Acclimatization Strategies: Physiological & Genomic Responses of the Coral Holobiont

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PUTNAM LAB

NSF

BSF
United States – Israel
Binational Science Foundation

Outline

LMU, Path to PhD

Coral Holobiont

Climate Change:
- Ocean acidification
- Temperature

Topic Background:
- Acclimatization
- Physiology
- Genomics

Current Projects

Future Directions

Conservation

Undergraduate Research

LOYOLA MARYMOUNT UNIVERSITY
Intertidal **Eco-physiology**

Undergraduate Research

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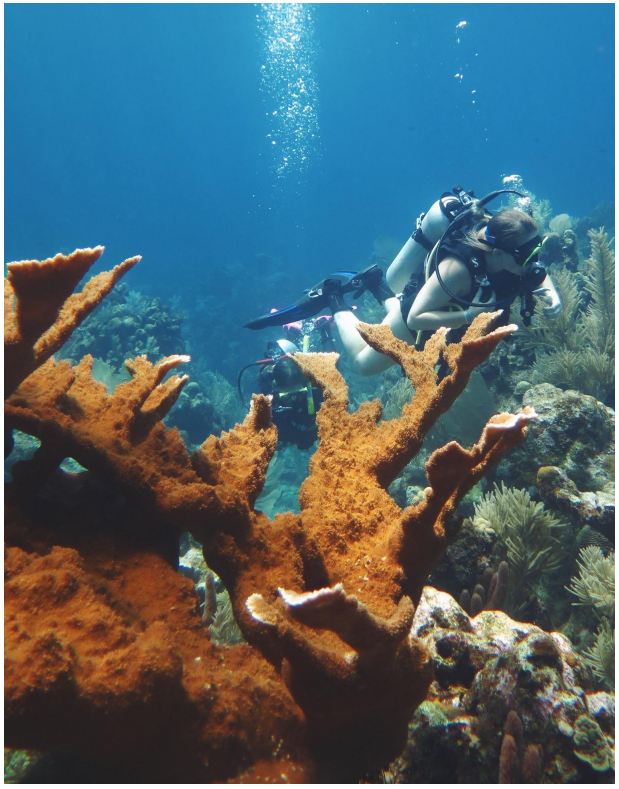
Intertidal **Eco-physiology**

ROATAN INSTITUTE FOR MARINE SCIENCES
Coral Reef Ecology



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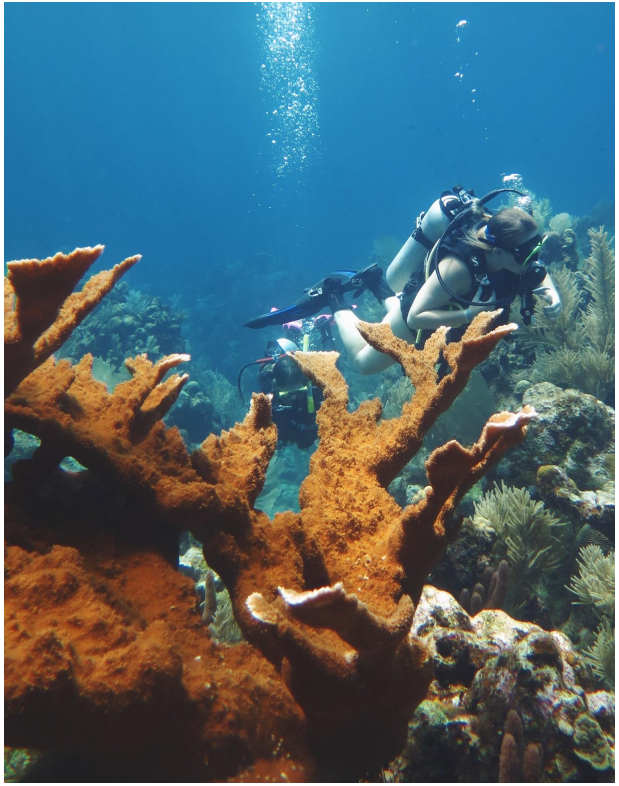
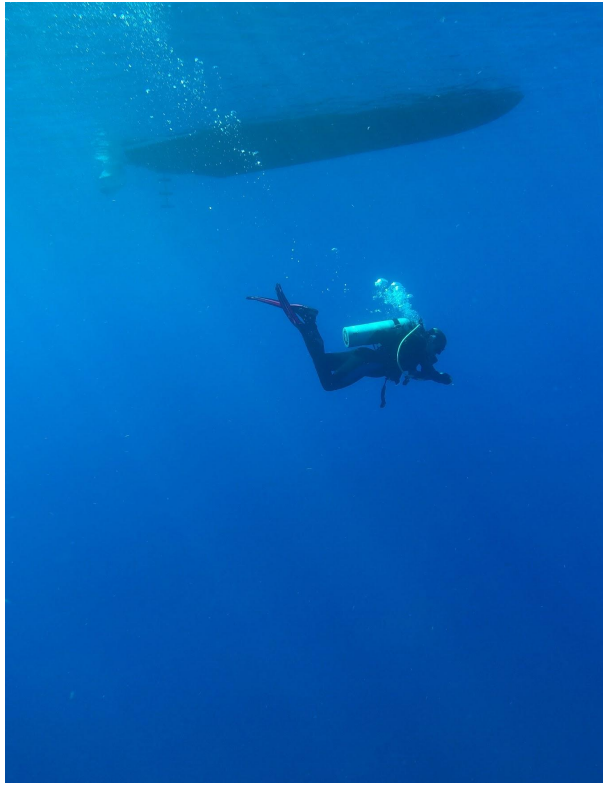
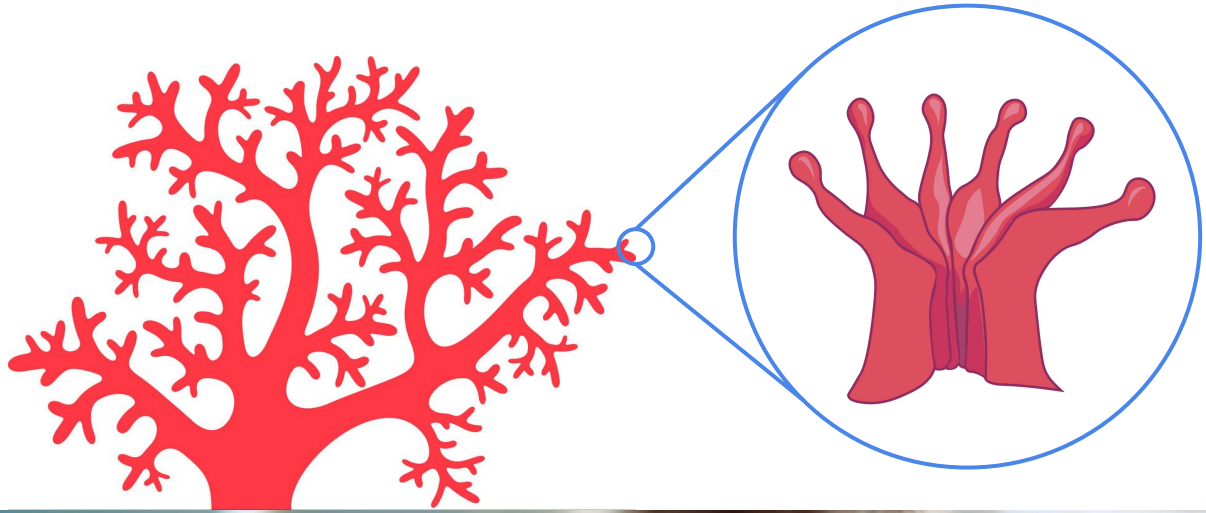


