Exploring the tolerance of Pacific geoduck to low pH through comparative physiology, genomics, and DNA methylation

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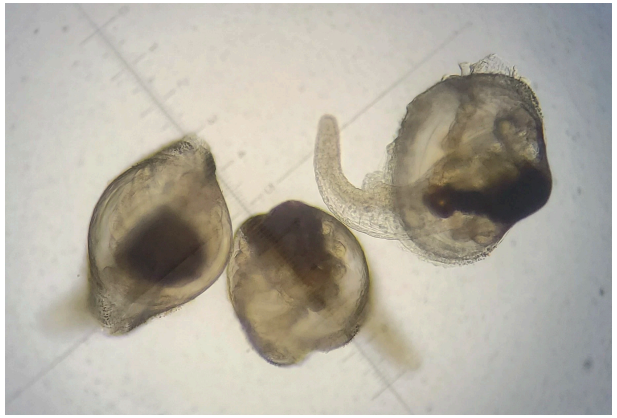
Matthew Henderson, Jamestown S'klallam Point Whitney Hatchery

12-minute talk

FOUNDATION FOR FOOD & AGRICULTURE RESEARCH

Pacific Geoduck are important

- Among most valuable farmed **shellfish** on a per acre basis
  - **>$20 M** in annual sales in Washington alone
- Serve ecosystems as biofilters and prey
- Tribal sustenance

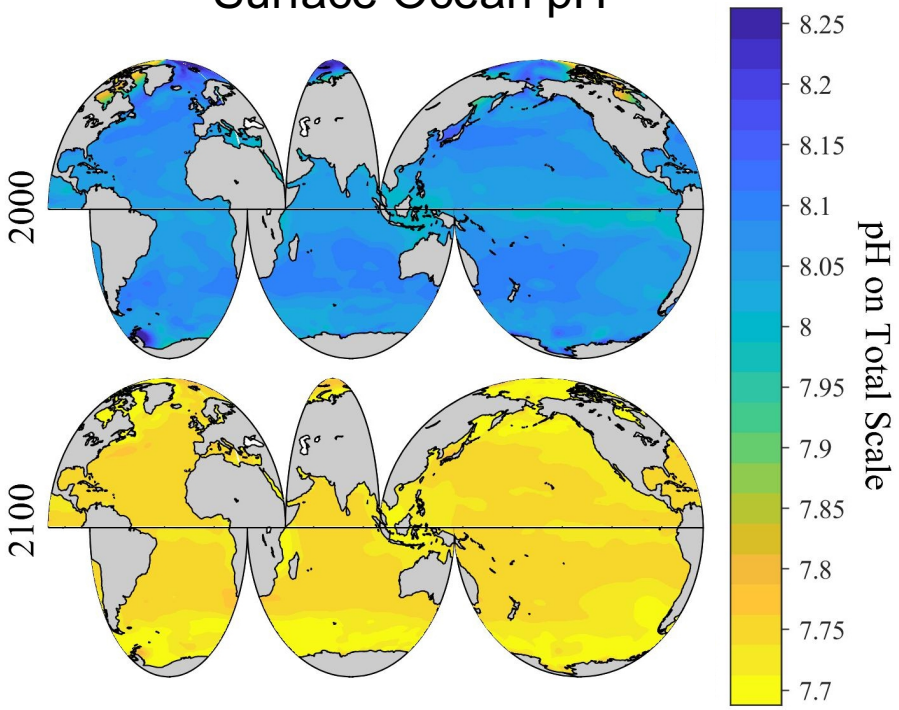


How does pH affect geoduck?

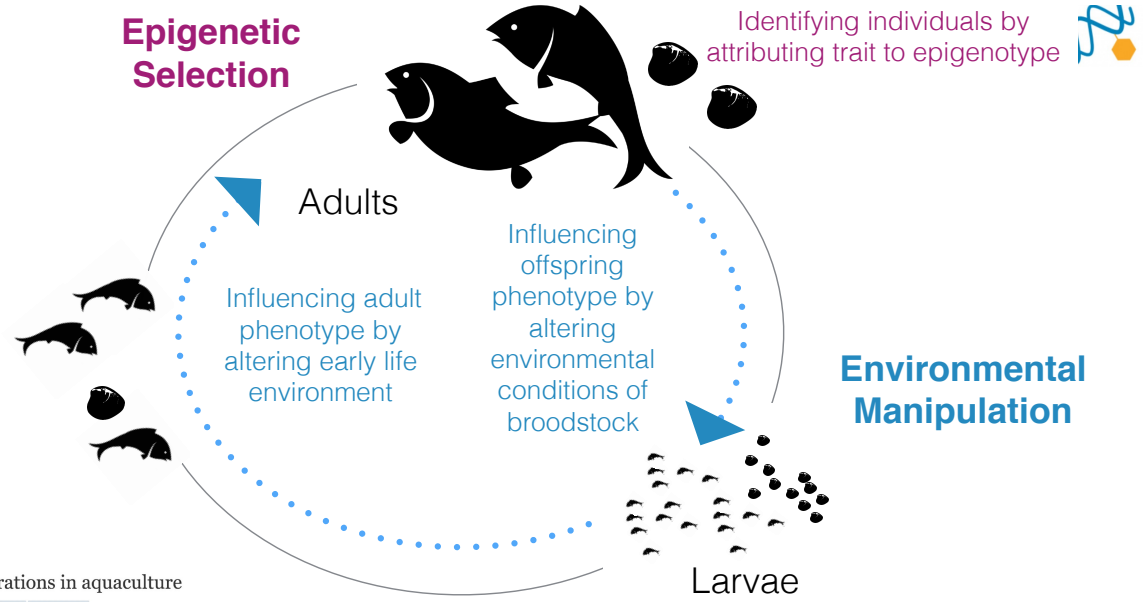
Overarching questions:

- How will they fare under ocean acidification conditions predicted for the future?
- Could stress conditioning be beneficial for aquaculture?

Surface Ocean pH



Sustainable fisheries and aquaculture production



Epigenetic considerations in aquaculture

Mackenzie R. Gavery, Steven B. Roberts

How does pH affect geoduck?

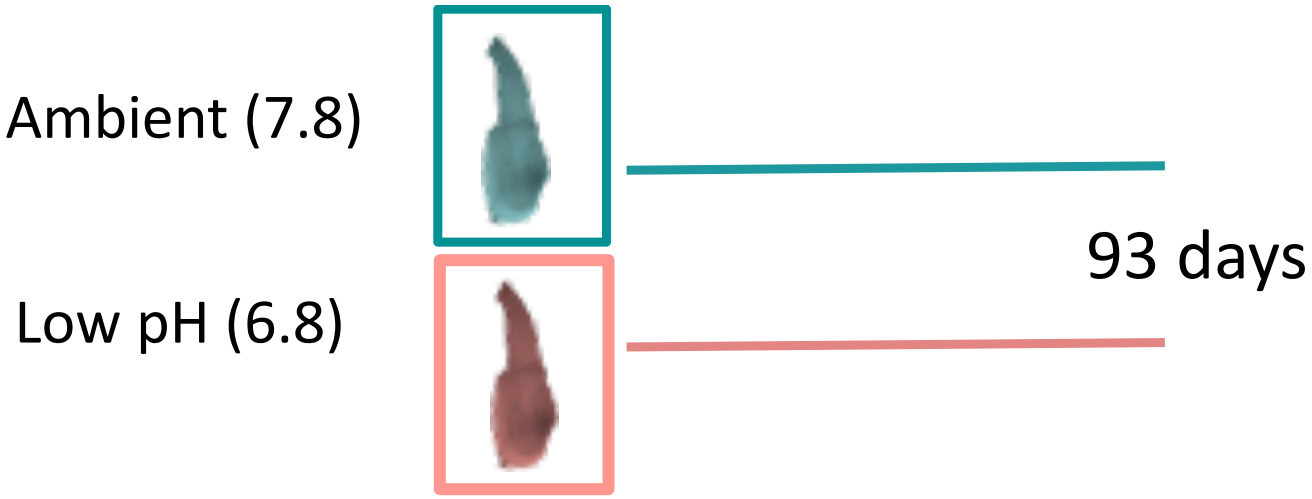
Overarching questions:

- How will they fare under ocean acidification conditions predicted for the future?
- Could stress conditioning be beneficial for aquaculture?

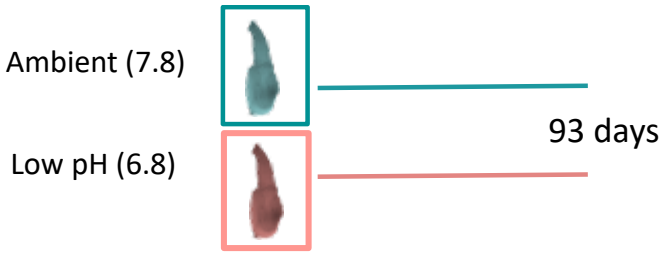
Aspects to investigate:

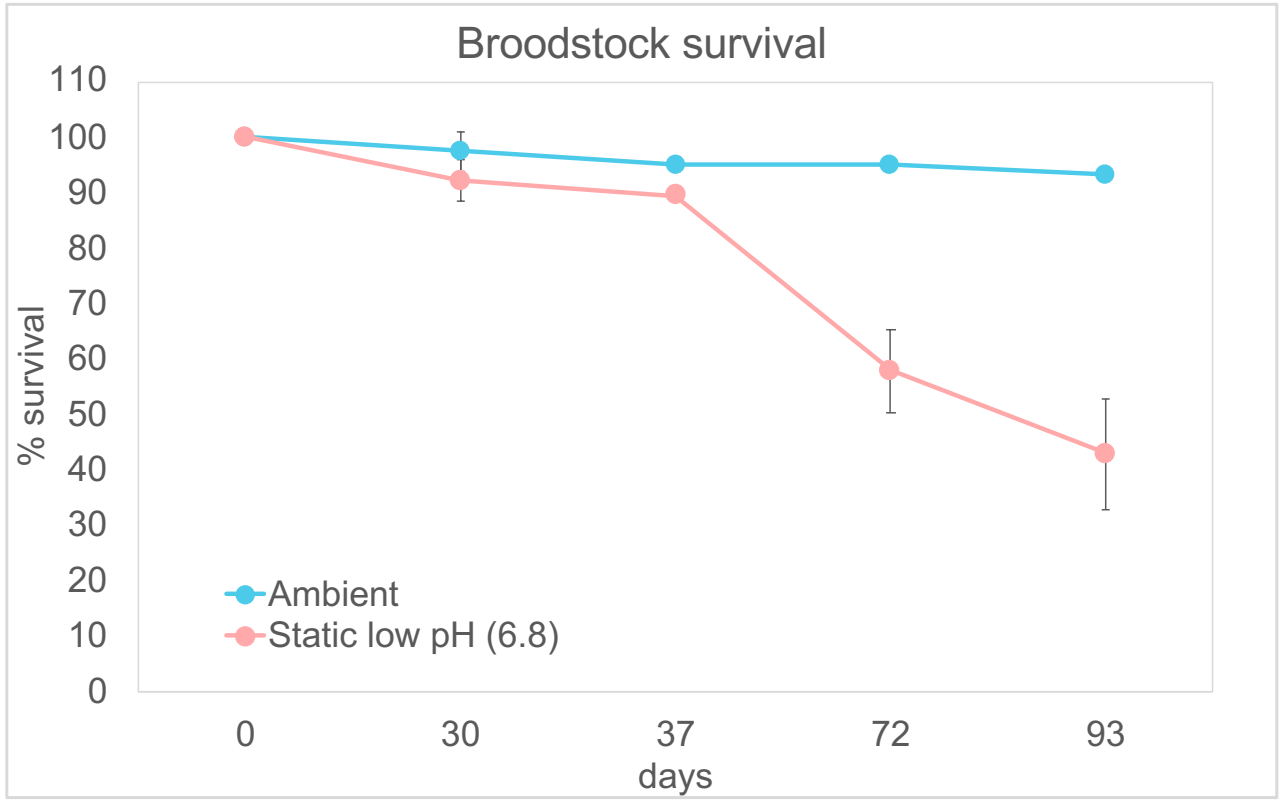
- Broodstock performance and reproductive development
- Juvenile development
- Carry over effects

