

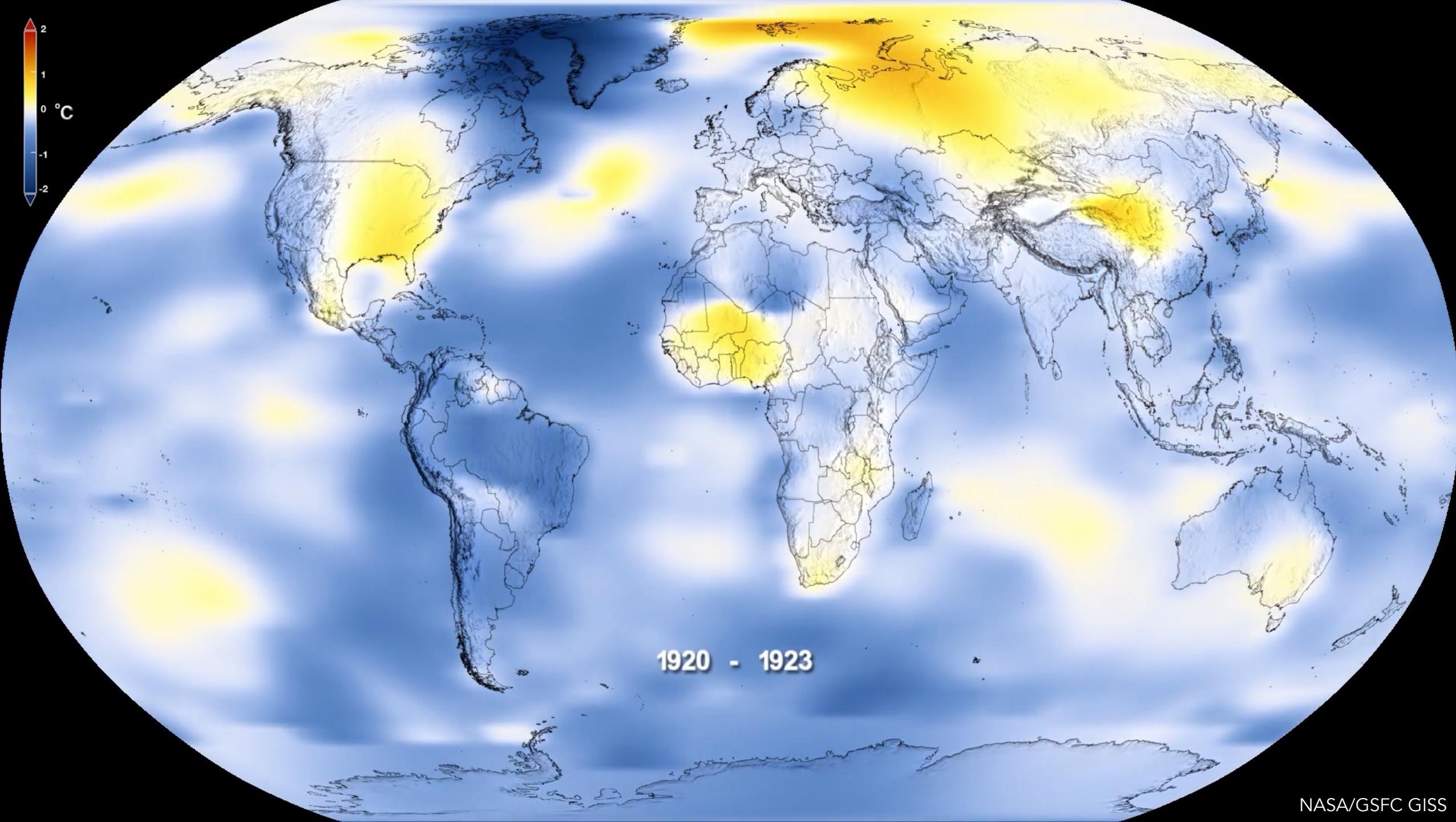
Early stages are...



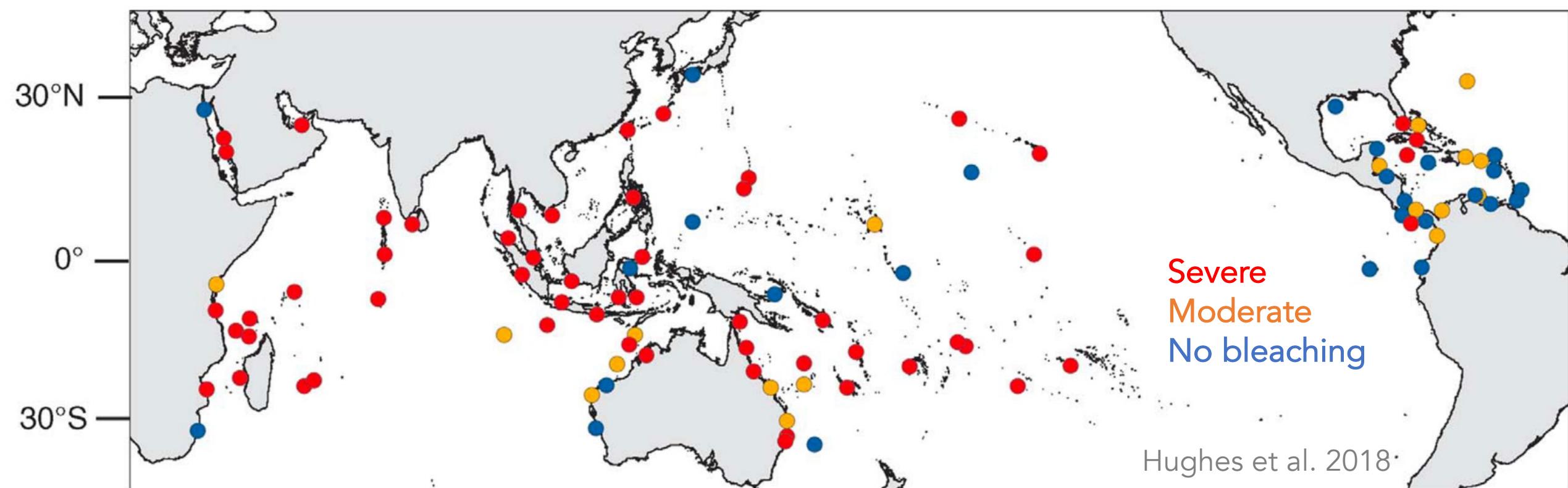
Smithsonian

...resilient than adults











Edmunds 2017

Photo: Kevin Wong, URI

Photo: Andrew Thurber, OSU



Kāne'ohe Bay Bleaching Events:
1996 • 2014 • 2015 • 2019



80-100% bleaching

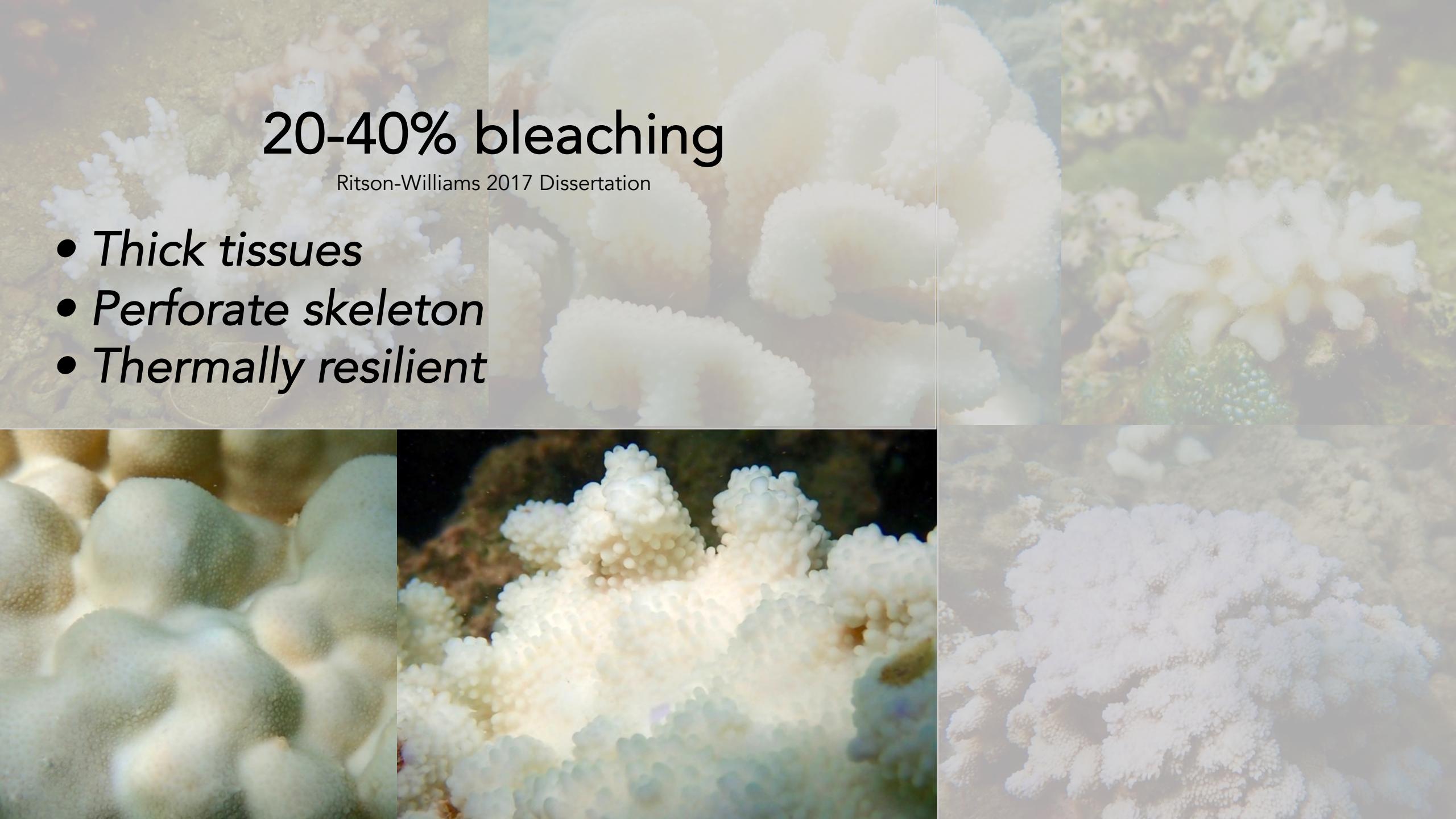
Ritson-Williams 2017 Dissertation

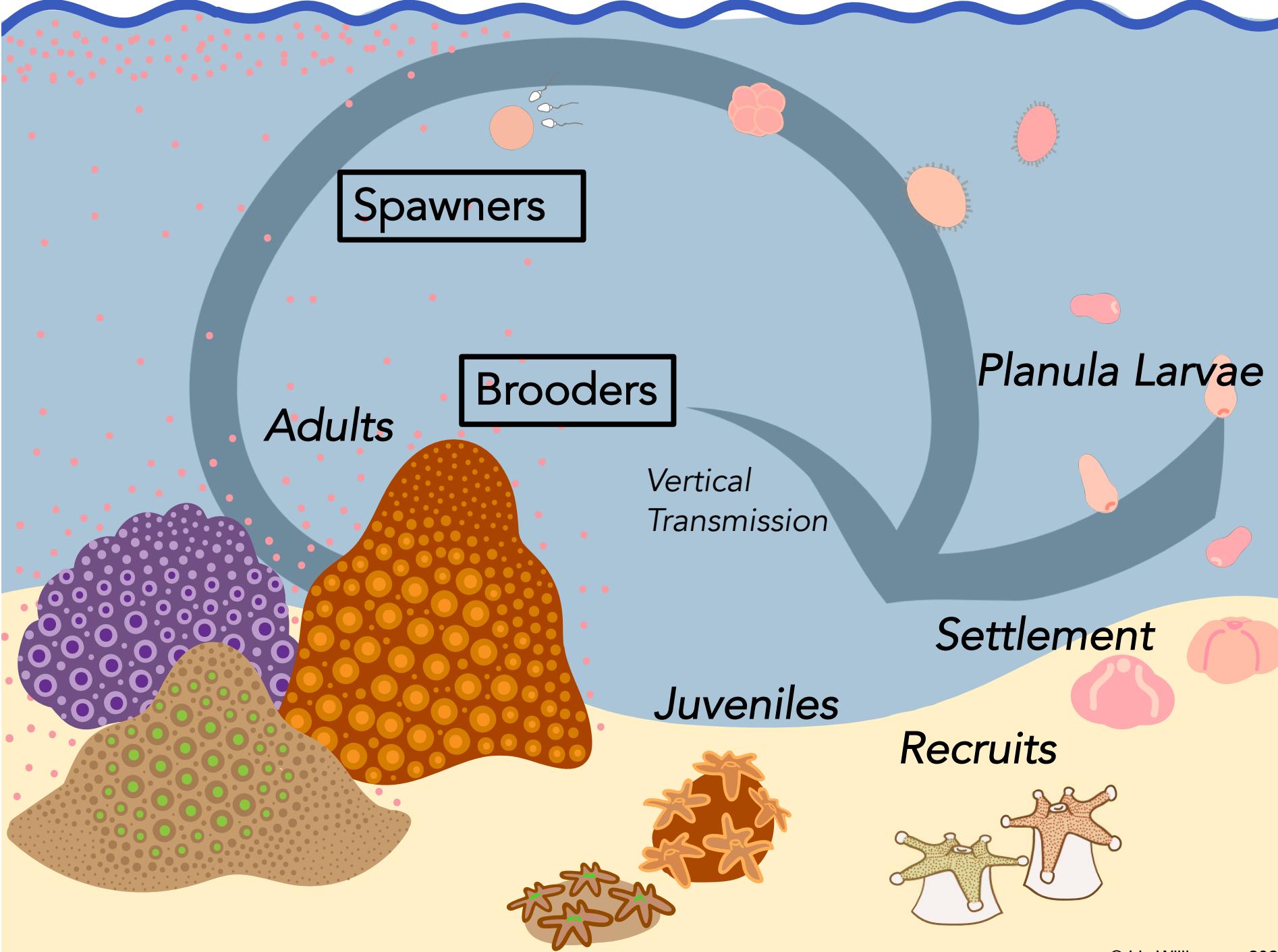
- *Thin tissues*
- *Non-perforate skeleton*
- *Thermally sensitive*

20-40% bleaching

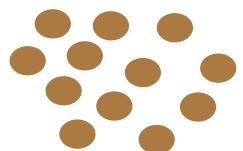
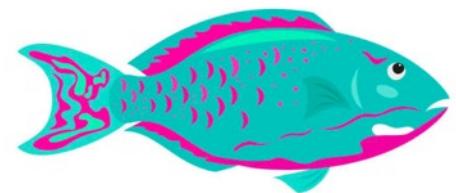
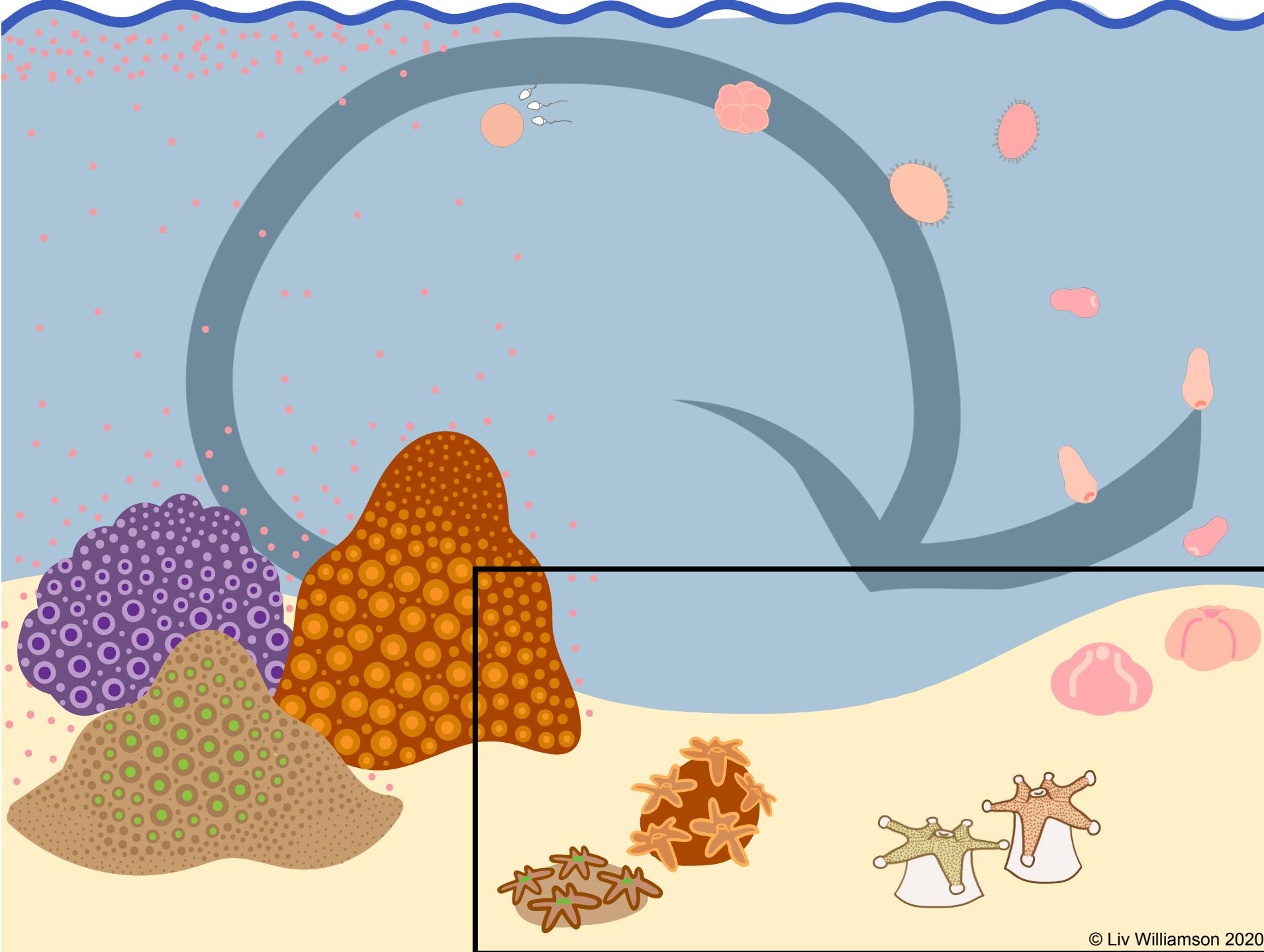
Ritson-Williams 2017 Dissertation

- Thick tissues
- Perforate skeleton
- Thermally resilient

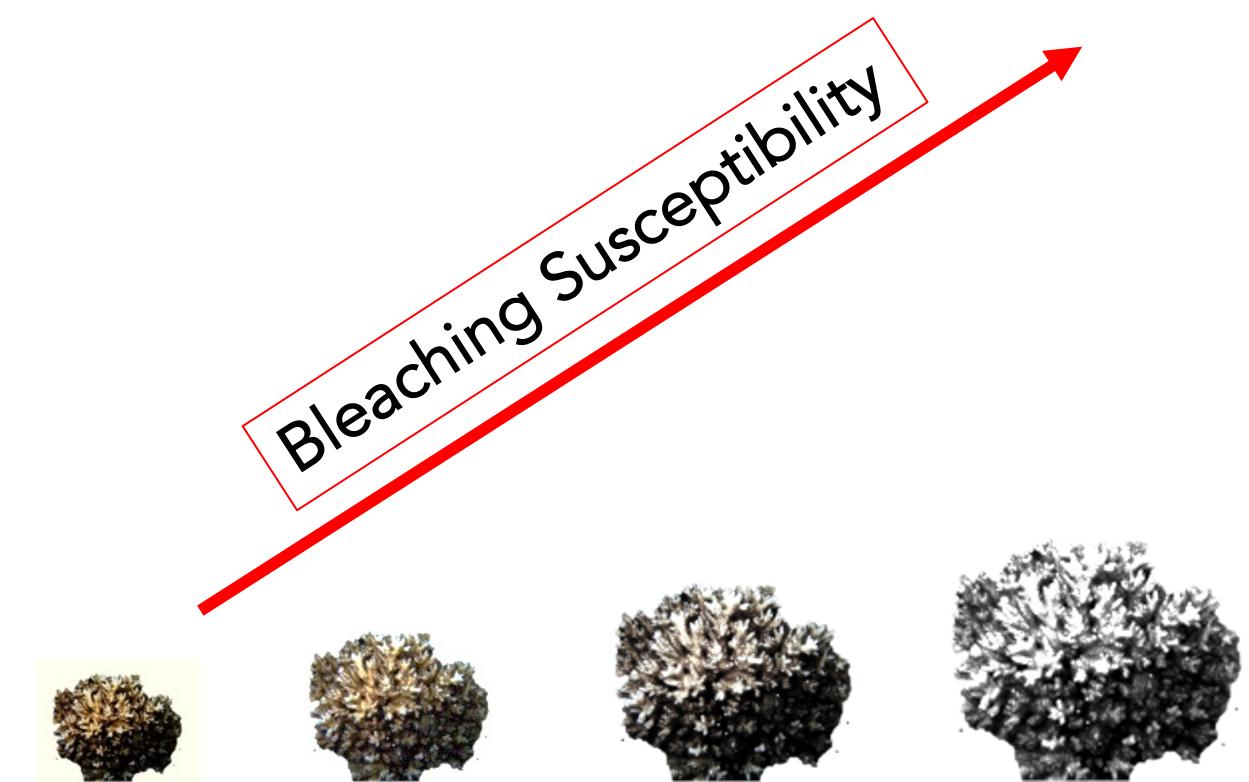




Liv Williamson
@livwilliamson



Liv Williamson
@livwilliamson



Adapted from Shenkar et al. 2005

Shenkar et al. 2005, Alvarez-Noriega et al. 2018

Are there environmental and biological conditions that promote juvenile survival in high temperature?



Larvae

Thermal exposure
Embryonic development
Settlement preferences

Juveniles

Thermal exposure
Nutrition
Tissue fusion

Parents

OA exposure
Thermal exposure
Nutrition



Larvae

Thermal exposure
Embryonic development
Settlement preferences

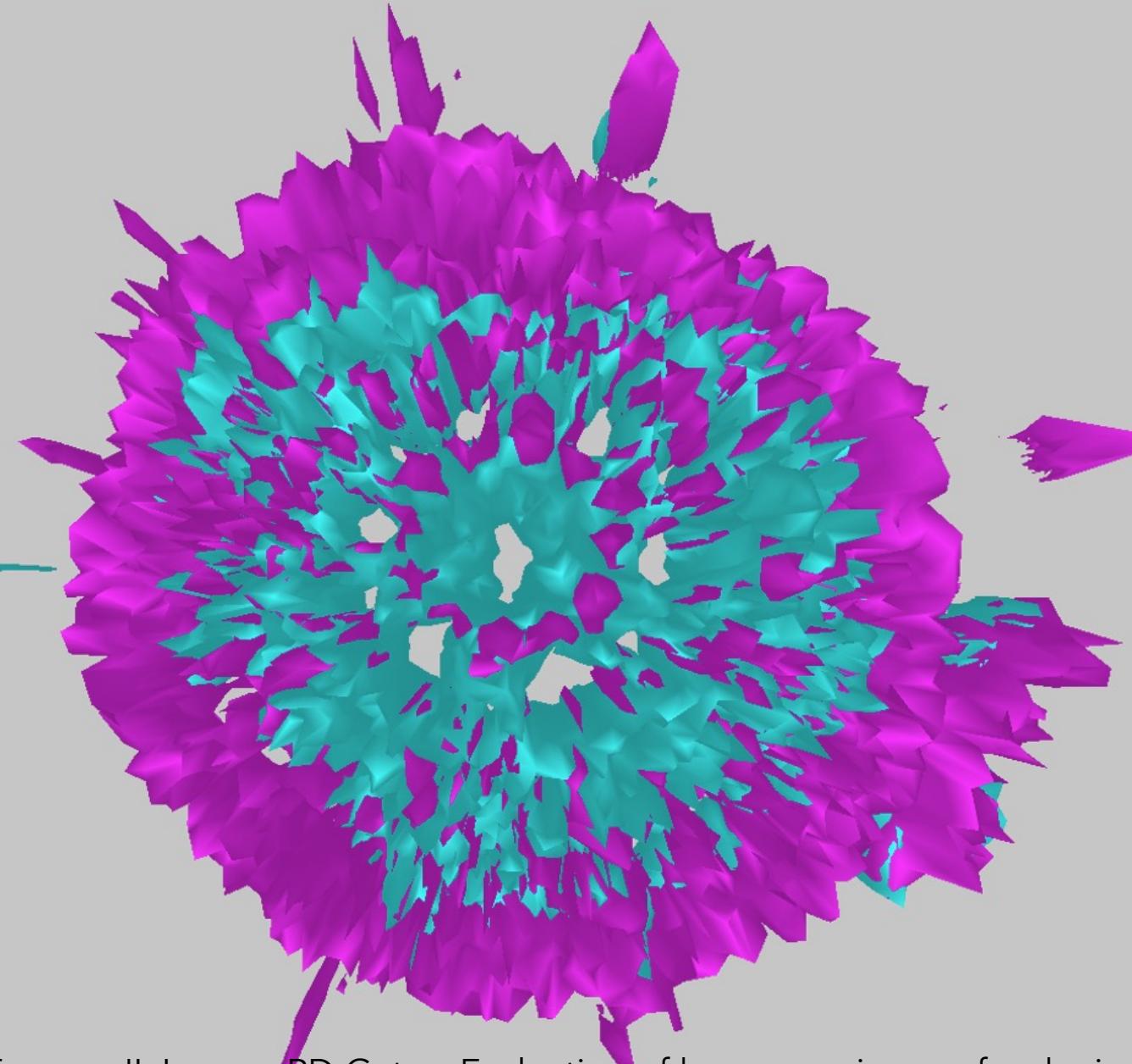
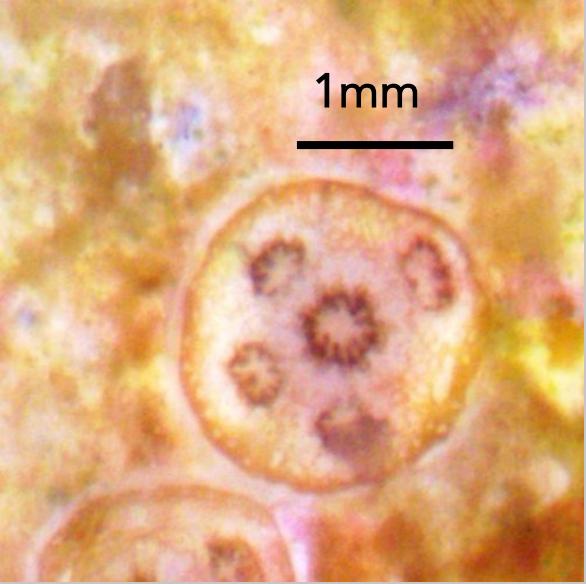
Juveniles

Thermal exposure
Nutrition
Tissue fusion

Parents

OA exposure
Thermal exposure
Nutrition





Shayle Matsuda

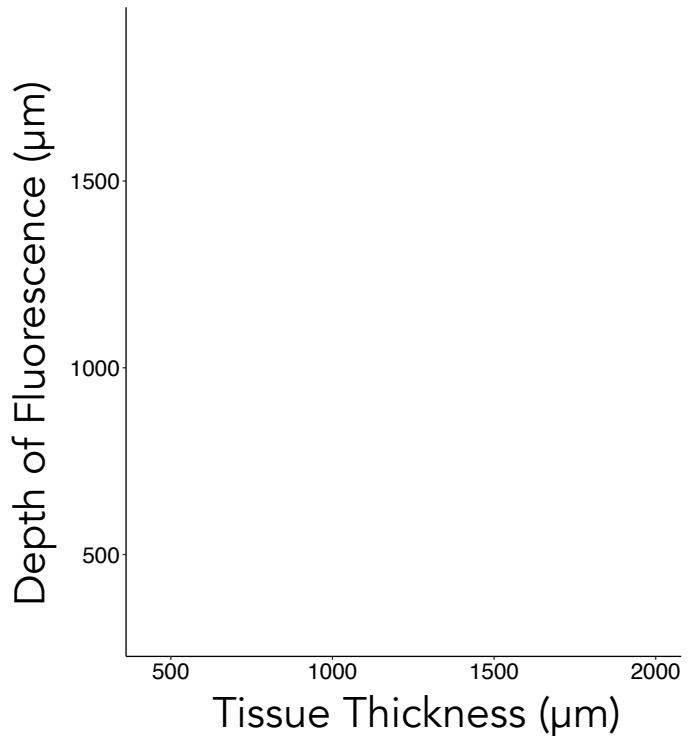


Amy Eggers

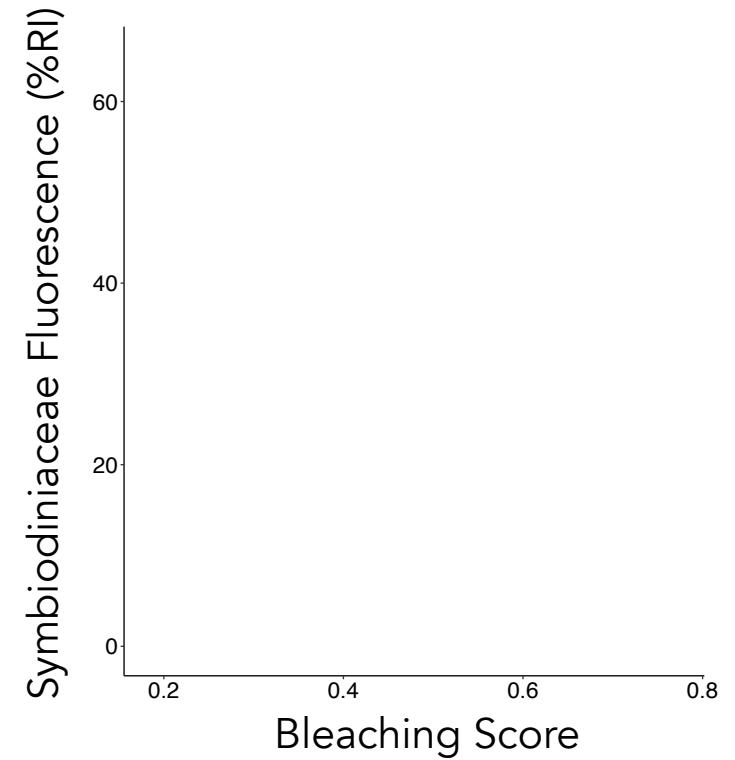
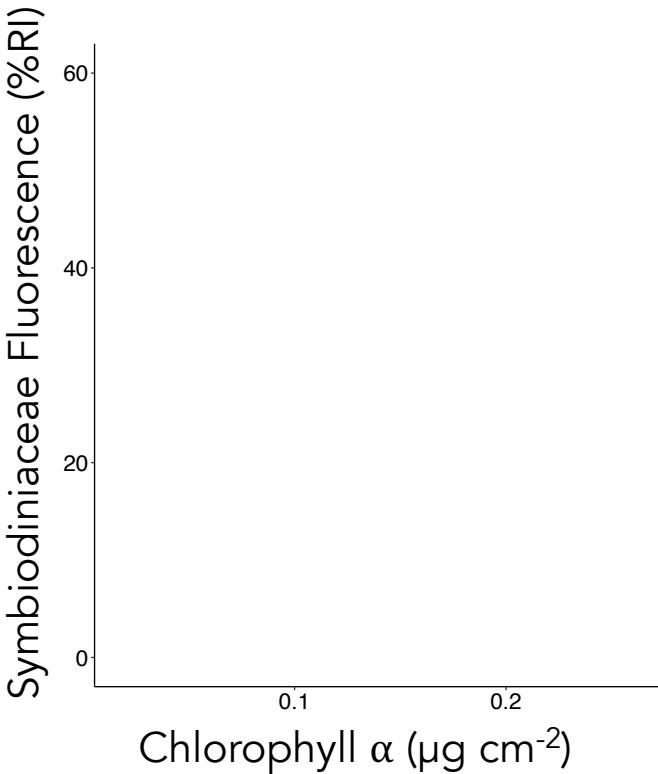
Huffmyer AS, SB Matsuda, AE Eggers, JL Lemus, RD Gates. Evaluation of laser-scanning confocal microscopy for measurement of reef-building coral tissue thickness and Symbiodiniaceae fluorescence. *In review. Journal of Experimental Biology.*

