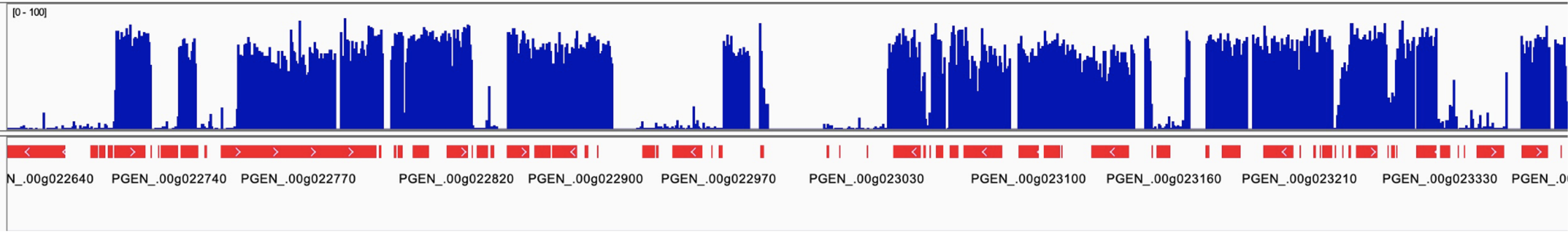
Dr. Hollie Putnam, URI

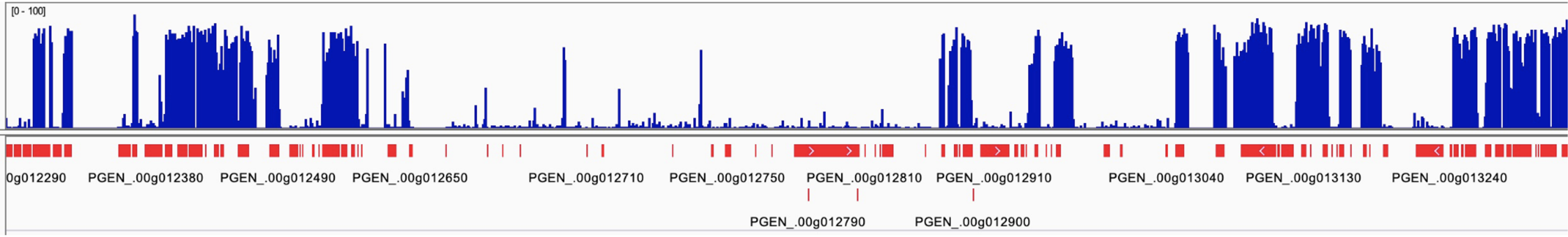
Static moderate and low pH initial exposure protects against growth delay induced by secondary low pH exposure



Dr. Hollie Putnam, URI

Geoduck genome methylation is primarily in genes





HM Putanm and SA Trigg *et al.* (2021) *In prep.*

Multistatistical approaches identify differentially methylated regions and genes

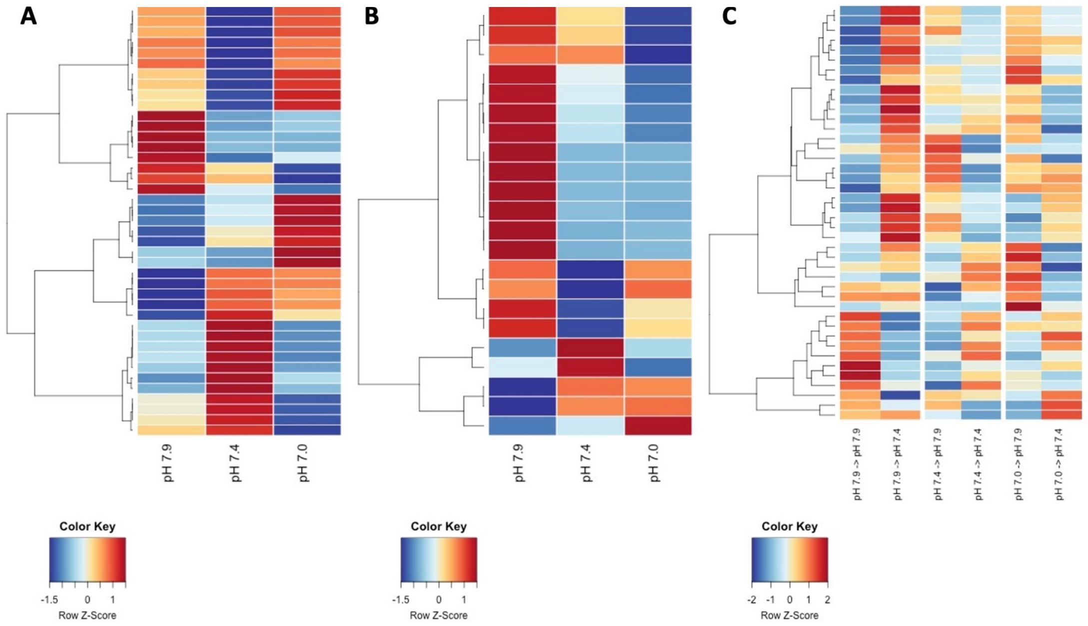
Permutation test + root mean square error test + ANOVA to identify regions