Impact of static low pH on broodstock

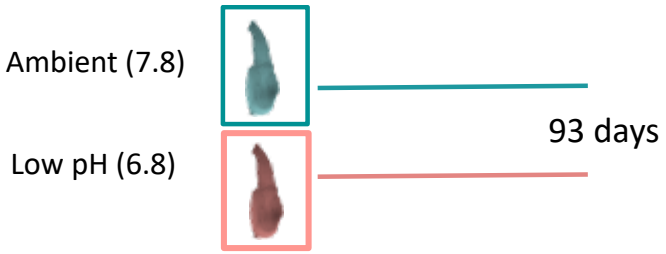


static low pH negatively impacts broodstock survival





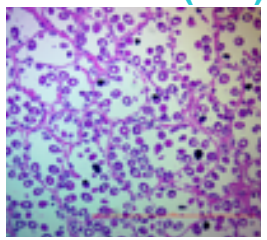
static low pH delays female reproductive development



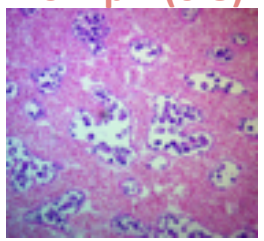
Egg size

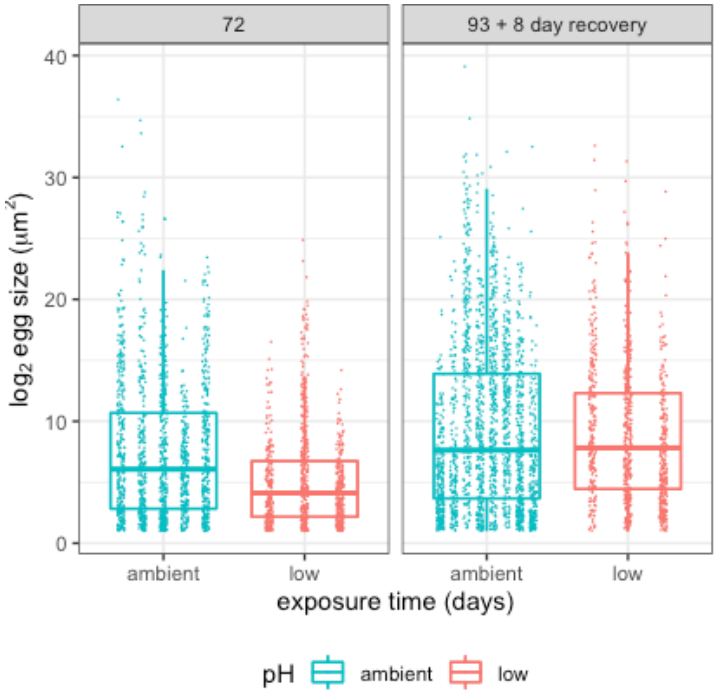
gonad tissue area

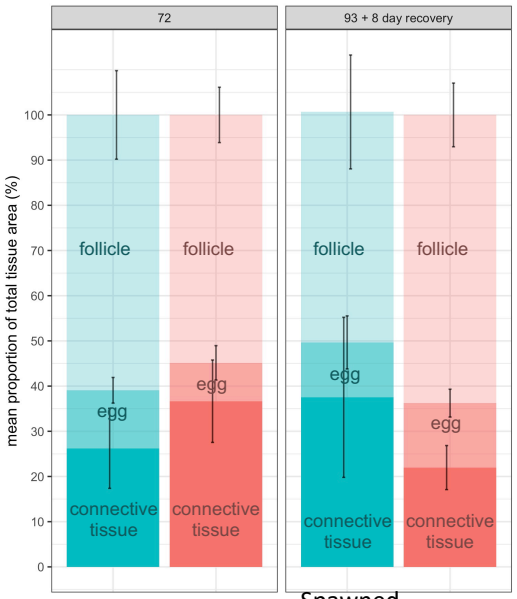
Ambient (8.0)



Low pH (6.8)







Spawned and resorbing

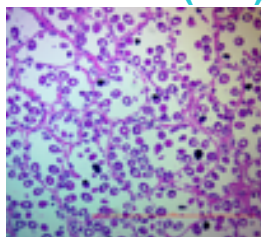
static low pH *does not* delay male reproductive development

Ambient (7.8)

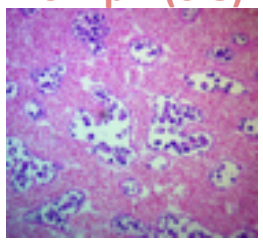
Low pH (6.8)

93 days

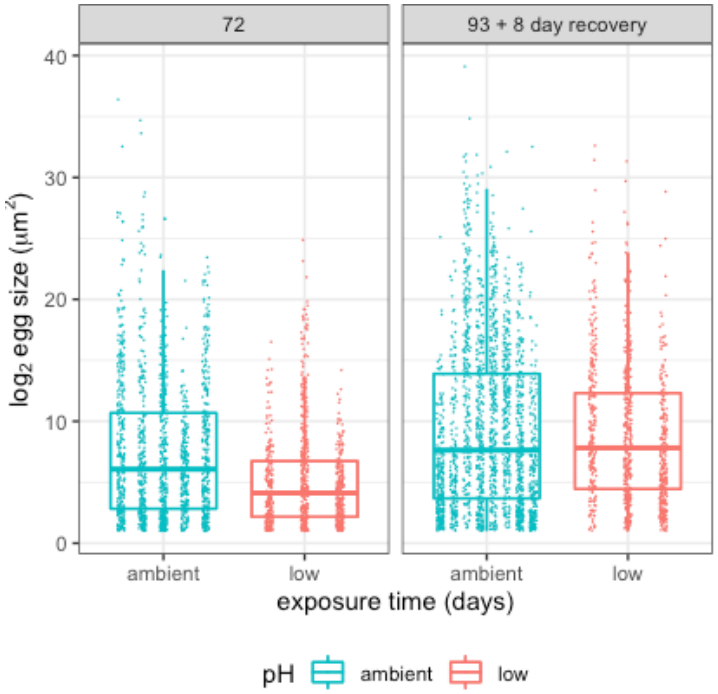
Ambient (8.0)



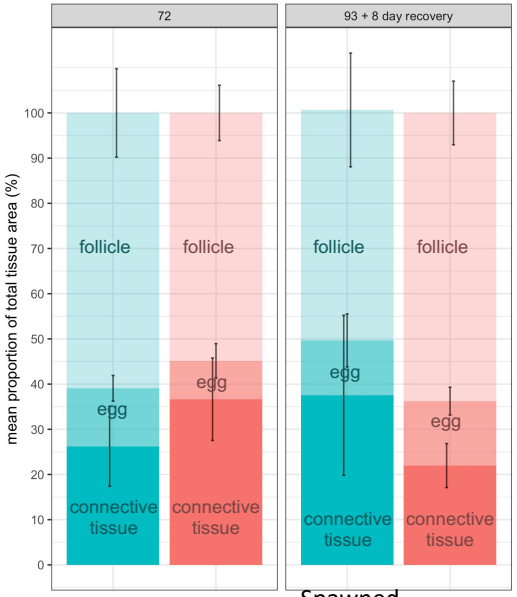
Low pH (6.8)