LSCM is a non-destructive tool to measure physiology

Tissue Thickness



Symbiodiniaceae Fluorescence



Ambient

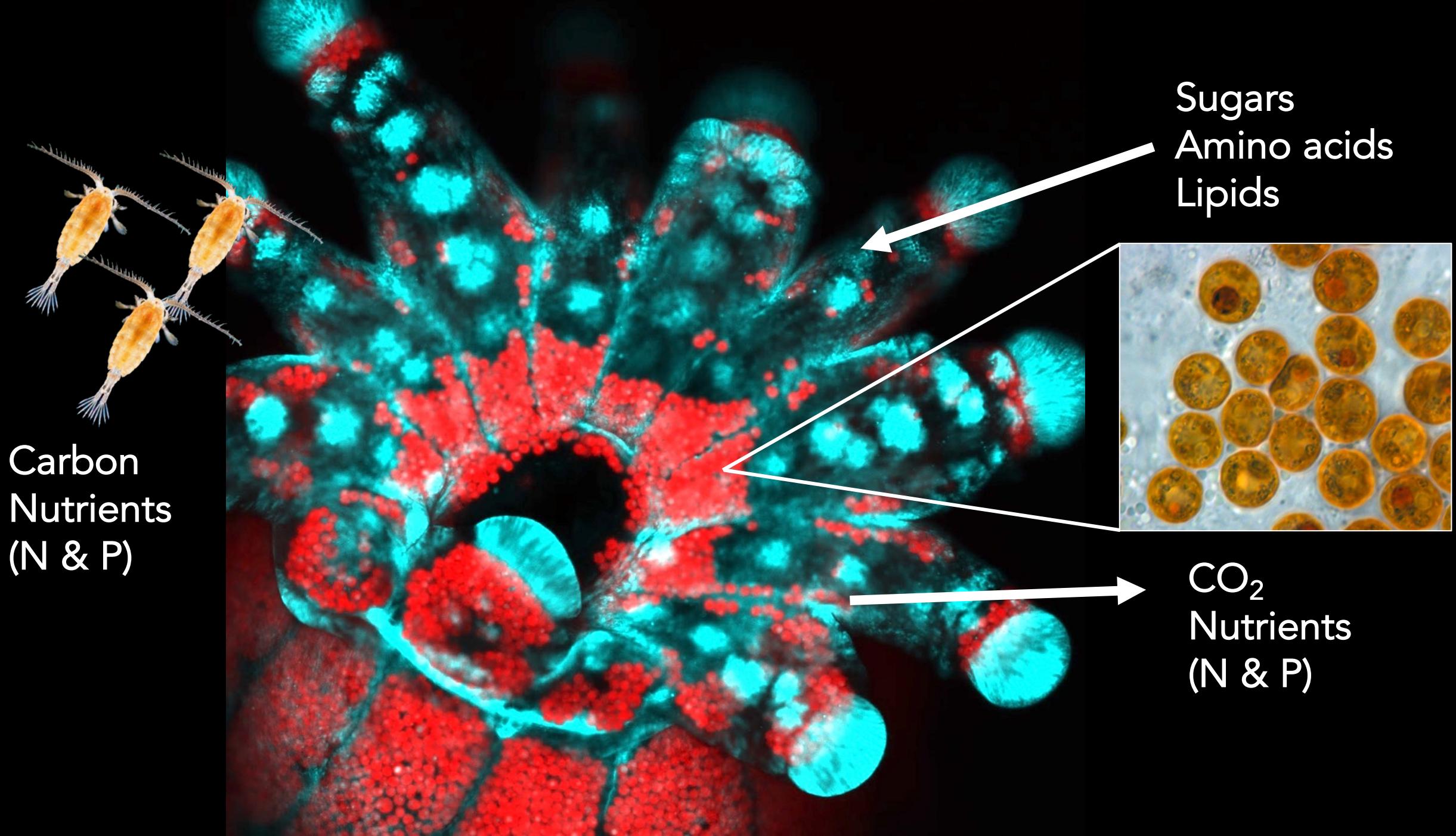
P. acuta

M. capitata

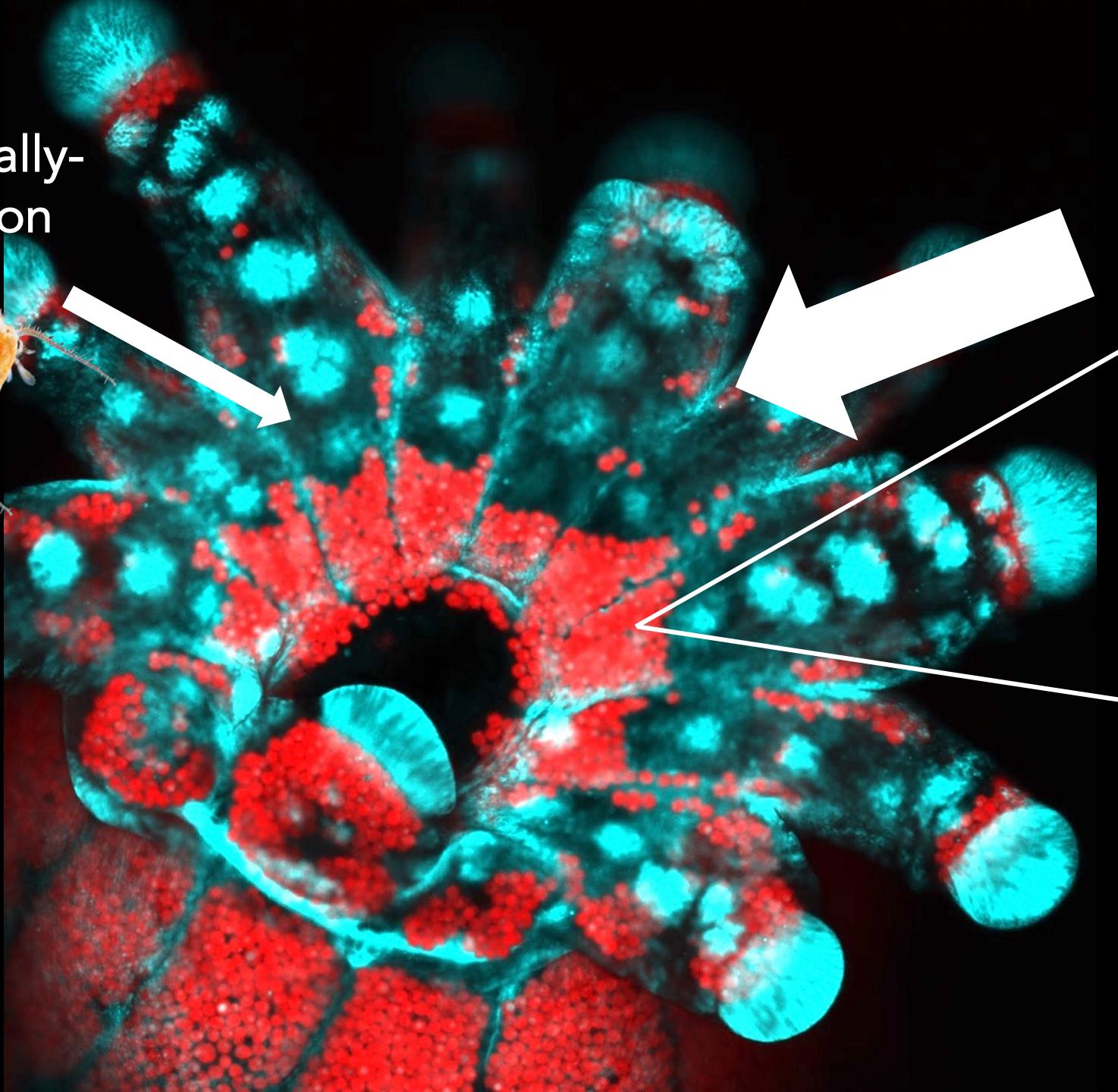
High

P. acuta

M. capitata



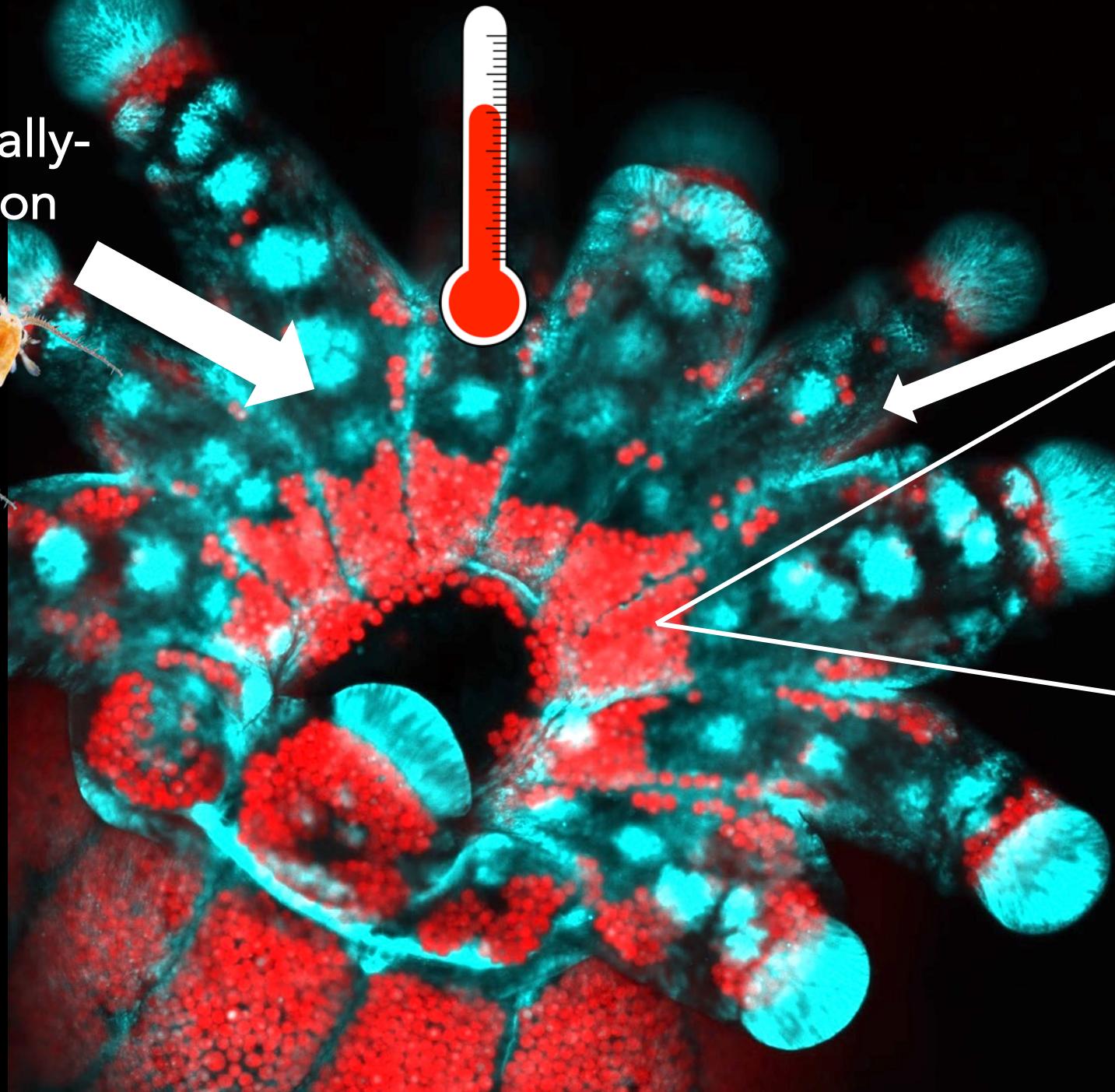
Heterotrophically-derived nutrition



Autotrophically-derived nutrition



Heterotrophically-derived nutrition



Autotrophically-derived nutrition

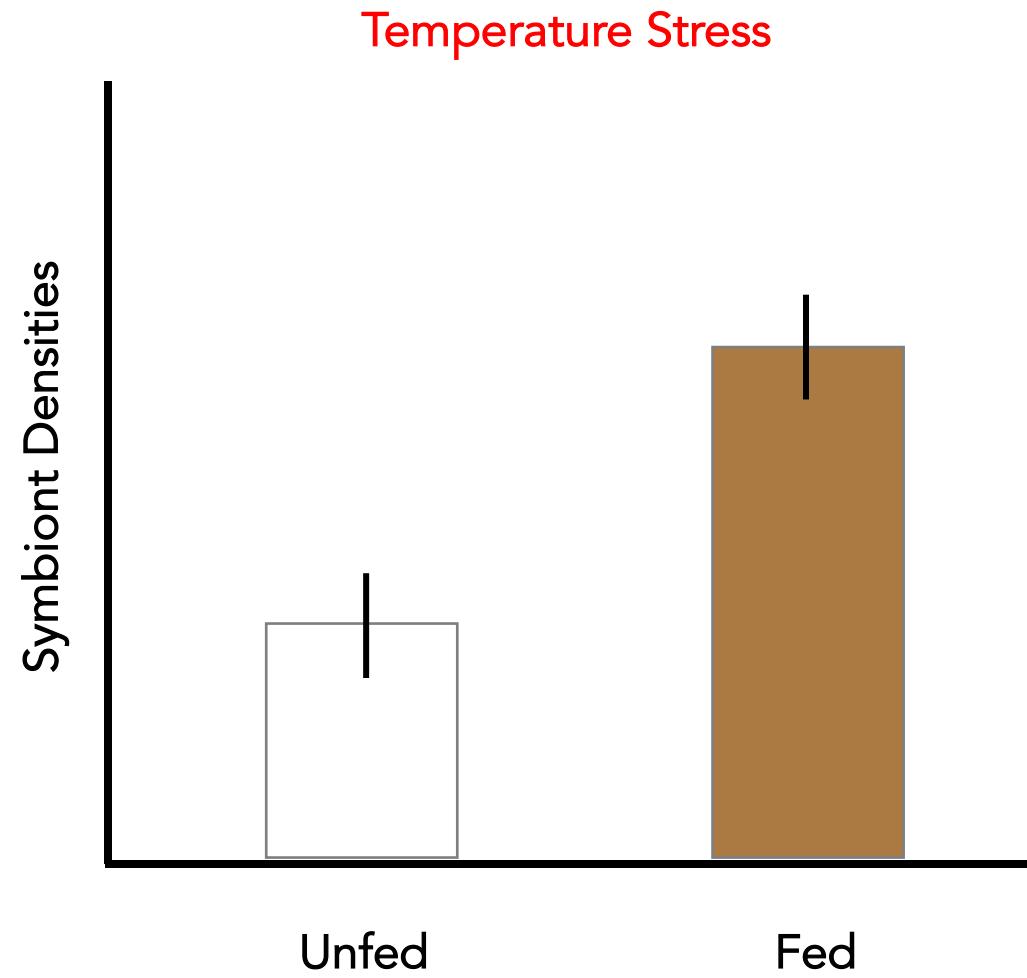


- + ROS
- Densities
- Chlorophyll

Feeding is an important component of coral nutrition

- Calcification
- Energetic storage (e.g. lipids)
- Symbiodiniaceae densities
- Symbiodiniaceae chlorophyll
- Photosynthesis

Houlbreque & Ferrier-Pages 2009, Baumann et al.
2014, Houlbreque et al. 2003

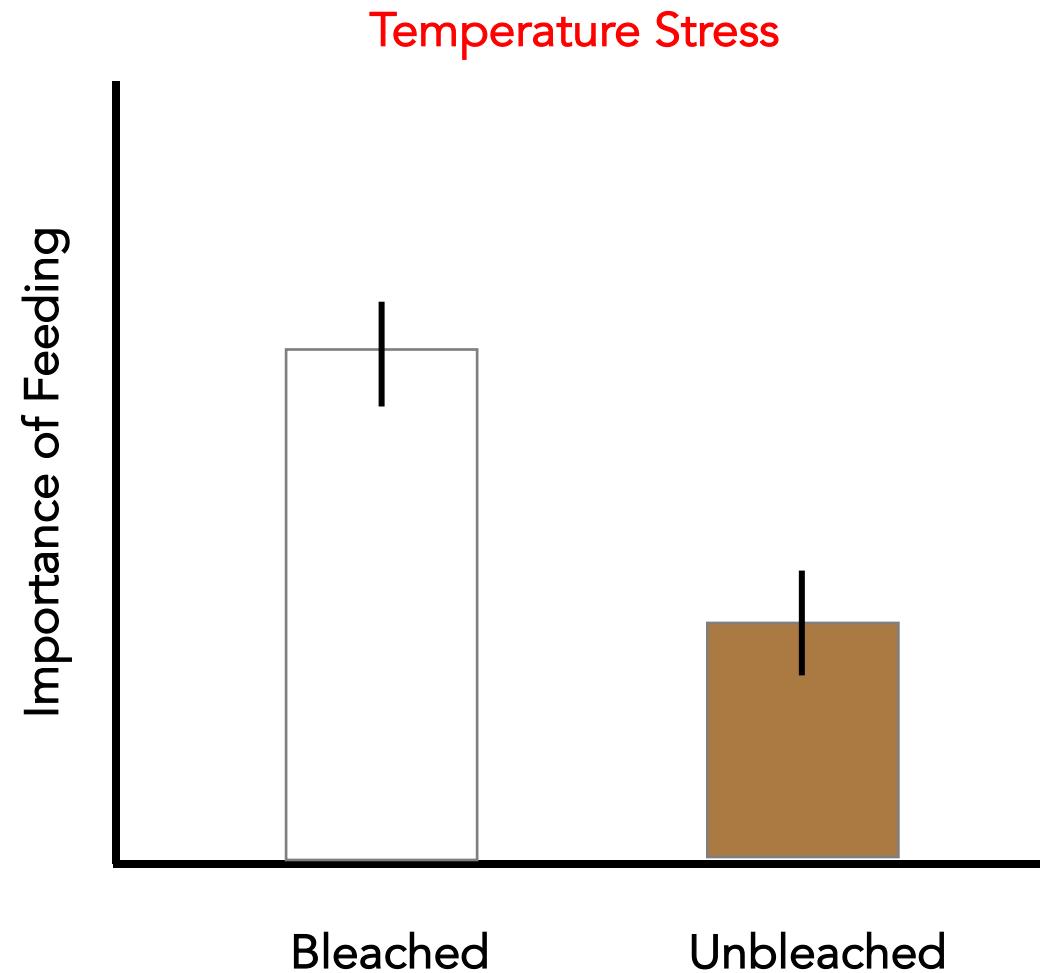


Adapted from Aichelman et al. 2013

Feeding is an important component of coral nutrition

- Calcification
- Energetic storage (e.g. lipids)
- Symbiodiniaceae densities
- Symbiodiniaceae chlorophyll
- Photosynthesis

Houlbreque & Ferrier-Pages 2009, Baumann et al.
2014, Houlbreque et al. 2003



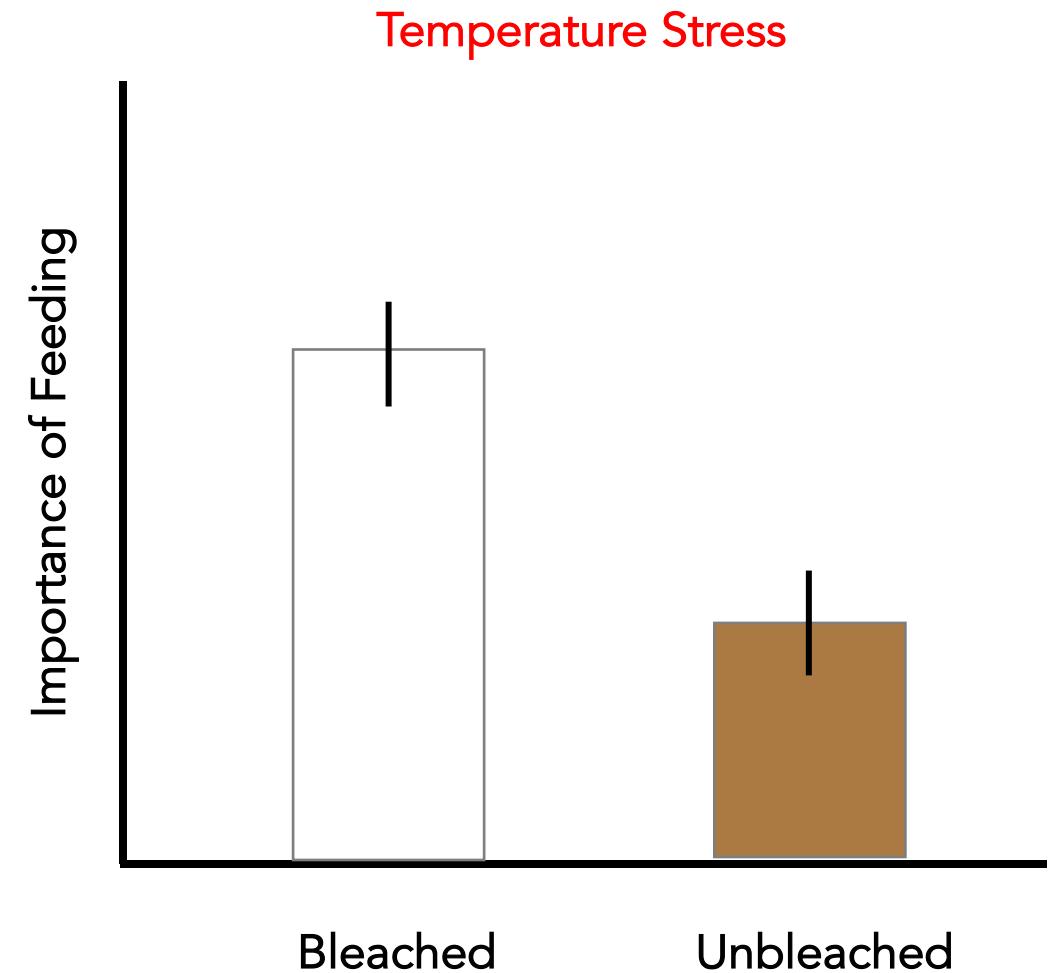
Adapted from Grottoli et al. 2006, Palardy et al. 2008

Feeding is an important component of coral nutrition

Variability in responses:

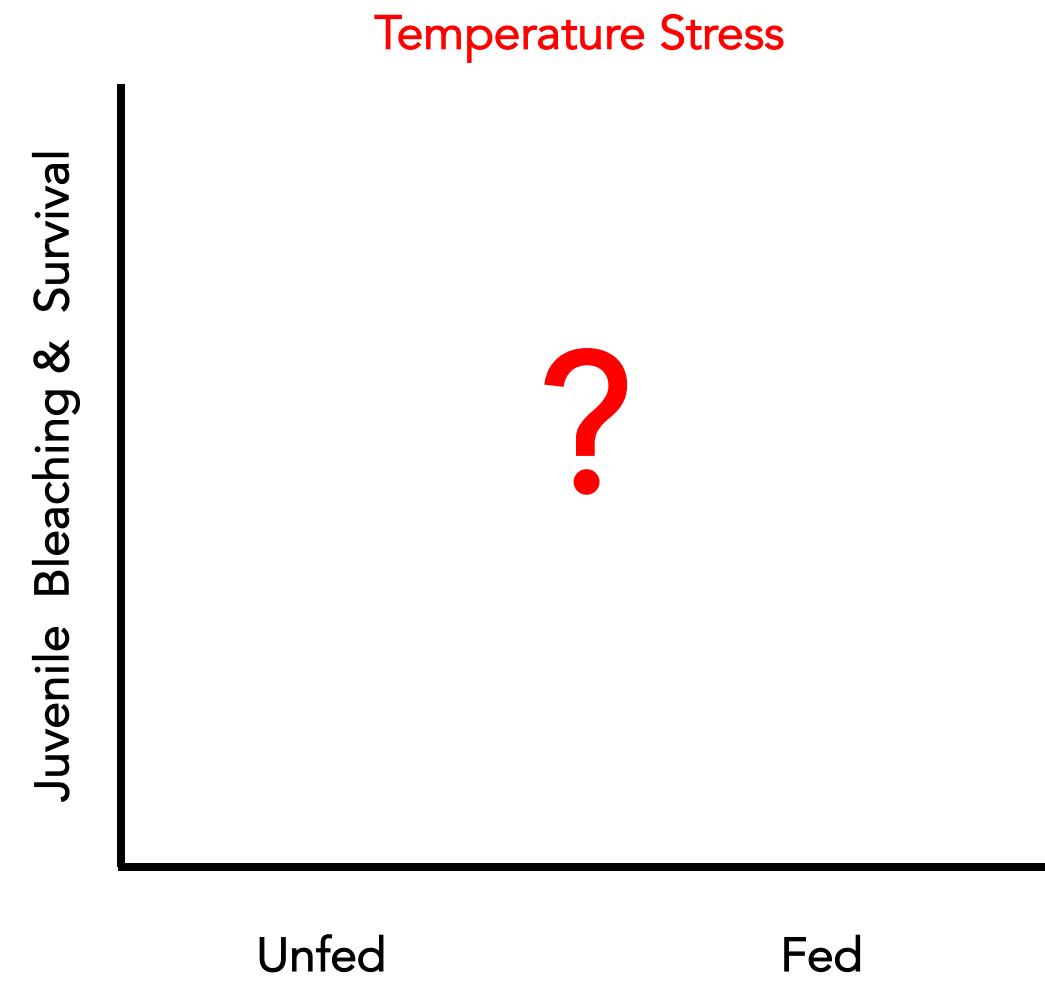
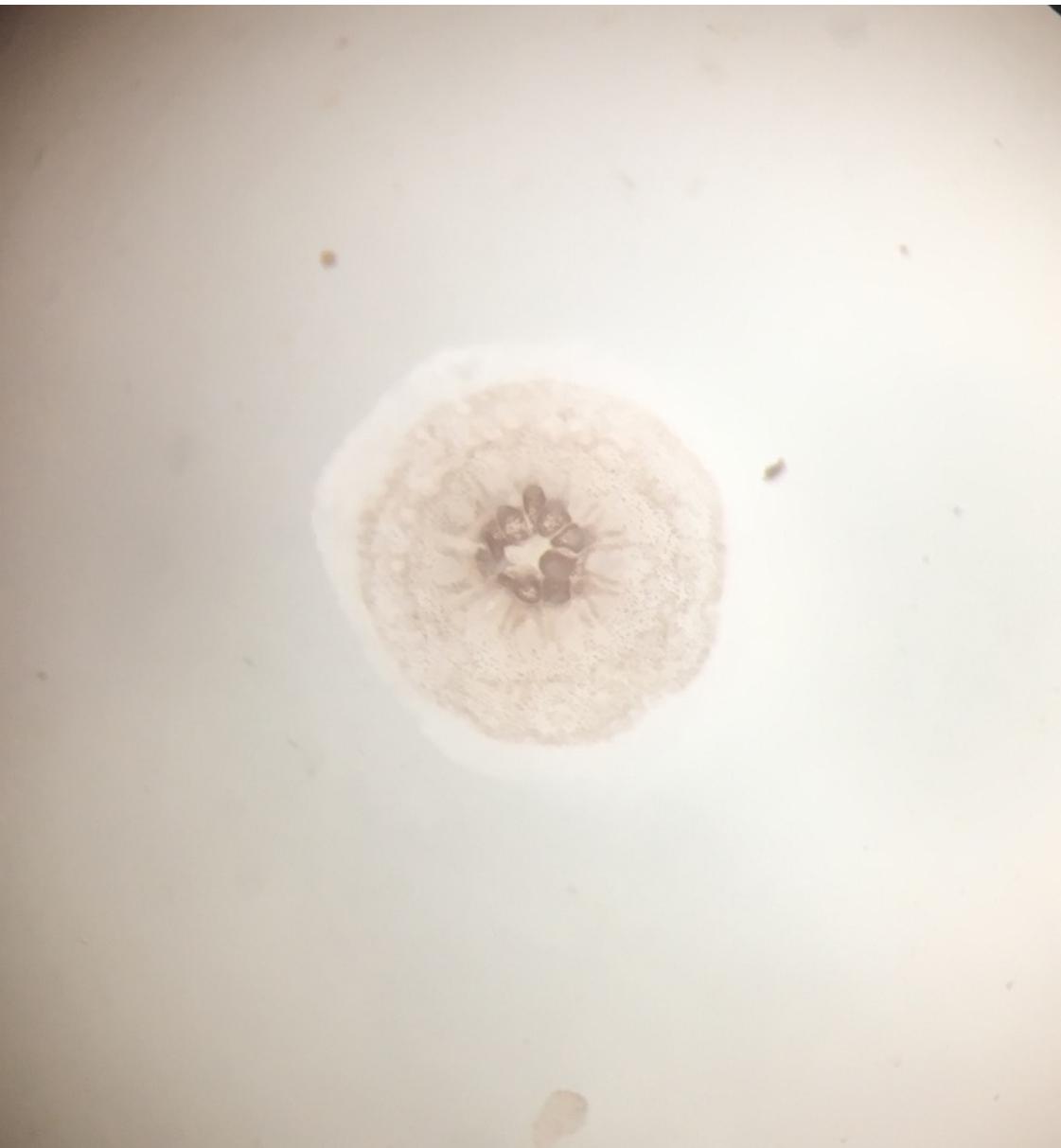
- Species
- Season
- Habitat

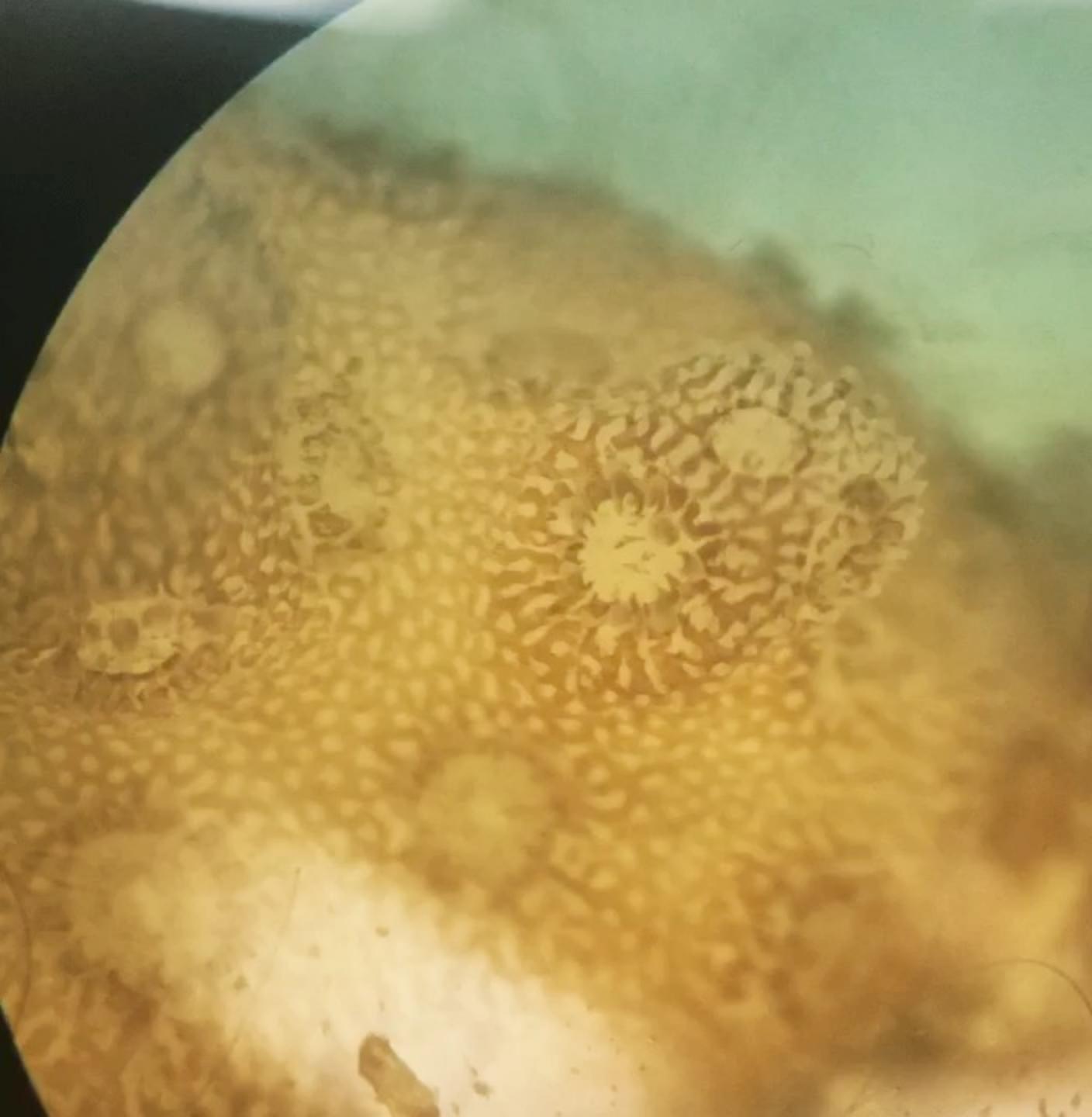
Fitt et al. 2000, Hoogenboom et al. 2010,
Wall et al. 2019,



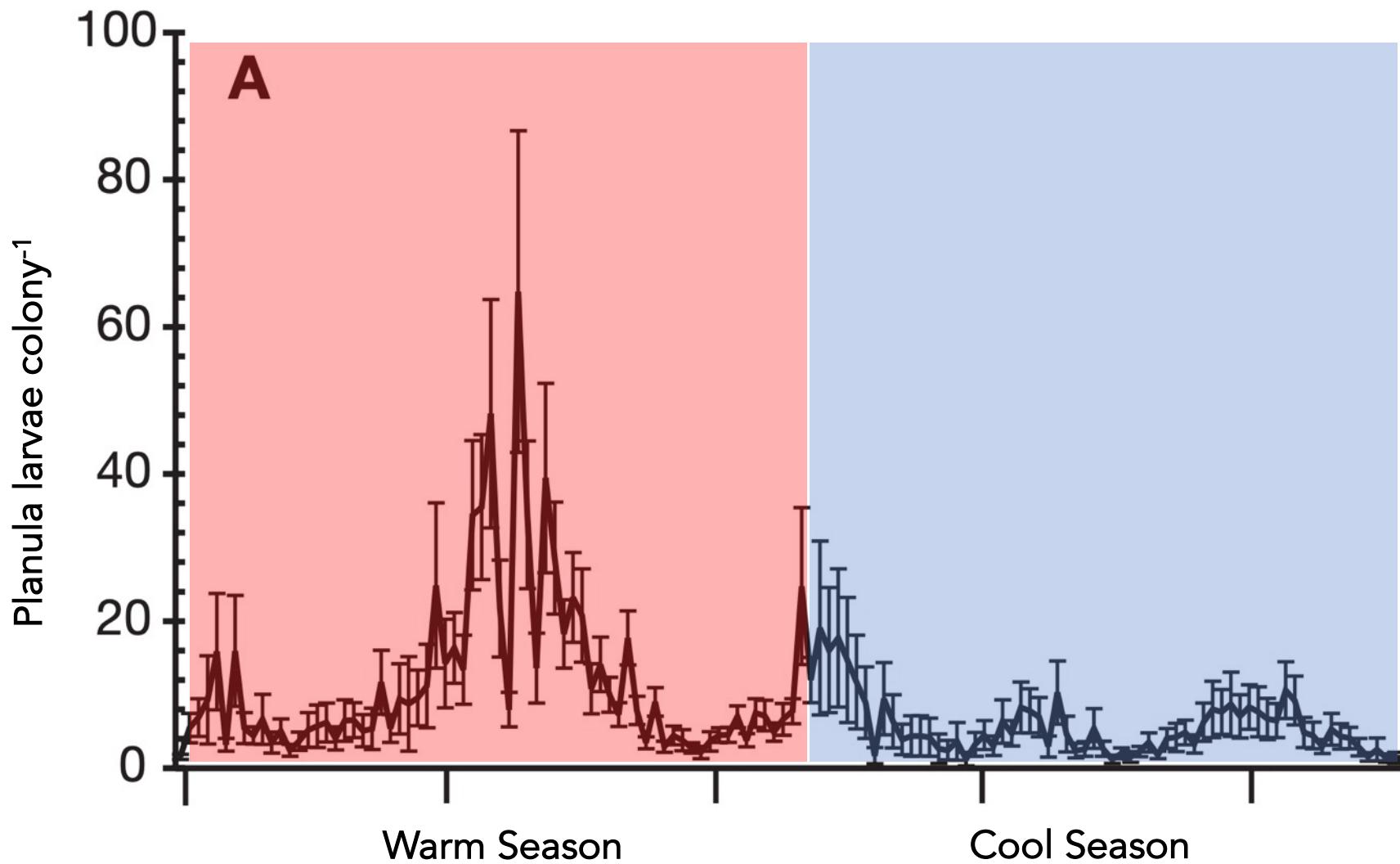
Adapted from Grottoli et al. 2006, Palardy et al. 2008

Feeding is an important component of coral nutrition

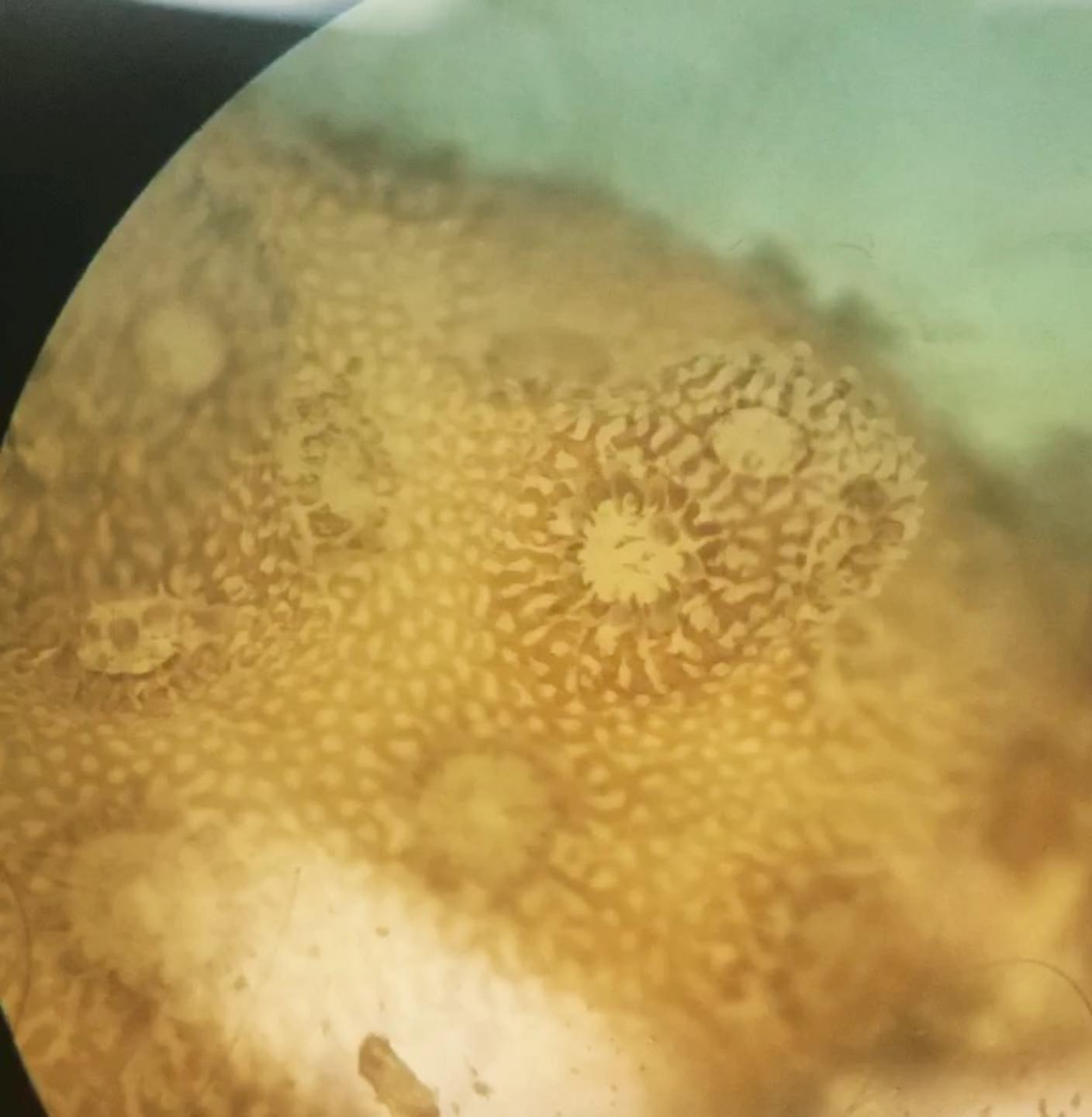




Does heterotrophy
increase juvenile *P.
acuta* survival in
high temperature?