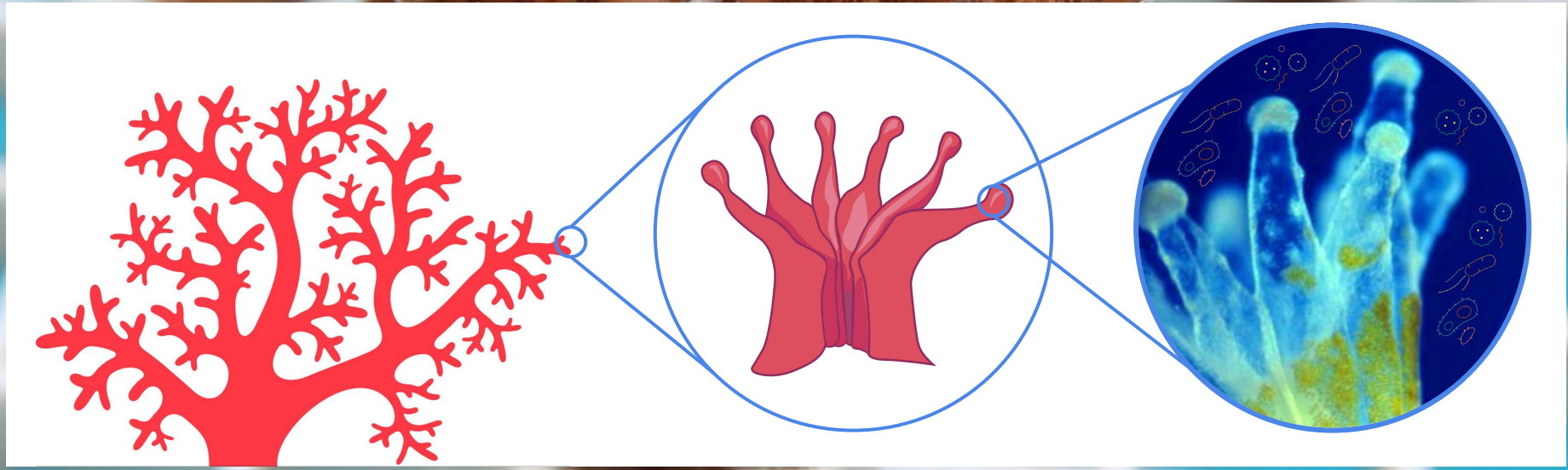
BERMUDA INSTITUTE OF OCEAN SCIENCES
Molecular Ecology

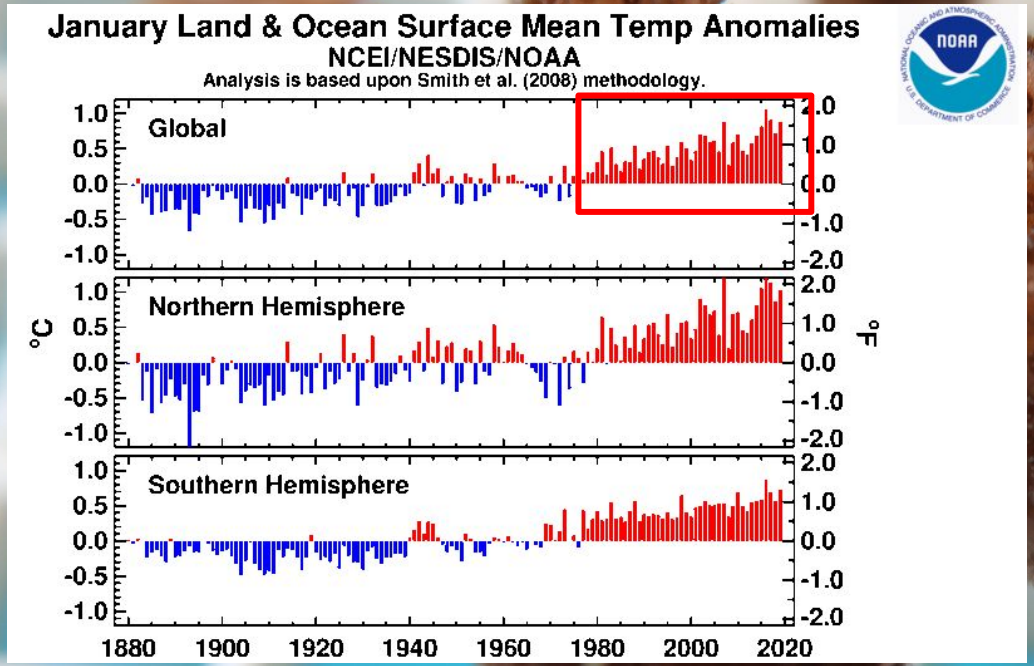


Coral Holobiont



Coral Holobiont
Coral + Symbionts + Microbiome





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- **Ocean acidification**
- **Temperature**

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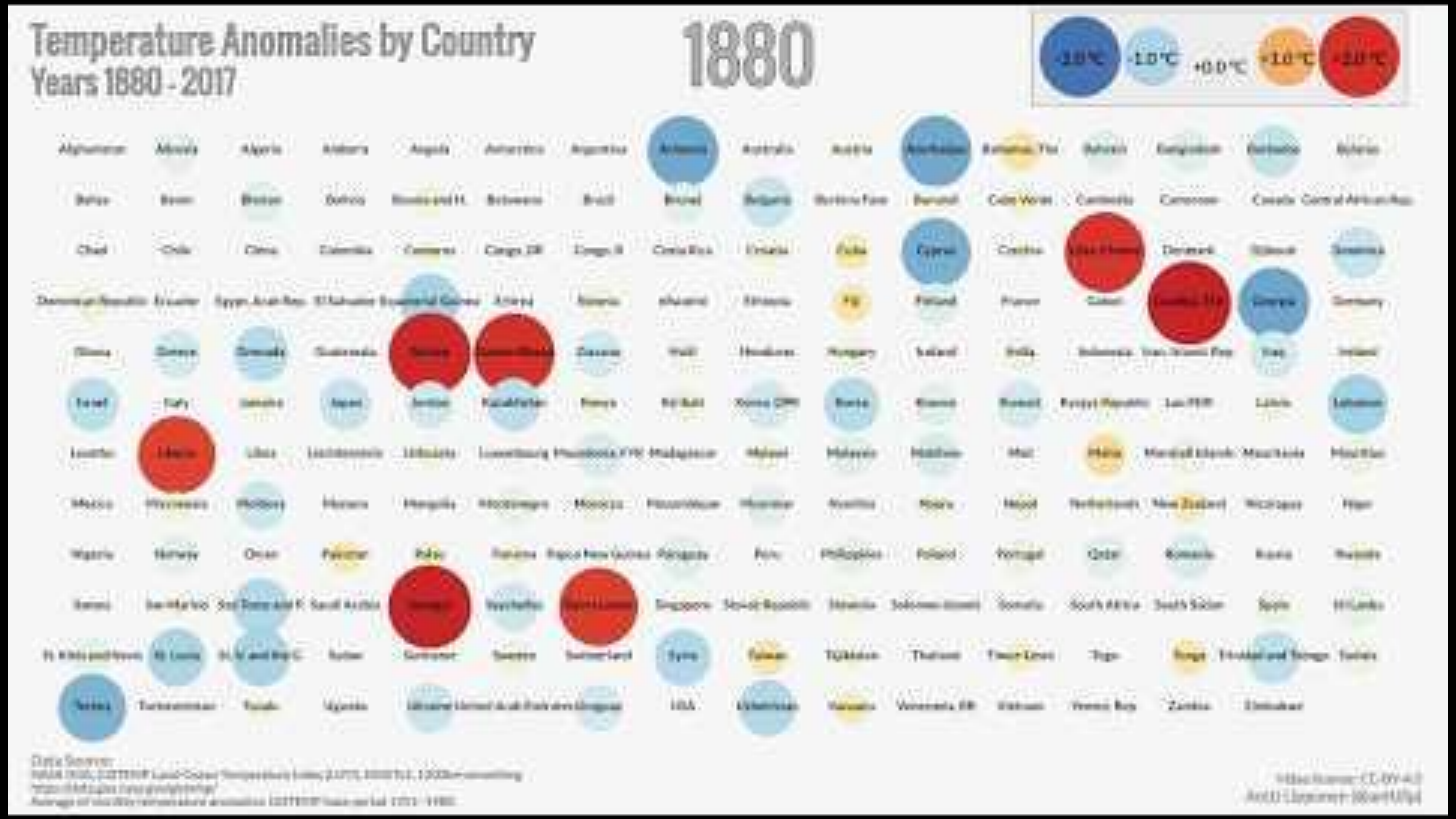
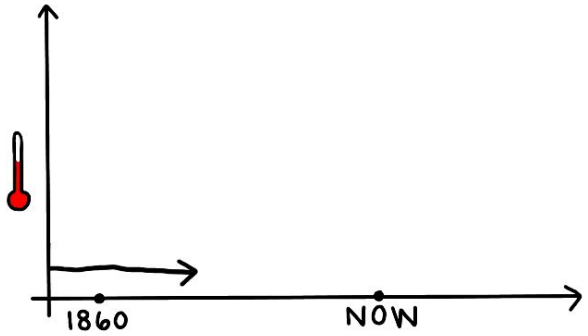

Temperature Anomalies by Country
Years 1880 - 2017
1880
-2.0°C
-1.0°C
+0.0°C
+1.0°C
+2.0°C

Why Half a Degree of Climate Change Is a Big Deal

The New York Times By: Brad Plumer & Nadja Popovich; Illustrations: Iris Gottlieb; 2018



Small Change, Big Impact

CORAL REEFS

1.5°C

Very frequent mass mortalities

2°C

Coral reefs mostly disappear worldwide.