Egg size



gonad tissue area



Spawned and resorbing

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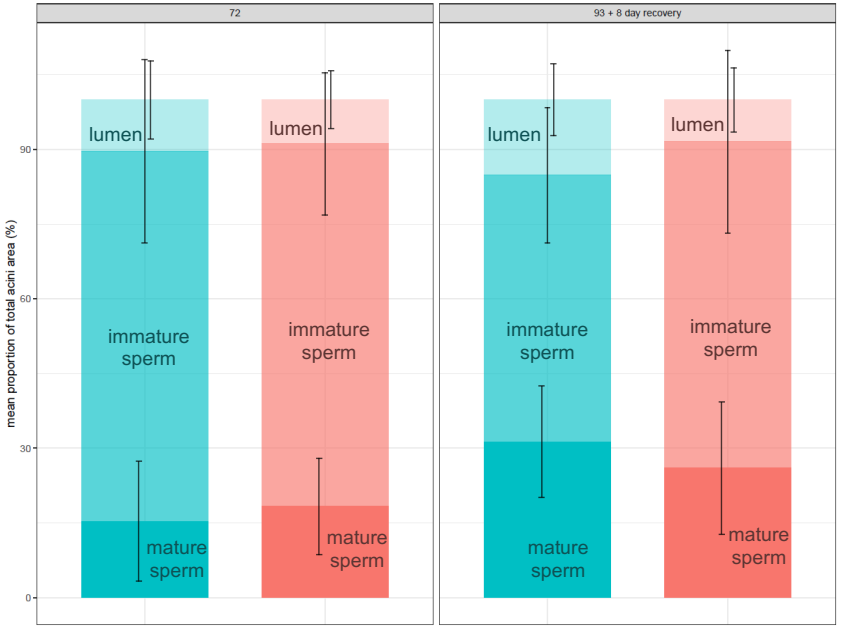
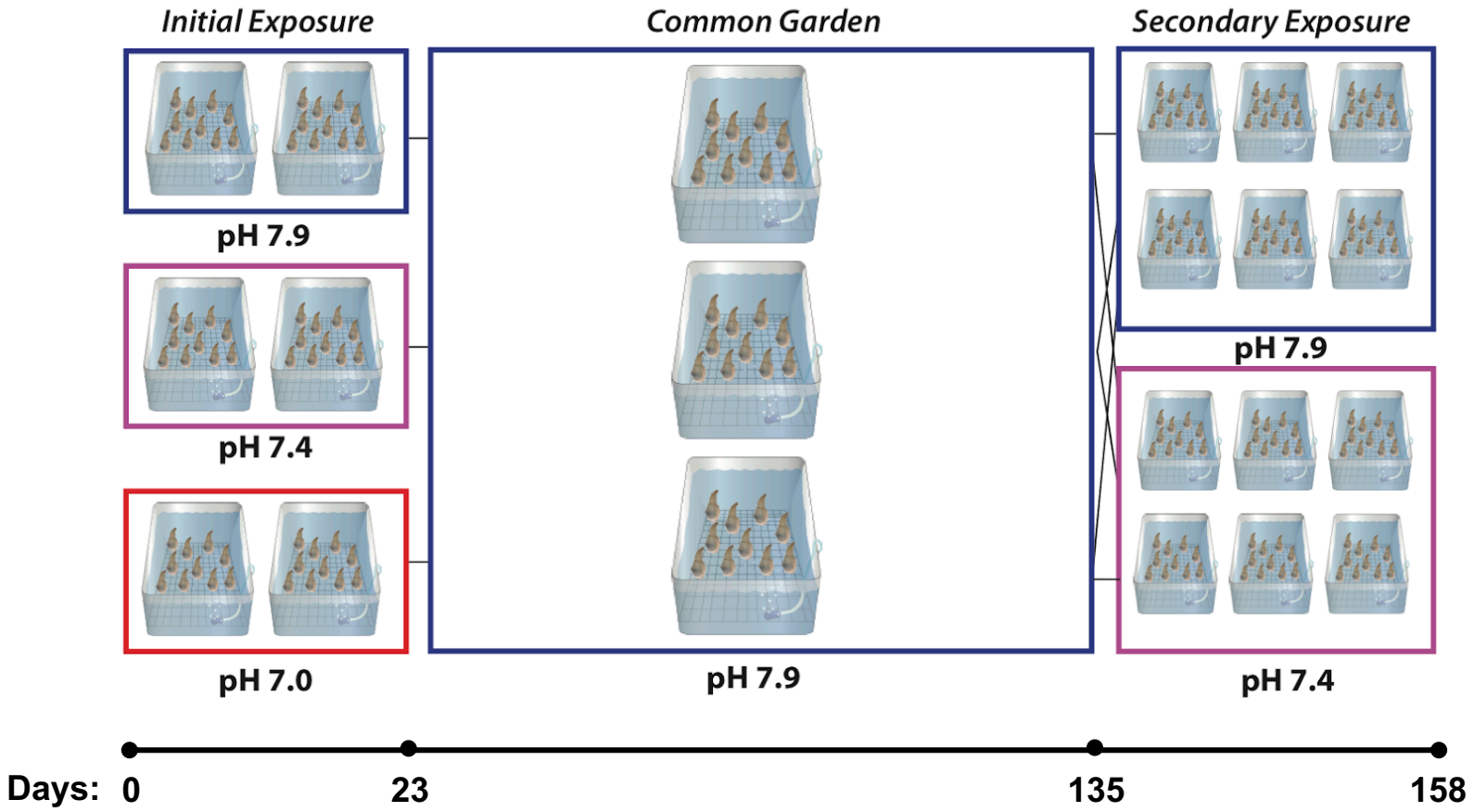


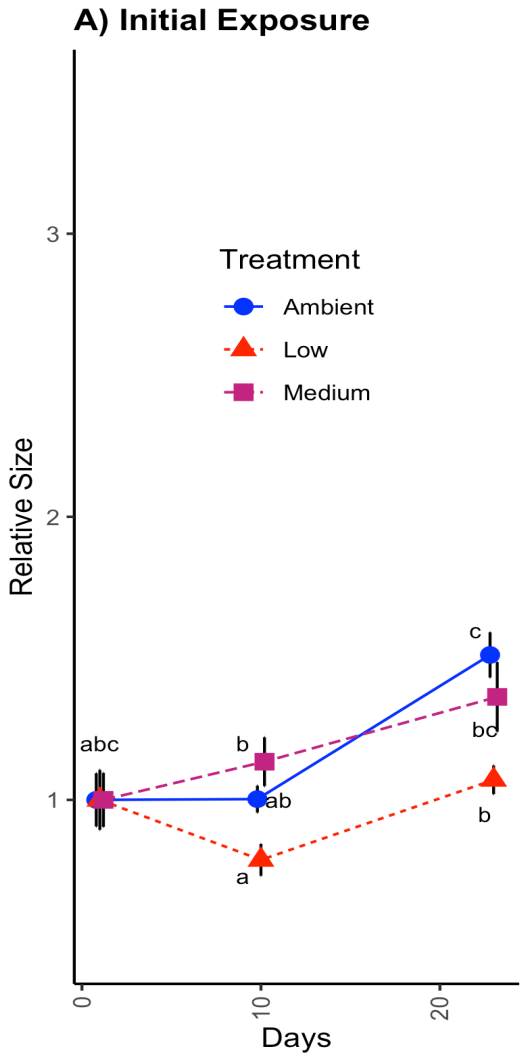
Impact of static pH on juvenile development