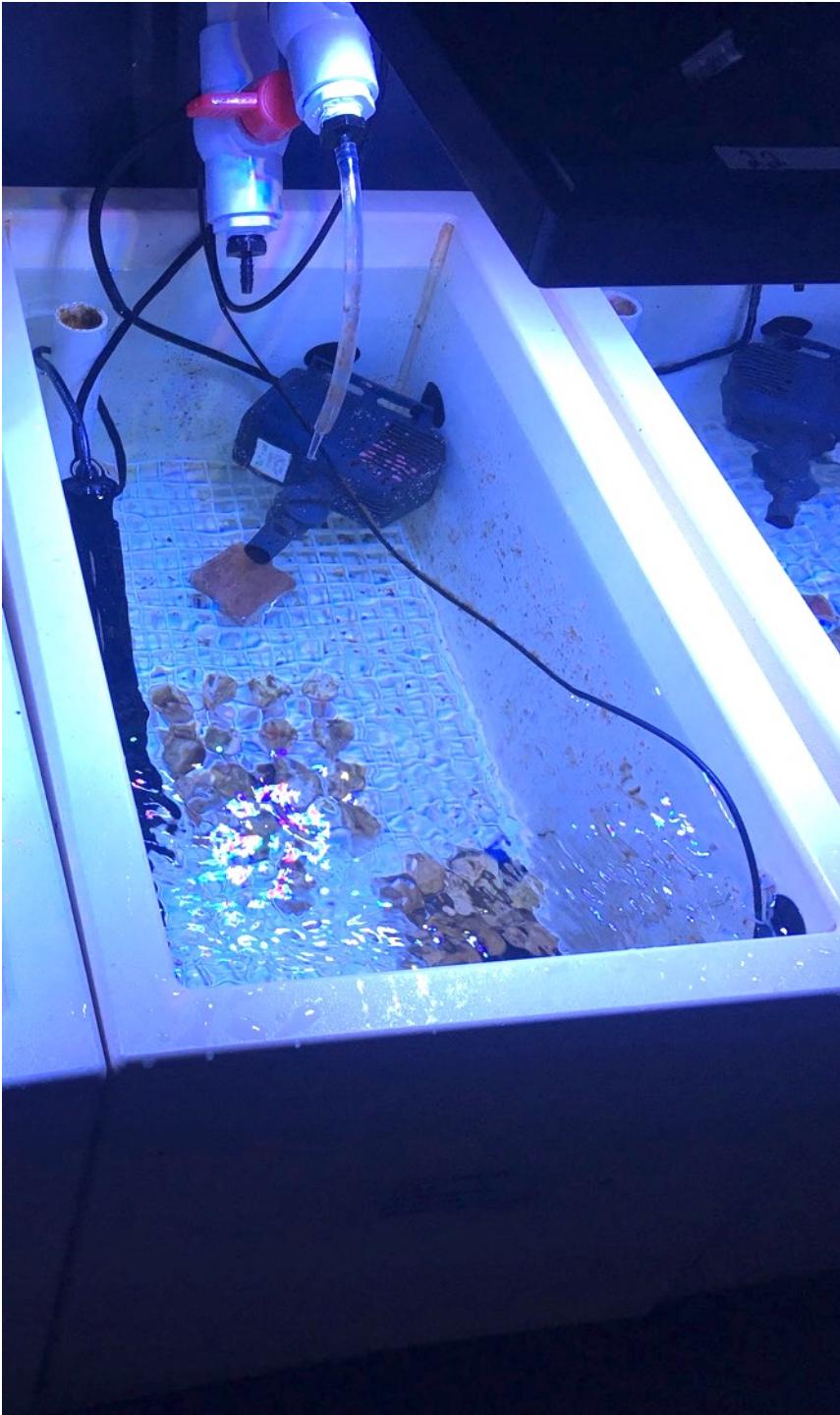


Adapted from Zakai et al. 2006

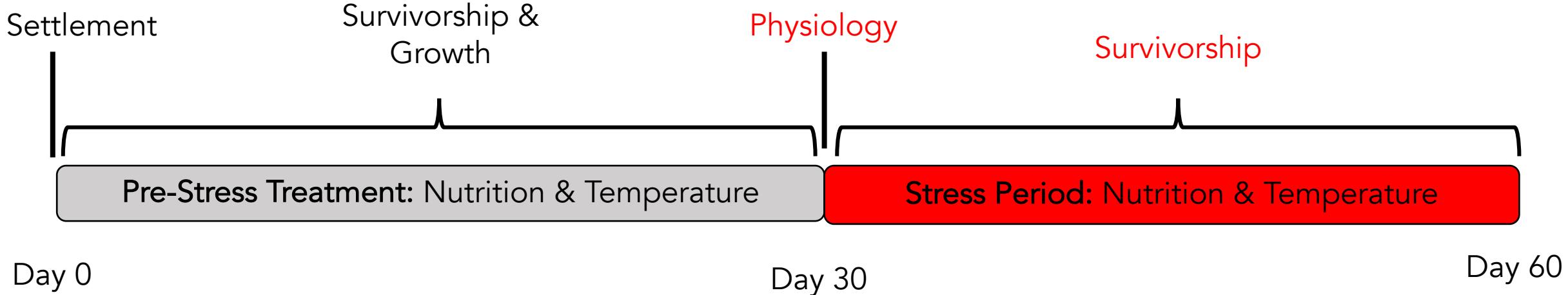
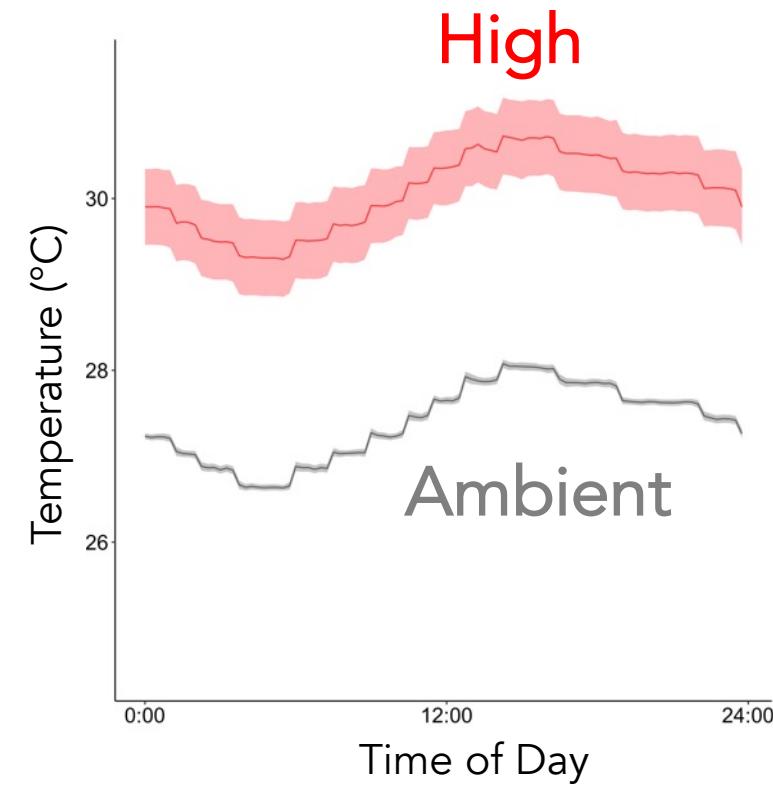
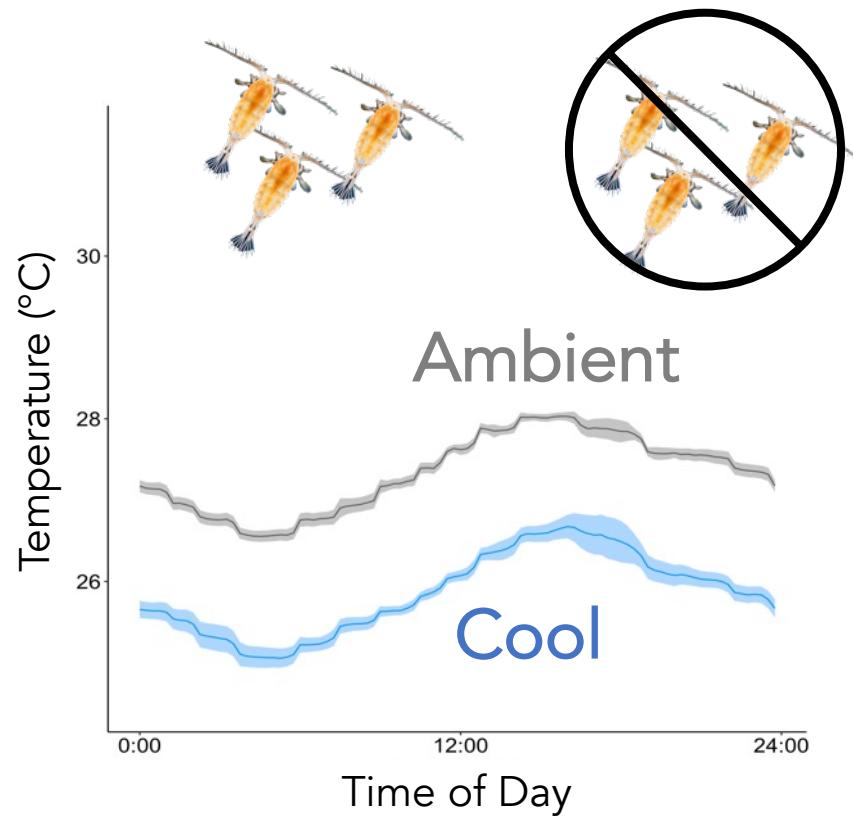


Does heterotrophy
increase juvenile
survival in high
temperature?

Do these effects
vary with exposure
to different
seasonal
temperatures?



S. Matsuda





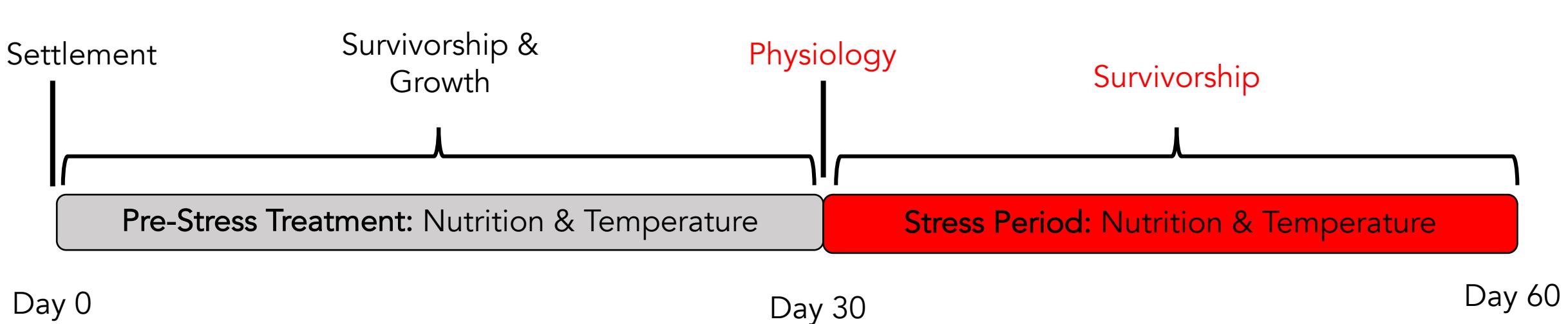
Colton Johnson

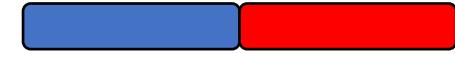
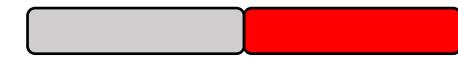
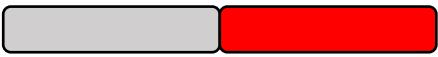
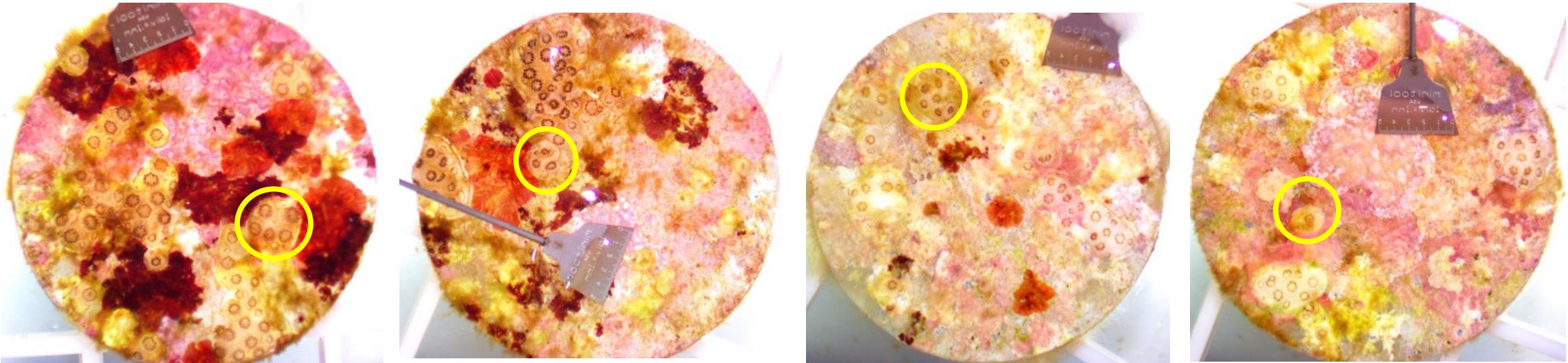


Ashleigh Epps



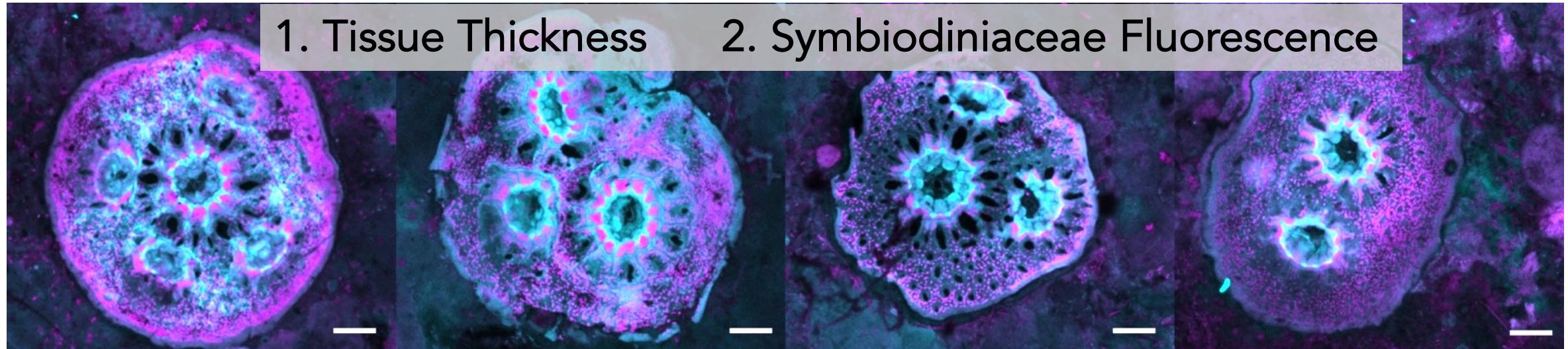
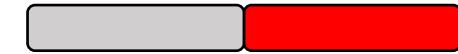
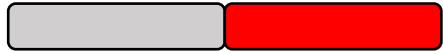
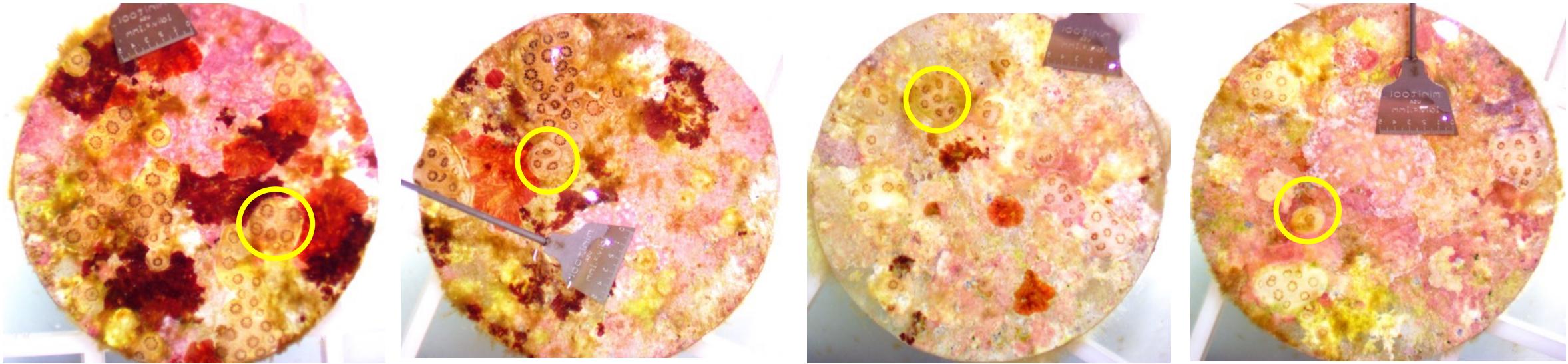
Jenna Dilworth





Growth (Linear Extension)

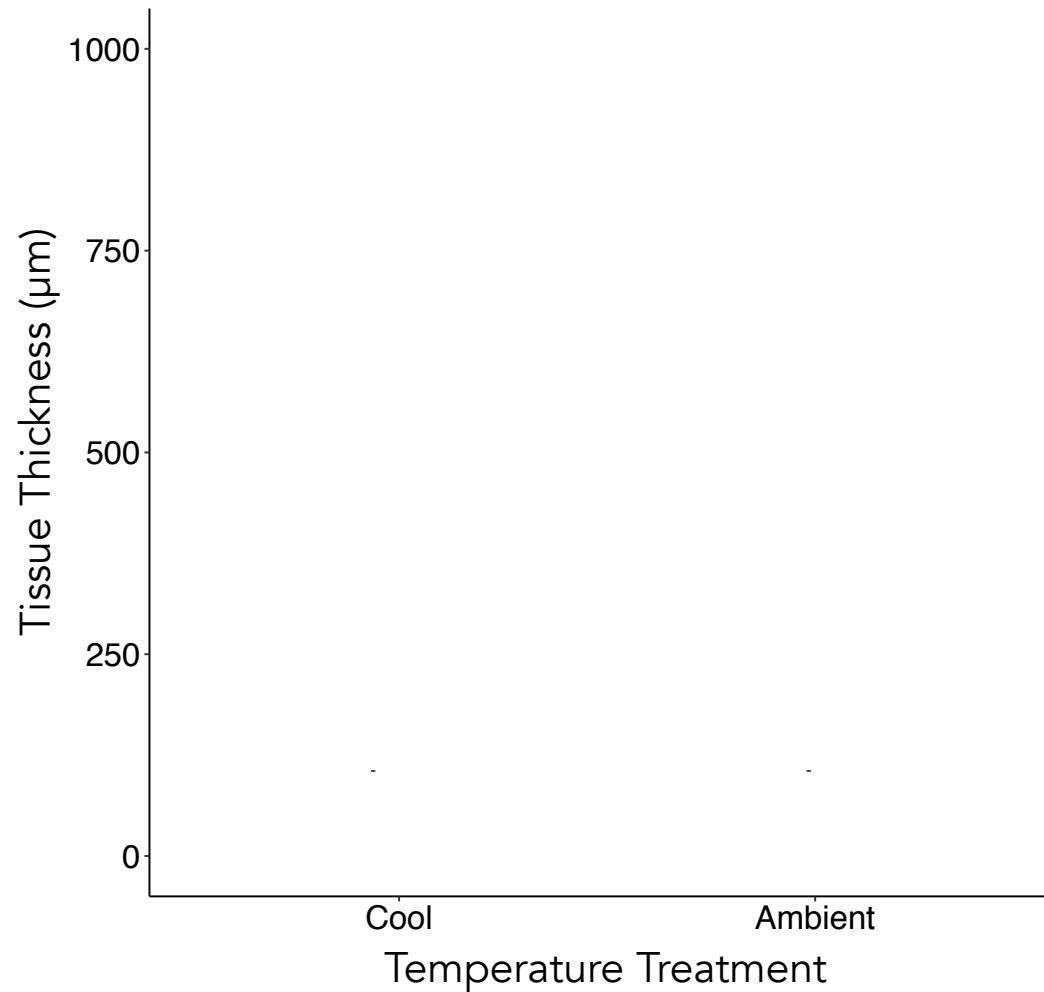




1. Tissue Thickness

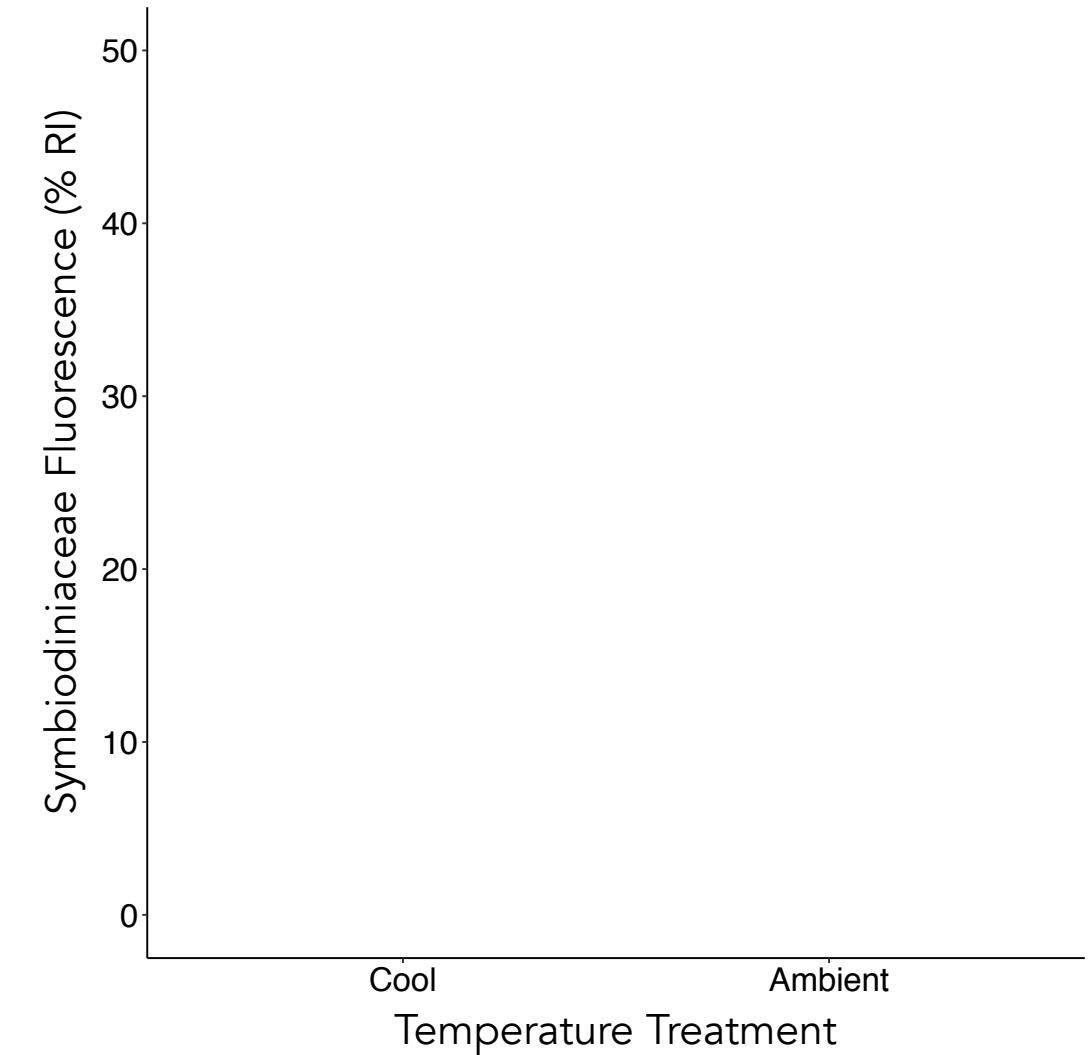
2. Symbiodiniaceae Fluorescence

Tissue Thickness



Heterotrophy

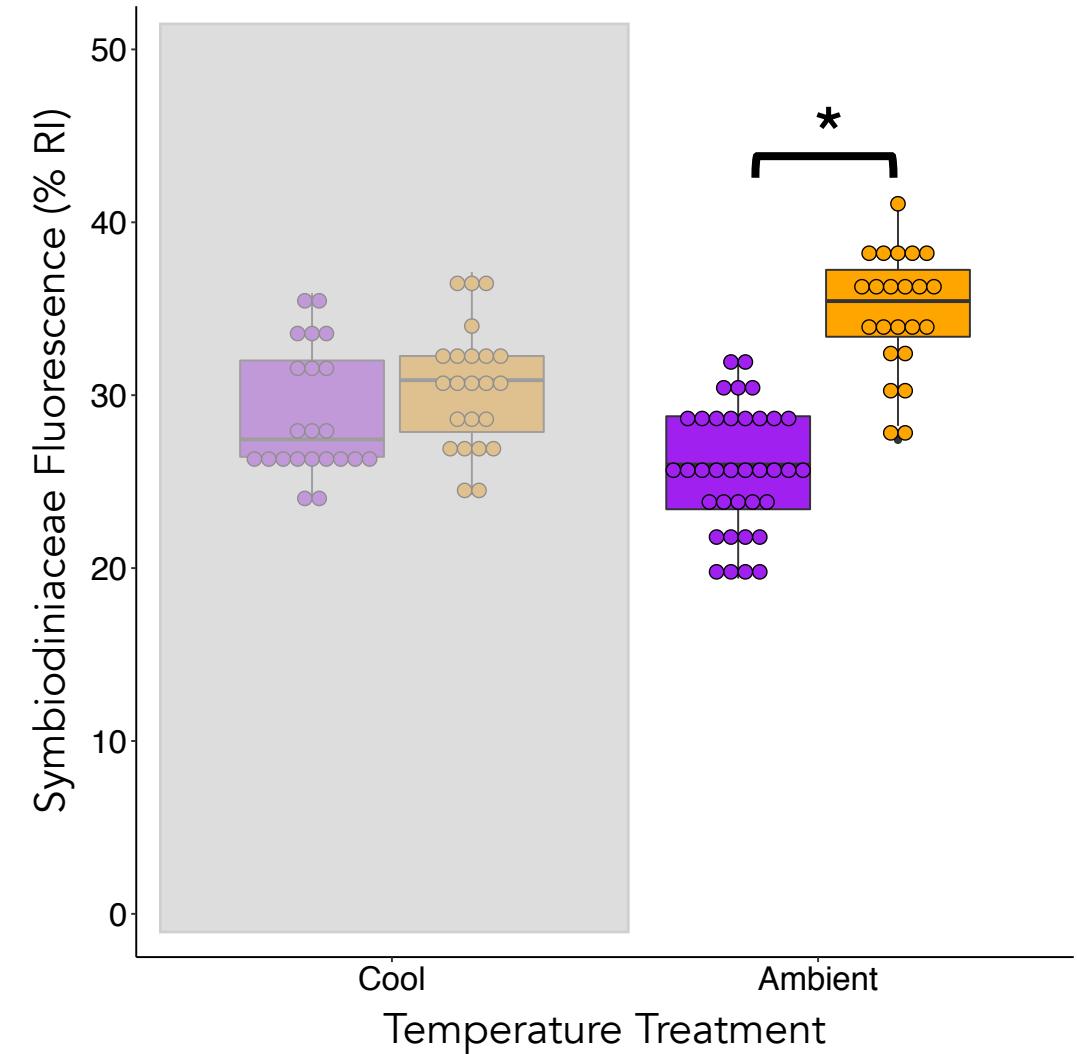
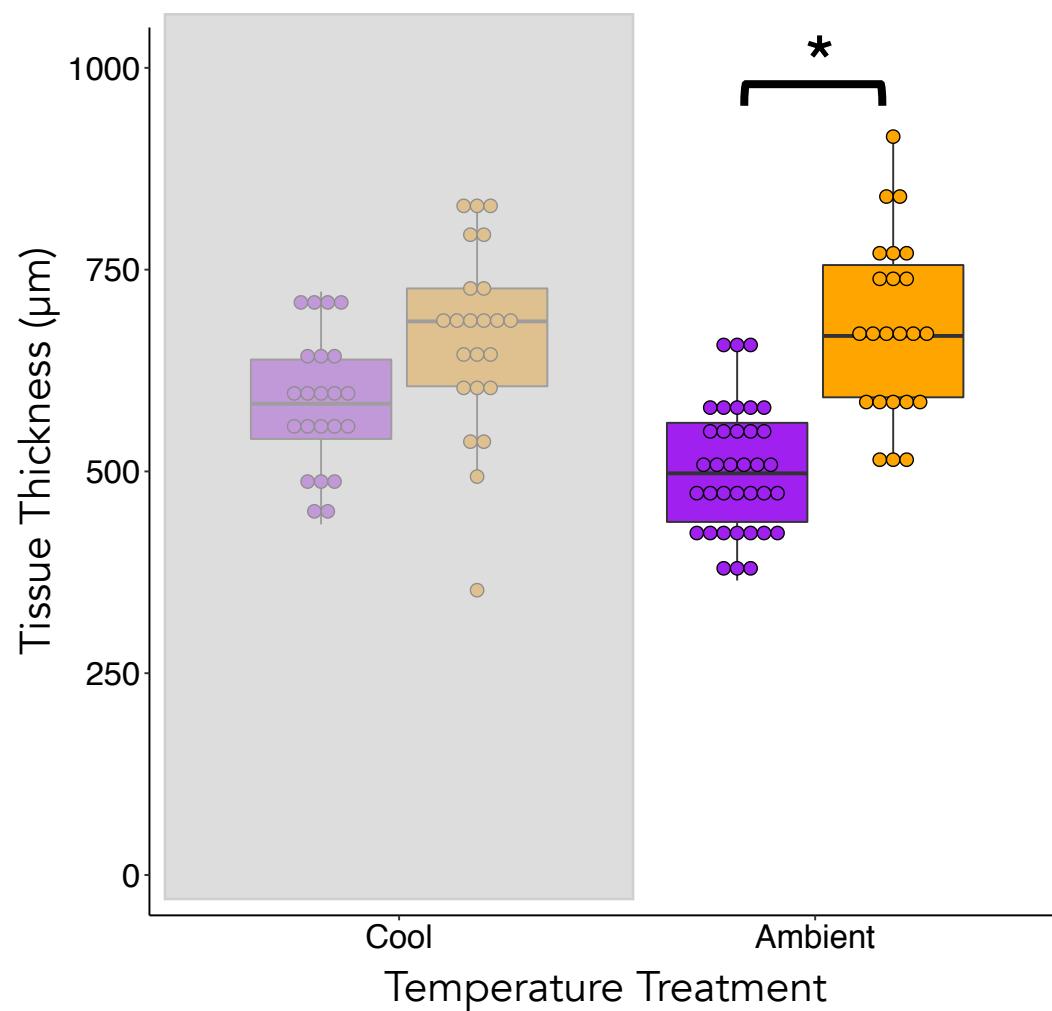
Symbiodiniaceae Fluorescence



No Heterotrophy

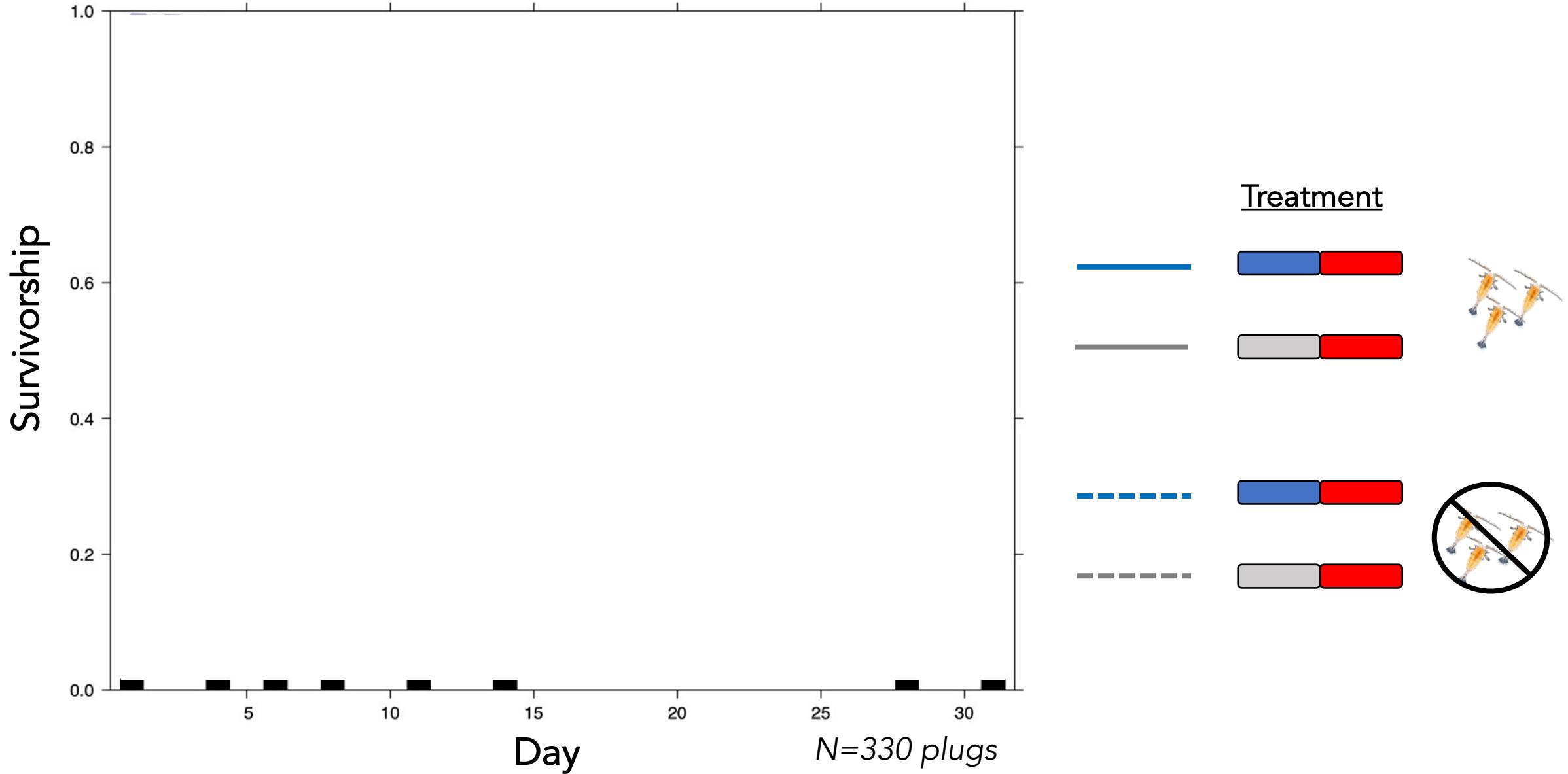
$\text{Imer}(\text{physiological characteristic} \sim \text{temperature} * \text{nutrition} + \text{surface area} + (1/\text{cohort}) + (1/\text{tank/plug}))$

Corals require heterotrophy to maintain tissue growth and symbiosis in ambient temp.