Ocean Acidification

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$$

Carbon dioxide & water

Carbonic acid

Hydrogen & bicarbonate ions

Hydrogen ions & carbonate

↓ pH

Ocean Acidification

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$

Carbon dioxide & water

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Hydrogen & bicarbonate ions

Hydrogen ions & carbonate

↓ pH

CO_3^{2-} Ca^{2+}

$CaCO_3$

Calcium carbonate

Ocean Acidification

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$

Carbon dioxide & water — Carbonic acid — Hydrogen & bicarbonate ions — Hydrogen ions & carbonate

↓ pH

CO_3^{2-} Ca^{2+}

$CaCO_3$

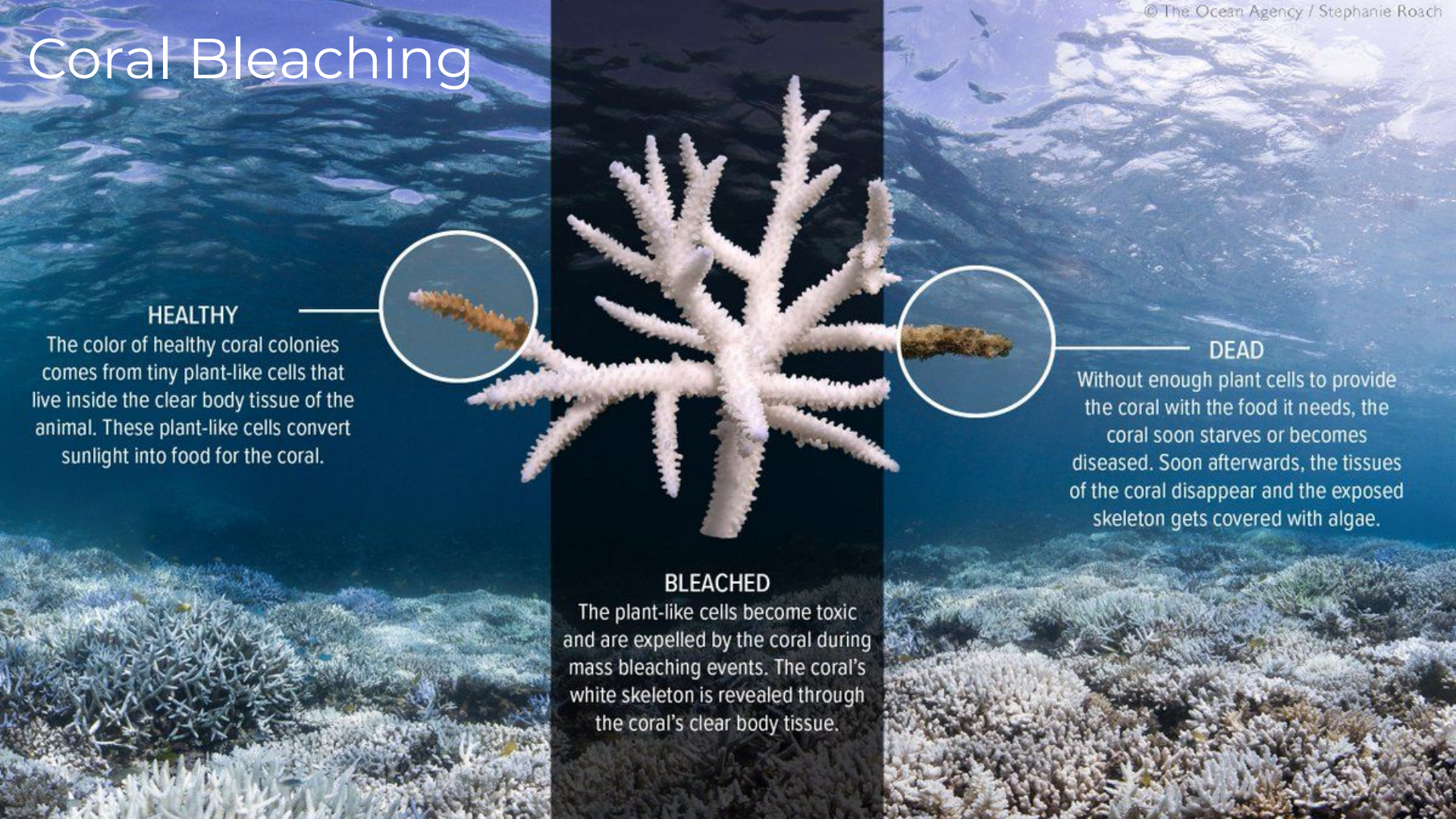
Calcium carbonate

$CaCO_3 + CO_2 + H_2O$

↓↑ Carbonate dissolution

$Ca^{2+} + 2HCO_3^-$

Coral Bleaching



HEALTHY

The color of healthy coral colonies comes from tiny plant-like cells that live inside the clear body tissue of the animal. These plant-like cells convert sunlight into food for the coral.

BLEACHED

The plant-like cells become toxic and are expelled by the coral during mass bleaching events. The coral's white skeleton is revealed through the coral's clear body tissue.

DEAD

Without enough plant cells to provide the coral with the food it needs, the coral soon starves or becomes diseased. Soon afterwards, the tissues of the coral disappear and the exposed skeleton gets covered with algae.

THE OCEAN AGENCY™

Okinawa, Japan; September 2016

THE OCEAN AGENCY™

Hawaii Institute of Marine Biology, 2018

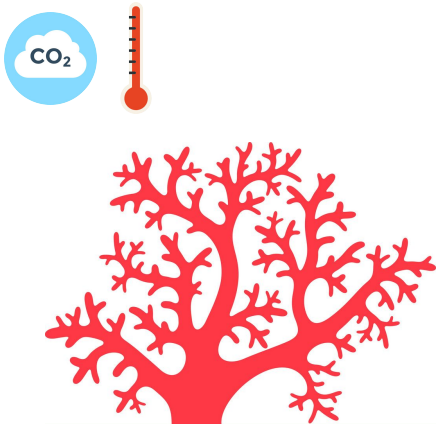
E. Strand

Major Questions:

1. What creates tolerance or sensitivity in corals?
2. Can that tolerance be “remembered”?

Acclimatization

A long-term physiological or biochemical change that occurs within the lifetime of an organism, resulting from exposure to new conditions in the environment (i.e. climate change)