Methylpy (M Schultz *et al*. 2015 *Nature; github.com/yupenghe/methylpy*)

10 days of exposure

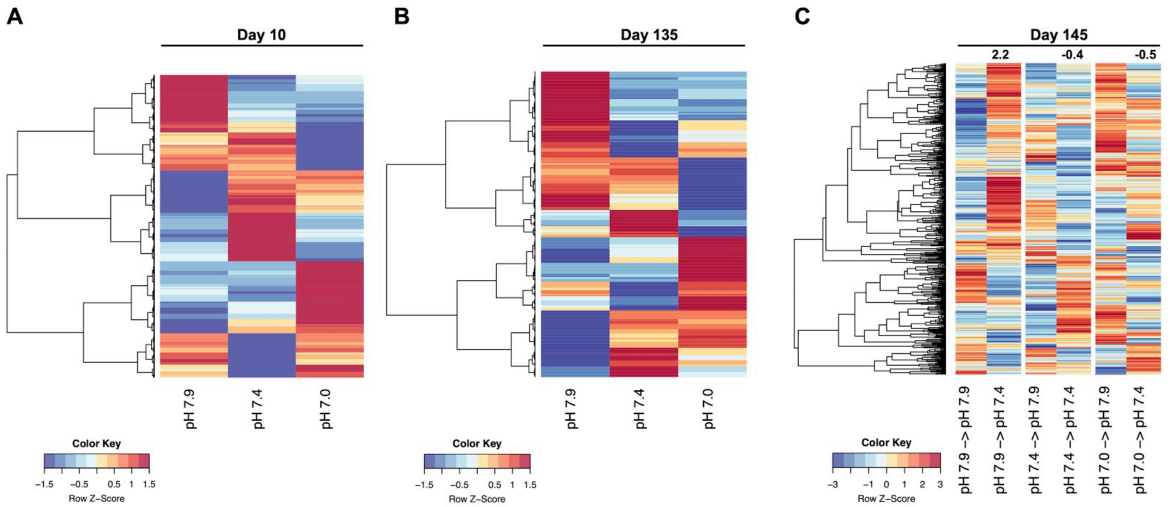
After common garden (112 days post-exposure)

10 days of 2[nd] exposure



Binomial GLM to identify genes

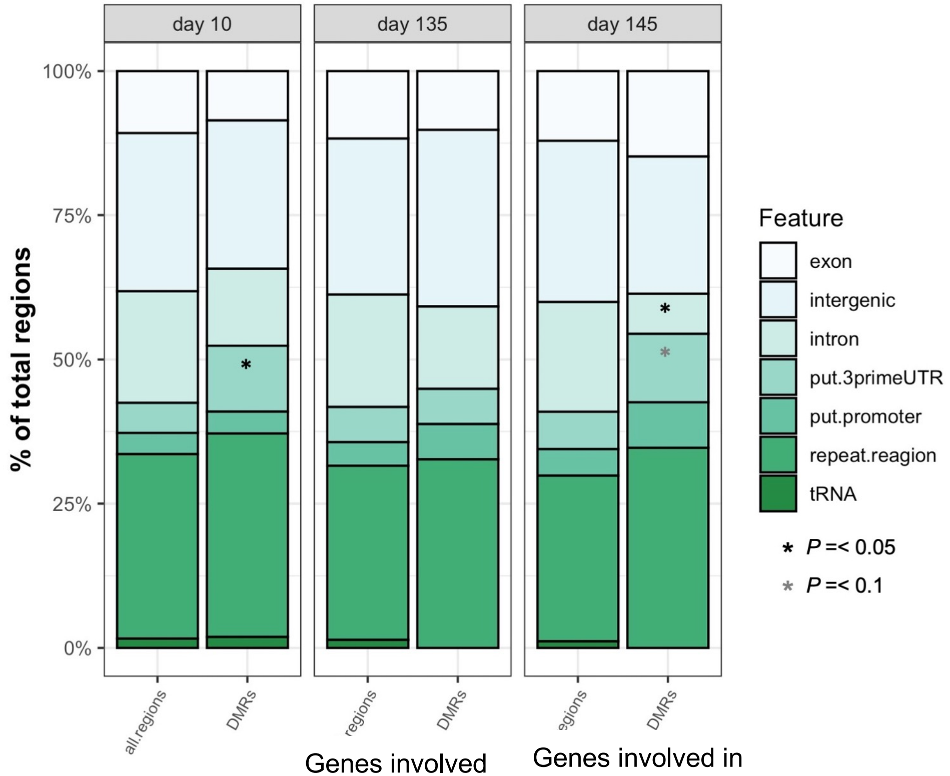
YJ Liew *et al.* 2019 *Science Advances*; github.com/lyijin