3 month old juveniles



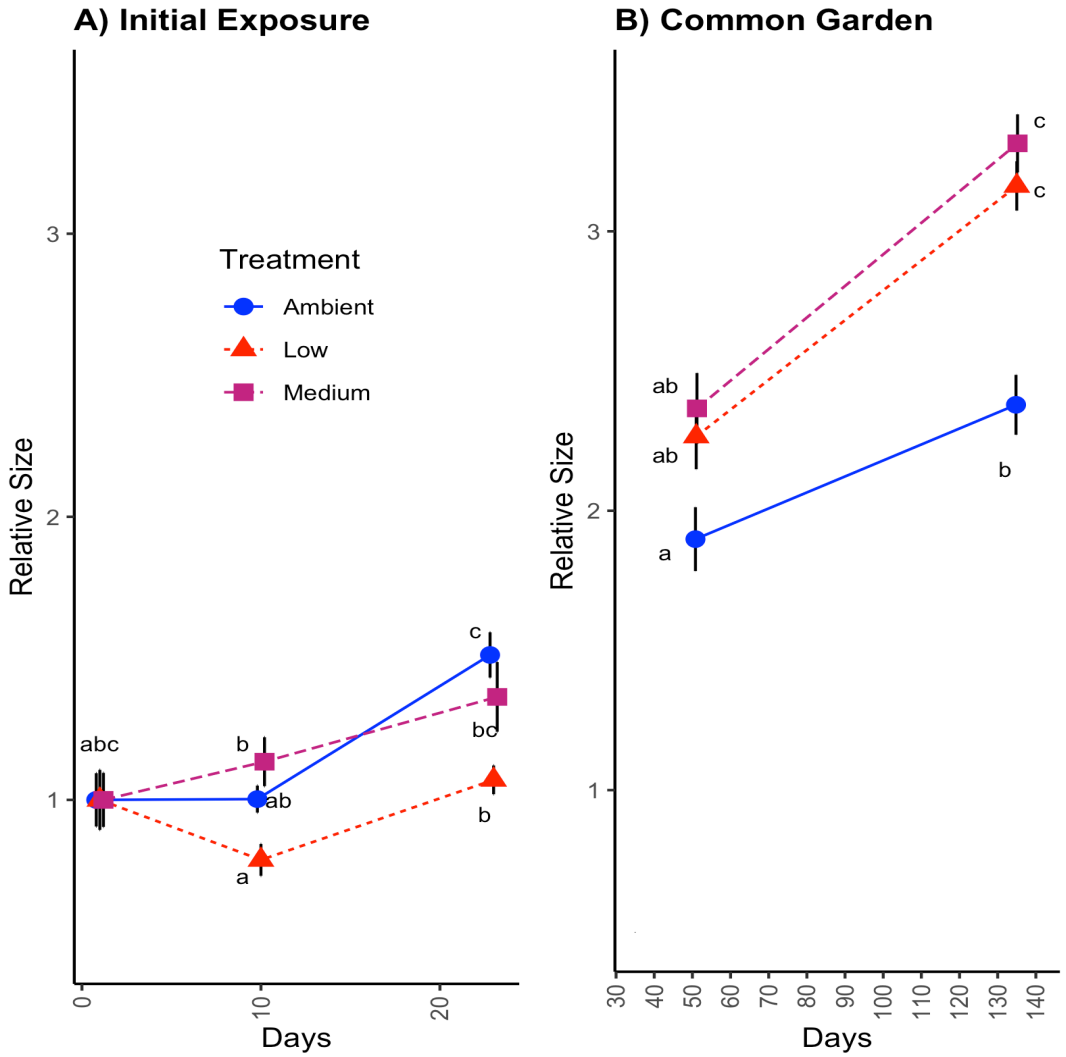
Hollie Putnam

static low pH initial exposure delays juvenile growth



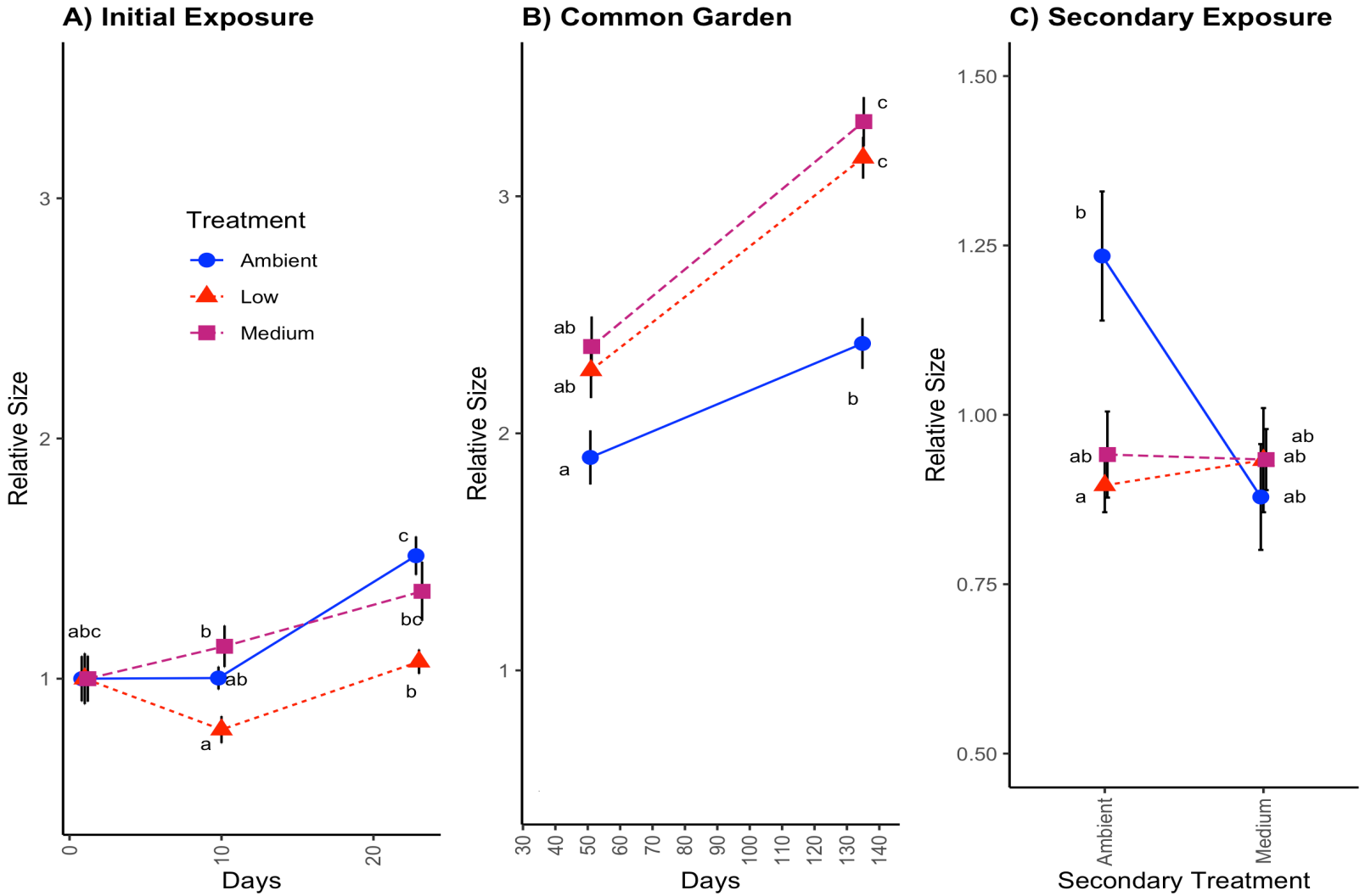
Hollie Putnam

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



Hollie Putnam

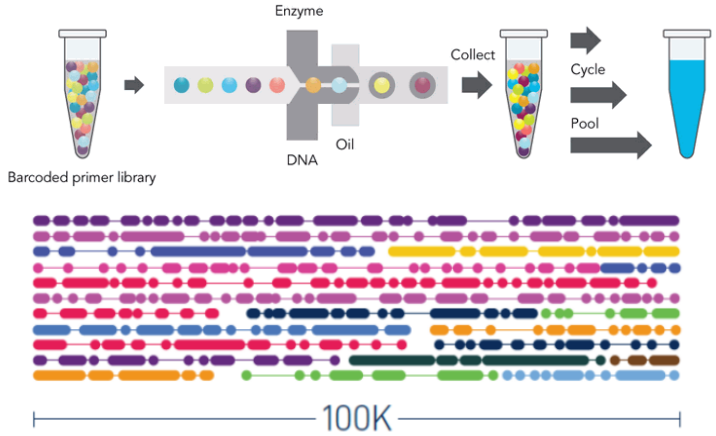
static moderate and low pH initial exposure protects against growth delay induced by secondary low pH exposure