Wilmer et al 2005

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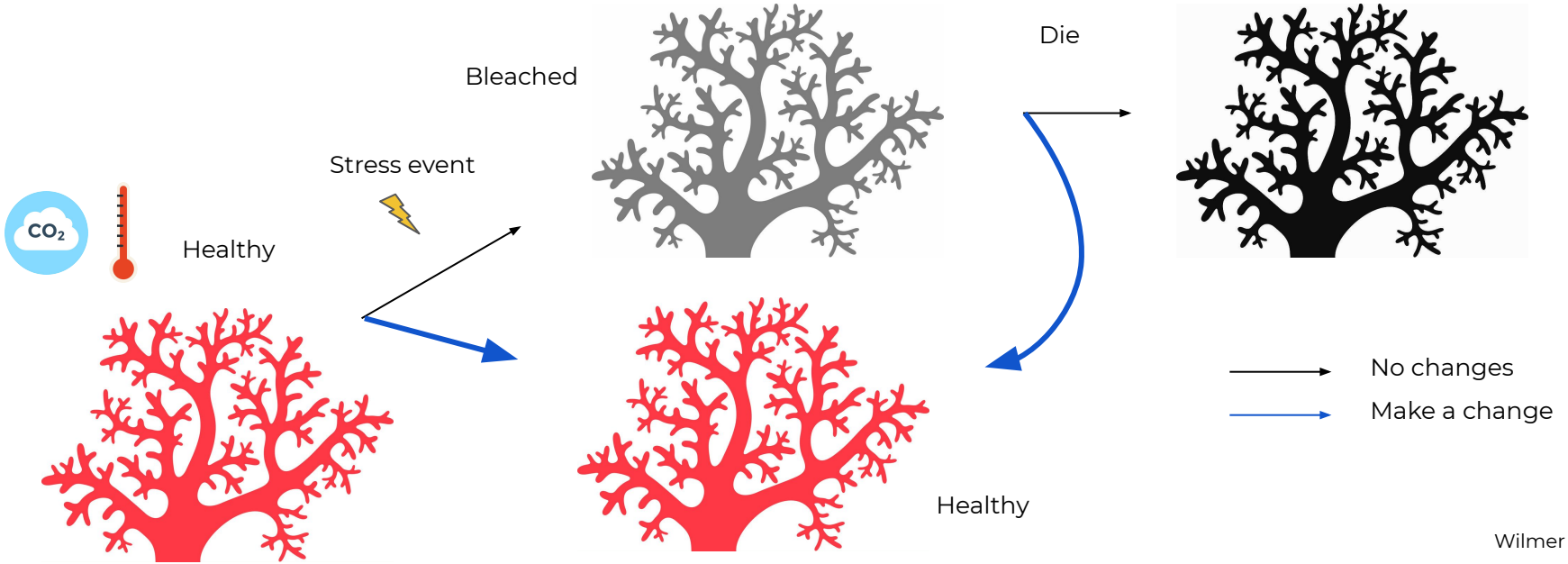
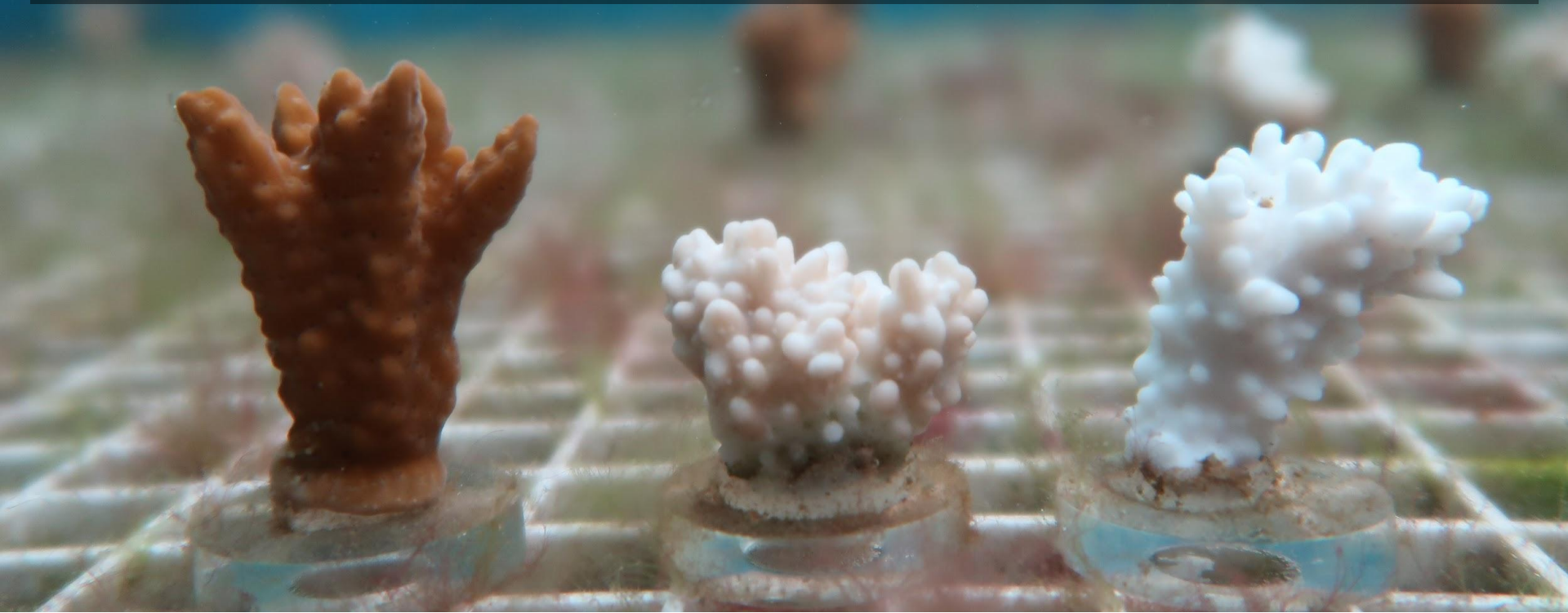


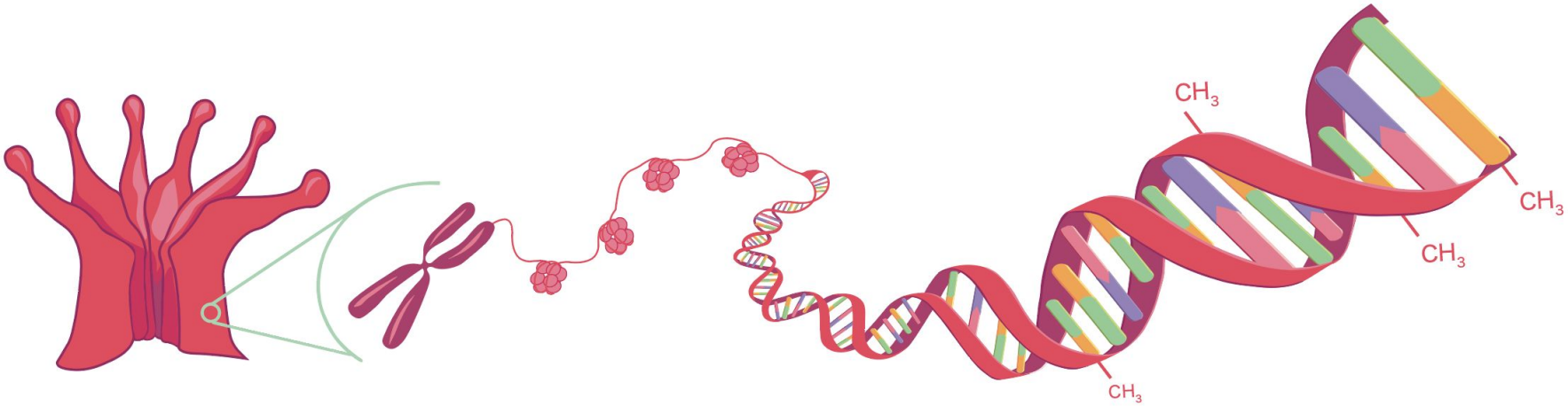
Wilmer et al 2005

What are the mechanisms underlying acclimatization?