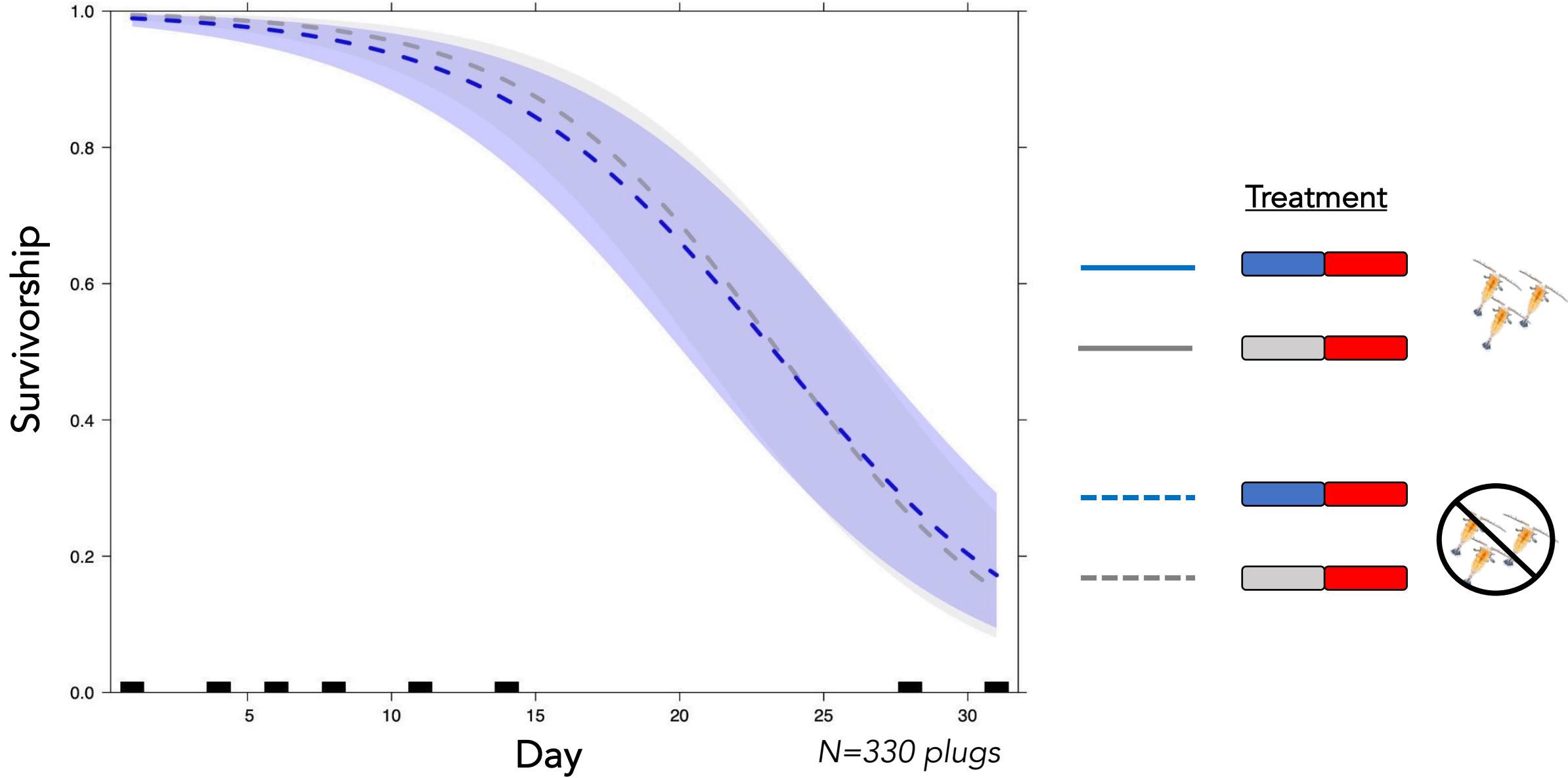
Elevated respiratory demand at ambient temperature (27.3°C) vs. cool temperature (25.6°C)

Survival in High Temperature



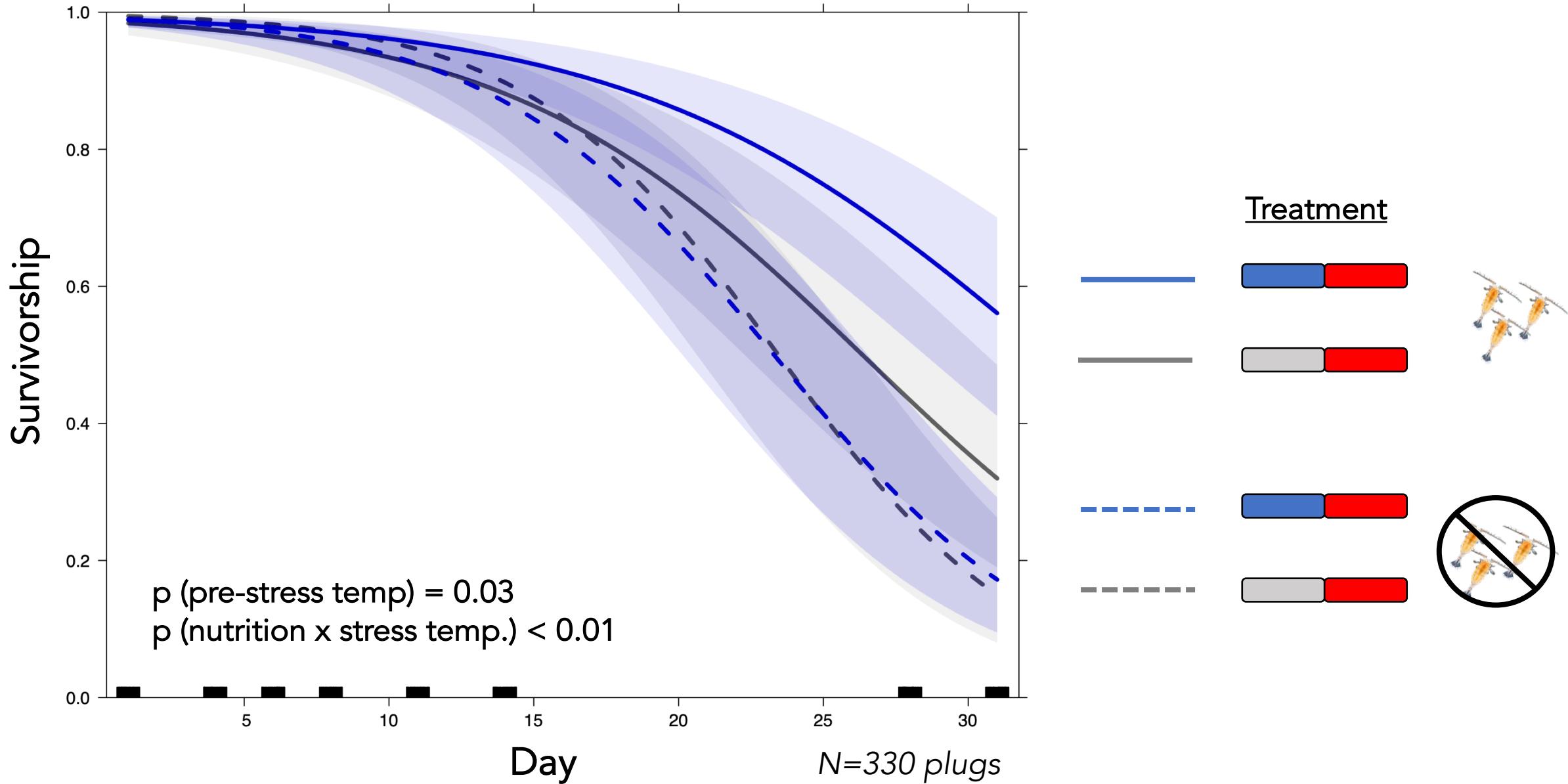
`lmer(survival ~ temperature * nutrition * stress test temperature * day + (1|tank/plug) + (1|cohort), family=binomial)`

Survival in High Temperature



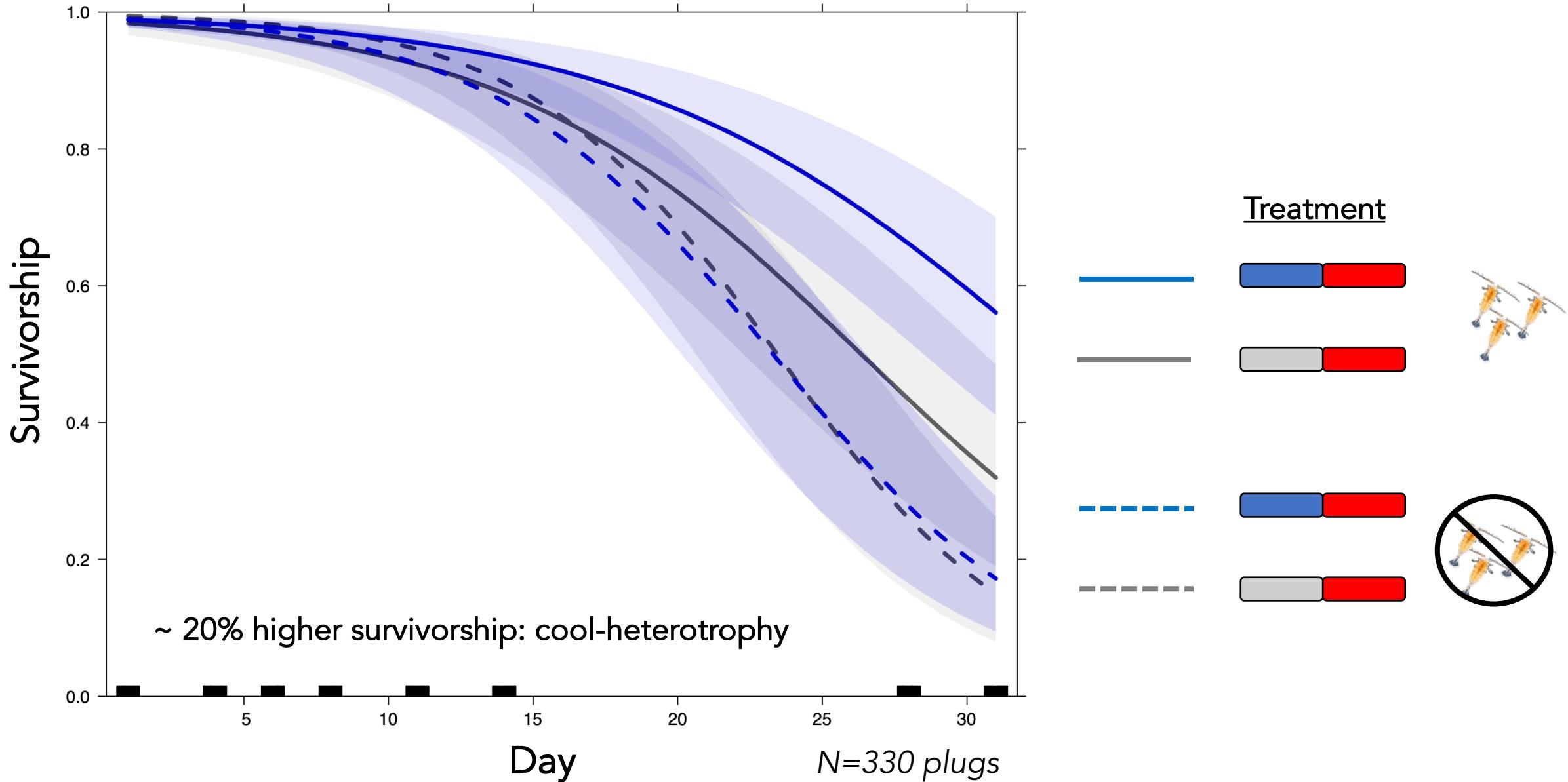
*lmer(survival ~ temperature * nutrition * stress test temperature * day + (1|tank/plug) + (1|cohort), family=binomial)*

Survival in High Temperature

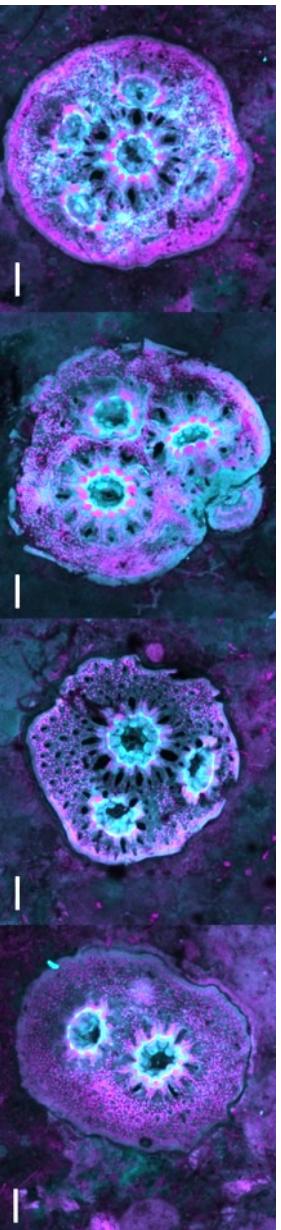


*lmer(survival ~ temperature * nutrition * stress test temperature * day + (1|tank/plug) + (1|cohort), family=binomial)*

Heterotrophy promotes juvenile survival in high temperature.



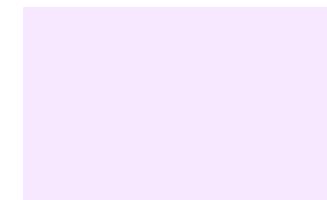
Temperature – Nutritional Treatment



Tissue Thickness



Symbiodiniaceae Fluorescence



High Temperature Survival



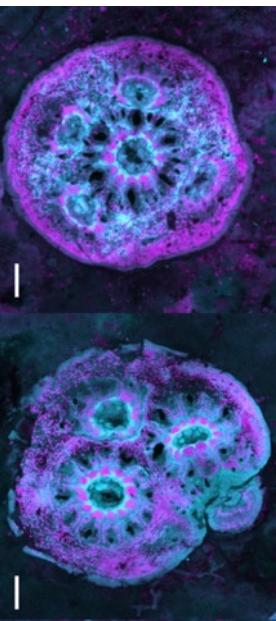
More



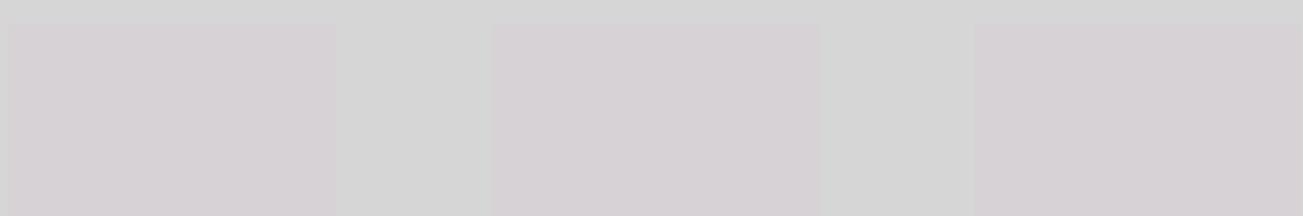
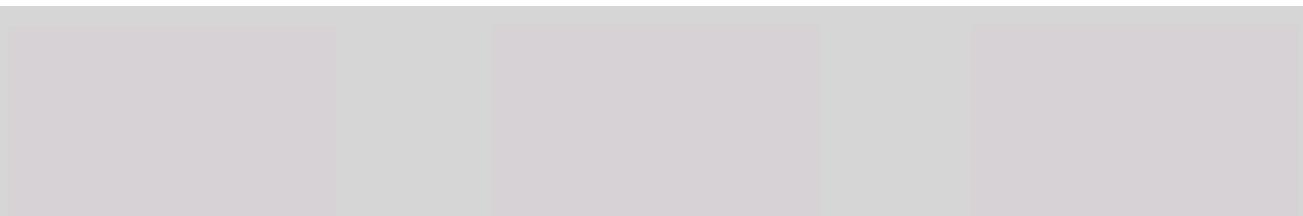
Less



Temperature – Nutritional Treatment



Tissue Thickness



Symbiodiniaceae Fluorescence



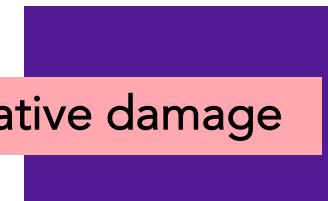
Higher risk of oxidative damage



Lower risk of oxidative damage

Cunning & Baker 2013

High Temperature Survival



More



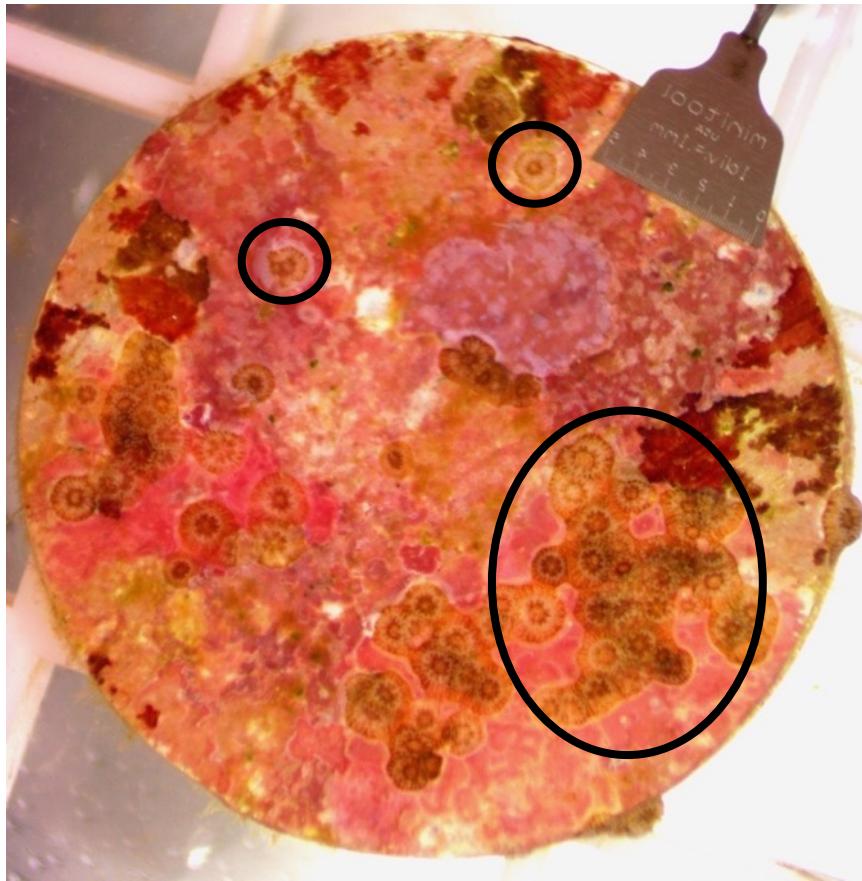
Less



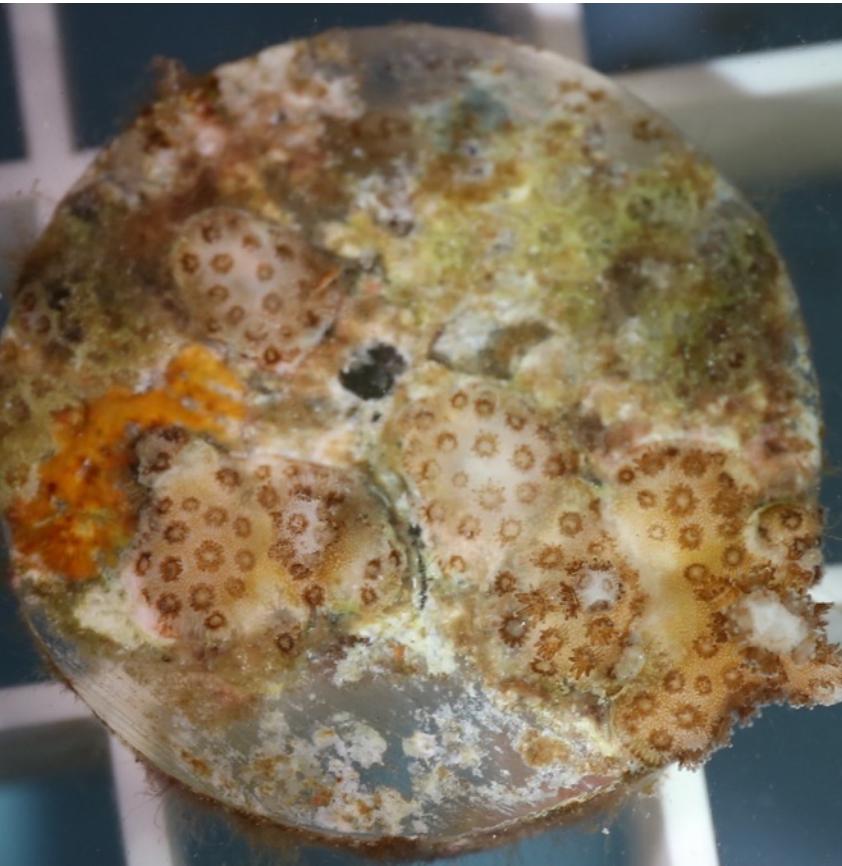
Heterotrophy is necessary for juvenile *P. acuta* tissue growth and stress tolerance.



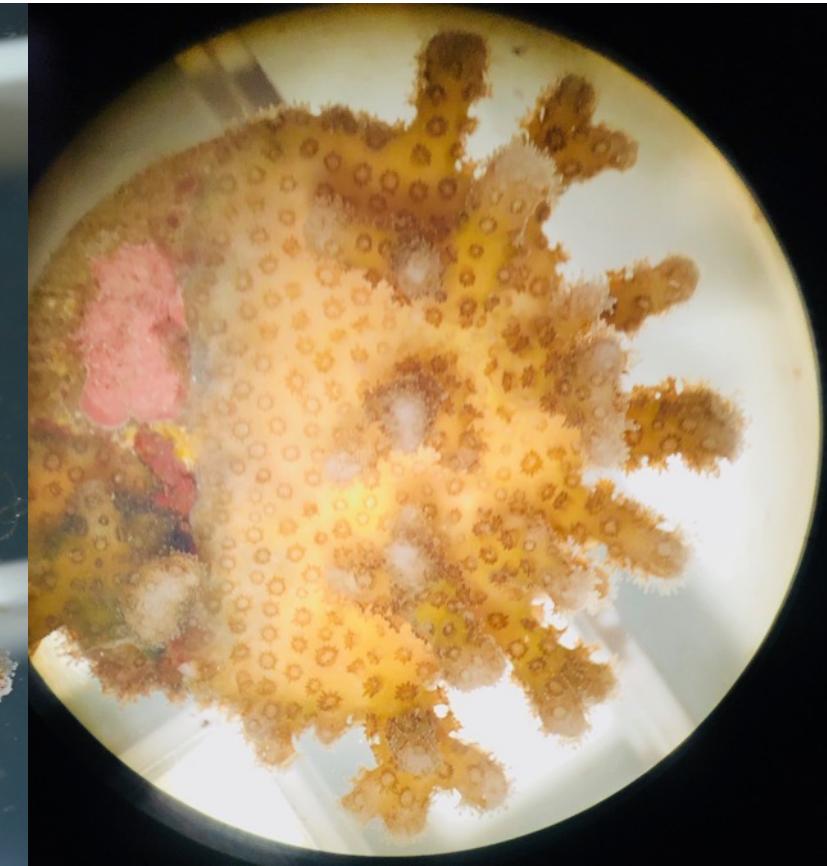
Huffmyer AS, CJ Johnson, AM Epps, JD Lemus, RD Gates. Heterotrophic feeding enhances tissue growth and thermal tolerance of *Pocillopora acuta* juvenile corals. *In prep.*



Settlement



6 months



12 months

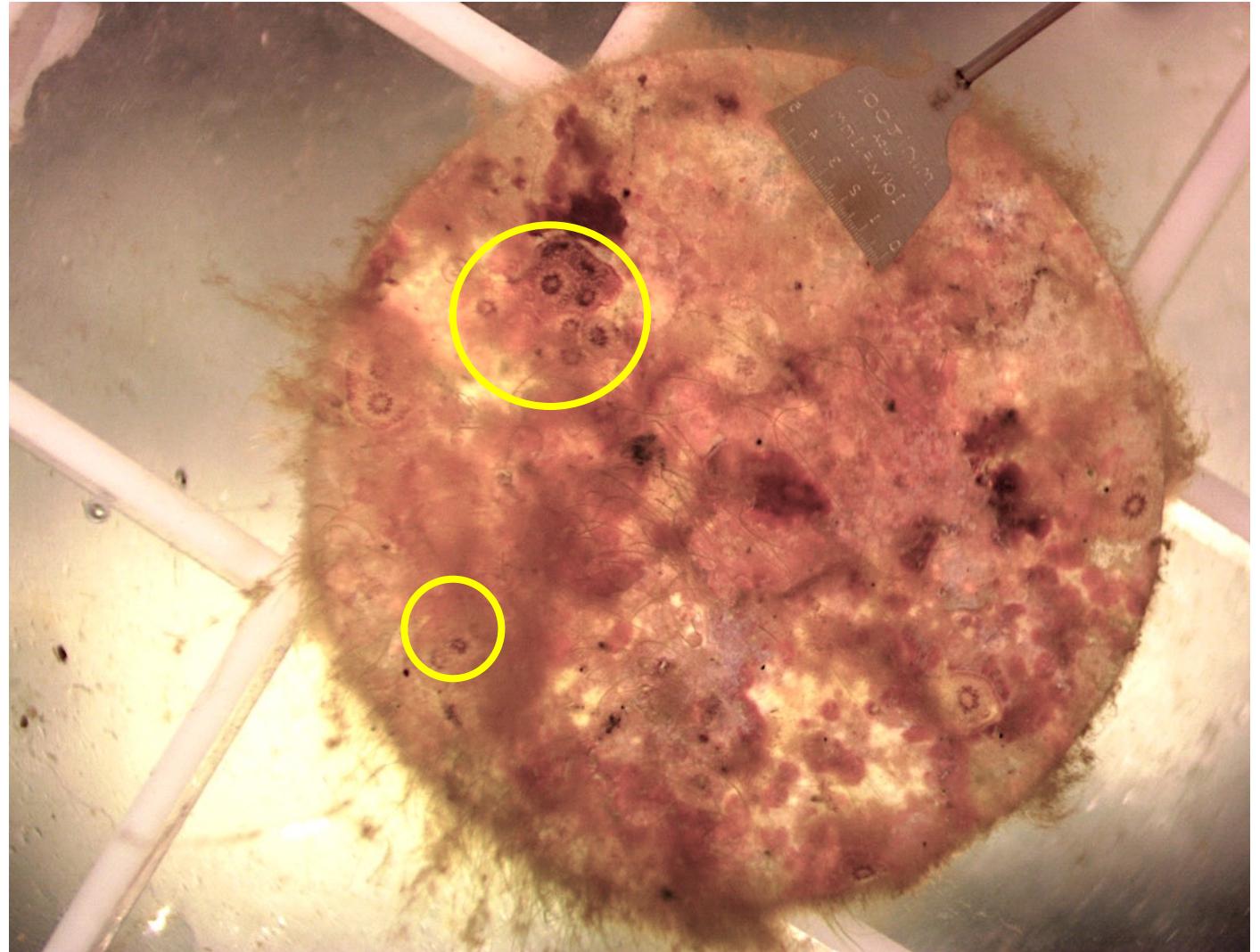
50% higher survivorship in fused juvenile corals

Fusion: Opportunity for increased colony size

Decreased mortality risk

Energetic resources and feeding capacity

Raymundo & Maypa 2004, Puill-Stephan et al. 2012, Rinkevich 2019



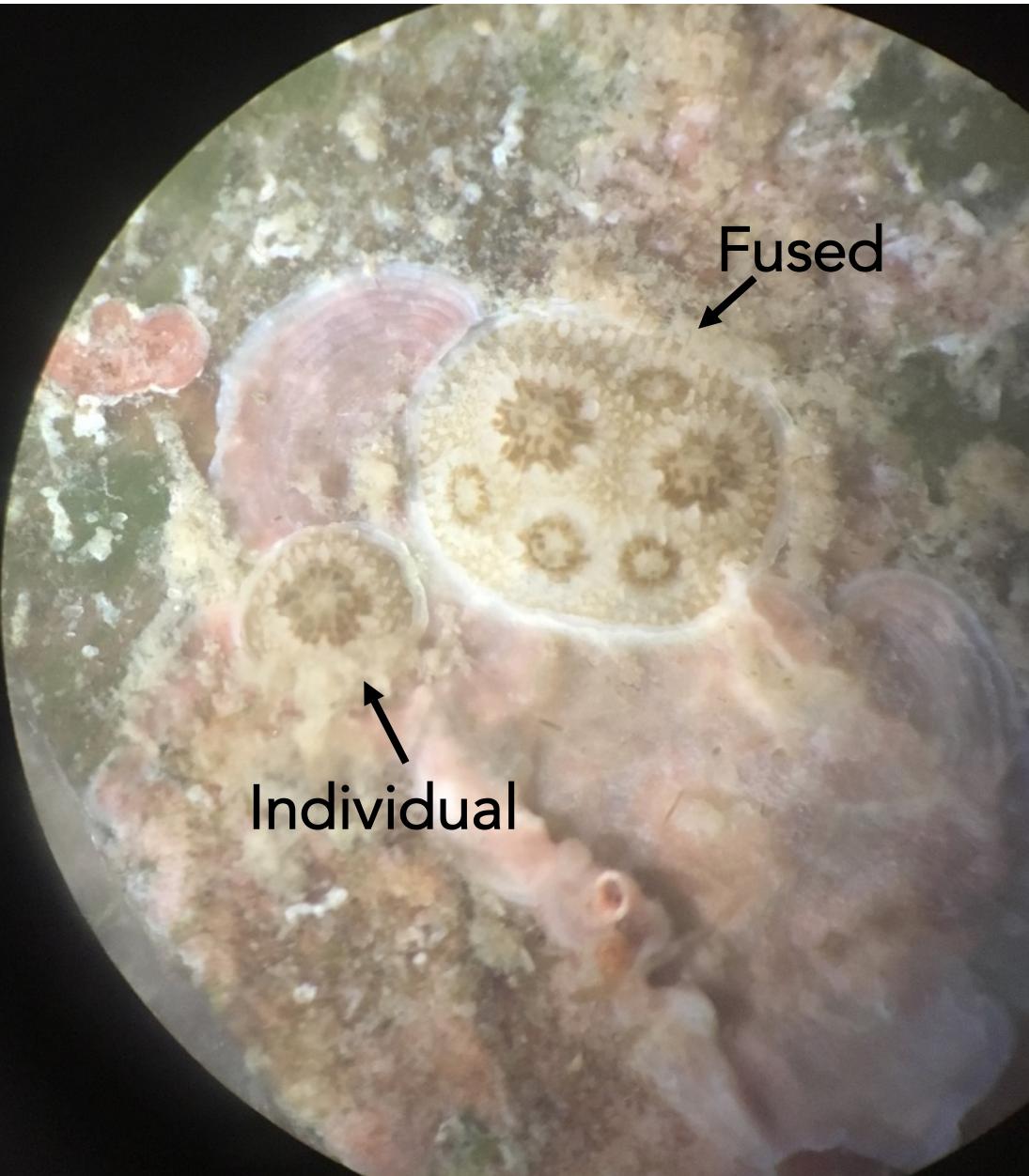
Fusion: Opportunity for increased genetic diversity