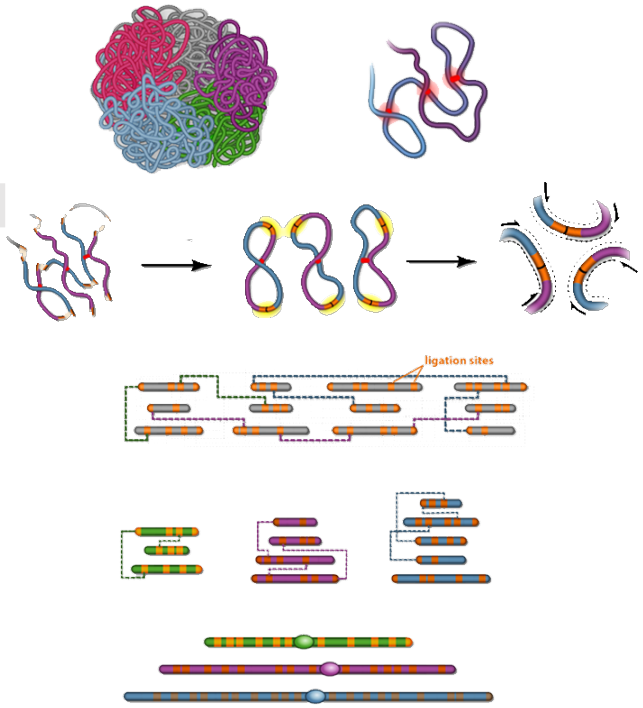
Hollie Putnam

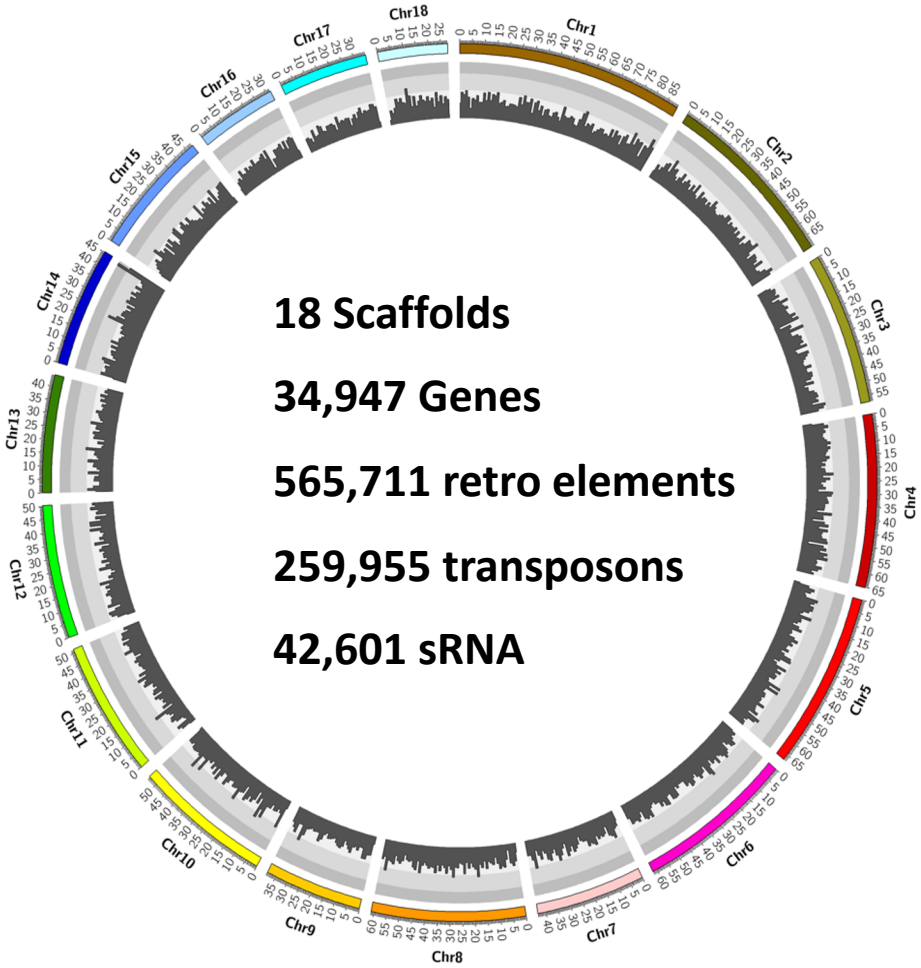
Sequencing the geoduck genome

10x Genomics
Linked-reads sequencing



Phase Genomics
Proximo Hi-C





18 Scaffolds

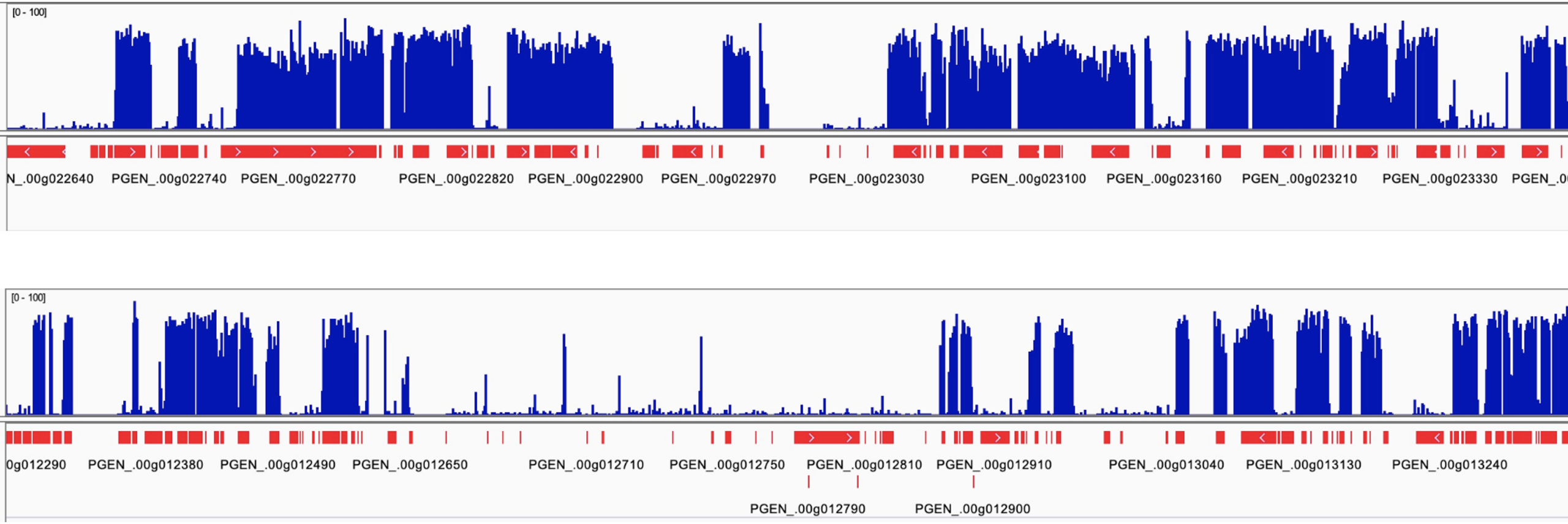
34,947 Genes

565,711 retro elements

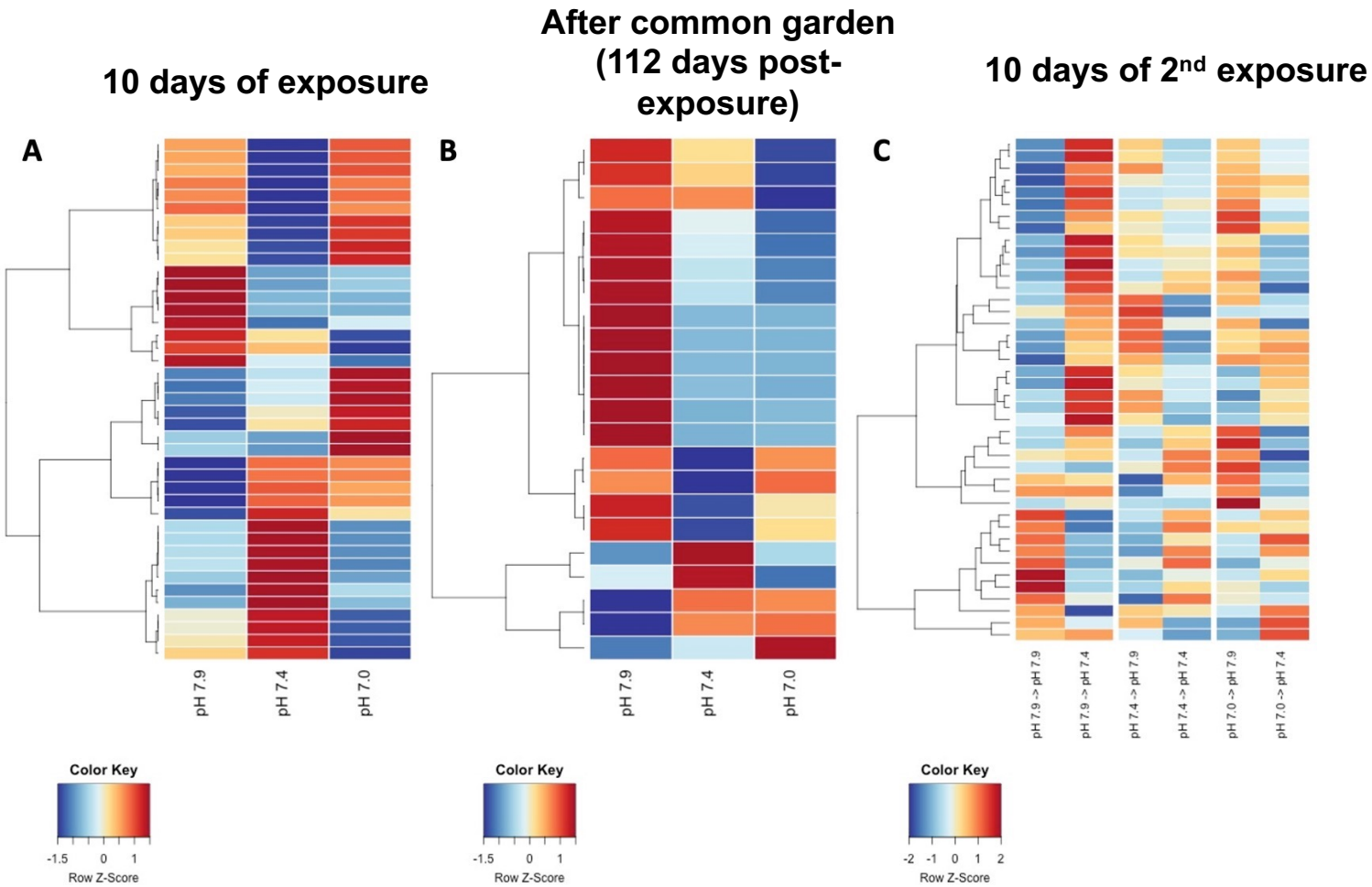
259,955 transposons

42,601 sRNA

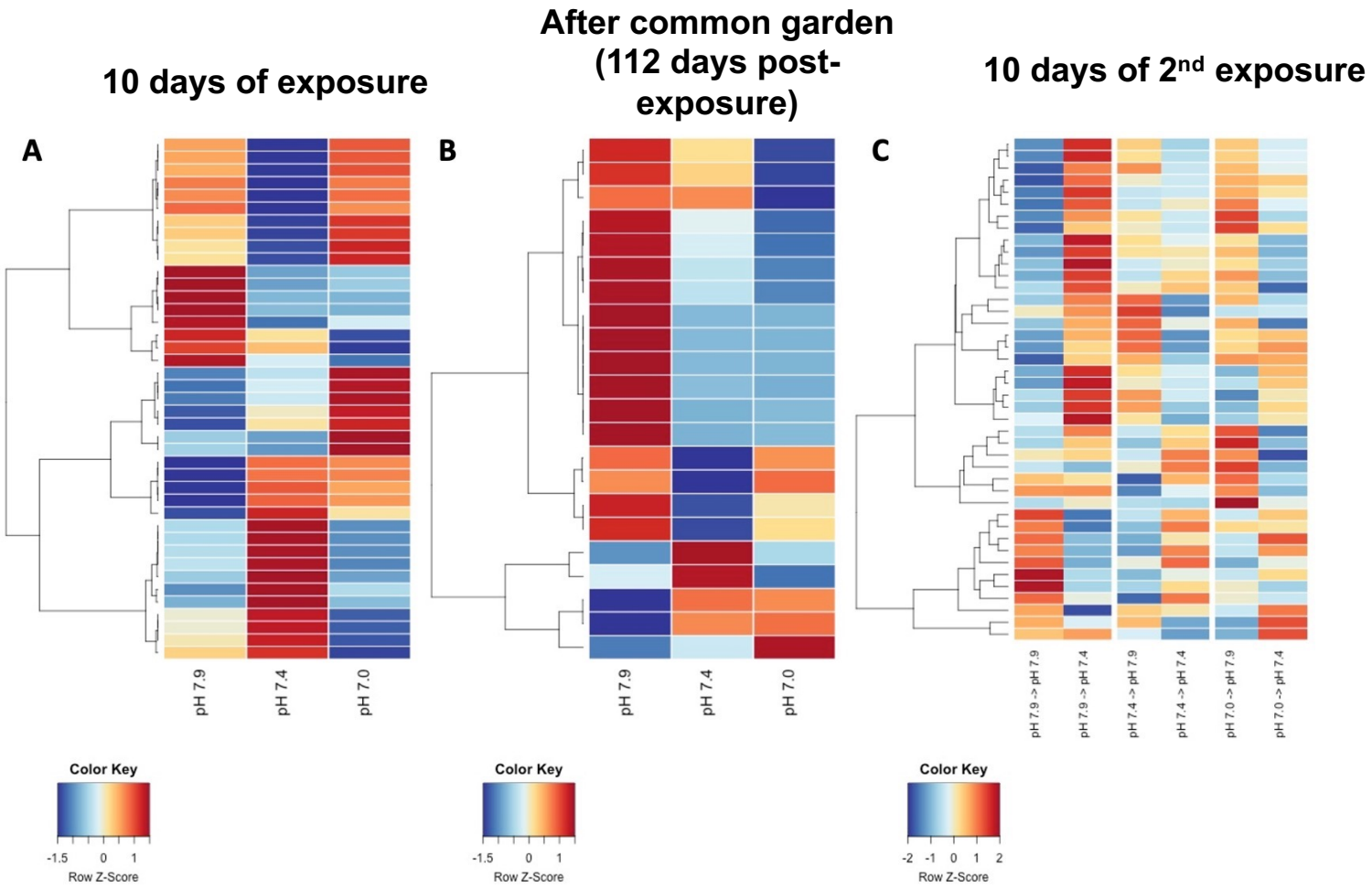
Geoduck genome methylation landscape

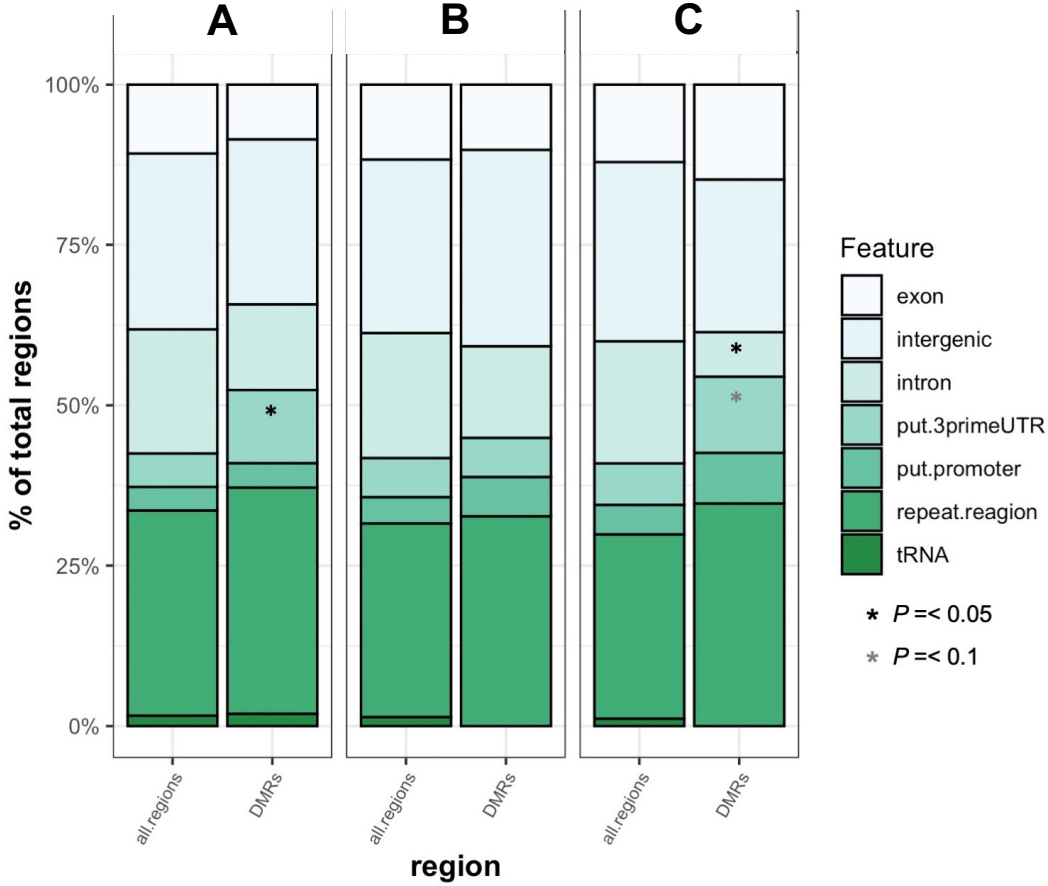