Coral Physiology & (Epi)Genomics



Epigenetics



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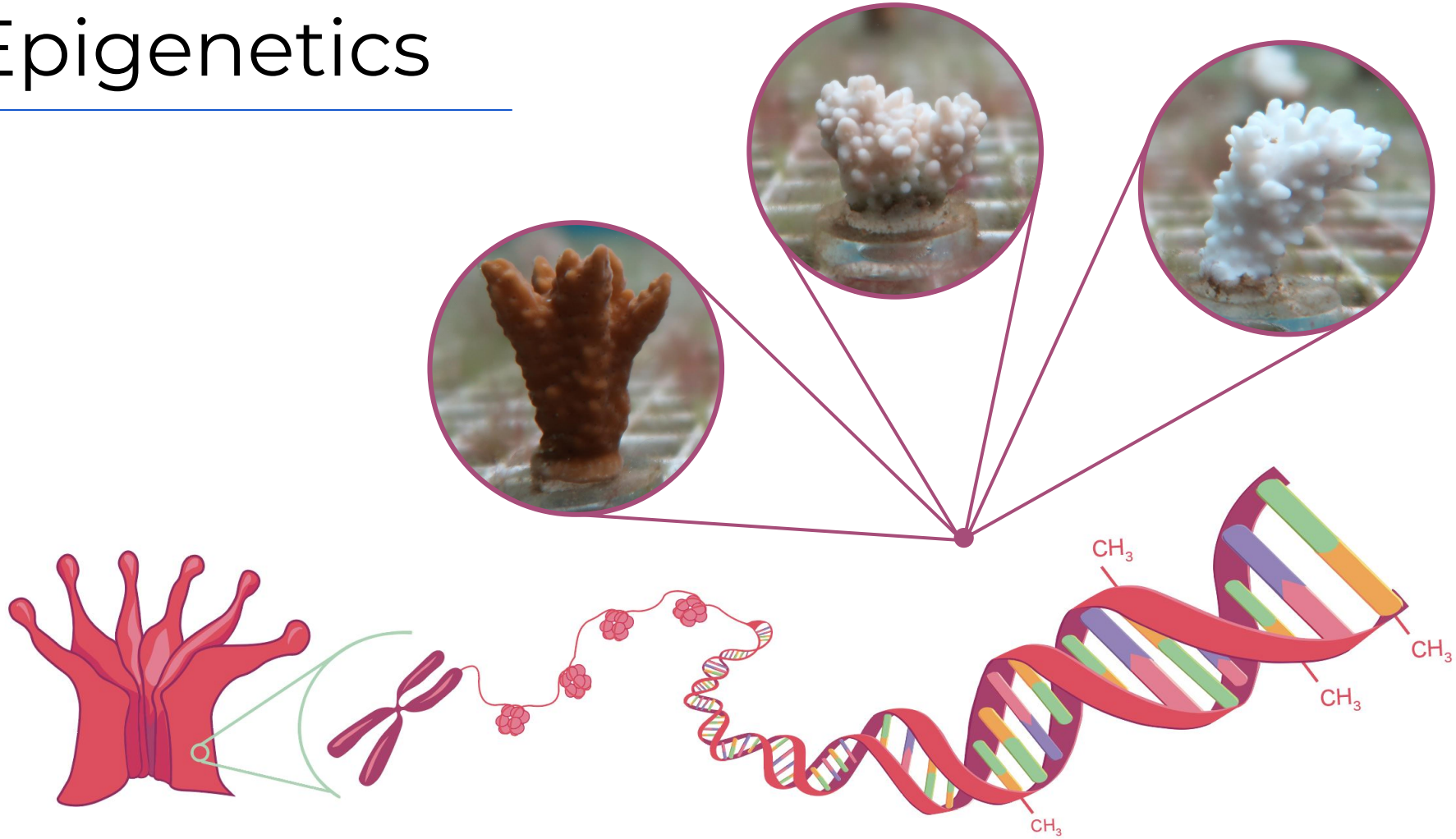
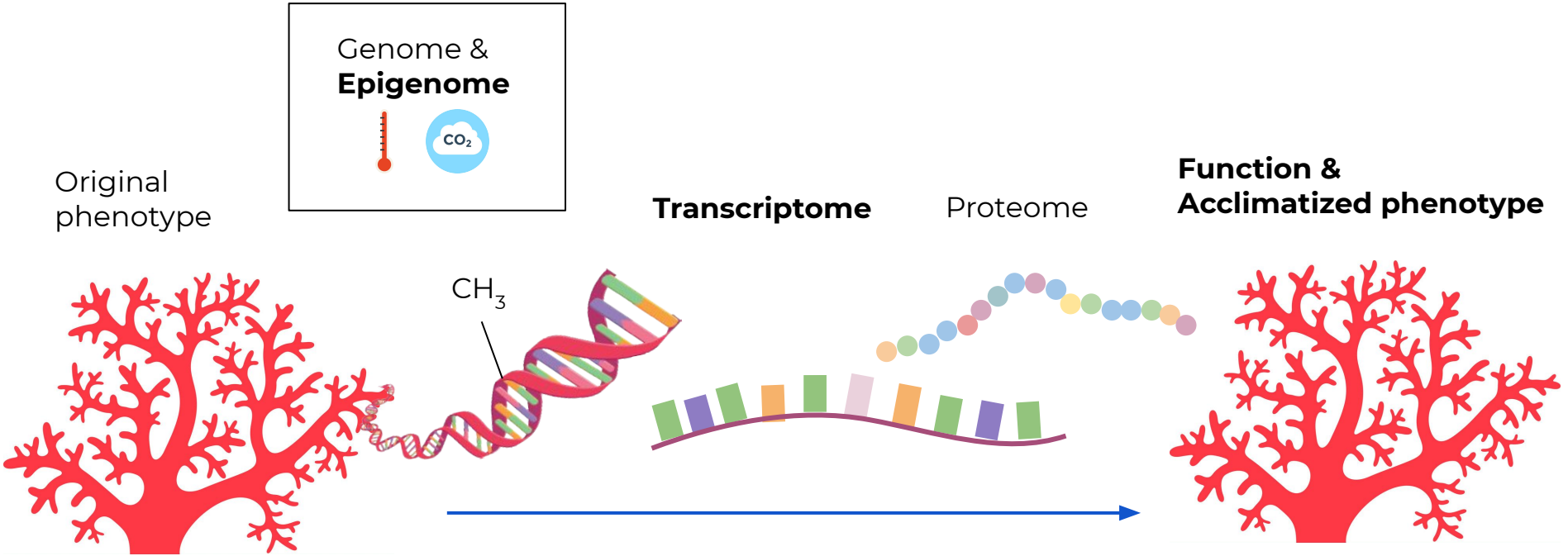


Environmental Epigenetics



Adult Coral Stress Timeseries

900 coral fragments from 6 sites in Kaneohe Bay, Oahu, Hawai'i
Montipora capitata, Pocillopora acuta
4 treatments, 12 tanks (3 per treatment)

- Ambient Temperature, Ambient pH
- High Temperature, Ambient pH
- Ambient Temperature, Low pH
- High Temperature, Low pH

2 months of stress, 2 months of recovery

Physiological Response

Coral Holobiont Metabolism:
Respiration Rates

Symbiont Metabolism:
Photosynthetic Rates

Physiological Response

Coral Holobiont Metabolism:
Respiration Rates

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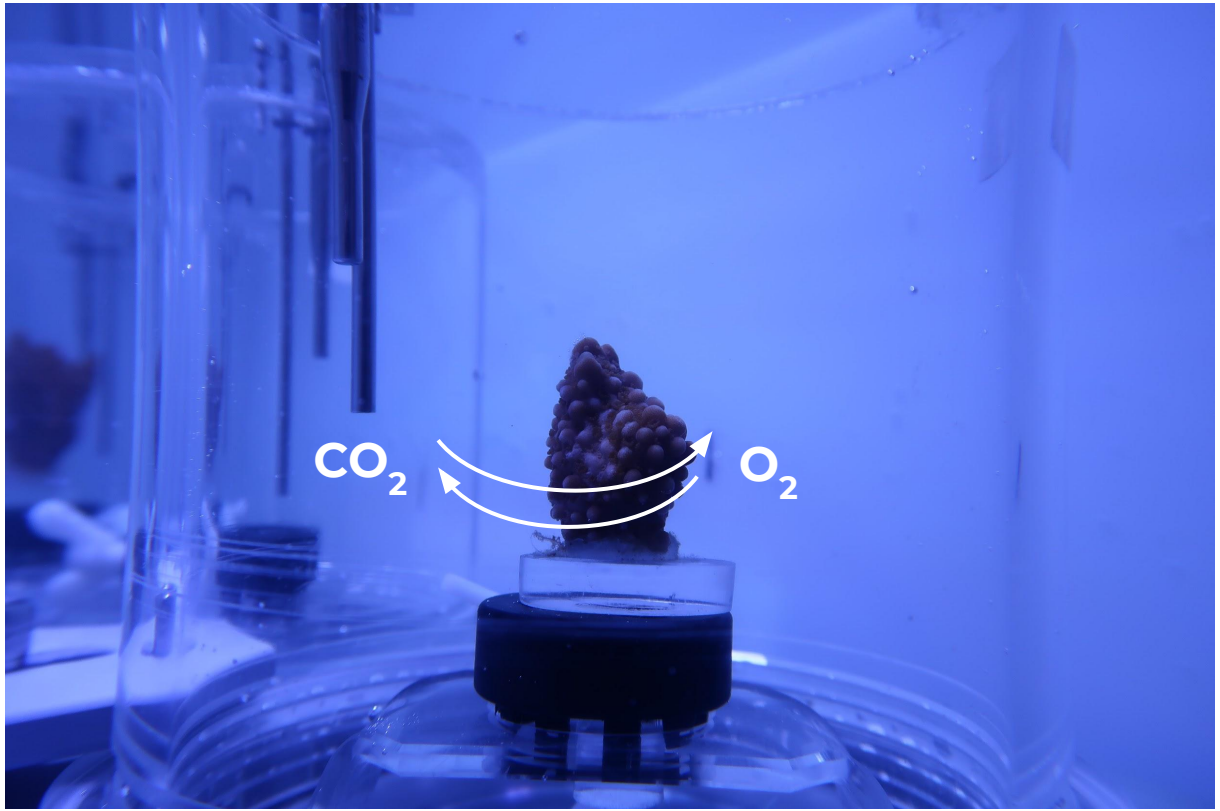
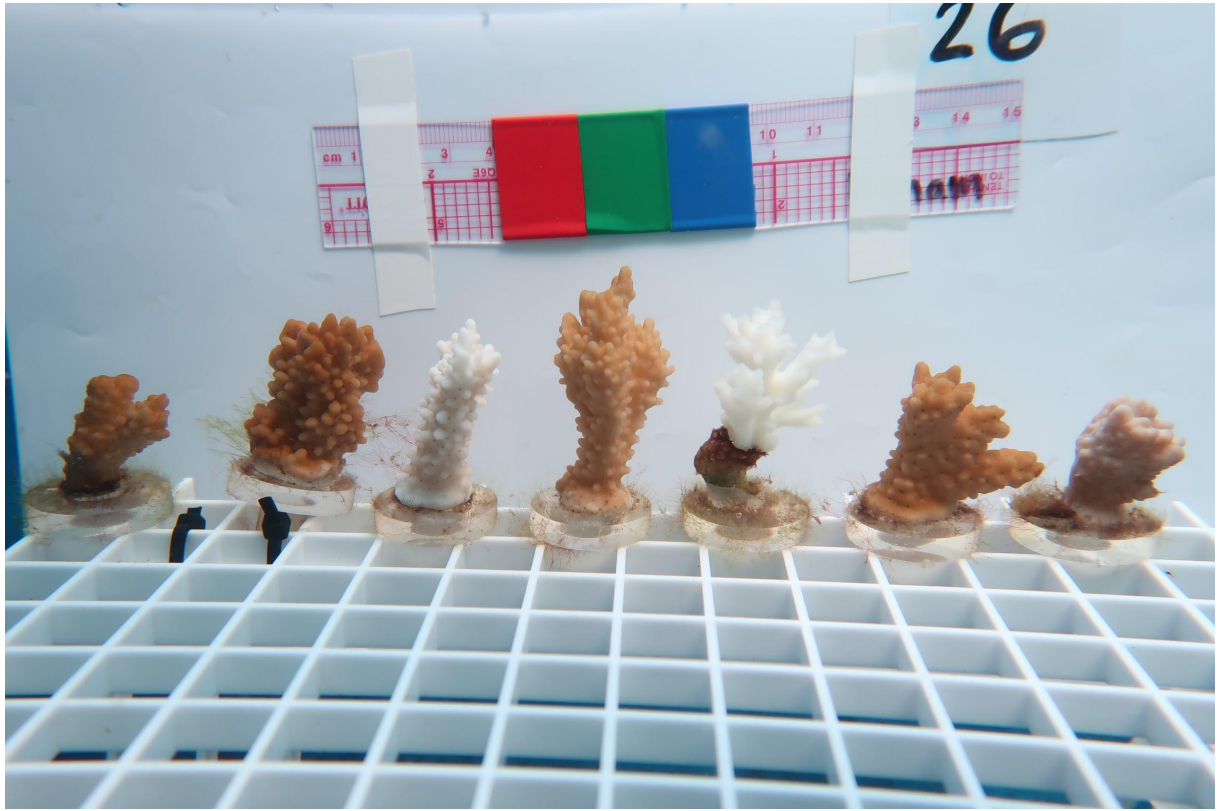
Photosynthetic Rates