- Risk of intra-colony competition
- Potential strategy to survive stress

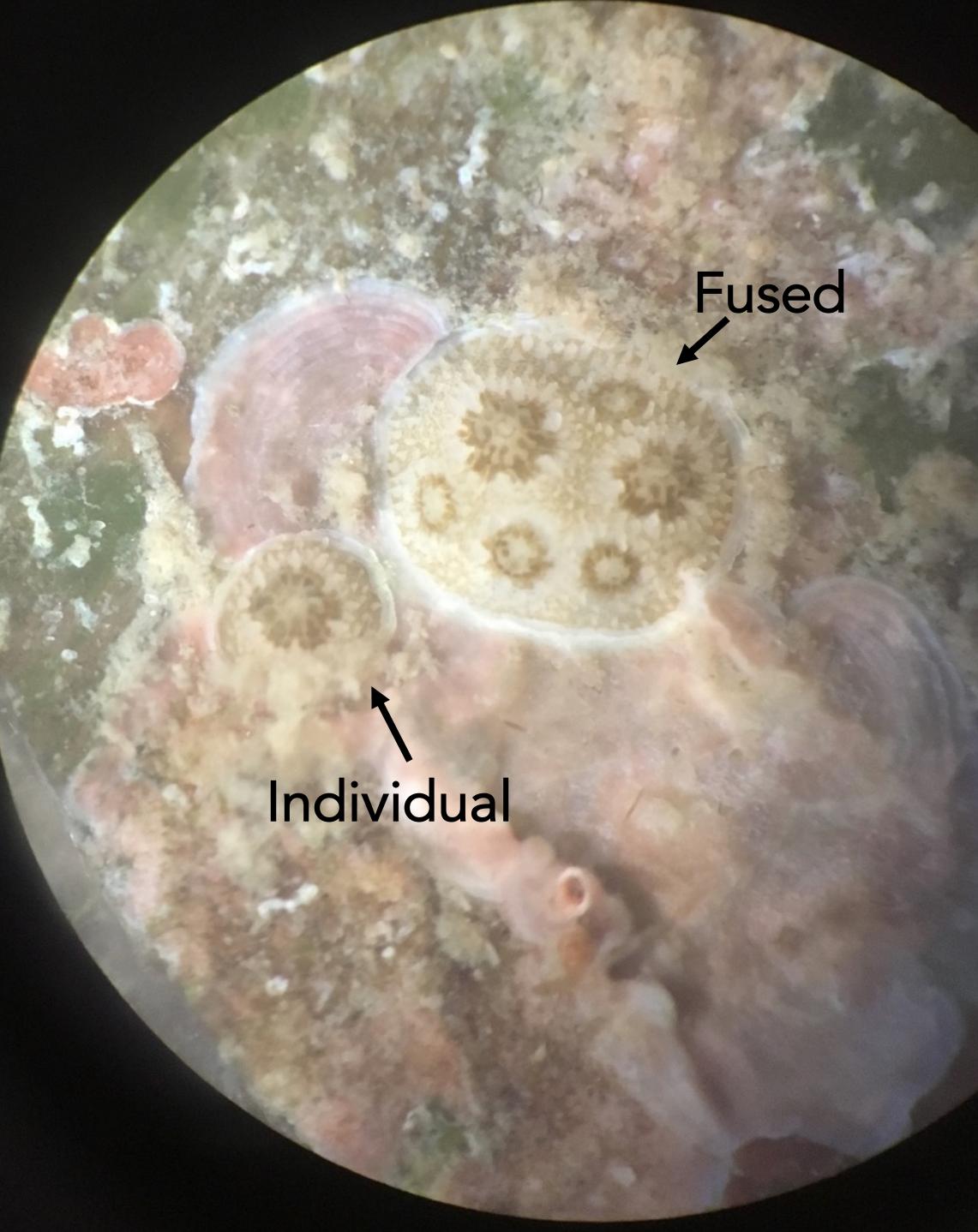
Puill-Stephan 2009, 2012; Hidaka 1985; Amar 2008, Rinkevich 2019

Fusion: Opportunity for increased genetic diversity



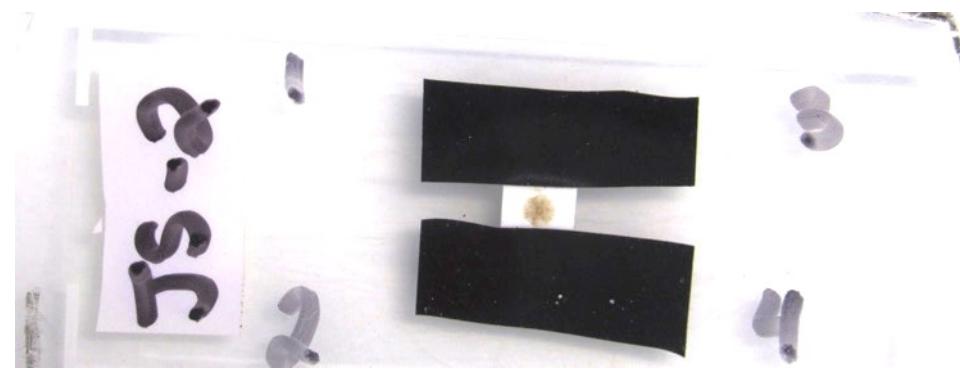
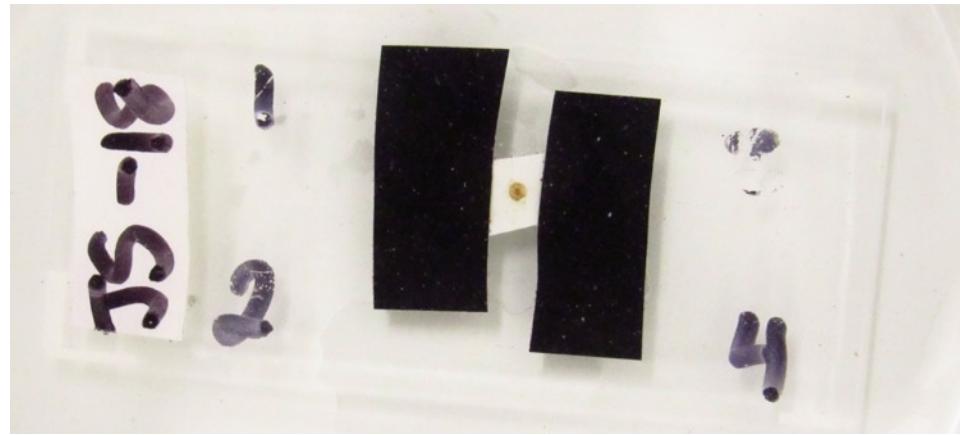
- “Window of opportunity” for multi-genotype fusions in early life stages

Puill-Stephan 2009, 2012; Hidaka 1985; Amar 2008, Rinkevich 2019



Does juvenile tissue fusion promote survival in thermal stress?

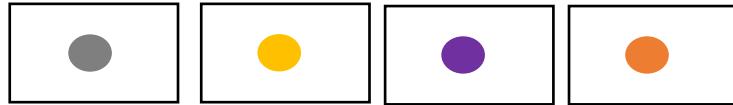
If so, are advantages due to an increase in size or genetic diversity?



Genotyping with Next Generation Sequencing, identity-by-state in ANGSD

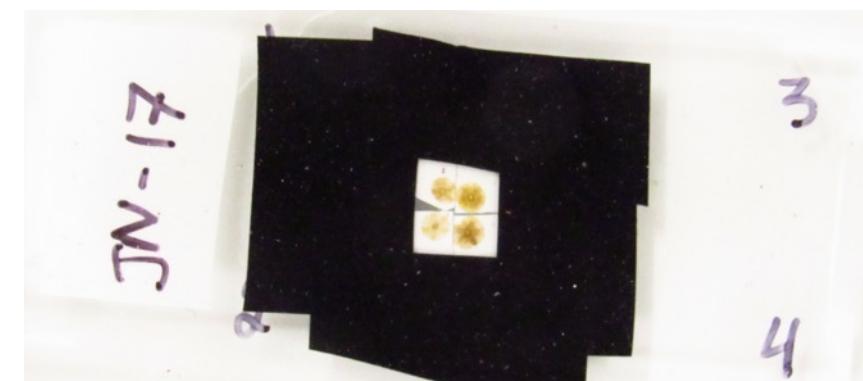
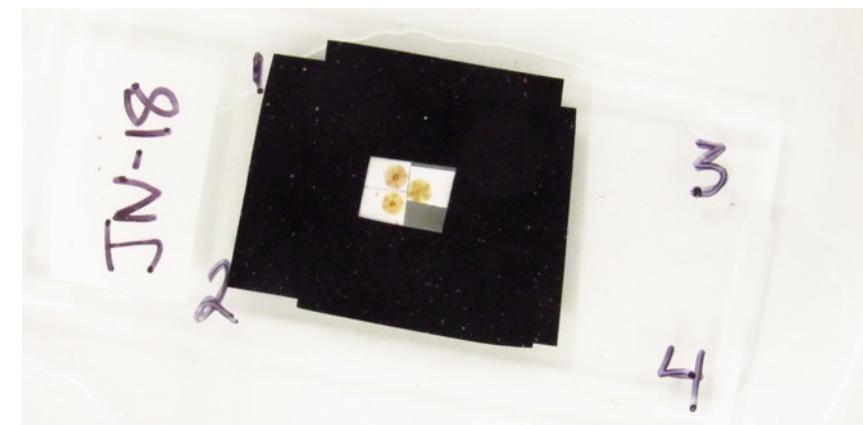
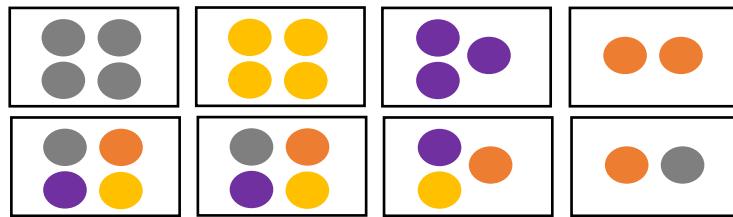
Genotypic Richness = 1

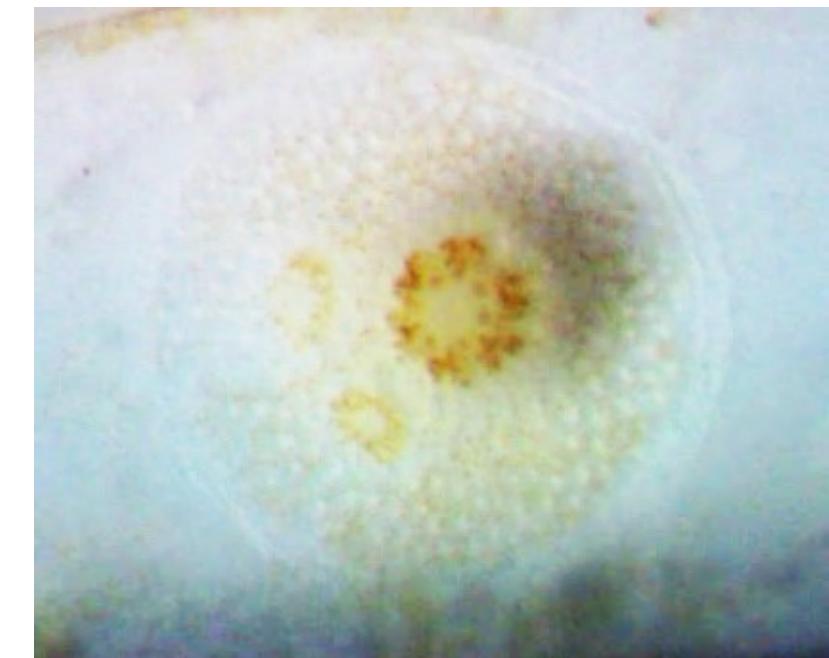
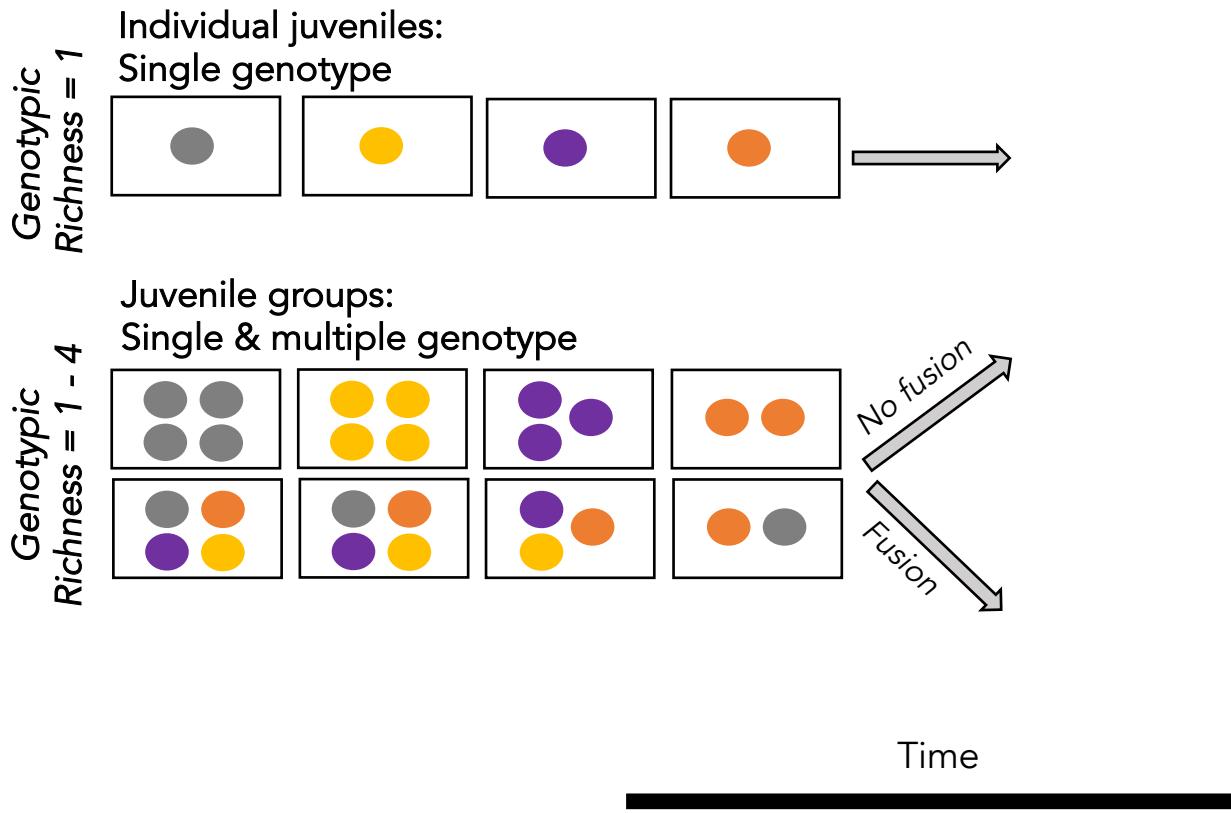
Individual juveniles:
Single genotype

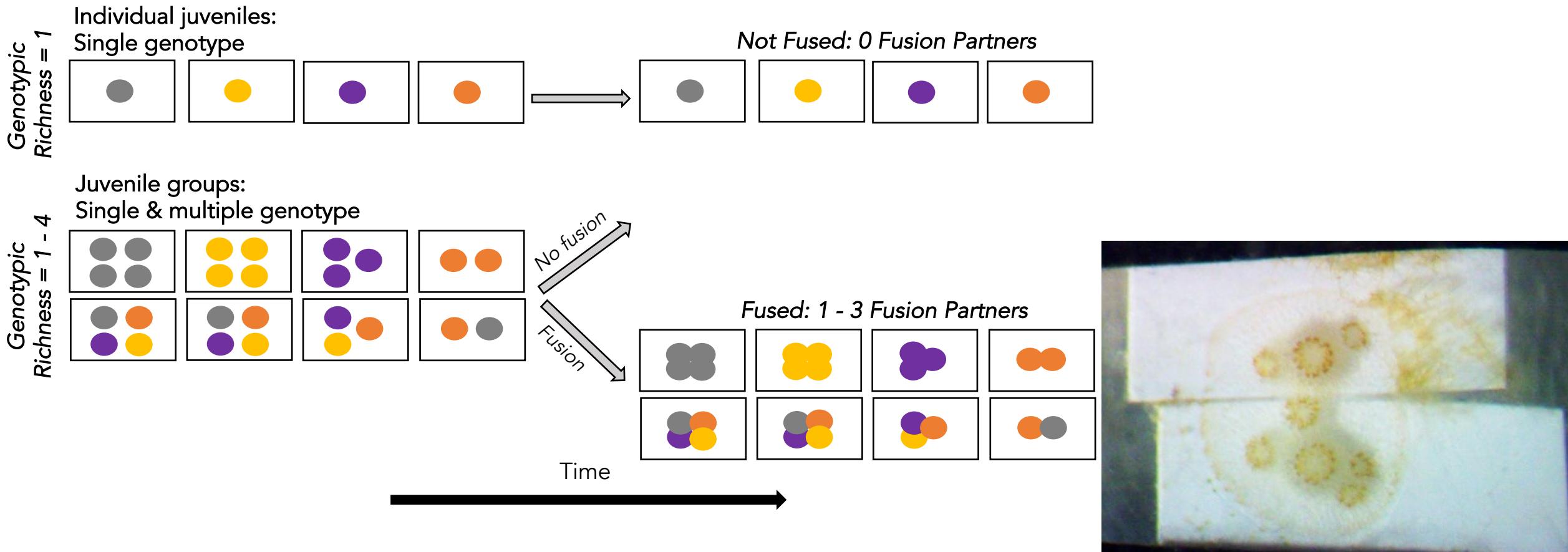


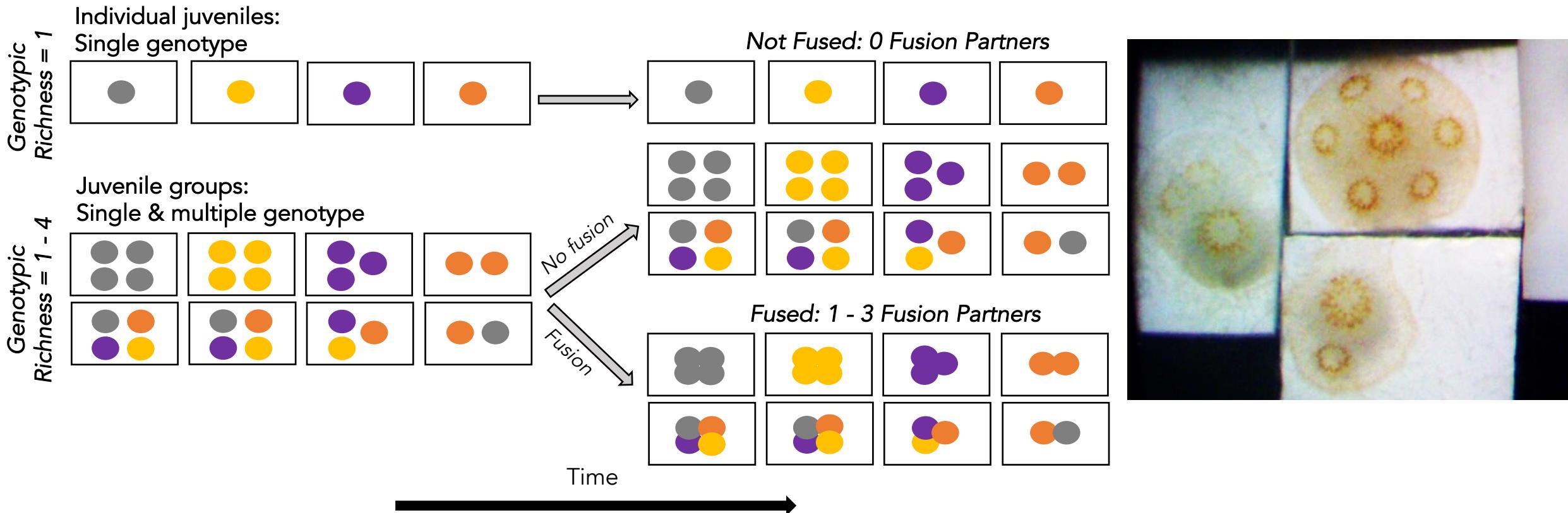
Genotypic Richness = 1 - 4

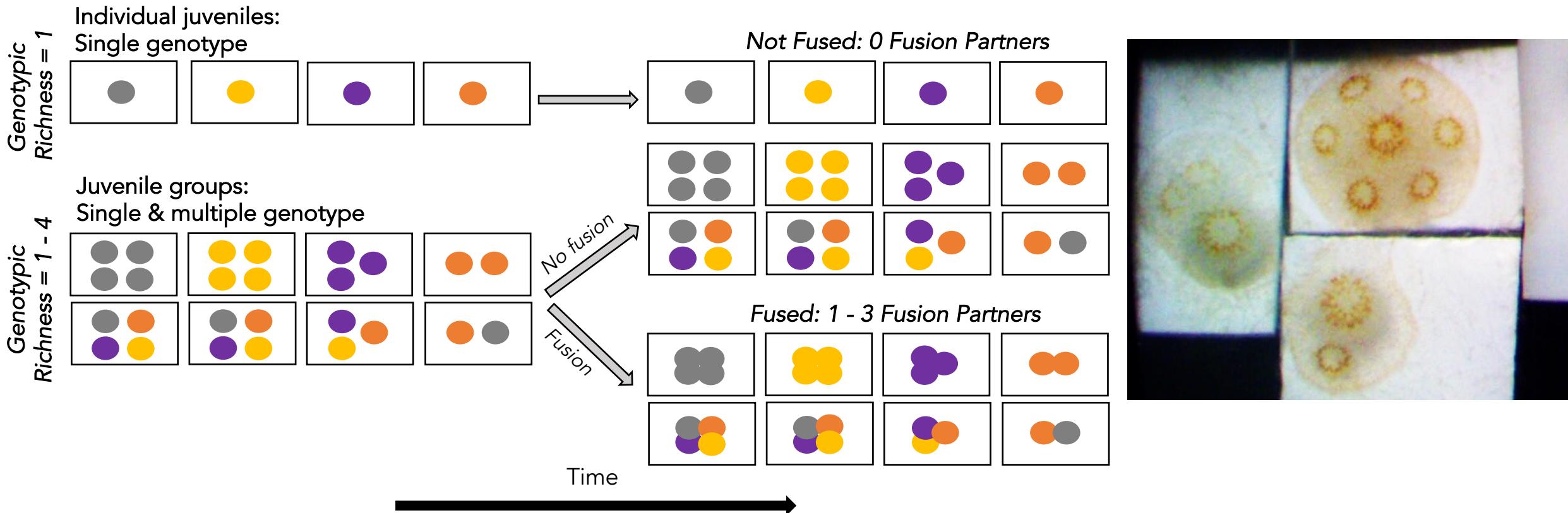
Juvenile groups:
Single & multiple genotype



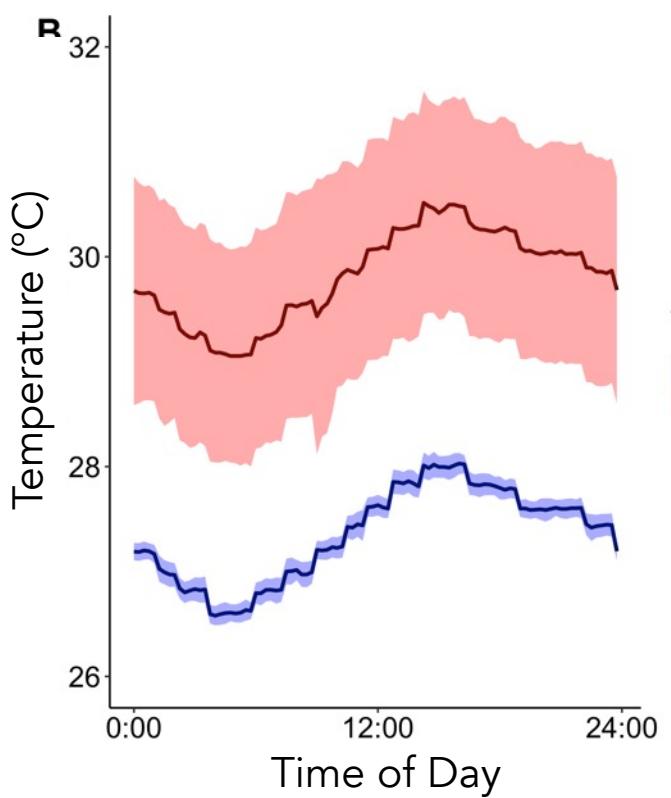
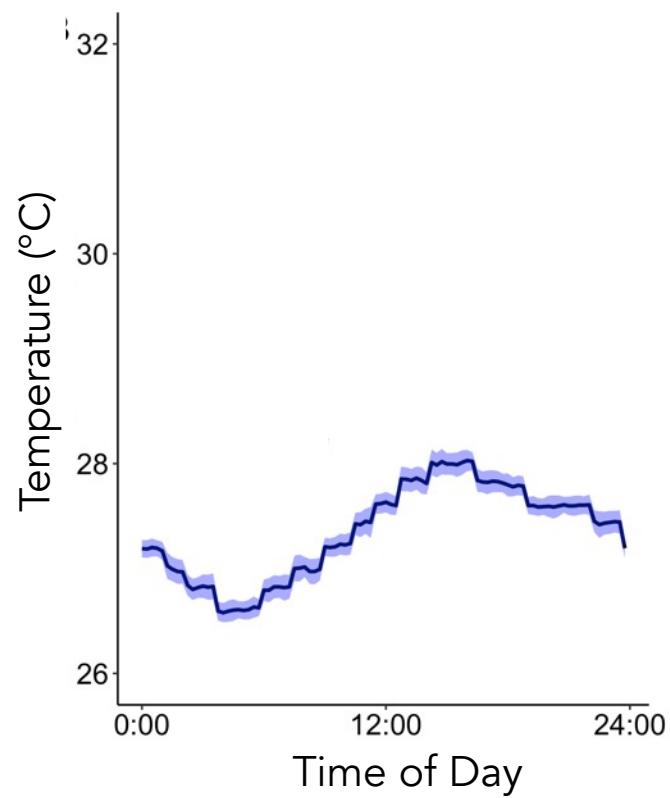








Collected data at the level of the *individual juvenile*



Manipulation

Survivorship,
Growth, Fusion

Grow-Out Period

Day 0

Day 15

Survivorship,
Growth, Fusion

Thermal Stress Period

Day 45



Nina Bean



Casey Harris

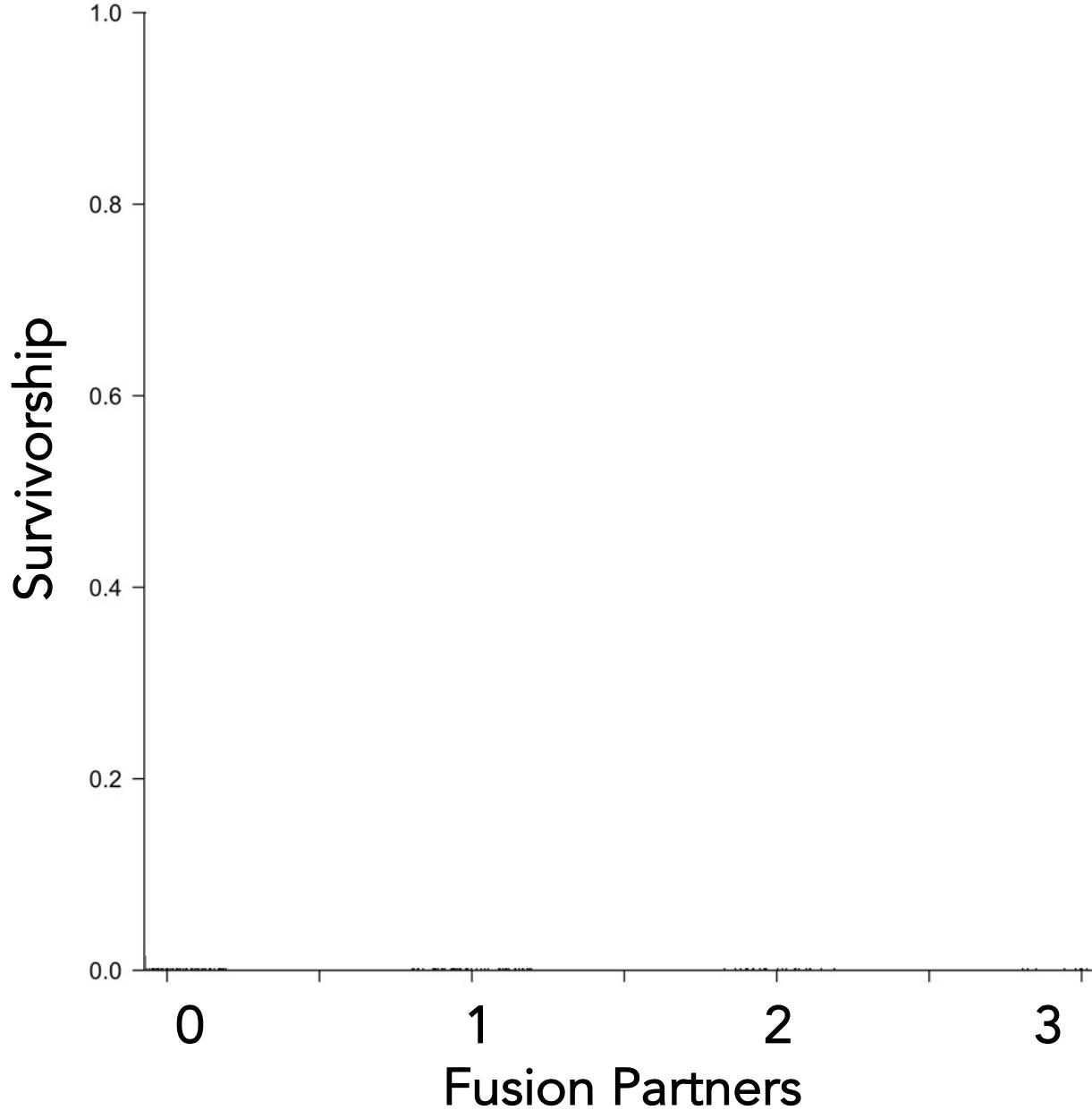


Eva Majerová



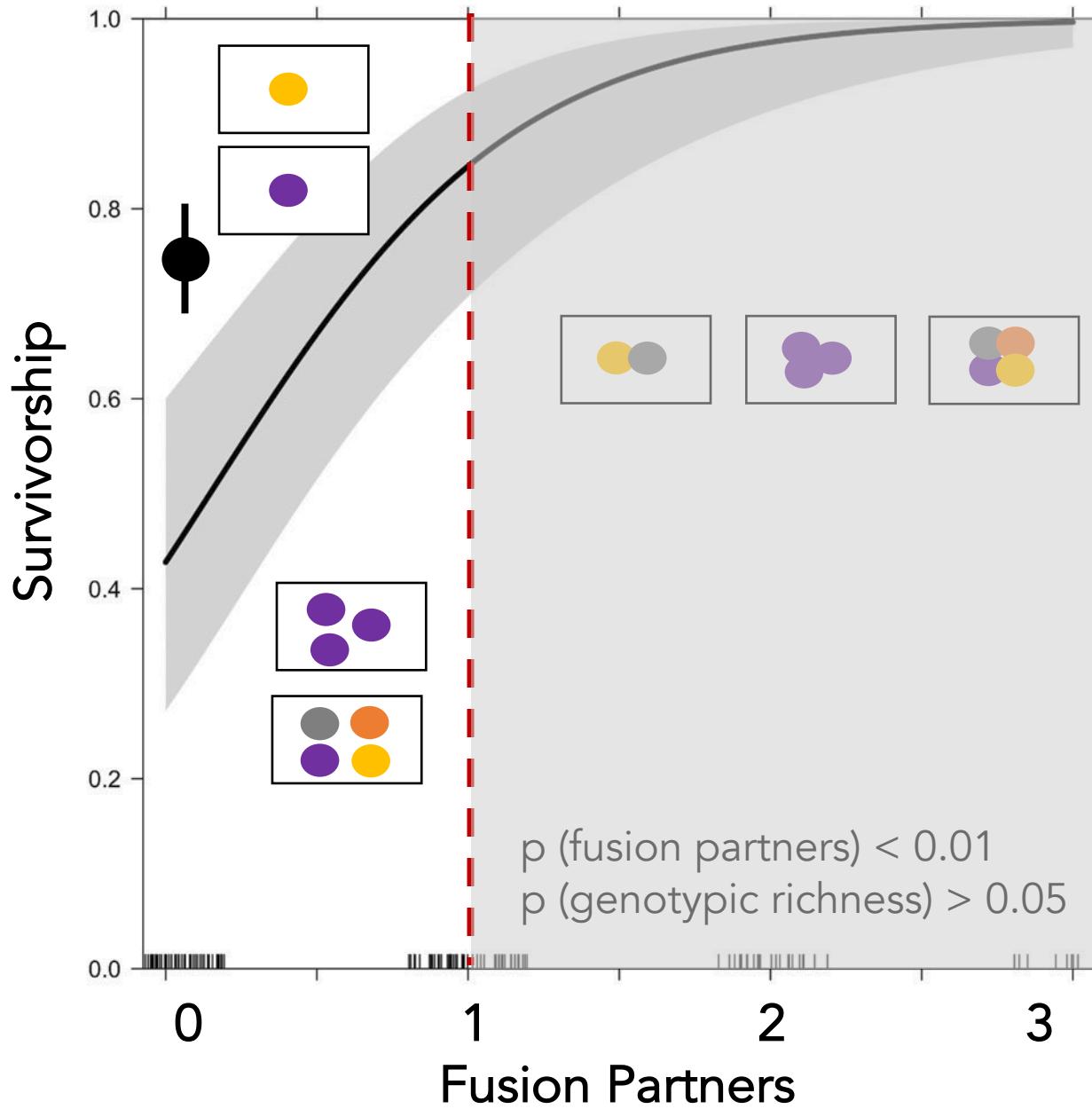
Ford Drury

Survival during grow-out period



```
glmer(survival ~ fusion partners * genotypic richness + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial, subset=c(Community=="Group"))
```