Differentially methylated regions across low pH conditions



Differentially methylated regions across low pH conditions



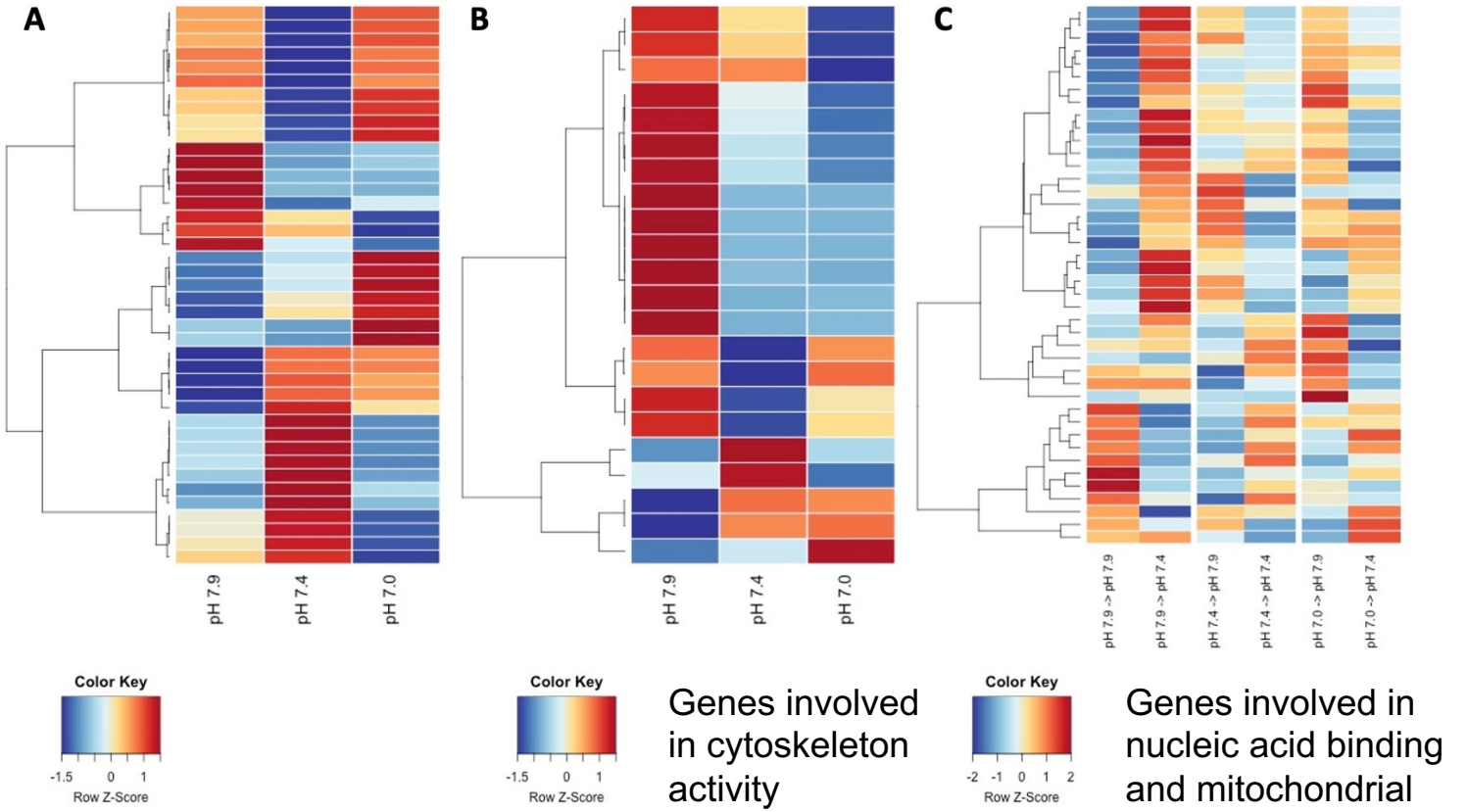


Differentially methylated regions across low pH conditions

10 days of exposure

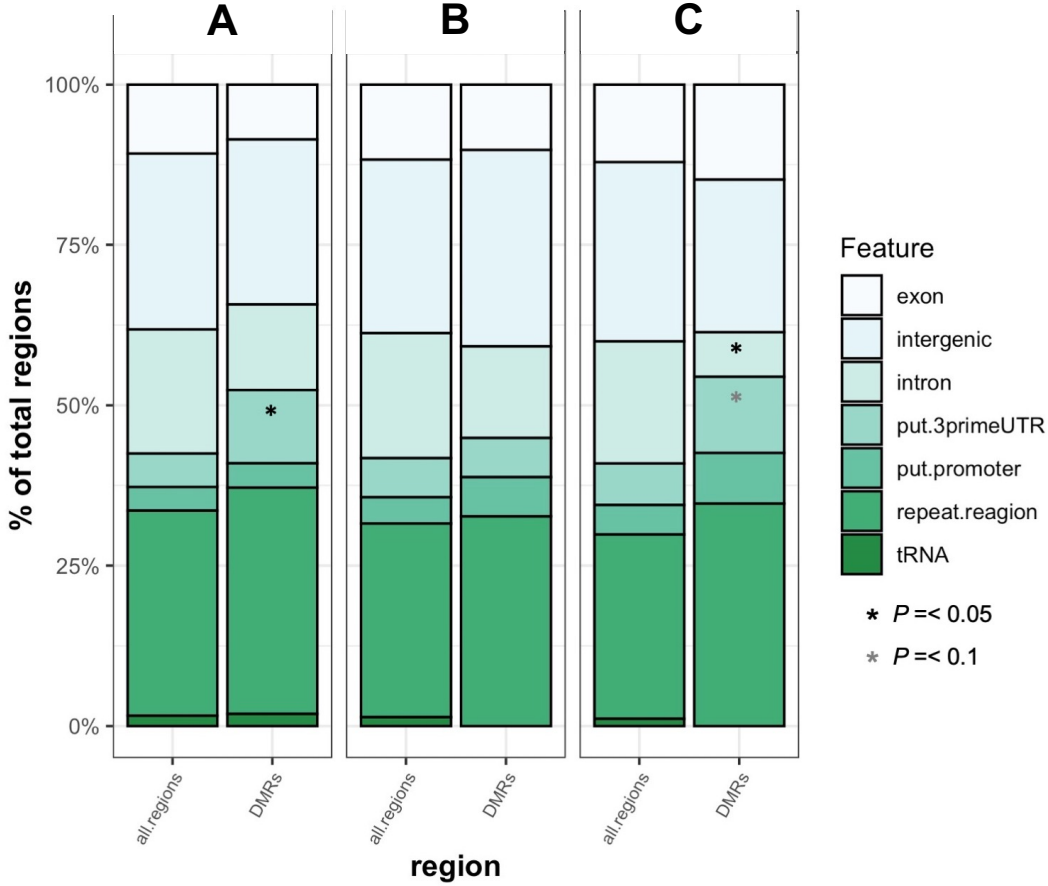
After common garden (112 days post-exposure)

10 days of 2nd exposure

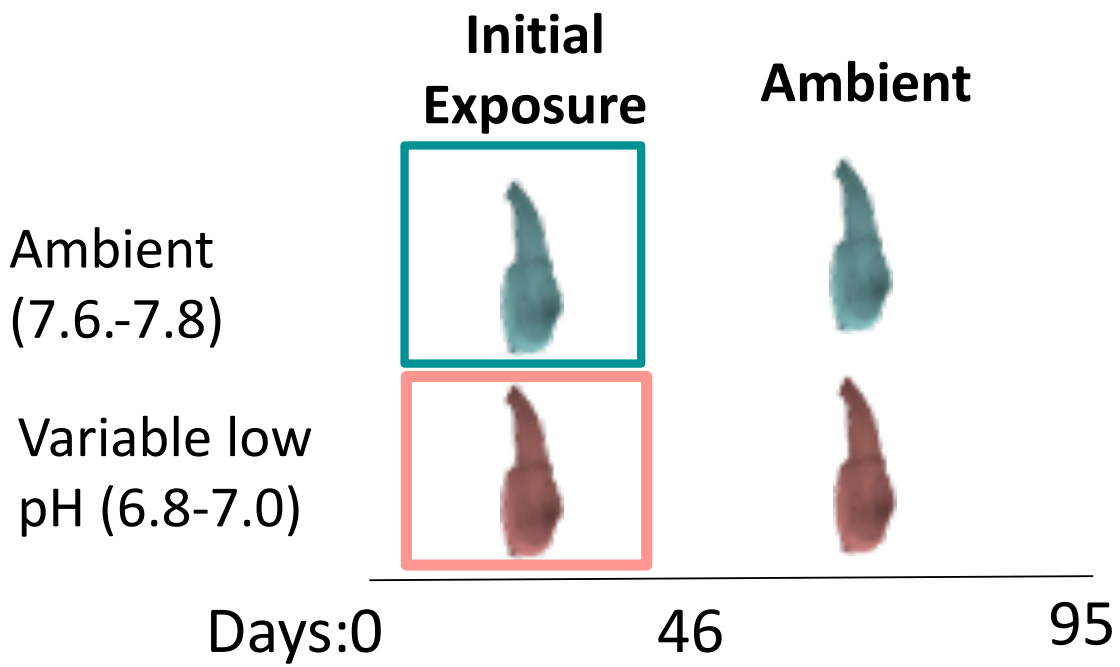


Genes involved in cytoskeleton activity

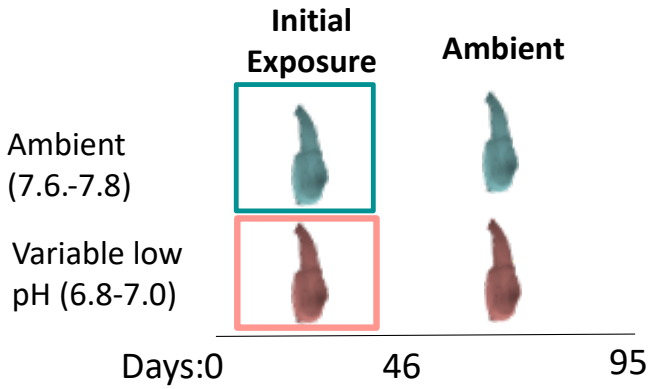
Genes involved in nucleic acid binding and mitochondrial activity