HM Putanm and SA Trigg *et al.* (2021) *In prep.*

pH resilience and compensatory growth linked to signaling pathways and cytoskeletal processes

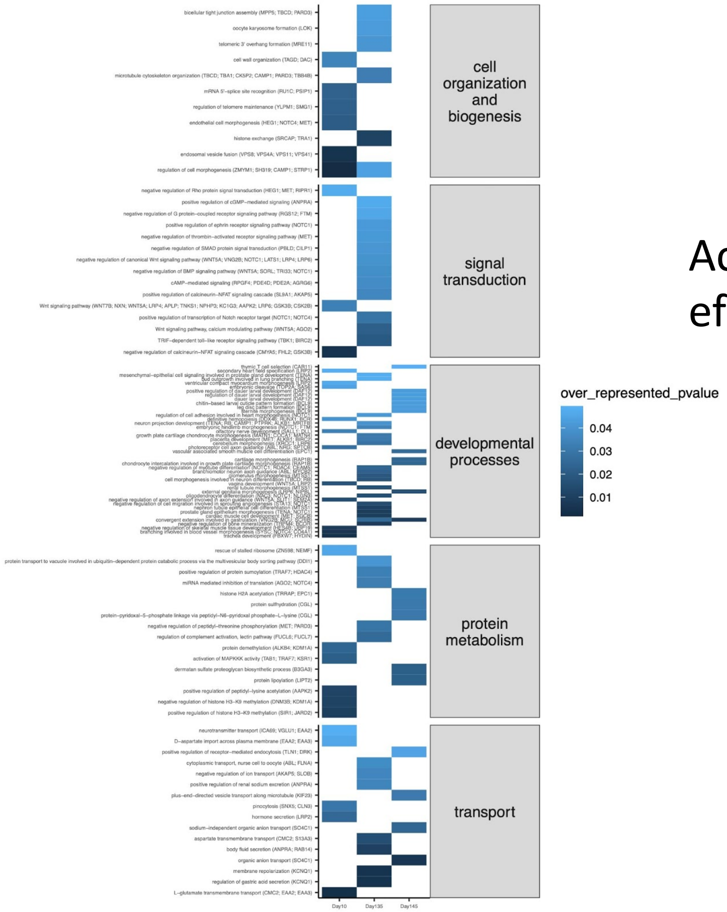
Differentially methylated regions are within or adjacent to genes



Genes involved in cytoskeletal activity

Genes involved in nucleic acid binding and mitochondrial activity

Differentially methylated genes implicate specific biological processes



Acute effect and longer-term effect on Wnt signaling

HM Putanm and SA Trigg *et al.* (2021) *In prep.*

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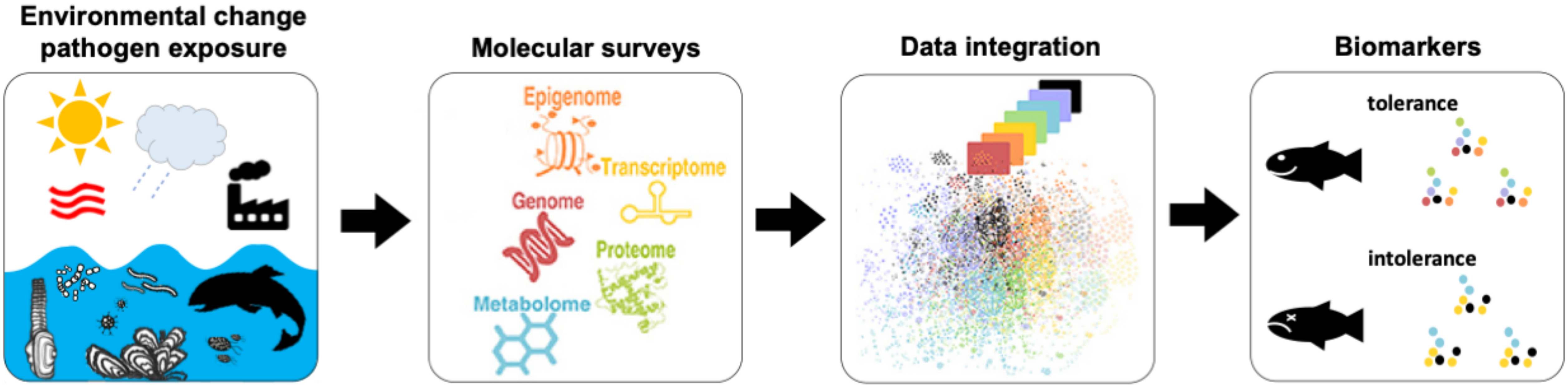
Diversity in animal response to environmental change