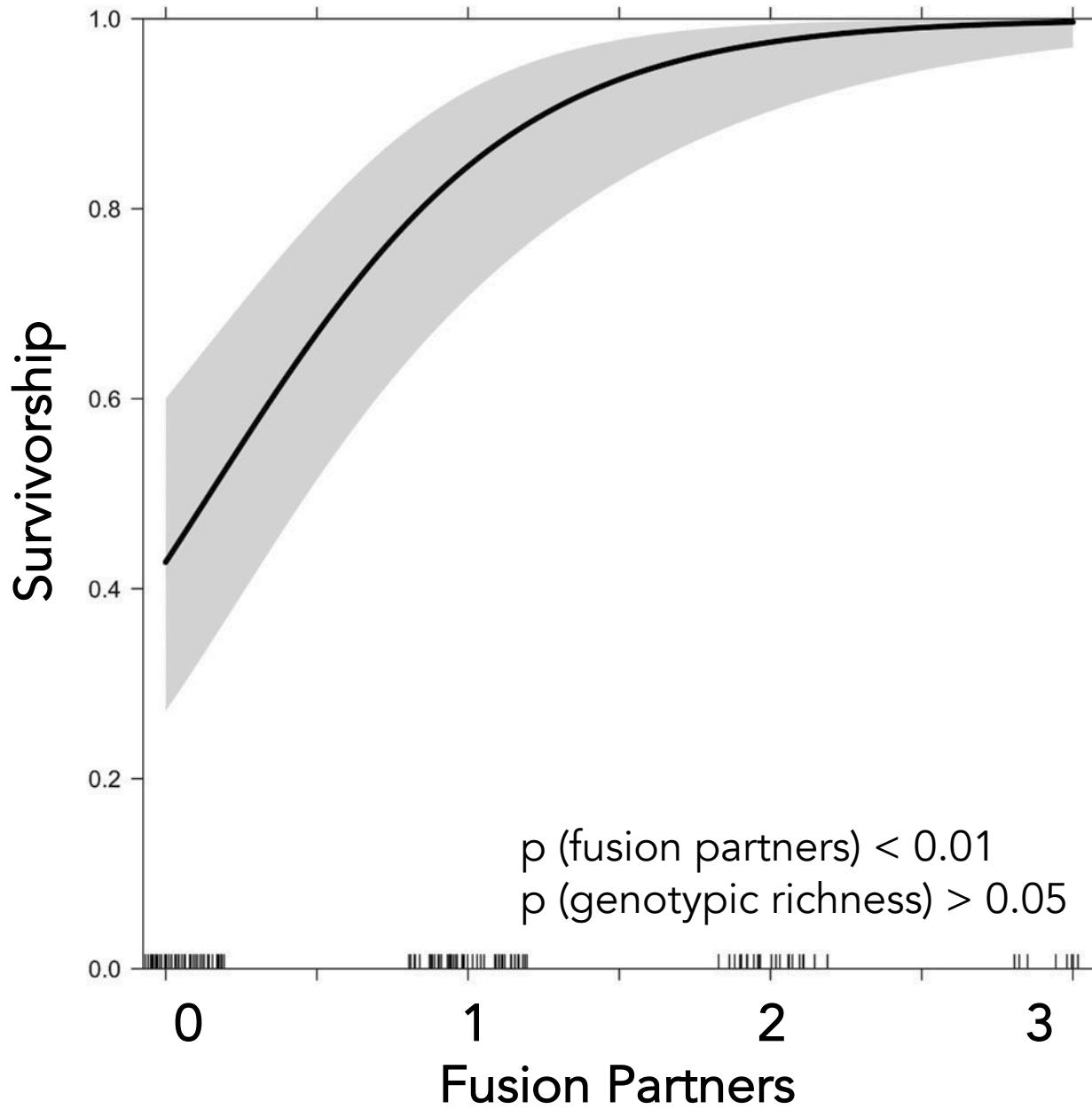
Survival during grow-out period



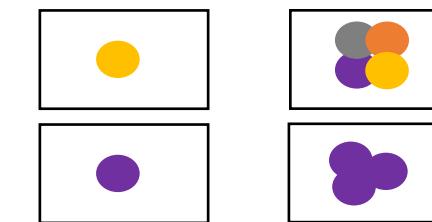
Survival increases with fusion

Competition between non-fused juveniles

Survival during grow-out period

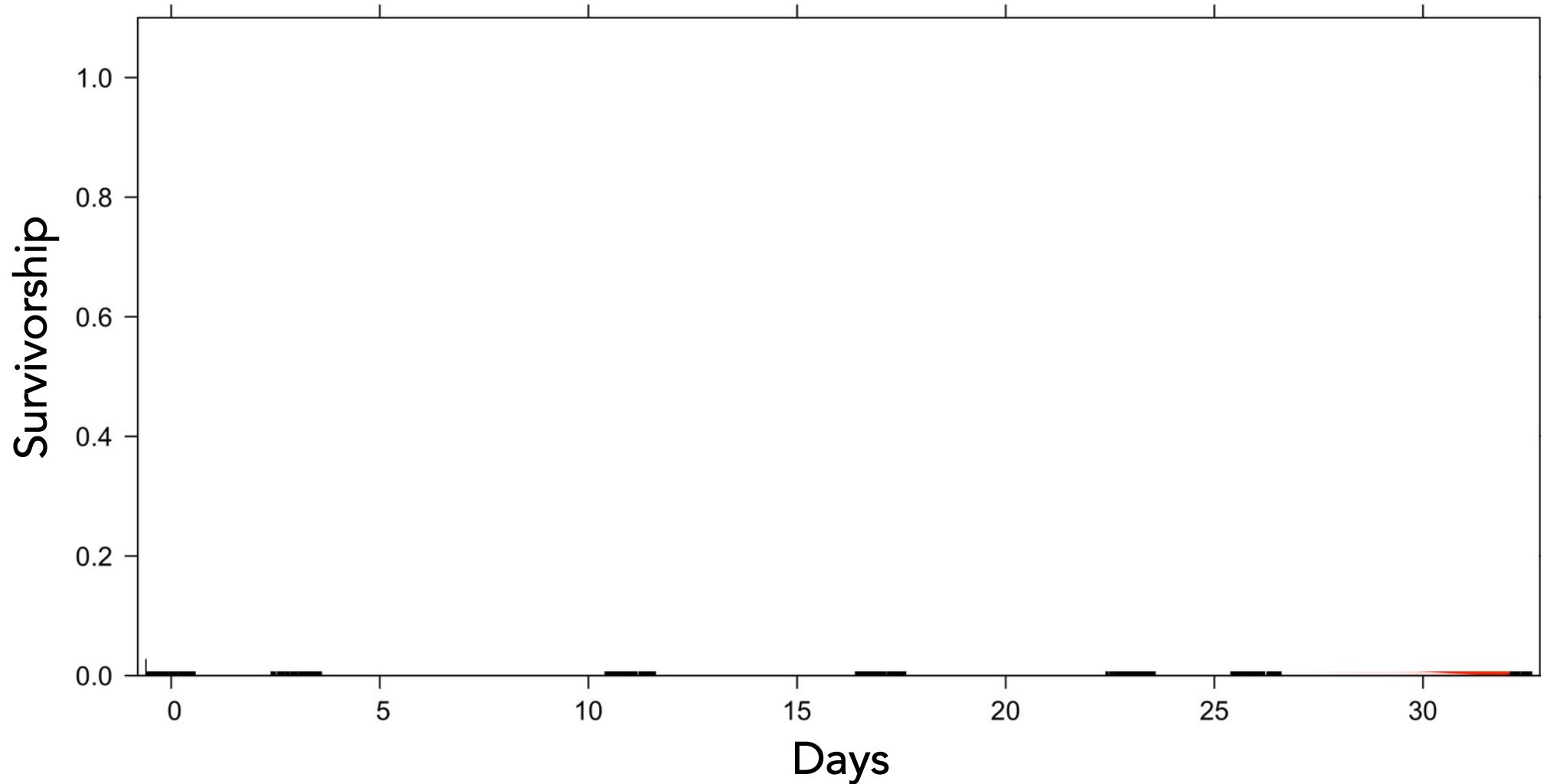


Thermal Stress Test:
Individual & fused juveniles

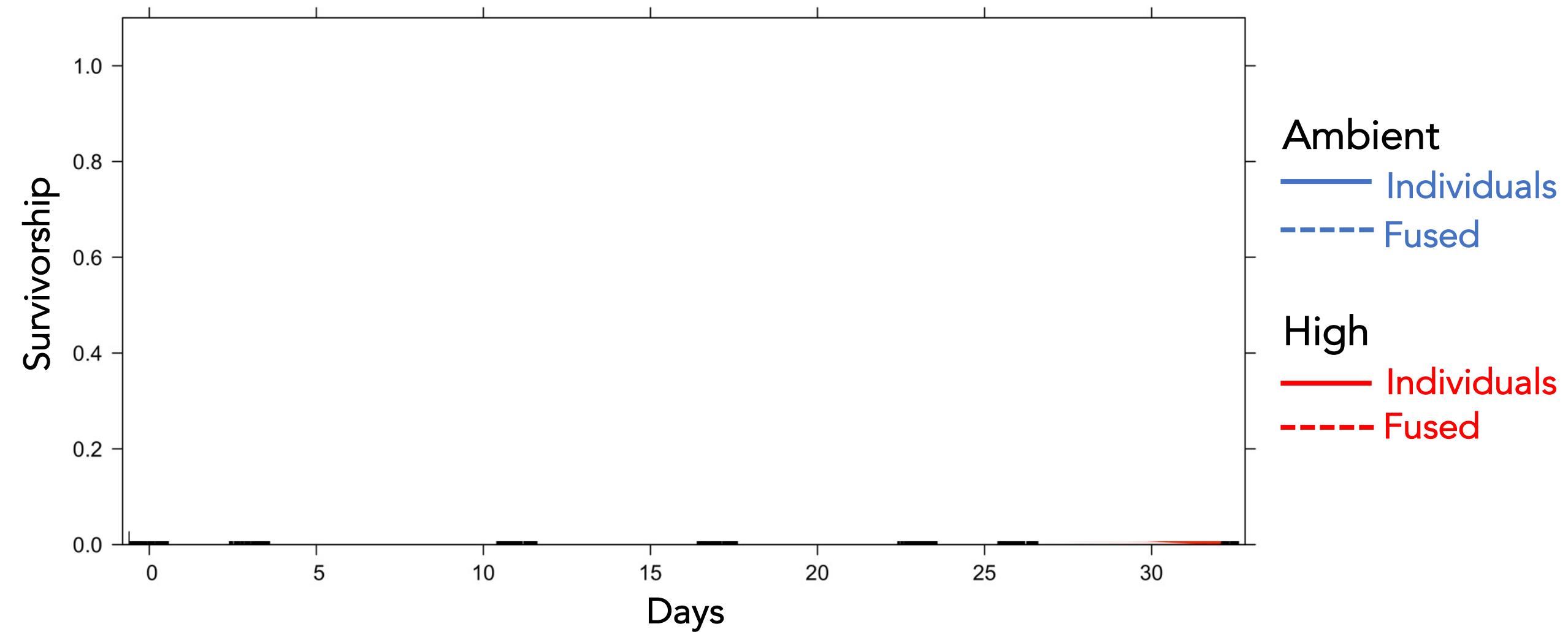


```
glmer(survival ~ fusion partners * genotypic richness + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial, subset=c(Community=="Group"))
```

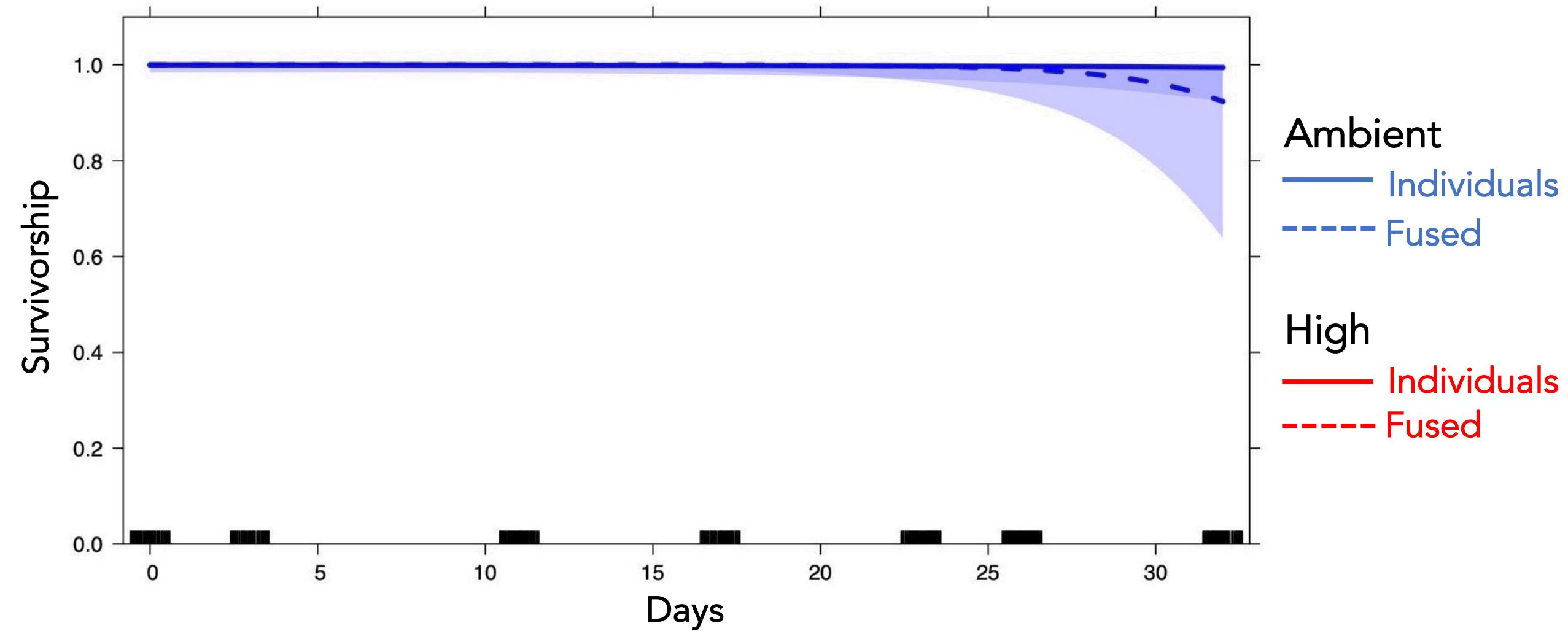
Survival during thermal stress period



`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

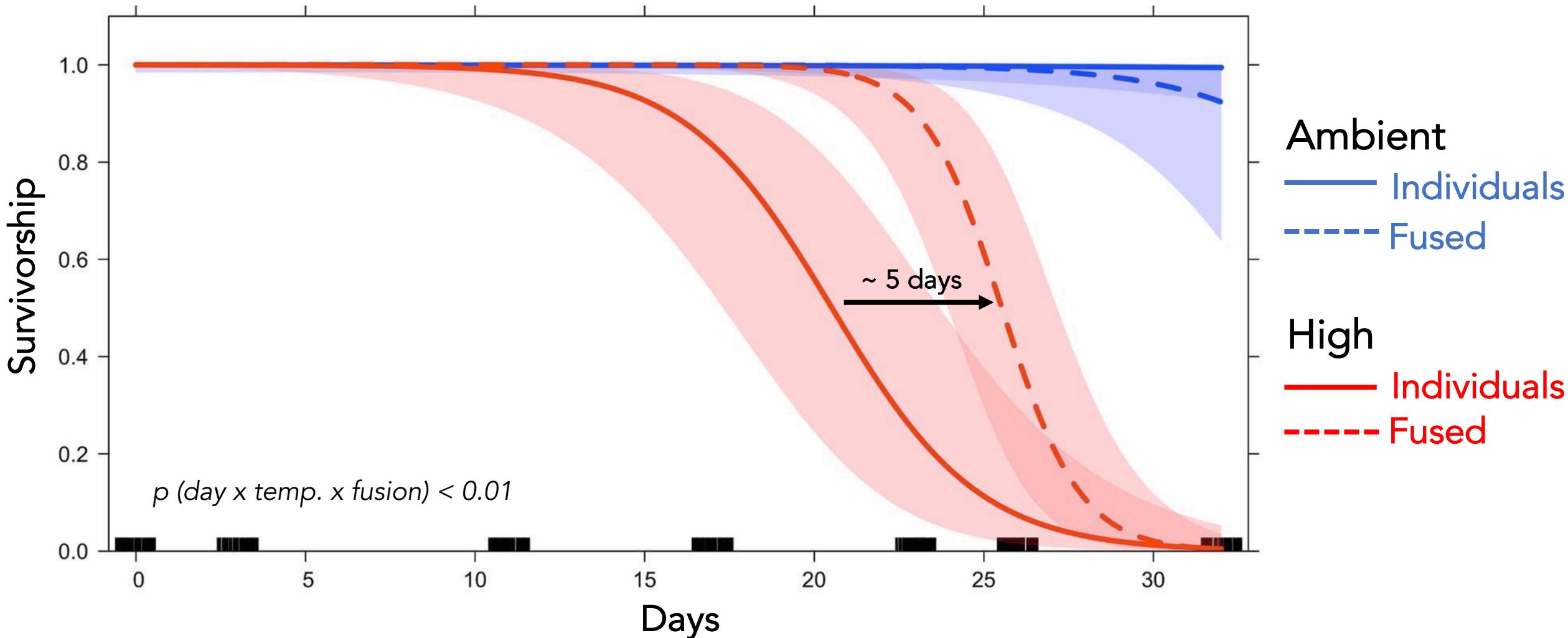


`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

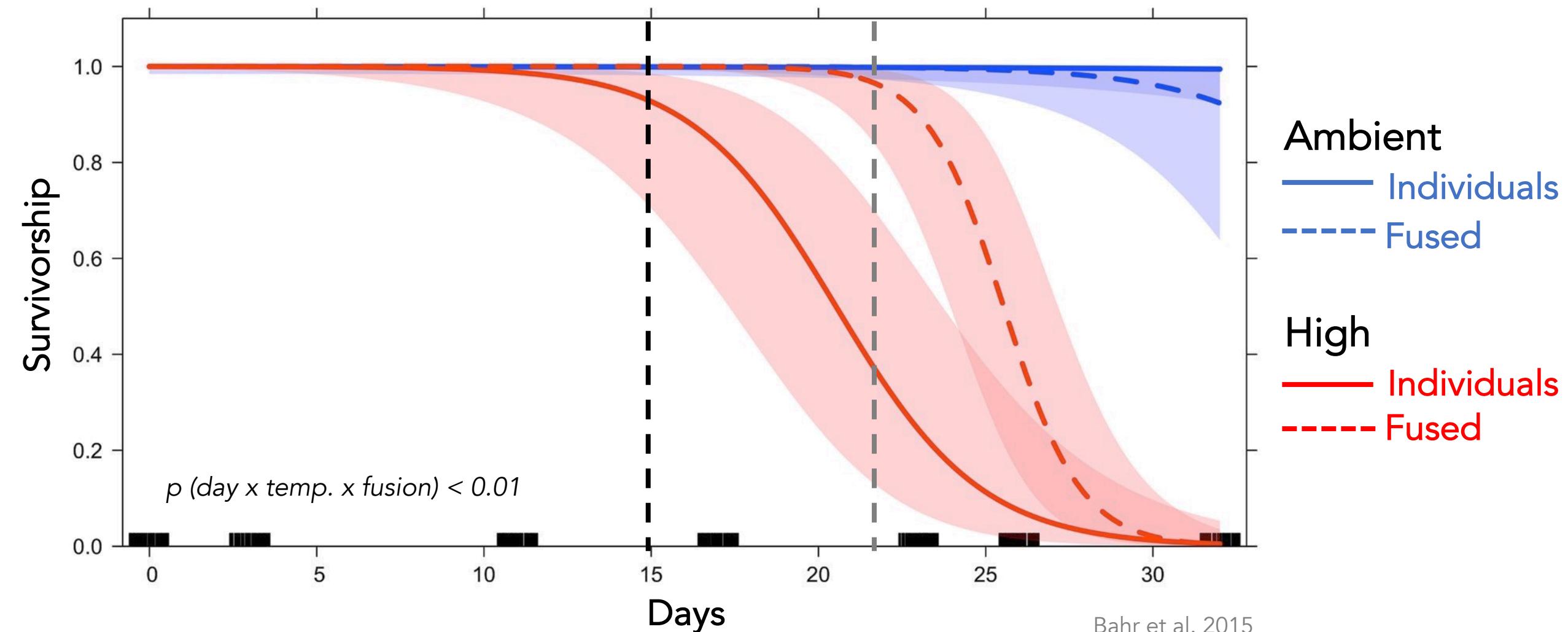


`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

Fused corals survive longer in high temperature.

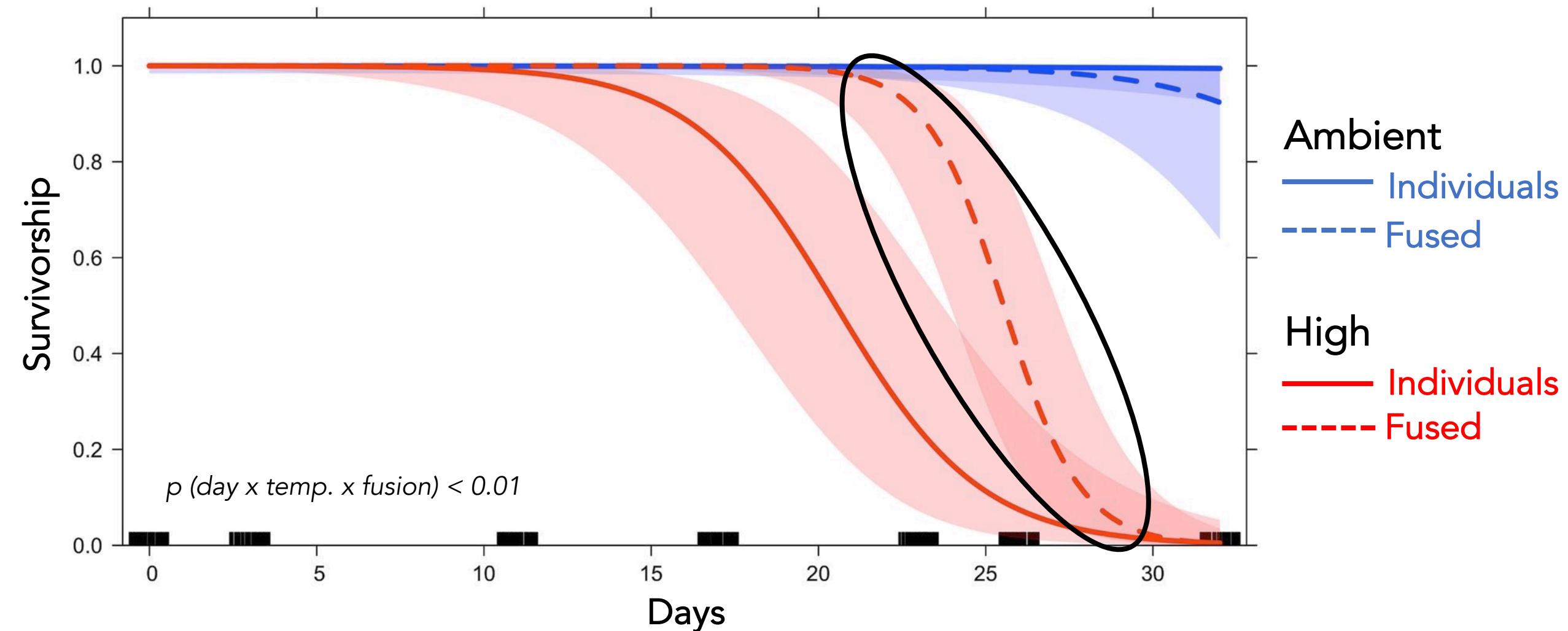


Fused corals survive longer in high temperature.



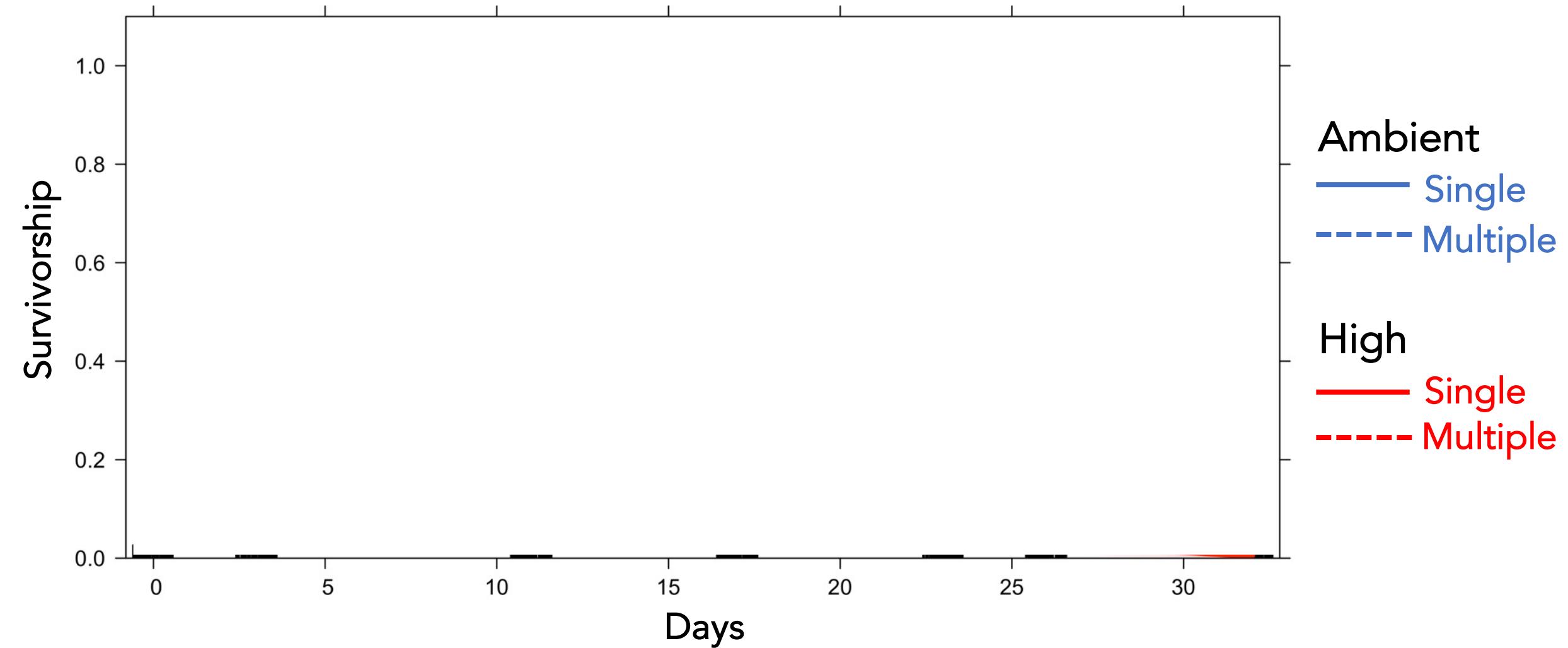
`glmer(survival ~ day * fusion * genotypic richness * temperature + (1/parent site/colony) + (1/tank) + (1/slides), family=binomial)`

Fused corals survive longer in high temperature.

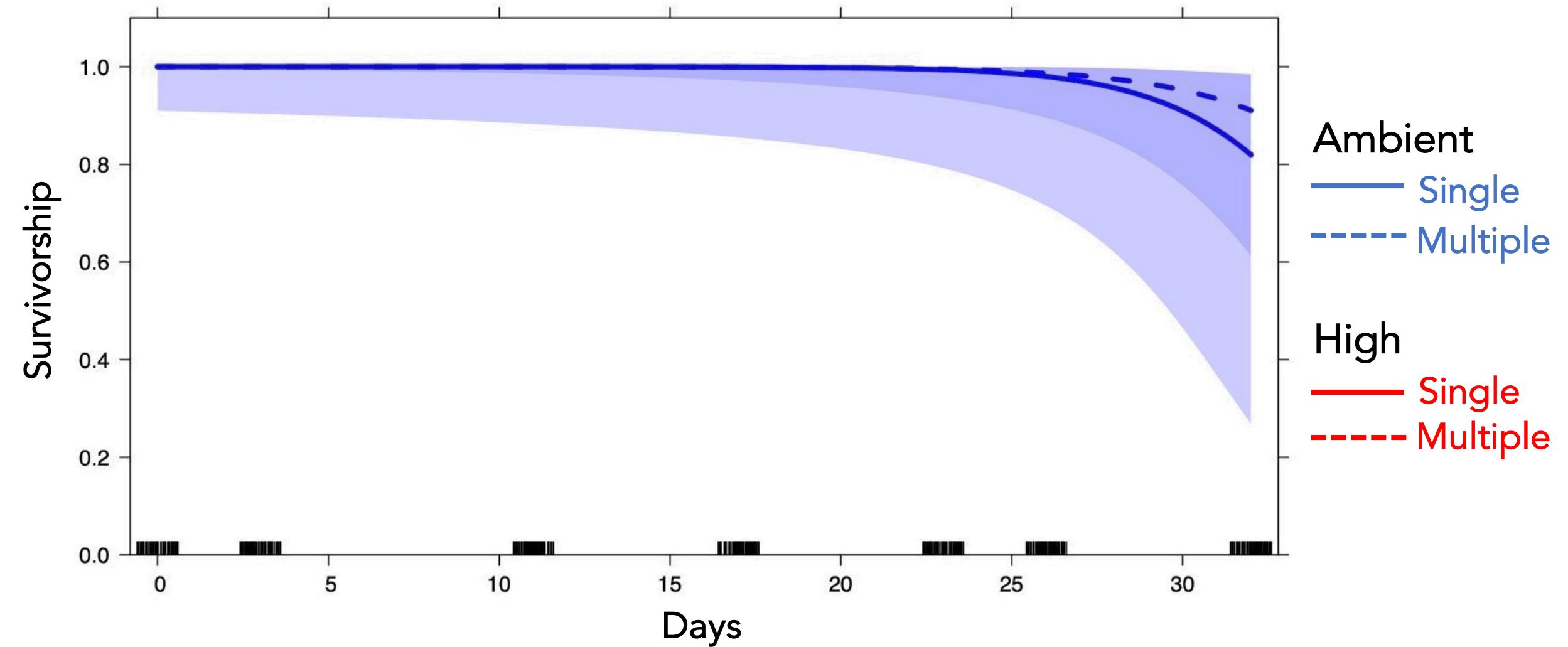




compared to

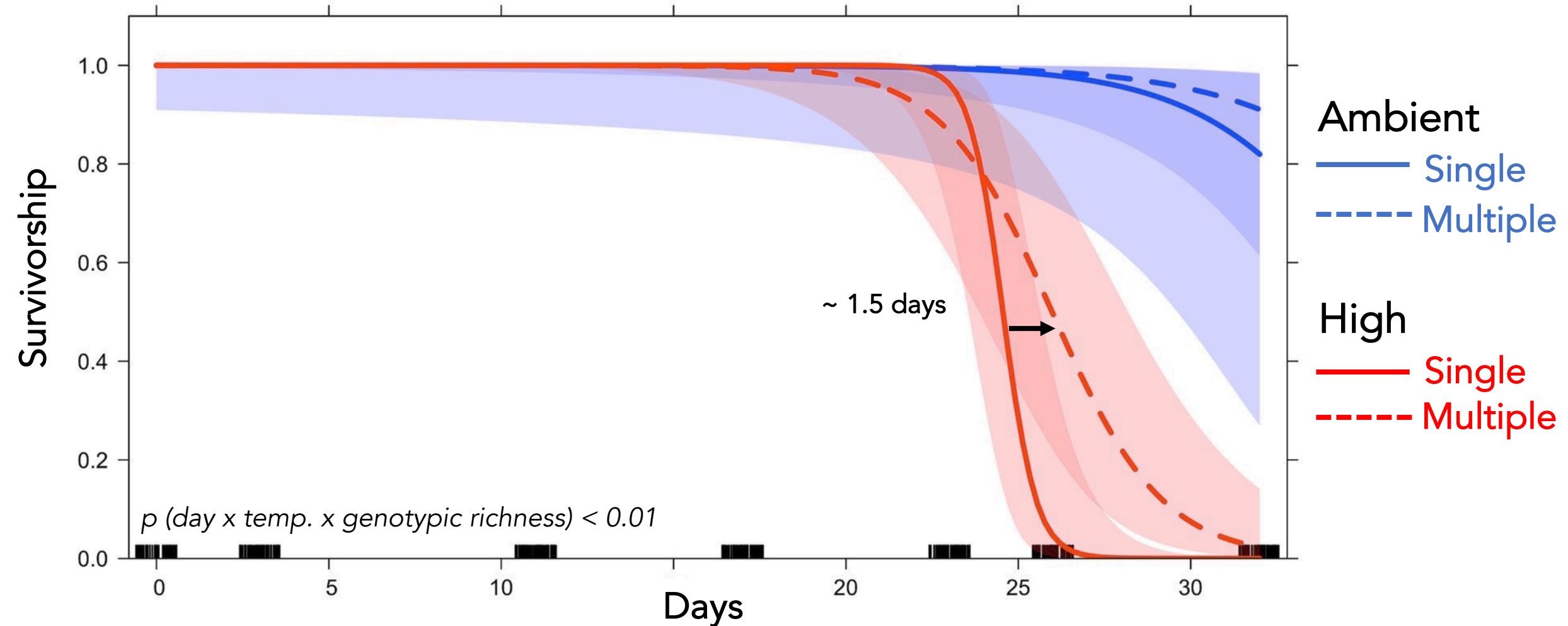


`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`



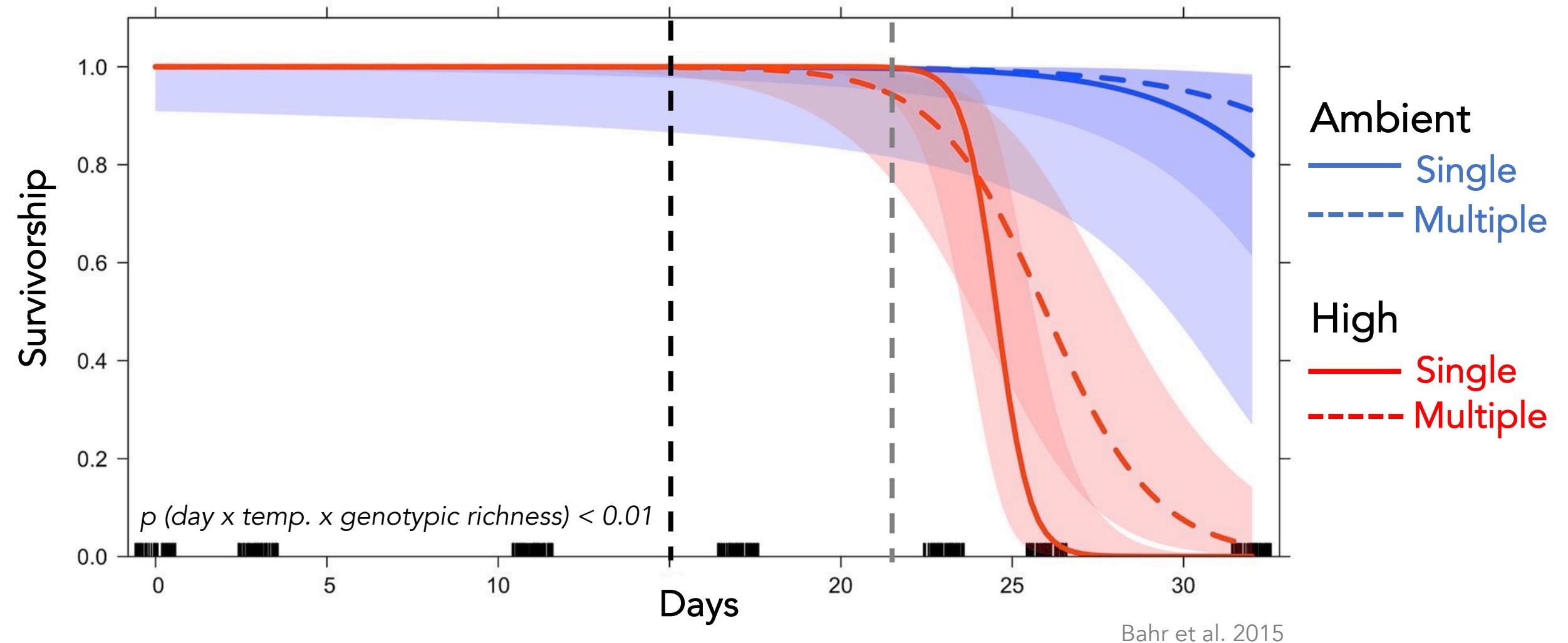
`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

Genetically diverse fusions survive longer in high temperature.