Physiological Response

Coral Holobiont Metabolism:
Respiration Rates
Bleaching Score
Growth

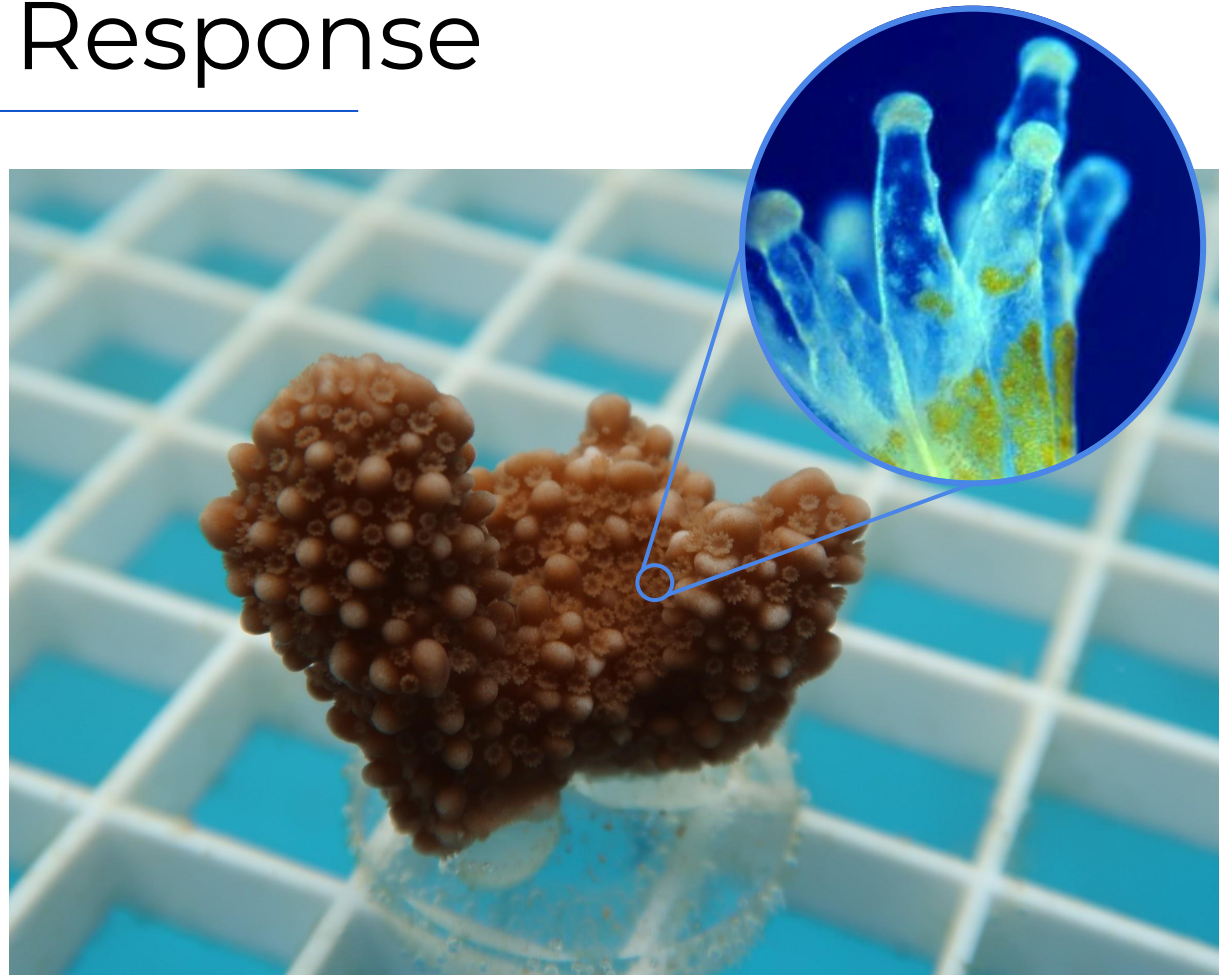
Symbiont Metabolism:
Photosynthetic Rates



Physiological Response

<u>Coral Holobiont Metabolism:</u>
Respiration Rates
Bleaching Score
Growth
Tissue Biomass
Total Protein
Total Antioxidant Capacity
Total Lipid Content

<u>Symbiont Metabolism:</u>
Photosynthetic Rates
Symbiont Density
Chlorophyll a/c Concentration

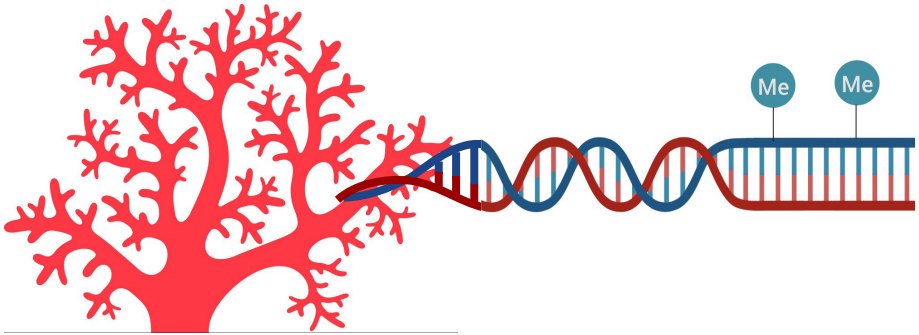


Genomic Response

Epigenetics, DNA Methylation

Differentially methylated regions of the regome

- Whole Genome Bisulfite (WGBS) and Methyl-CpG-Binding Domain Sequencing (MBD-Seq)