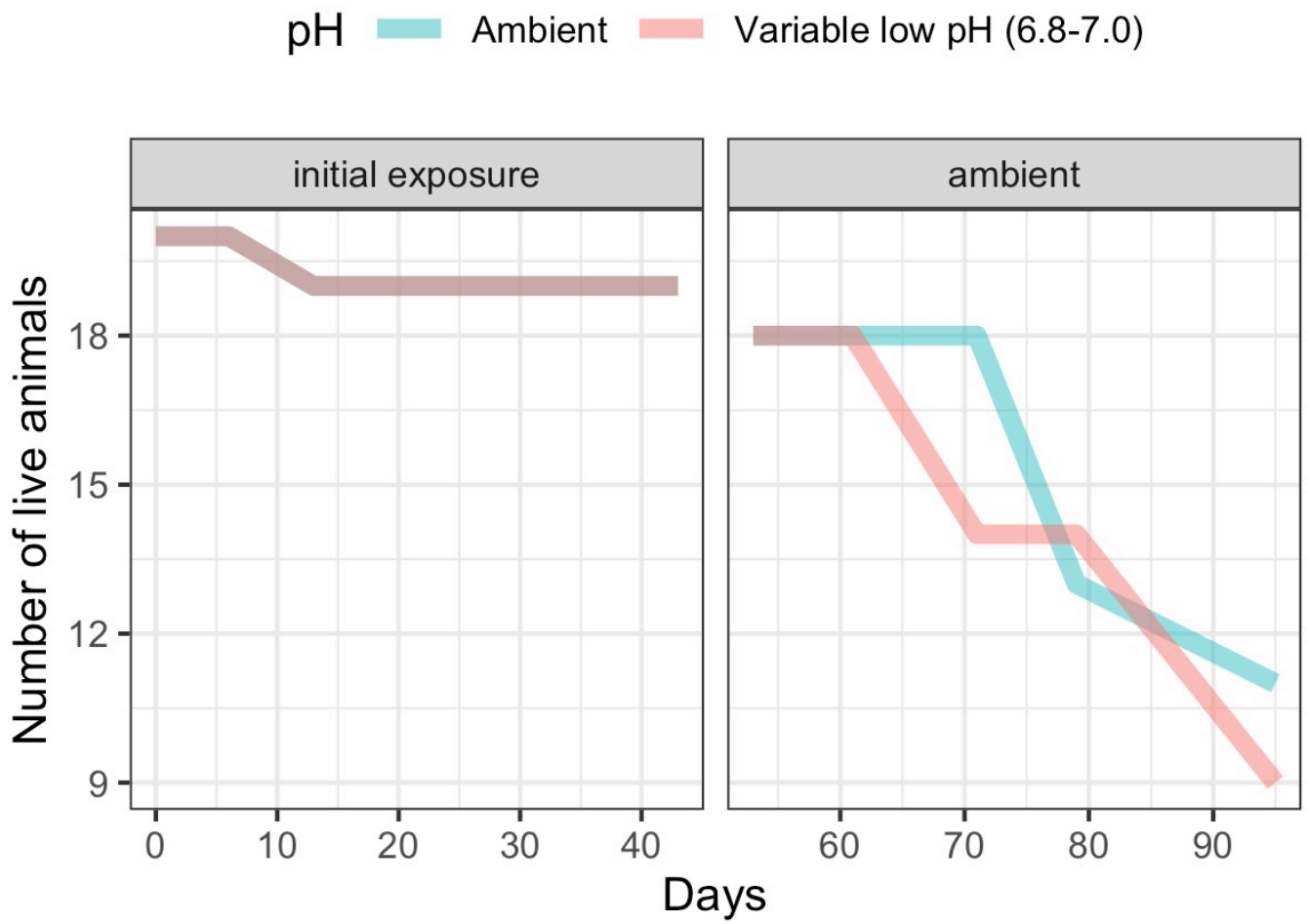


Impact of variable low pH on broodstock



variable low pH does not affect broodstock survival



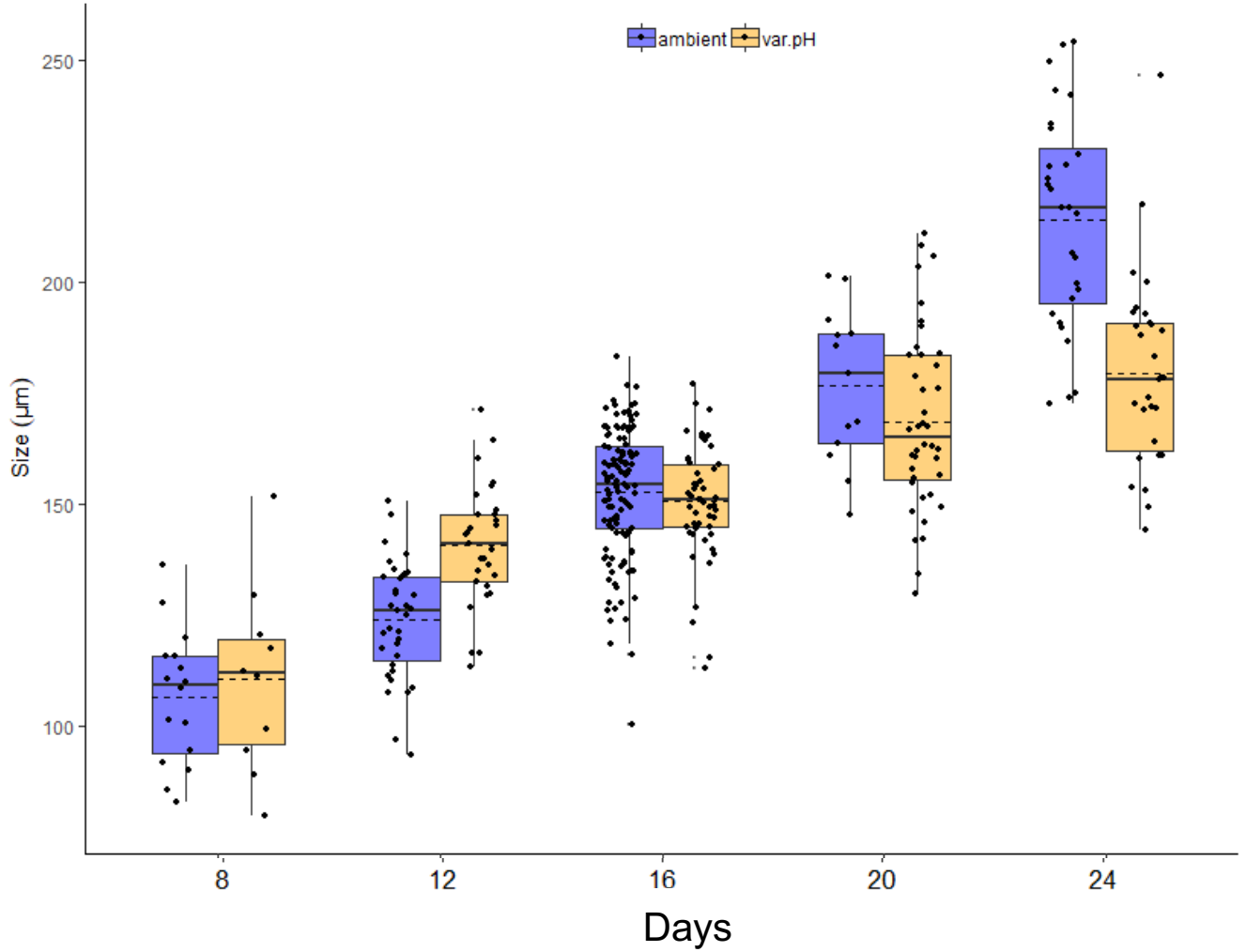


Impact of variable low pH on offspring development

Larval offspring reared under ambient conditions

Generally little impact from parental conditioning on larval growth

Larval offspring reared under ambient conditions

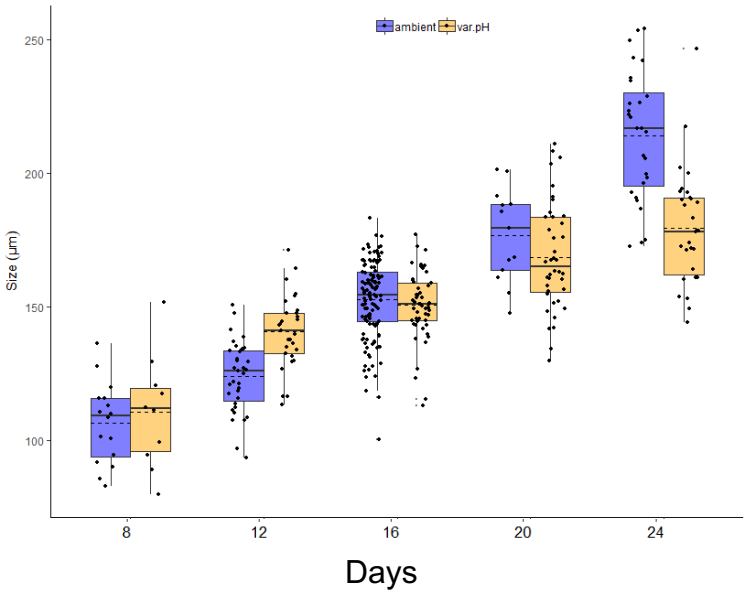


Sam Gurr

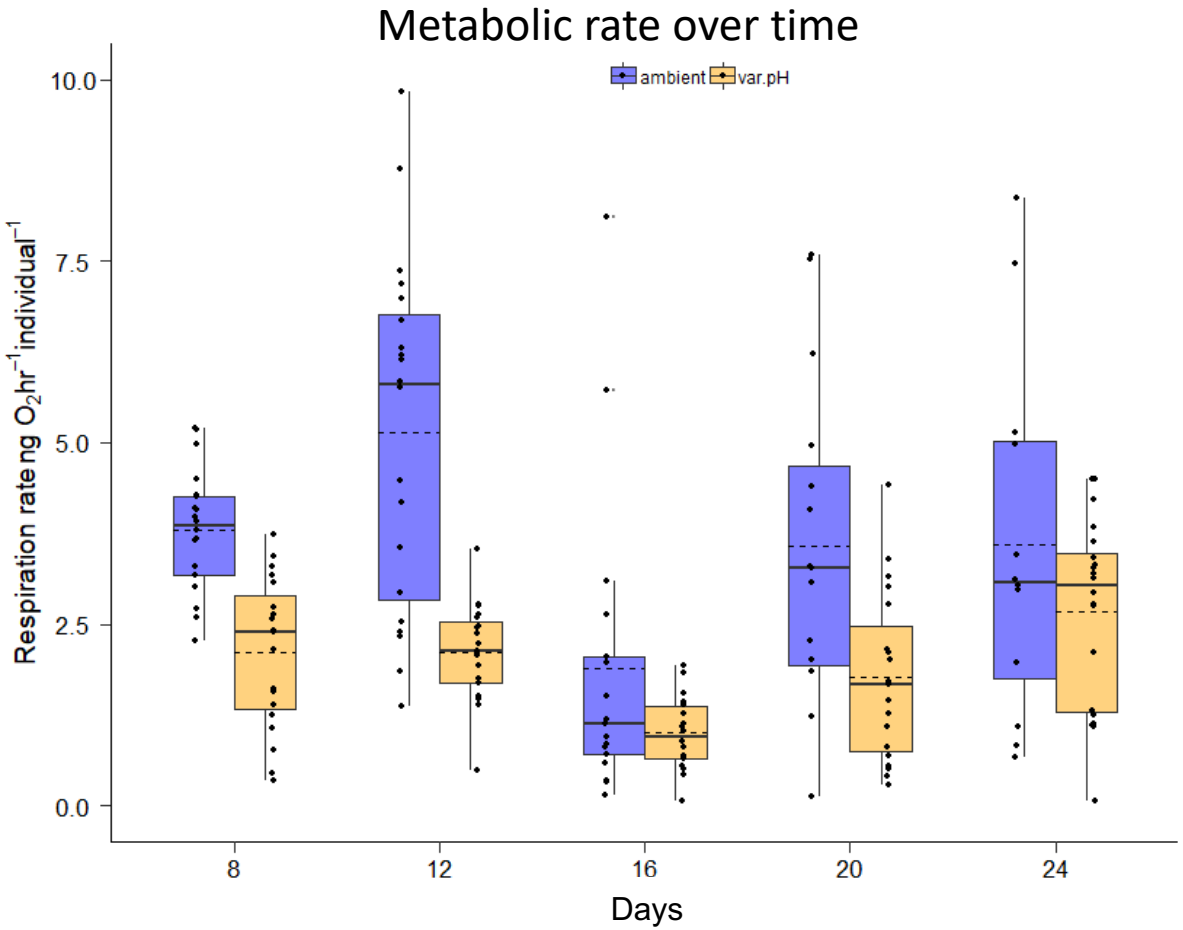
Parental variable low pH exposure leads to reduced metabolic rates in larvae

Larval offspring reared in ambient conditions

Growth over time



Metabolic rate over time



Sam Gurr

Impact of variable low pH on juvenile offspring development

Juvenile offspring

Ambient (7.6-7.8)

Variable low pH (6.8-7.0)