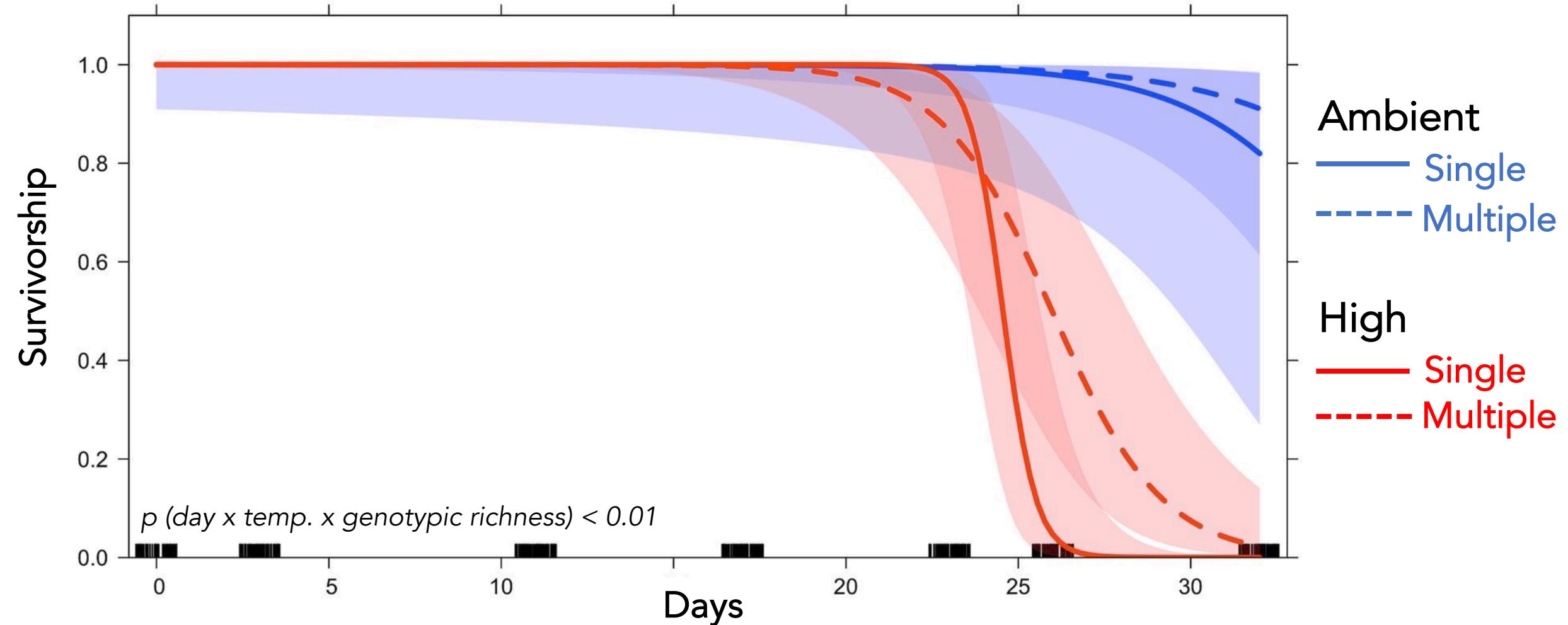
`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

Genetically diverse fusions survive longer in high temperature.

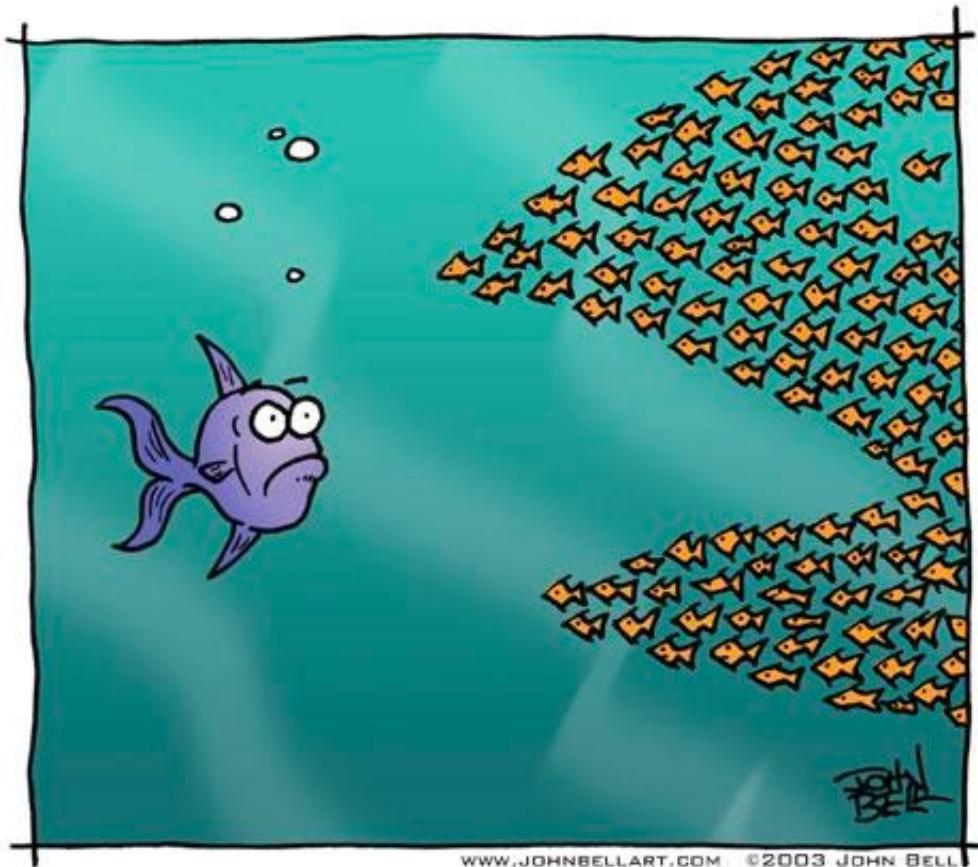


`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

Prolonged exposure to high temperature results in high mortality.



`glmer(survival ~ day * fusion * genotypic richness * temperature + (1|parent site/colony) + (1|tank) + (1|slide), family=binomial)`

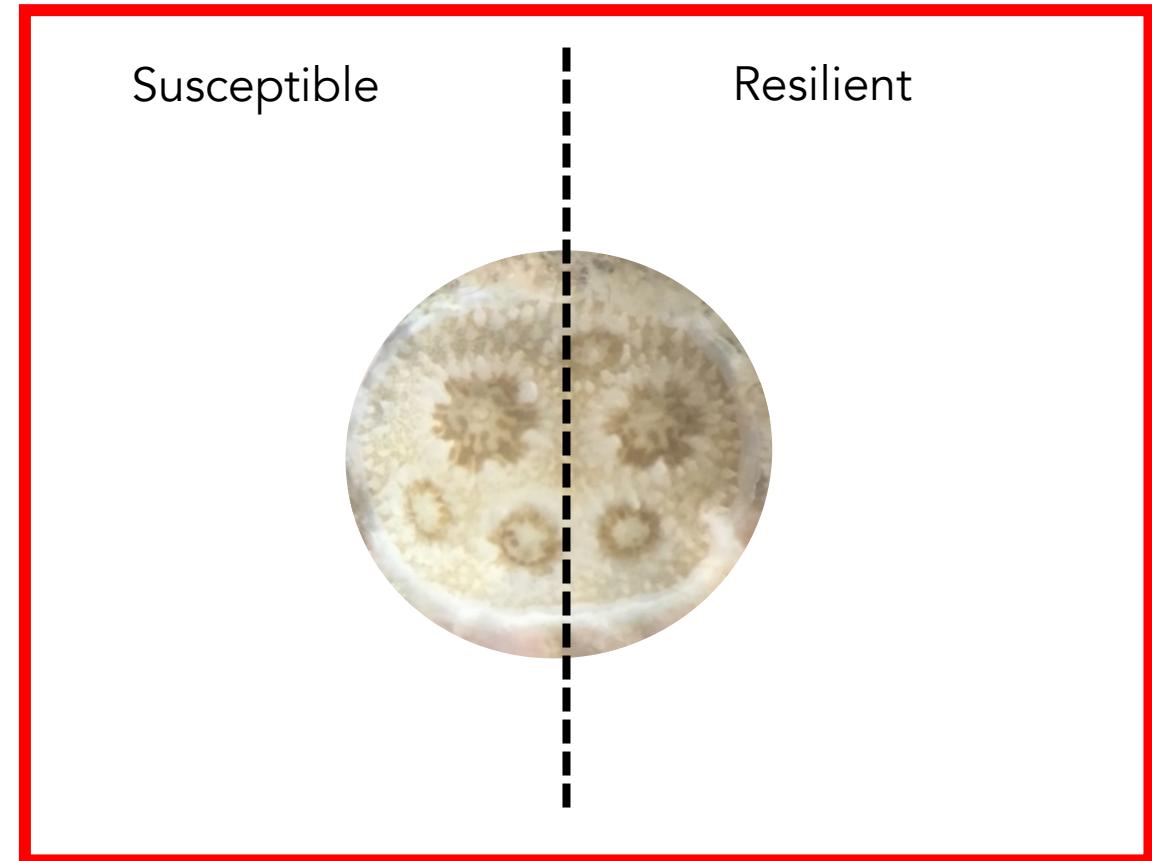
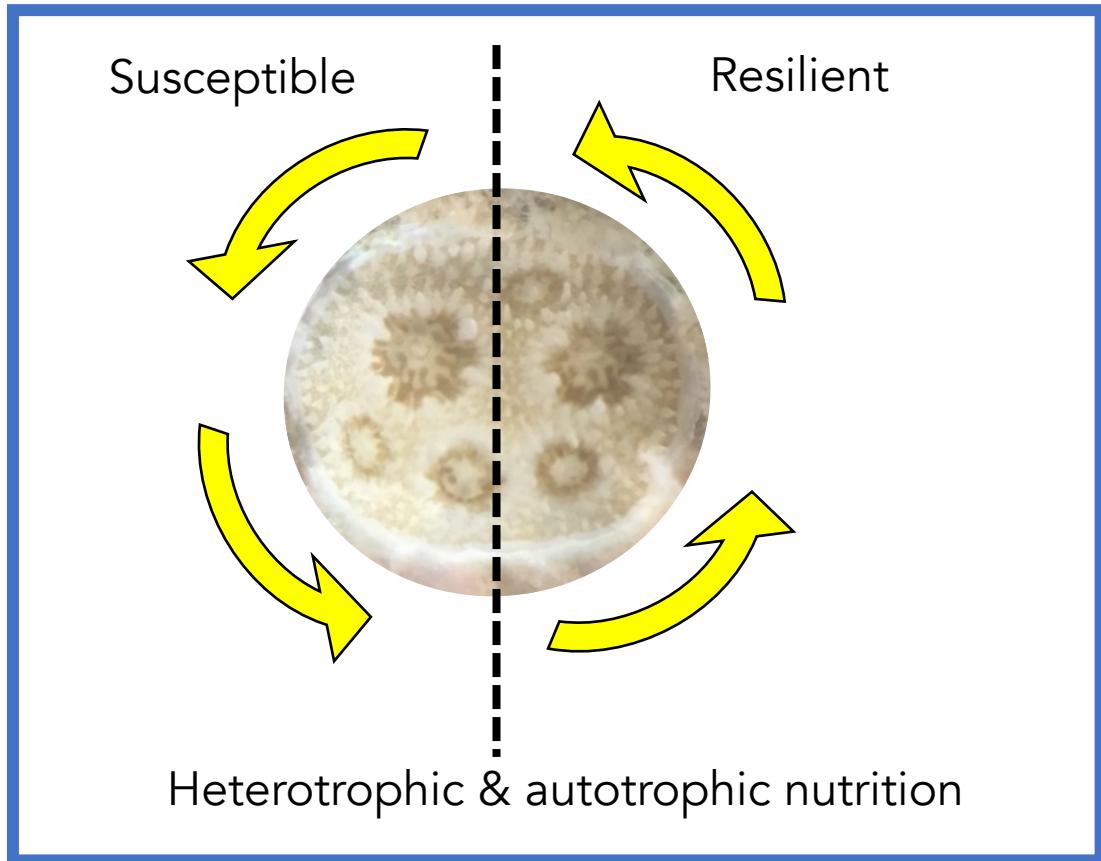


Tissue fusion: safety in numbers

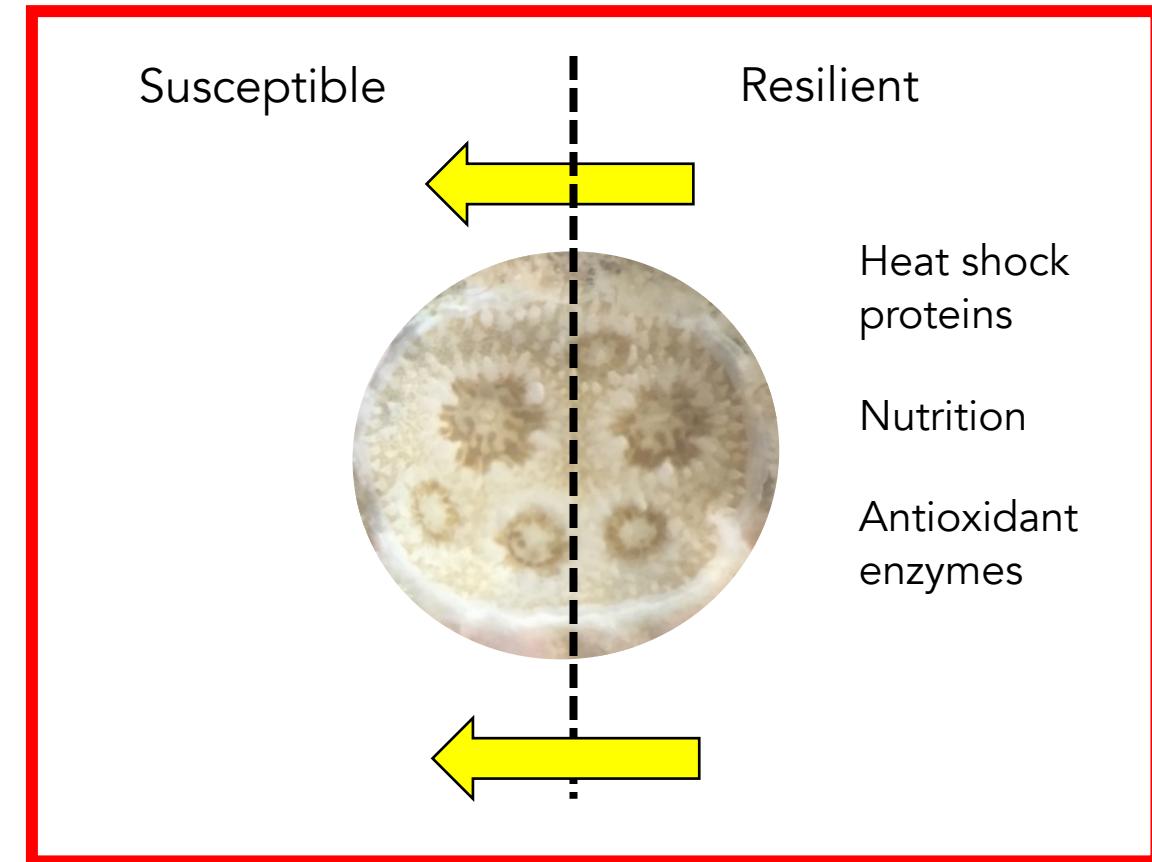
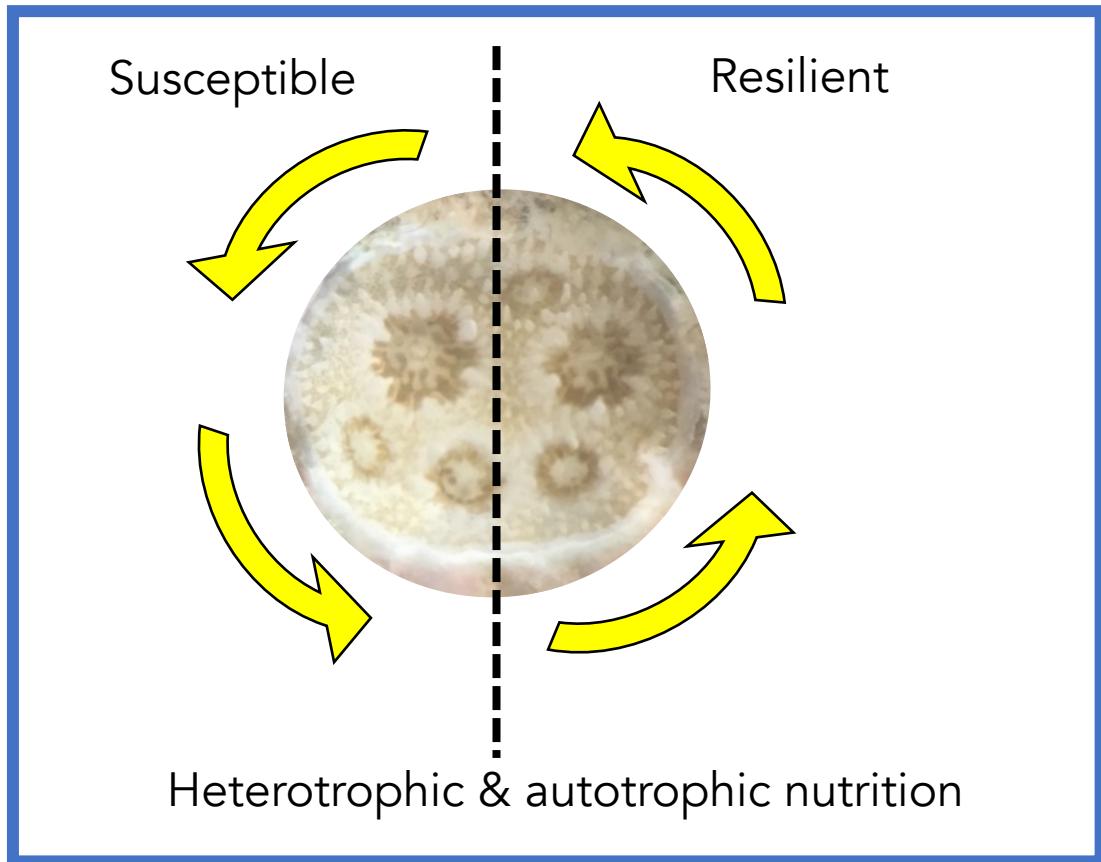
- Increase survival
- Ameliorate competitive interactions

Huffmyer AS, C Drury, E Majerova, N Bean, C Harris, JD Lemus, RD Gates. Tissue fusion provides a survival advantage for juvenile *Pocillopora acuta* corals during thermal stress. *In prep.*

“Rescue effect” in fusions with genetic diversity



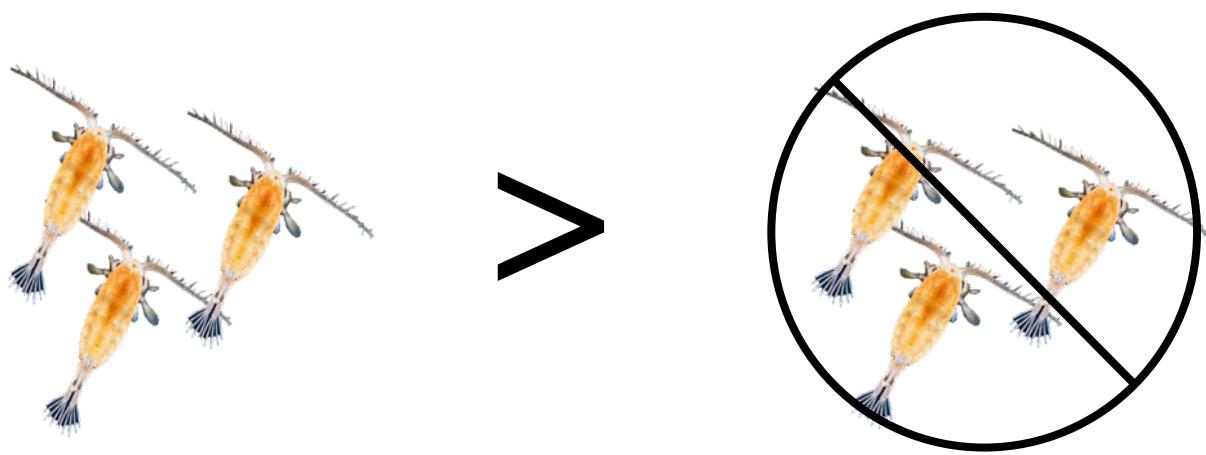
“Rescue effect” in fusions with genetic diversity





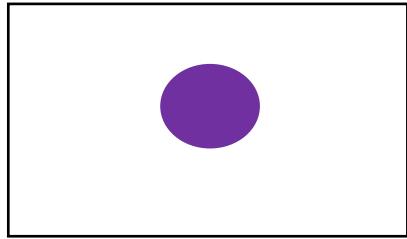
Are there environmental and biological conditions that promote juvenile survival in high temperature?



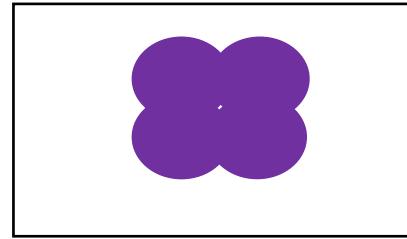


Huffmyer AS, CJ Johnson, AM Epps, JD Lemus, RD Gates. Heterotrophic feeding enhances tissue growth and thermal tolerance of *Pocillopora acuta* juvenile corals. *In prep.*

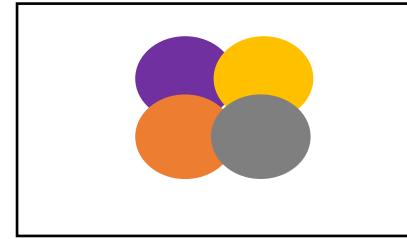




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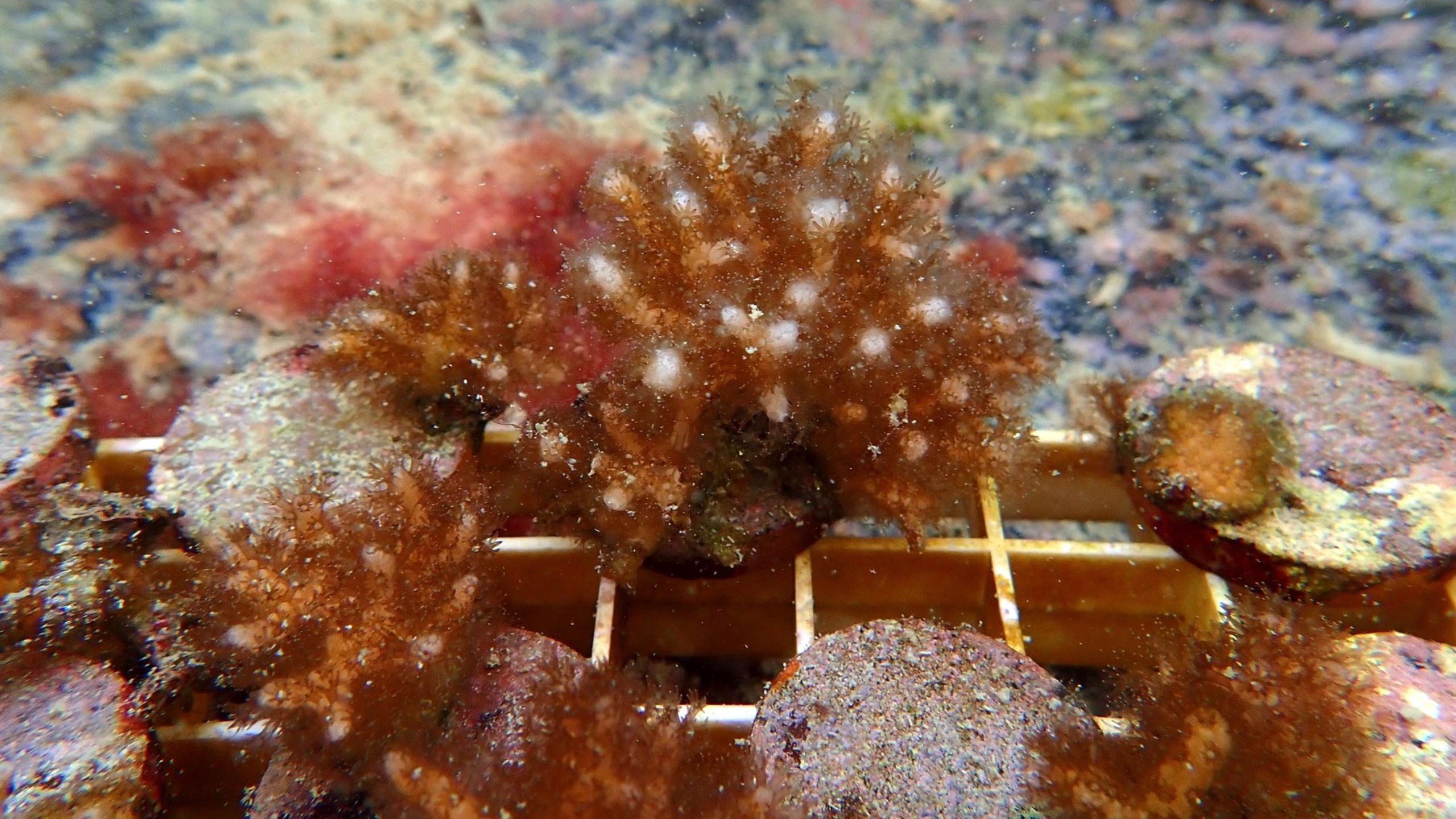


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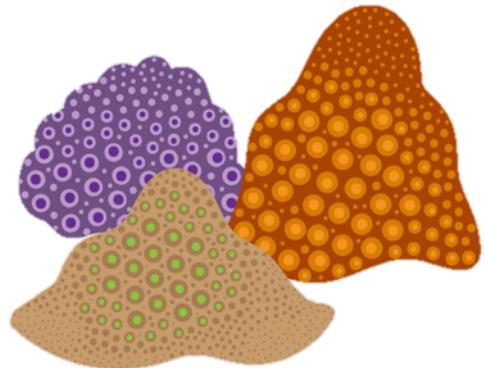
Huffmyer AS, C Drury, E Majerova, N Bean, C Harris, JD Lemus, RD Gates. Tissue fusion provides a survival advantage for juvenile *Pocillopora acuta* corals during thermal stress. *In prep.*





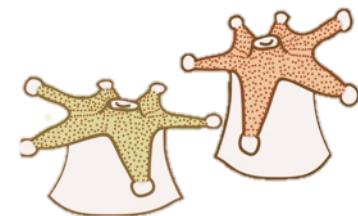
Early scientists:
Initial interest in science

Foster next-generation of scientists

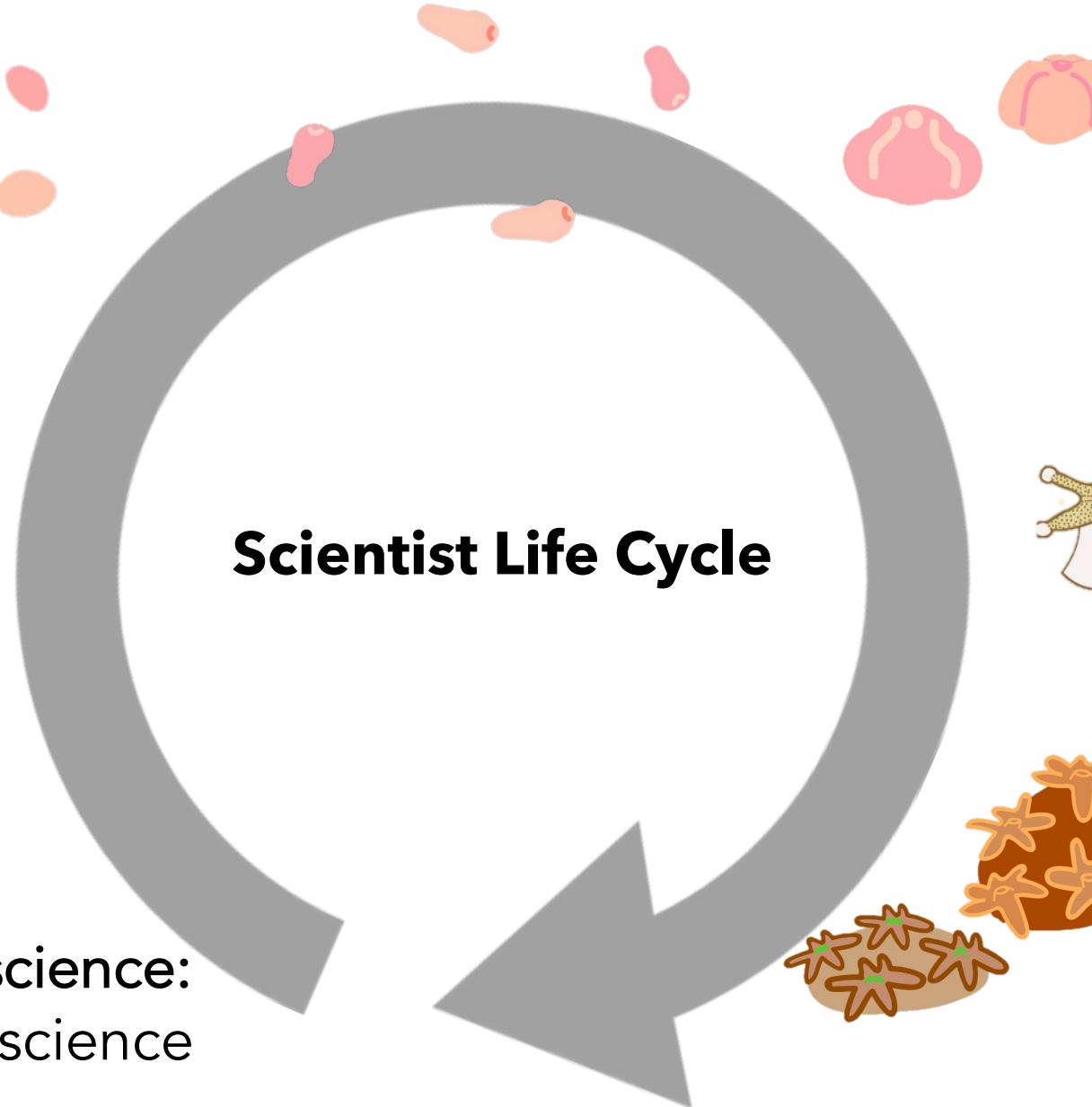
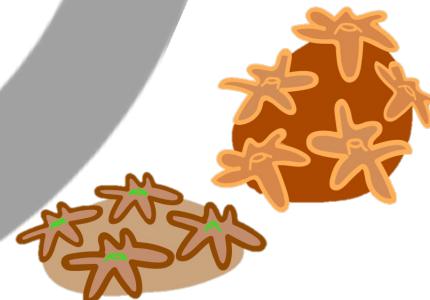


Maturation in science:
Reach desired science career

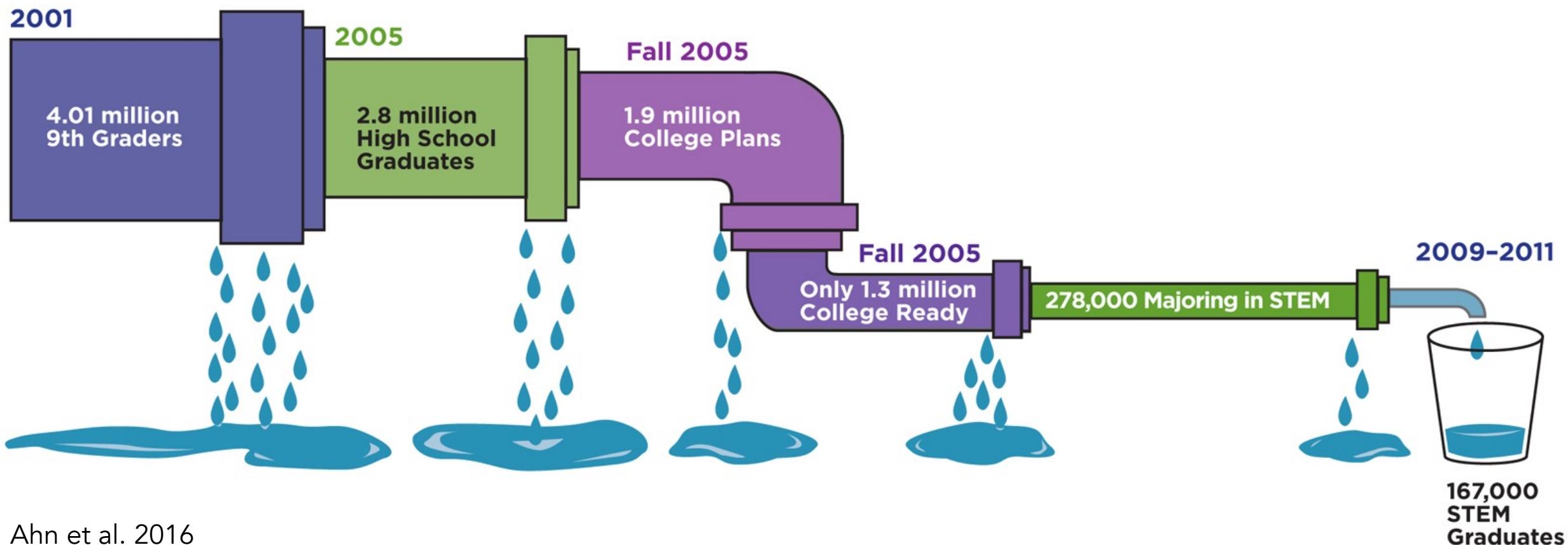
Science “recruits”:
Start science education