Animal	Condition	Duration	Life stage	Performance phenotype	Omics data	Molecular phenotype
Dungeness crab	Low pH x Low O2	31 days	larvae -> juvenile	• No survival difference	metabolomics	• pH increases energy generation pathways • Low O2 increases energy conservation pathways • Low O2 response is dominant
Pteropods	Low pH x Low O2	7 days		• No survival difference	metabolomics	• Low O2 increases phosphatidylcholine metabolism • Low pH increases large sugar acids
Pacific oyster	Warming (23C vs 29C)	13 days	larvae -> juvenile	• No survival difference • Larger size	proteomics	• Increased growth pathways • Decreased immune response pathways
Pacific geoduck	Low pH reciprocal exposure	20 days then 10 days	juvenile	• No survival difference • Larger size and resilience to growth delay	DNA methylation	Wnt signaling
Montipora capitata vs. *Pocillopora acuta*	Ambient	n/a	mature	• Environmental change resilience	DNA methylation	Dense gene body methylation
Atlantic salmon + sea lice	Warming and reduced salinity	30 days	juvenile	• No survival difference	DNA methylation and transcriptomics	• Putative promoter methylation is enriched • Reduced salinity increases methylation

Outline

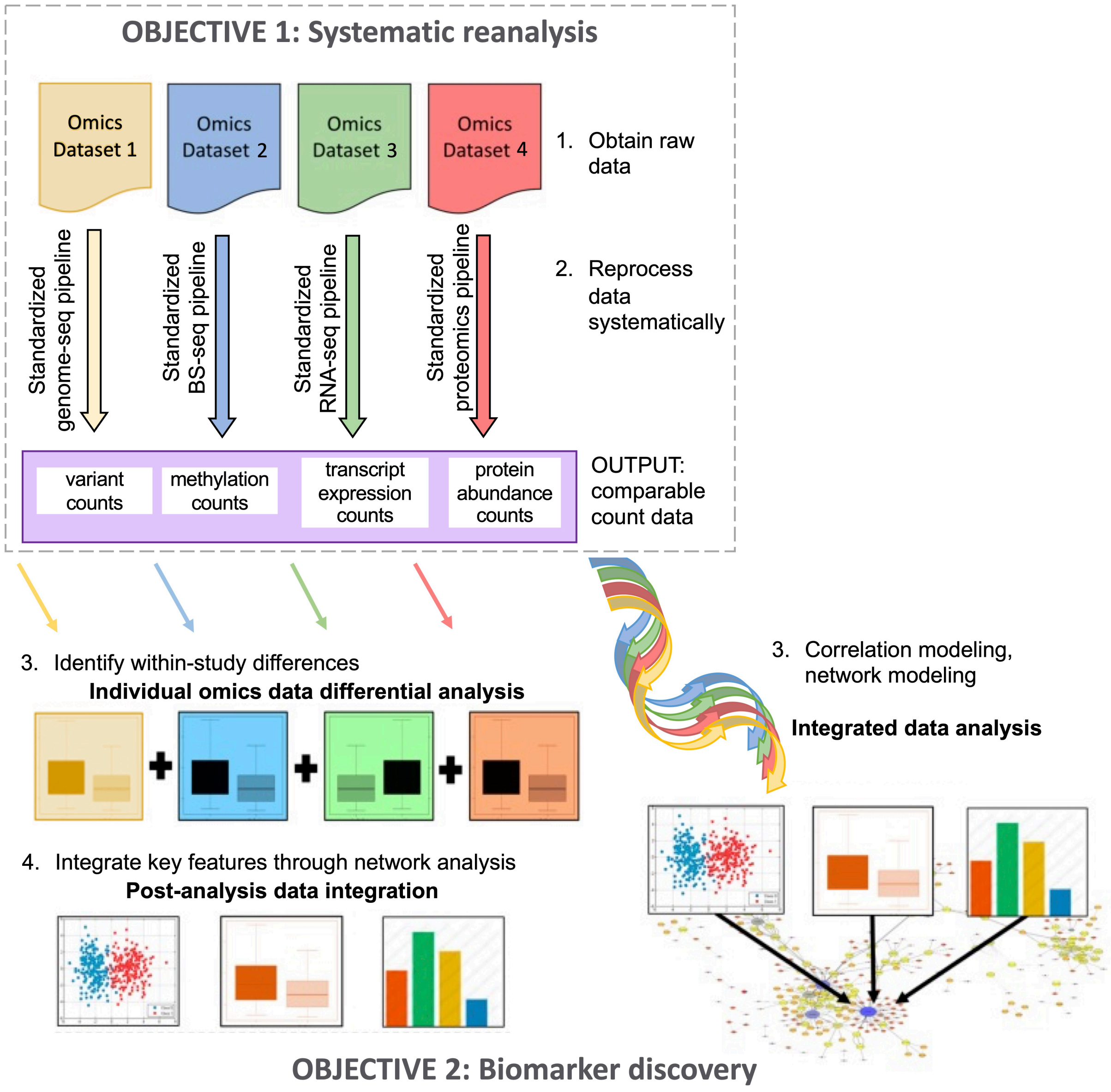
I. Background on environmental change and omics
II. Exposure experiments and omics analyses in different marine animals
III. Summary of the diversity in animal responses
IV. Future directions