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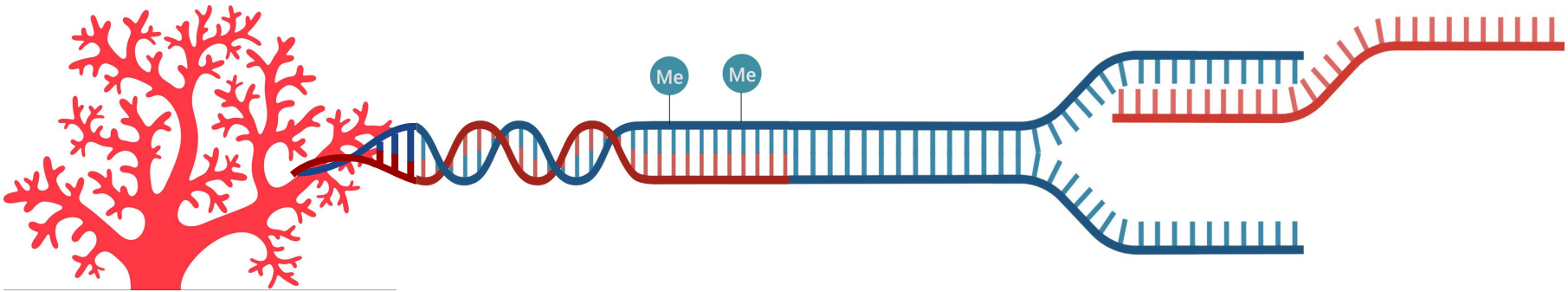
Transcriptomics, Gene Expression

Differentially expressed genes

- RNAseq



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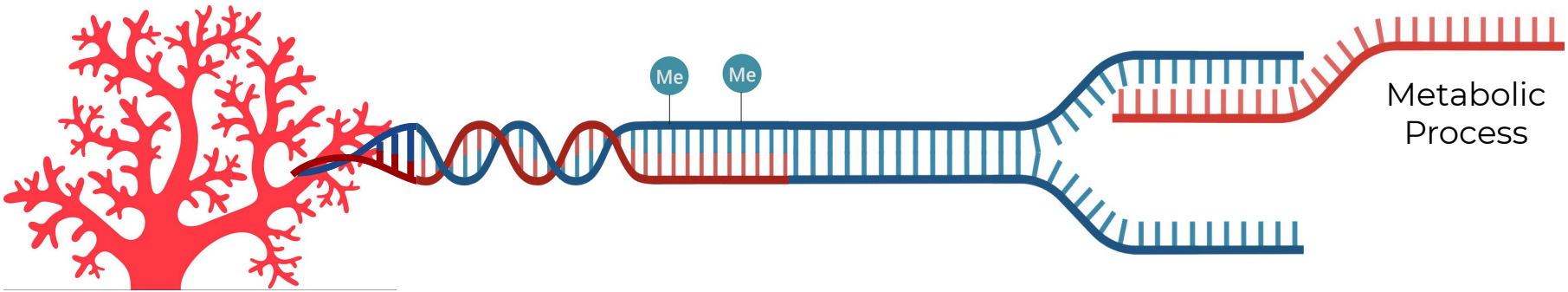
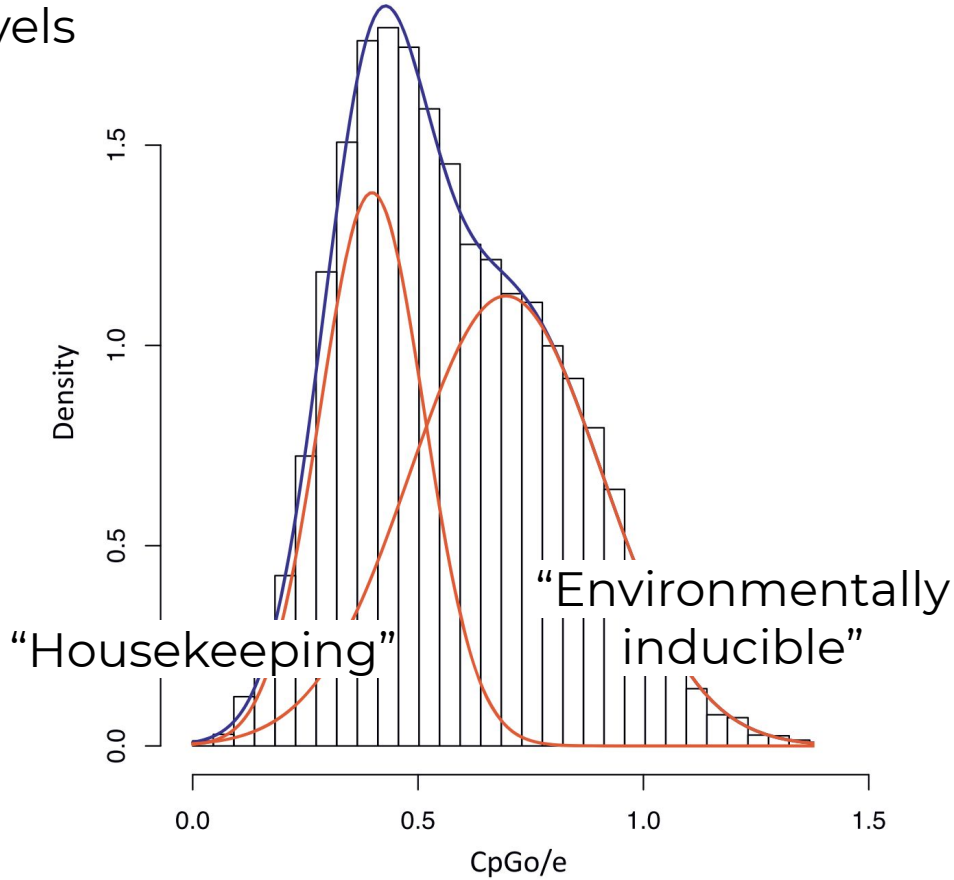
Gene Ontology, Functional Application