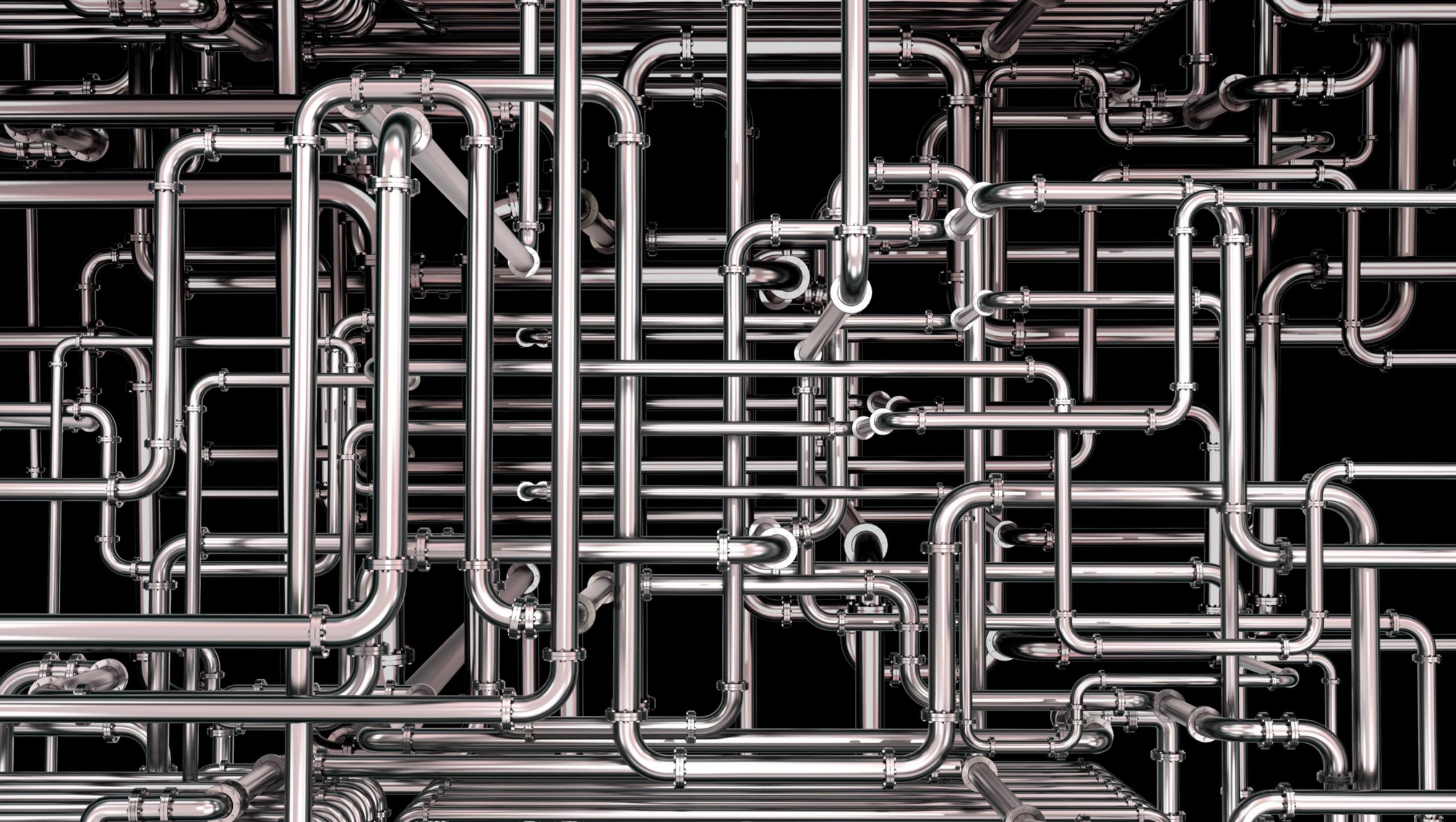
Science “juveniles”:
Development & growth in education pathway



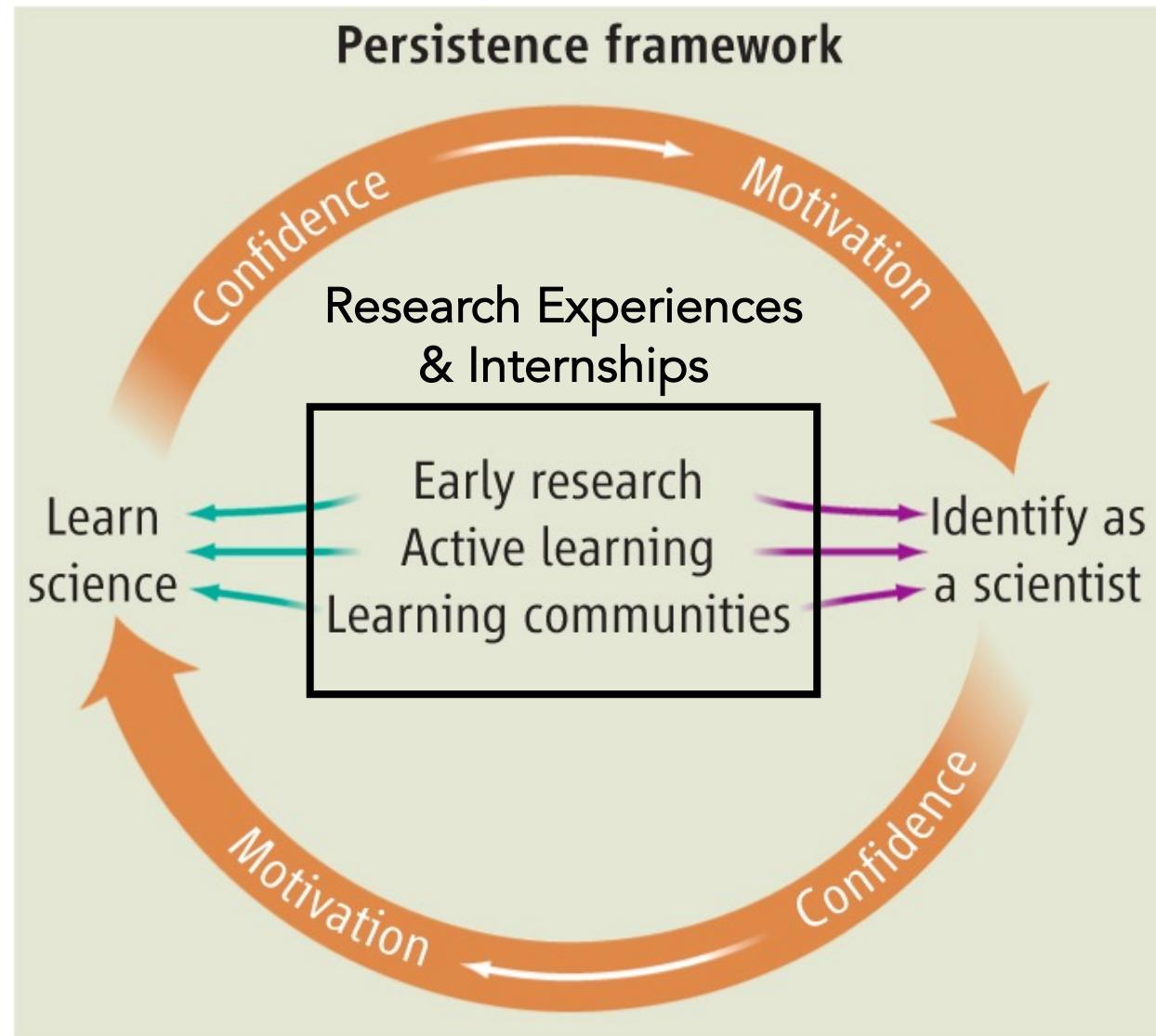
A Leaking STEM Pipeline



Underrepresented groups in STEM: Gender, race, ethnicity inequities

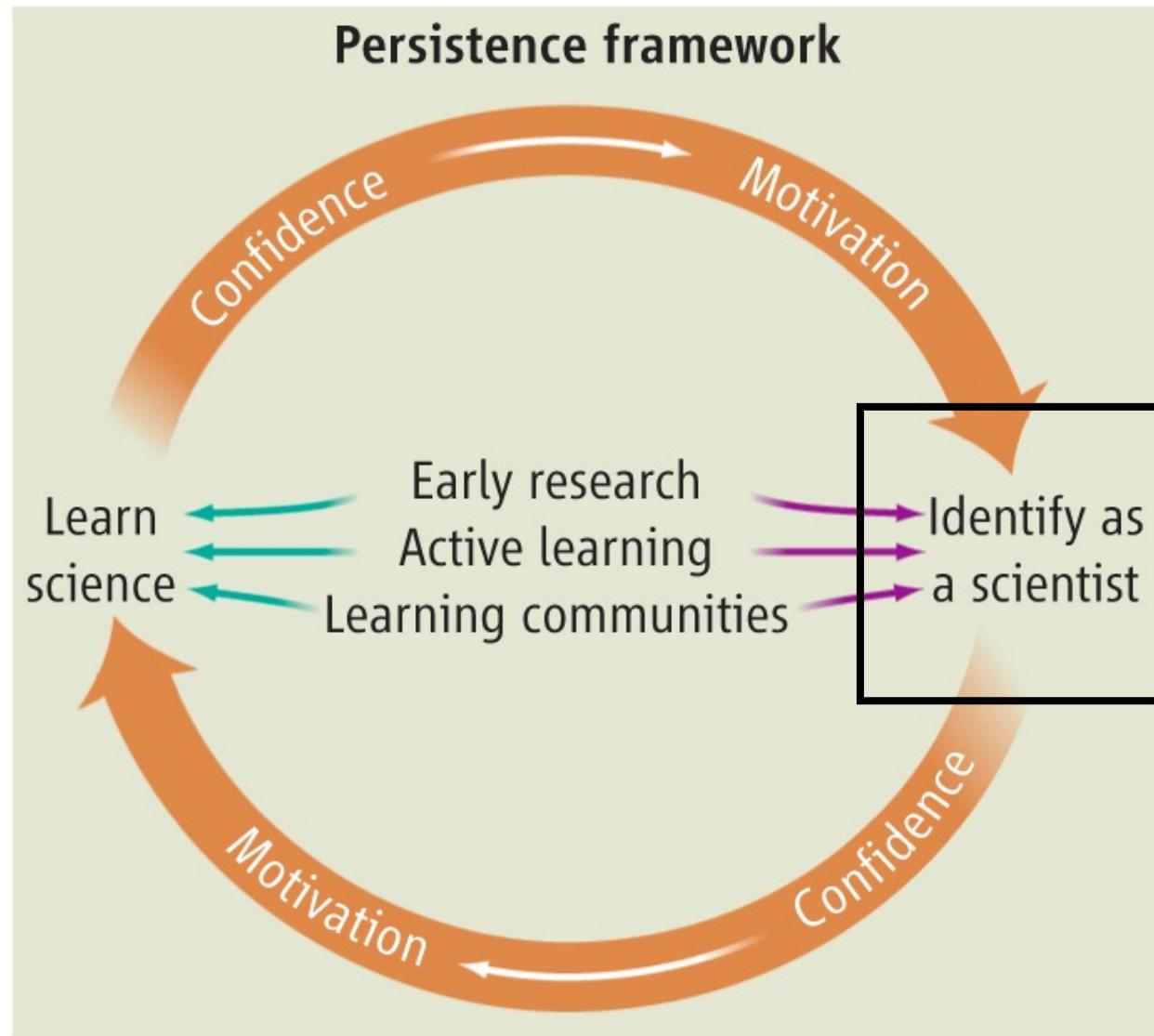


Supporting student persistence in science



Graham et al. 2013

Supporting student persistence in science



Graham et al. 2013

Expectancy-value: *Can I be successful in science?*

Personal views: *Am I a scientist?*

Interest: *Am I interested in science?*

Views of others: *Do others view me as a scientist?*

Science Identity

Mismatches: *Is science what I expected it to be?*

Values: *Is science important to me?*

Motivation: *What kind of scientist am I?*

Social environment: *Do I “fit in” in science?*

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Persistence

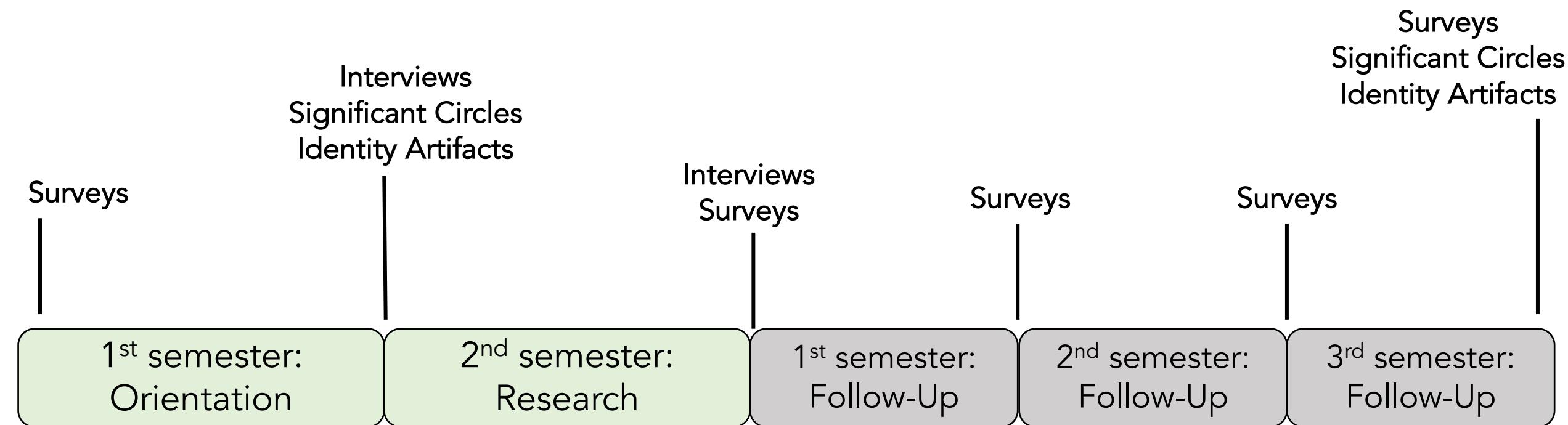
Values: *Is science important to me?*

Motivation: *What kind of scientist am I?*

Social environment: *Do I “fit in” in science?*

How does early participation in research influence community college student science identities and career trajectories?

Impacts of experience, science identity, trajectories





Independent research projects in coral biology

||

1st semester:
Orientation

2nd semester:
Research

1st semester:
Follow-Up

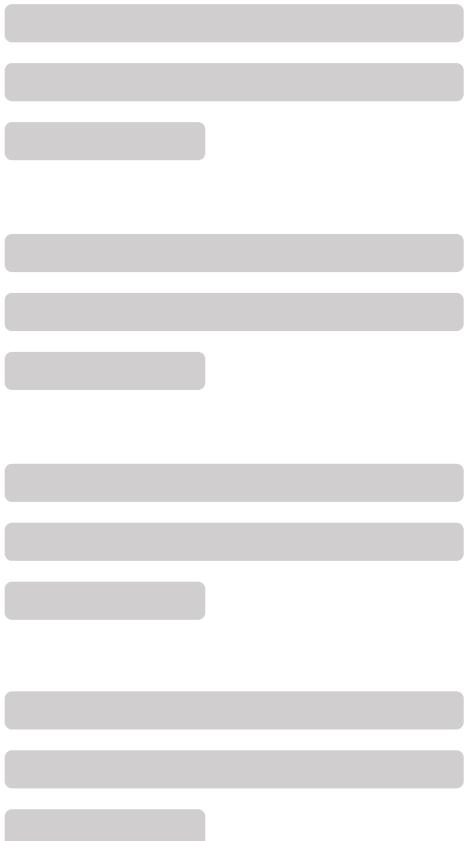
2nd semester:
Follow-Up

3rd semester:
Follow-Up

Qualitative research: Thematic analysis

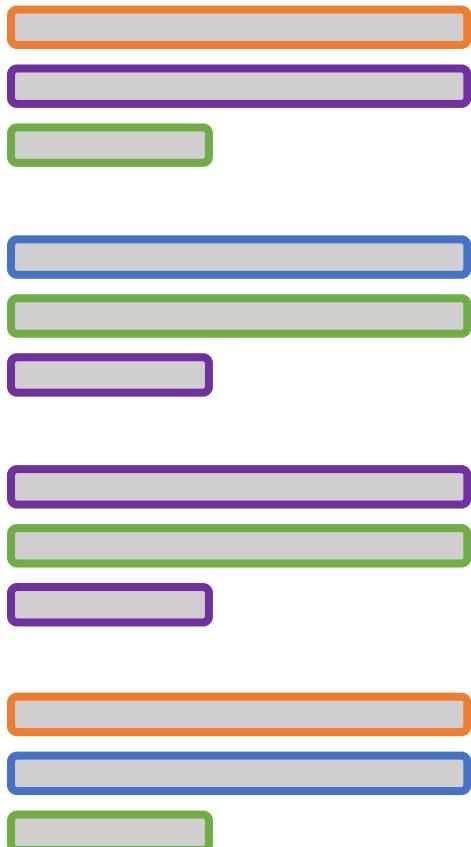
Raw Data: Transcript

Open Coding

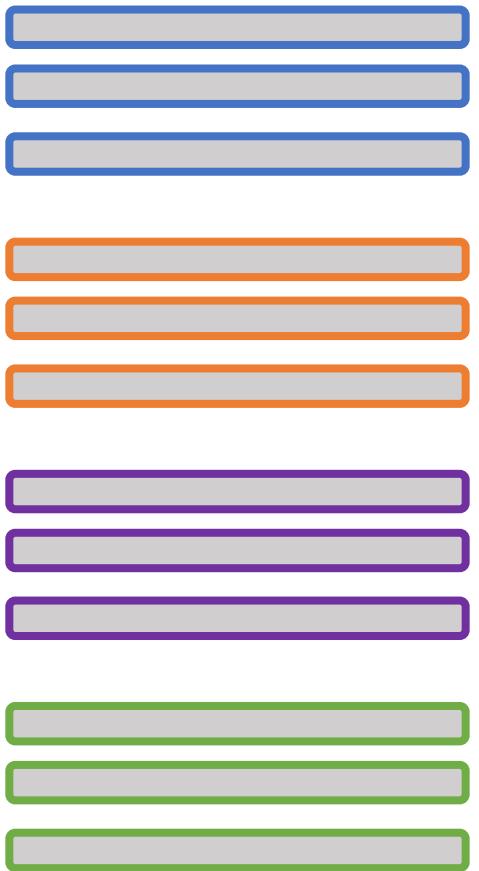


Qualitative research: Thematic analysis

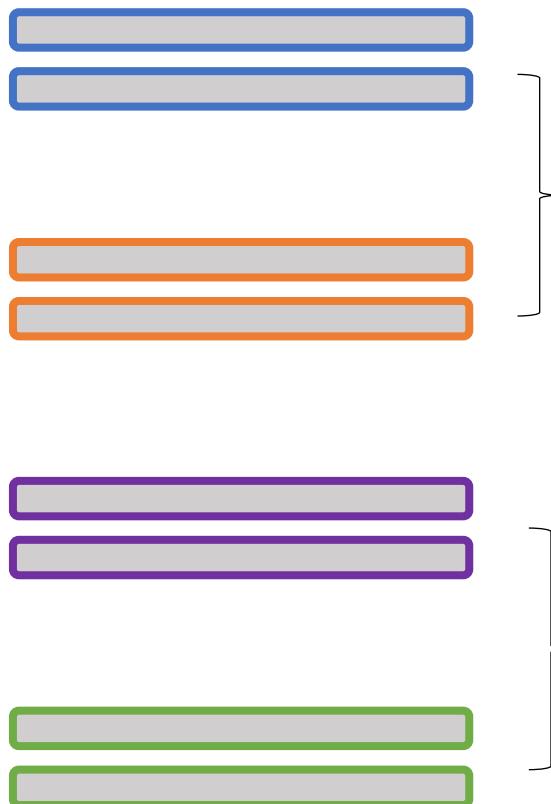
Raw Data: Transcript
Open Coding



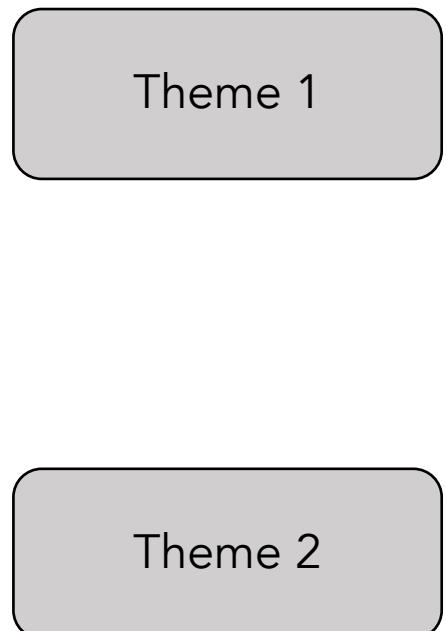
Secondary Coding



Axial Coding



Themes



1. Students reported increases in science understanding

Coral Biology

"I gained more knowledge about corals."

"I loved learning about corals."

Scientific Practices

"Showed me how real research is done."

"I learned science is never linear."

Understanding of their own interests

"I realized I could not see myself in a lab."

"Helped me realize my passionate interests."

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Involve early education students in internships

2. Students were challenged by data analysis

"I am good at everything in research except the math."

"I need to work on how to understand data sheets."

"I had a hard time with data analysis and making graphs."

"Numbers and math are not my strong suit."

2. Students were challenged by data analysis

"I am good at everything in research except the math."

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"Numbers and math are not my strong suit."

Provide early & often data analysis practice during internships

3. Students expressed science identities

Views of science identity

1. Curiosity & desire to learn
2. Benchmarks & qualifications

"Yes, I am a scientist. Anyone who wants to learn more about the environment or world around them is a scientist."

"I'm not at the PhD level, but I think I fit along the lines of a scientist because I'm curious and I want to know about life. So, I think that's good enough."

"Junior scientist... I feel like [scientists] have at least an Associate's or some experience like a real job."

... but were unsure of their professional identity

Professional Identity

Student identification with a career that fits their motivations, interests, and goals in science.

“I don’t really know what I would do as a job.”

“I don’t know if there is a job description out there for me.”

Five Semesters

Research in a lab



Marine geology

Marine biology



Marine research

Work with animals



Wildlife conservation

Ocean engineering



Environmental planning

Marine research
& education



Biology, conservation &
community outreach

Five Semesters

Research in a lab



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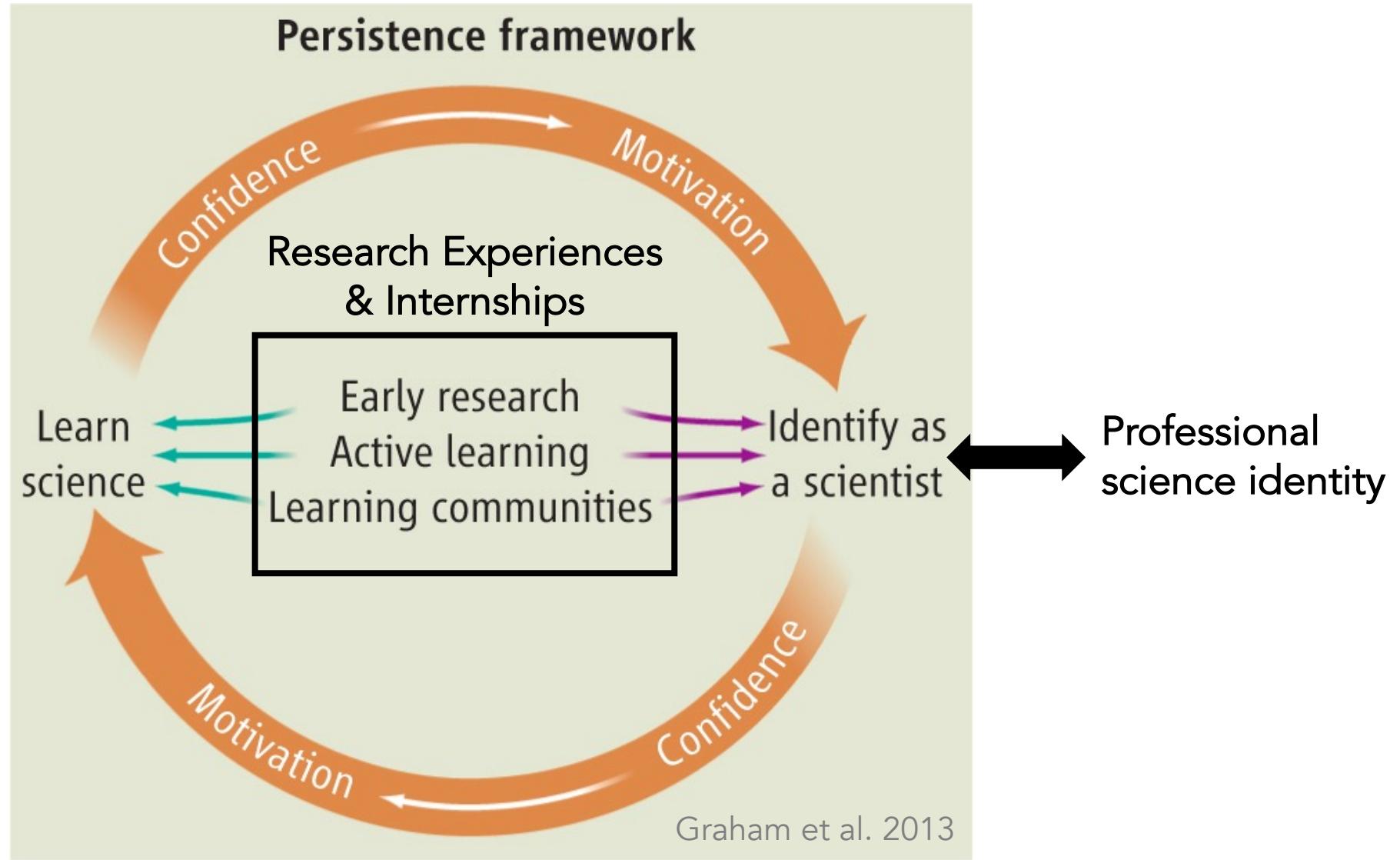
Marine research
& education



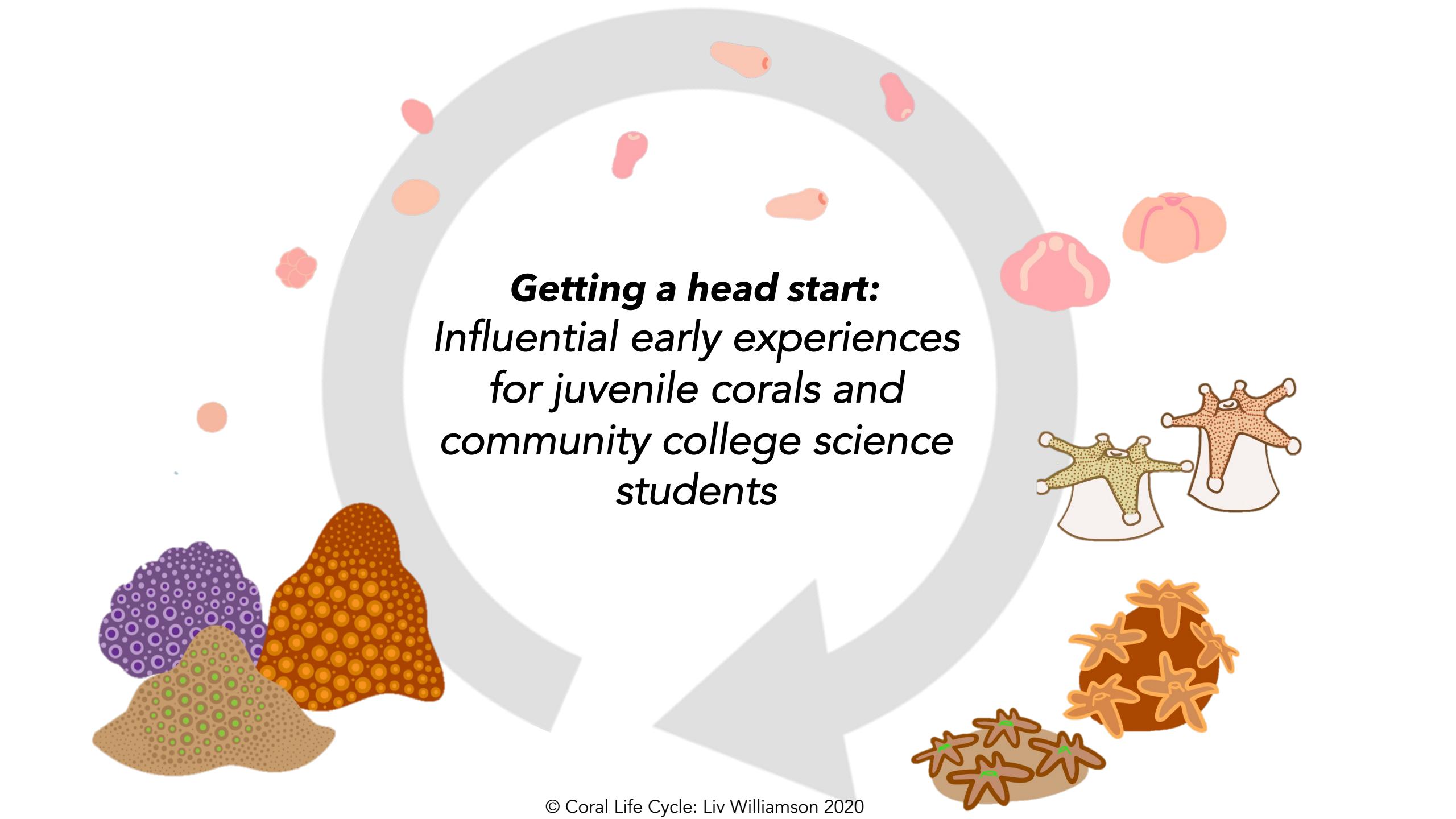
Biology, conservation &
community outreach

Incorporate student identity discussions and career coaching

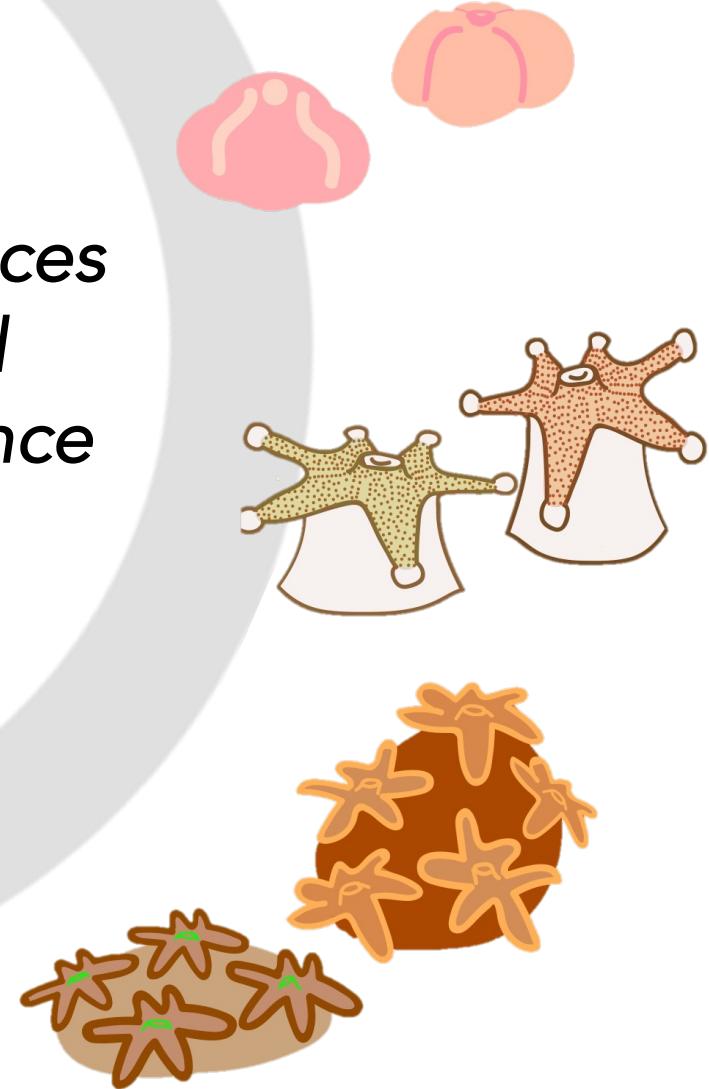
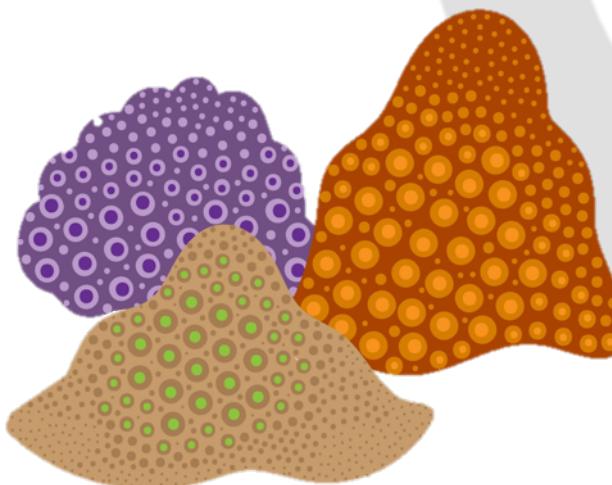
Supporting identity development in early education



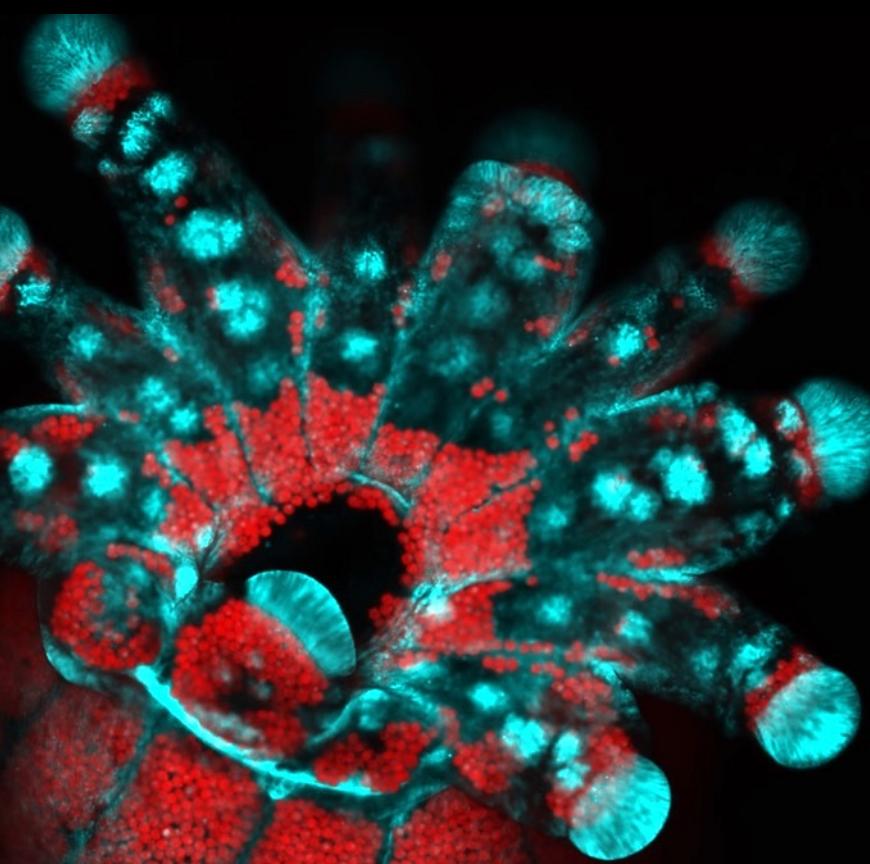
Huffmyer AS, T O'Neill, JD Lemus. Expanding our understanding of science internships for community college students: A need to integrate learning and science practice with support for professional identity in science. *In prep.*



Getting a head start:
Influential early experiences
for juvenile corals and
community college science
students



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