Leveraging genomics datasets to predict animal response



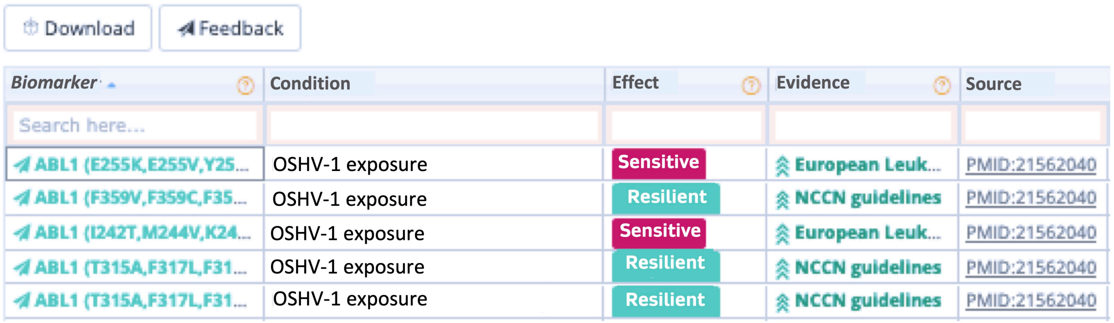
- Growing genomics resources and tools in marine species
  - Many species, many phenotypes, lots of omics data
- Biomarker discovery for biomonitoring (e.g. early detection of disease or pollution) and predicting species response to environmental change (e.g. migration patterns)
- Comparative species genomics analysis to identify markers associated with environmental variation and performance phenotypes

Stratifying data to predict how animals will fare in the future



Outcomes

Biomarker database



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Biomarker	Condition	Effect	Evidence	Source
ABL1 (E255K,E255V,Y25...	OSHV-1 exposure	Sensitive	European Leuk...	PMID:21562040
ABL1 (F359V,F359C,F35...	OSHV-1 exposure	Resilient	NCCN guidelines	PMID:21562040
ABL1 (I242T,M244V,K24...	OSHV-1 exposure	Sensitive	European Leuk...	PMID:21562040
ABL1 (T315A,F317L,F31...	OSHV-1 exposure	Resilient	NCCN guidelines	PMID:21562040
ABL1 (T315A,F317L,F31...	OSHV-1 exposure	Resilient	NCCN guidelines	PMID:21562040

- detect early signs of poor performance
  - Energy efficient vs. not

Marine omics for future biomonitoring

Promises

1. Quicker, cheaper, more efficient data collection
2. A lot more data than traditional methods
3. High resolution answers to research questions
4. May lead to more sensitive and accurate biomonitoring

CHALLENGES

1. Many factors to consider
   - Species
   - Life stage
   - Environmental parameters
   - Experiment duration
   - Performance phenotype
   - Sequencing technology variation
     - Potentially could be normalized with commonly measured molecules
   - Data quality
     - Thresholds could be set based on internal standards
2. Data storage/management and computing power needs
   - Storage is becoming cheaper
3. Integration across different fields/disciplines
   - Ripe for collaborations!

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Questions?

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