44 days

~ 100 juveniles per silo

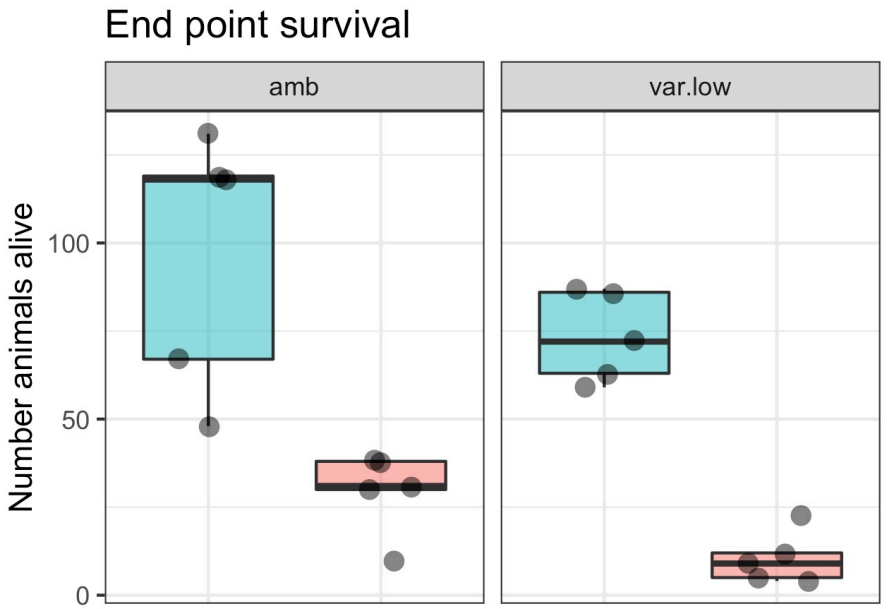
Variable low pH exposure led to lower survival regardless of parental conditions

Juvenile offspring

Ambient (7.6-7.8)

Variable low pH (6.8-7.0)

44 days



alpha

0.2

juvenile pH exposure

amb

var.low

Significant effect from juvenile conditions (P = 6.69e-06)

Marginal effect from parental conditions (P = 0.0863)

Linear mixed effect model:
live animals ~ Parental condition + pH exposure + (1 | Silo)

Parental and juvenile variable low pH exposure led to larger size

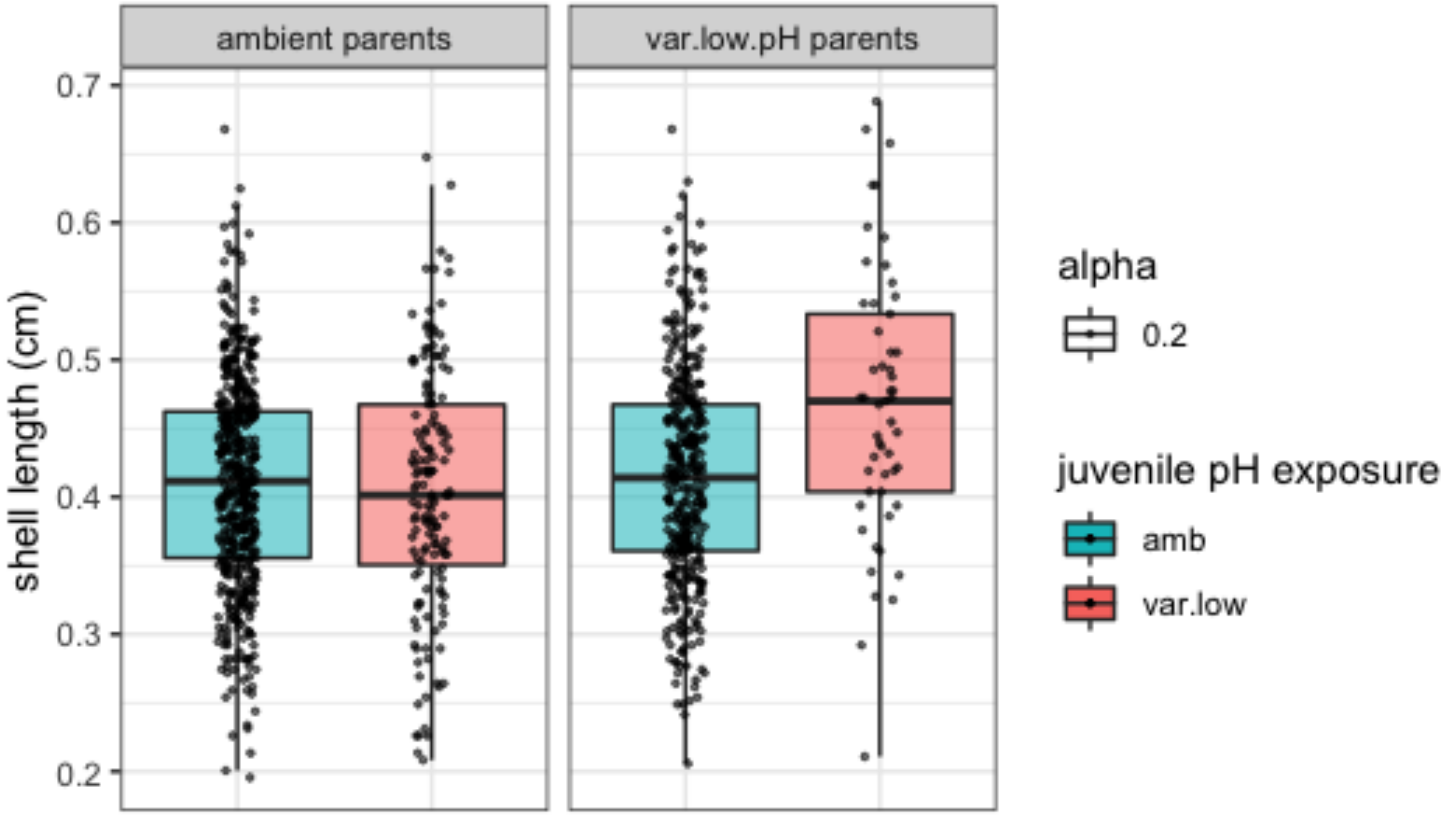
Juvenile offspring

Ambient (7.6-7.8)

Variable low pH (6.8-7.0)

44 days

Endpoint size distribution



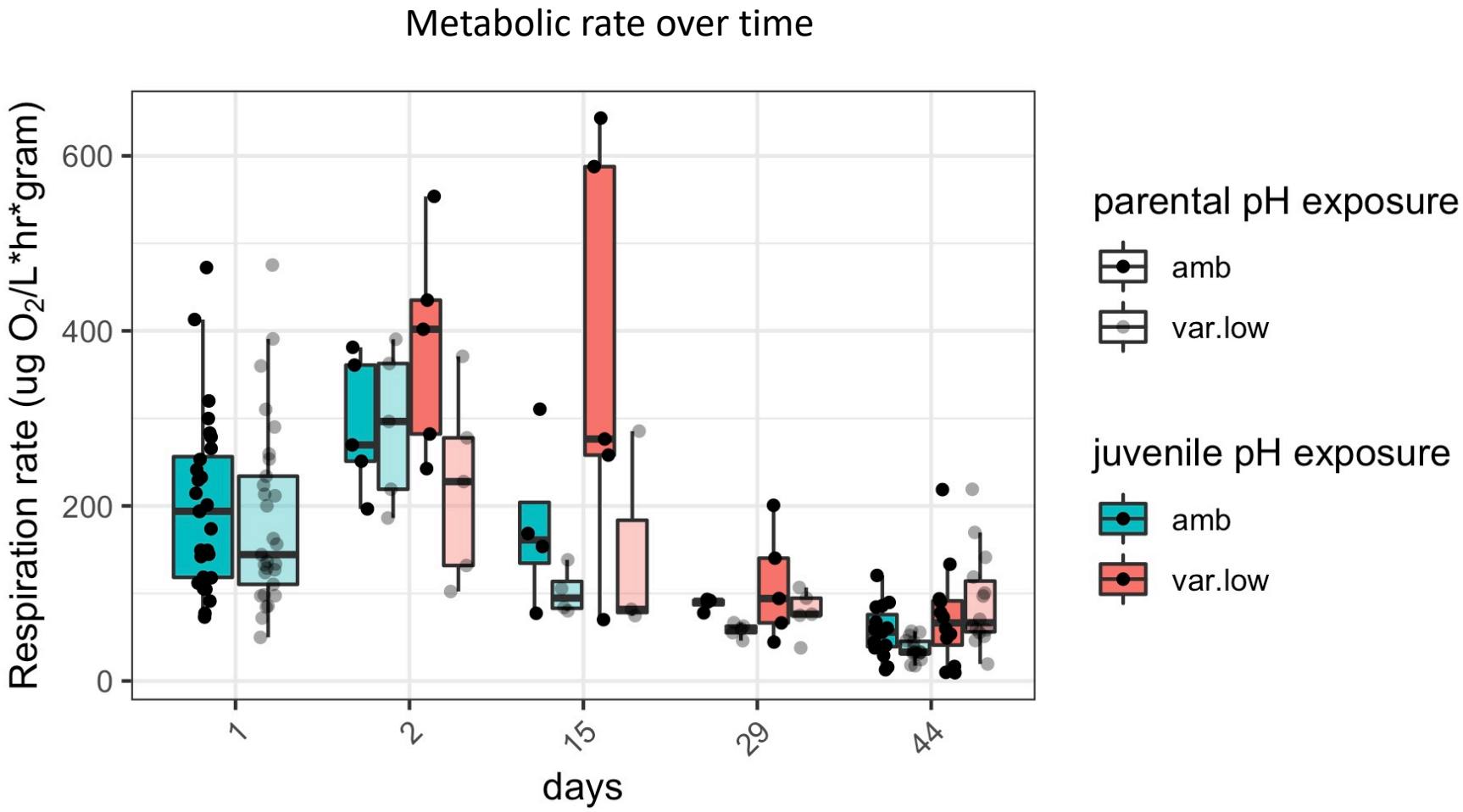
Parental variable low pH exposure generally led to lower metabolic rate in juveniles

Juvenile offspring

Ambient (7.6-7.8)

Variable low pH (6.8-7.0)

44 days



Summary

- **Broodstock and reproductive development**
  - Longer duration and constant low pH exposure is more detrimental to survival
  - Female reproductive development is more sensitive to low pH than males
- **Juvenile development**
  - Evidence for environmental memory
    - Initial low pH exposure led to larger animals 4 months after exposure
      - associated with methylation changes in genes related to cytoskeletal activity
    - Initial low pH exposure prevented growth delay seen in naïve juveniles
      - associated with methylation changes in genes related to nucleic acid binding and mitochondrial activity
- **Carry over effects**
  - Parental variable low pH conditioning leads to reduced energy demand in offspring that achieve the same or larger size under low pH conditions
    - Generally didn't impact larval growth
    - Led to reduced metabolic rates in larvae
    - Didn't impact survival in juveniles exposed to variable low pH
    - Led to larger size juveniles when exposed to variable low pH
    - Generally led to lower metabolic rate in juveniles

Implications

- pH can be used to induce beneficial traits that persist over time
- Effects seems to be stage dependent
- Conditions need to be optimized

Questions?

- Message me on the Pathable SICB meeting platform (Shelly Trigg)
- Email me at strigg@uw.edu