Genomic Response

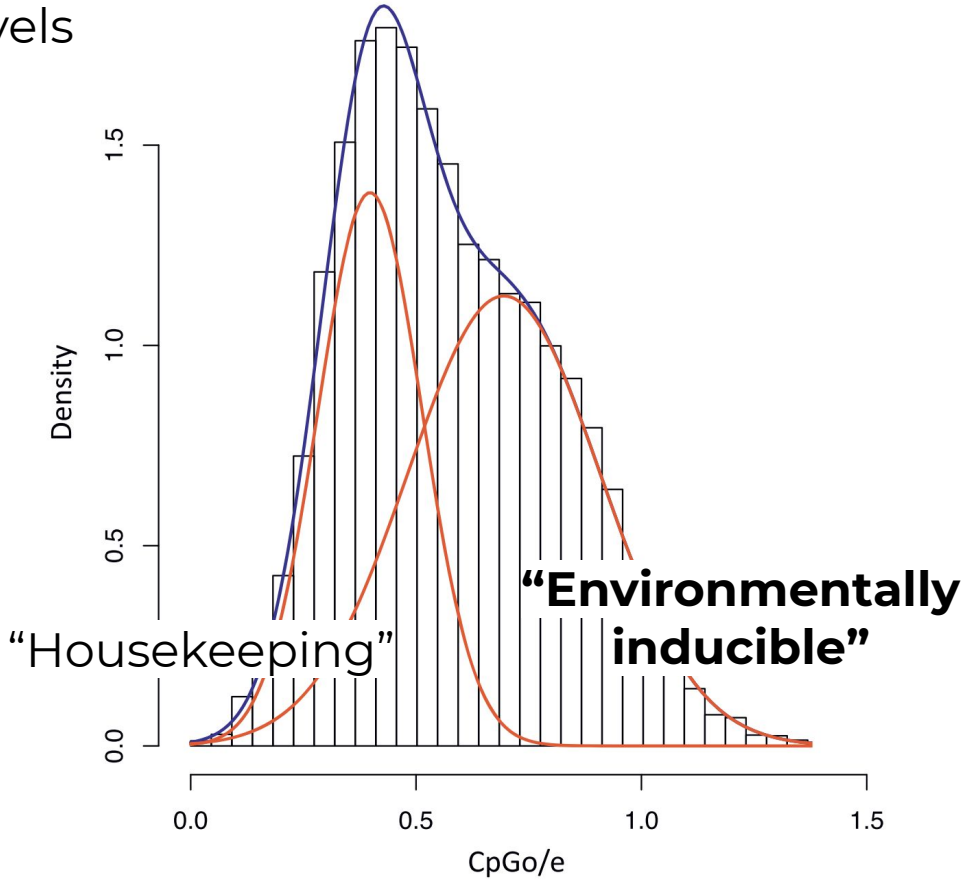
DNA Methylation levels



Gavery and Roberts et al 2010

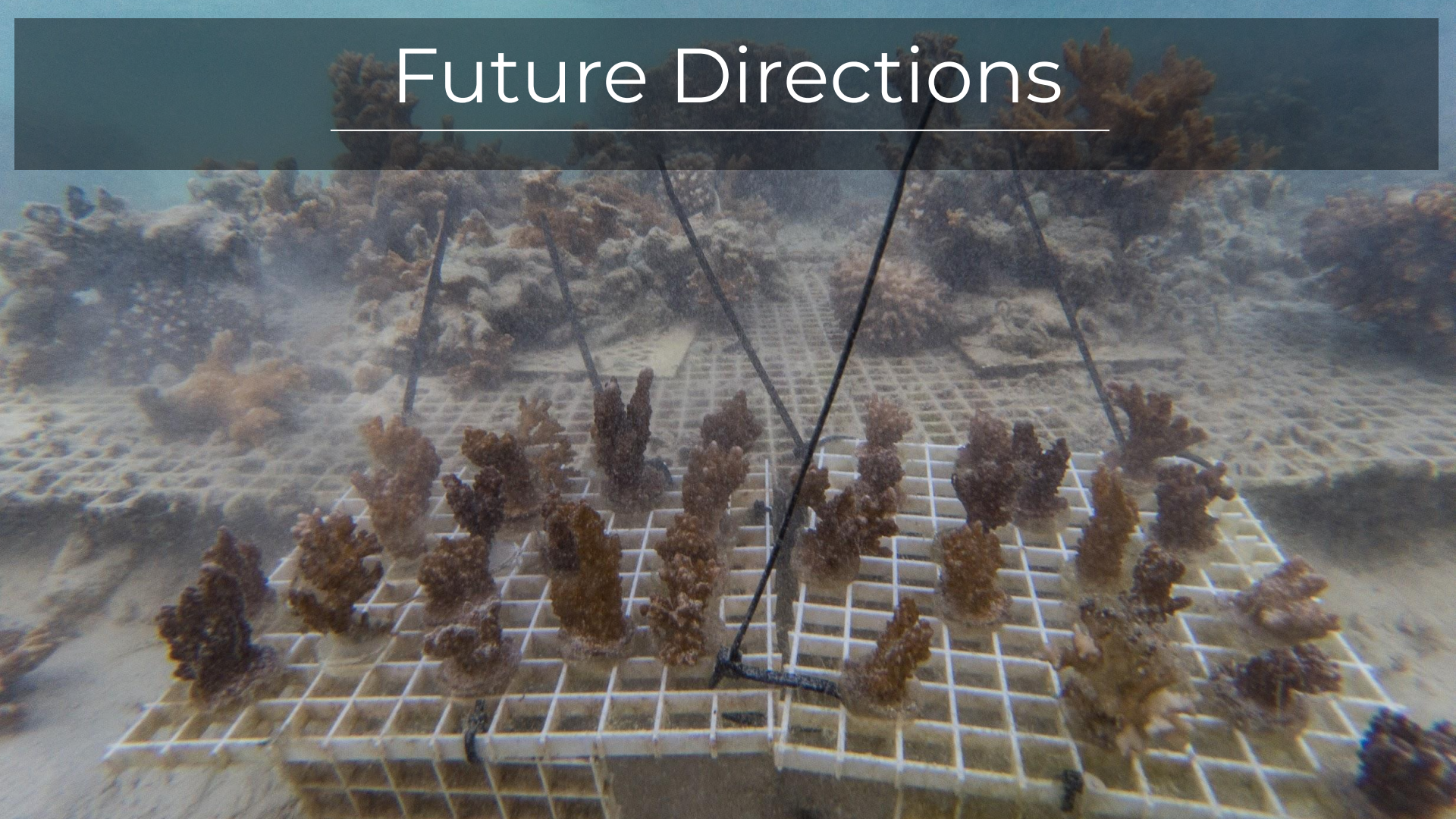
Genomic Response

DNA Methylation levels



Gavery and Roberts et al 2010

Future Directions



History Matters

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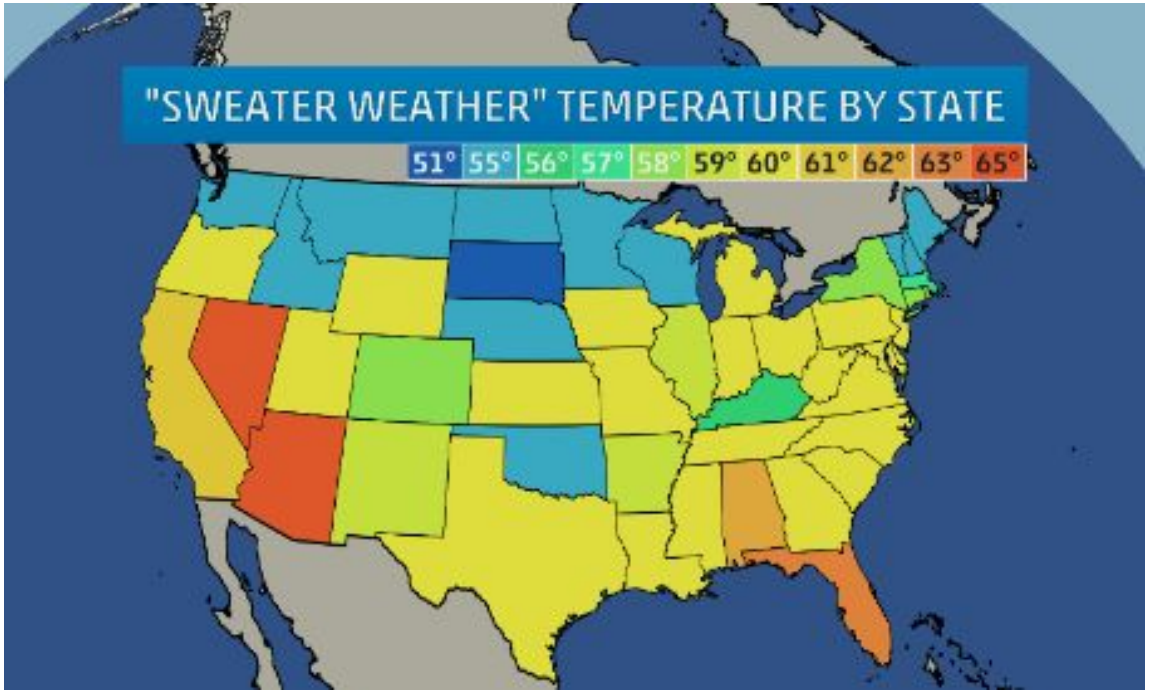

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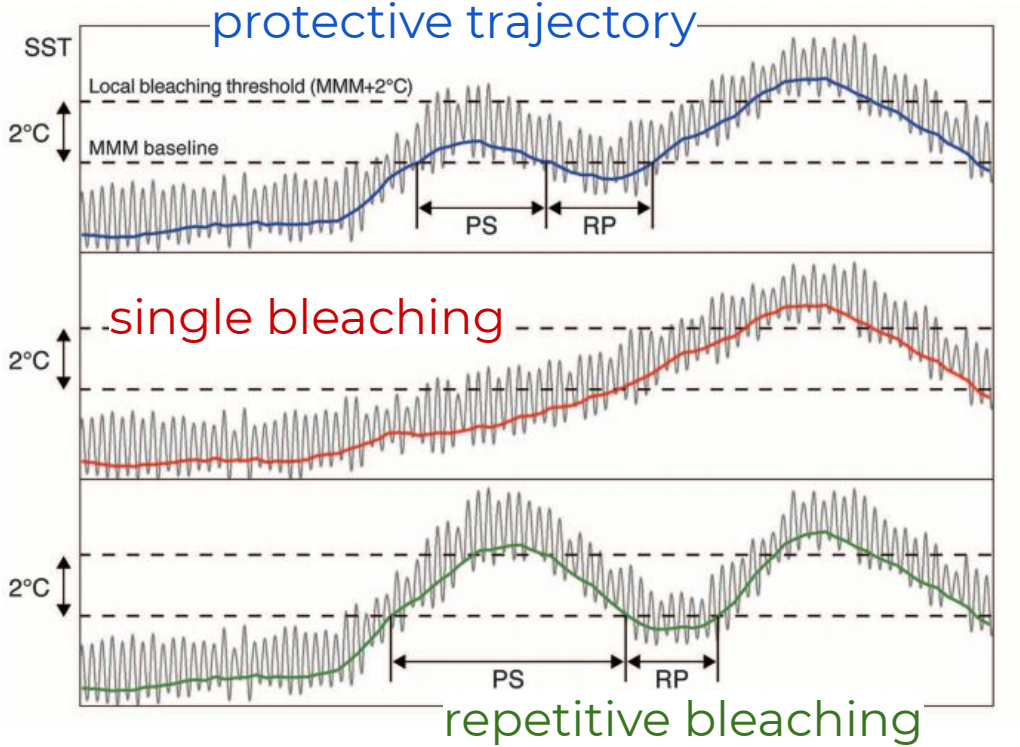
Prior Exposure:



Ainsworth et al 2016

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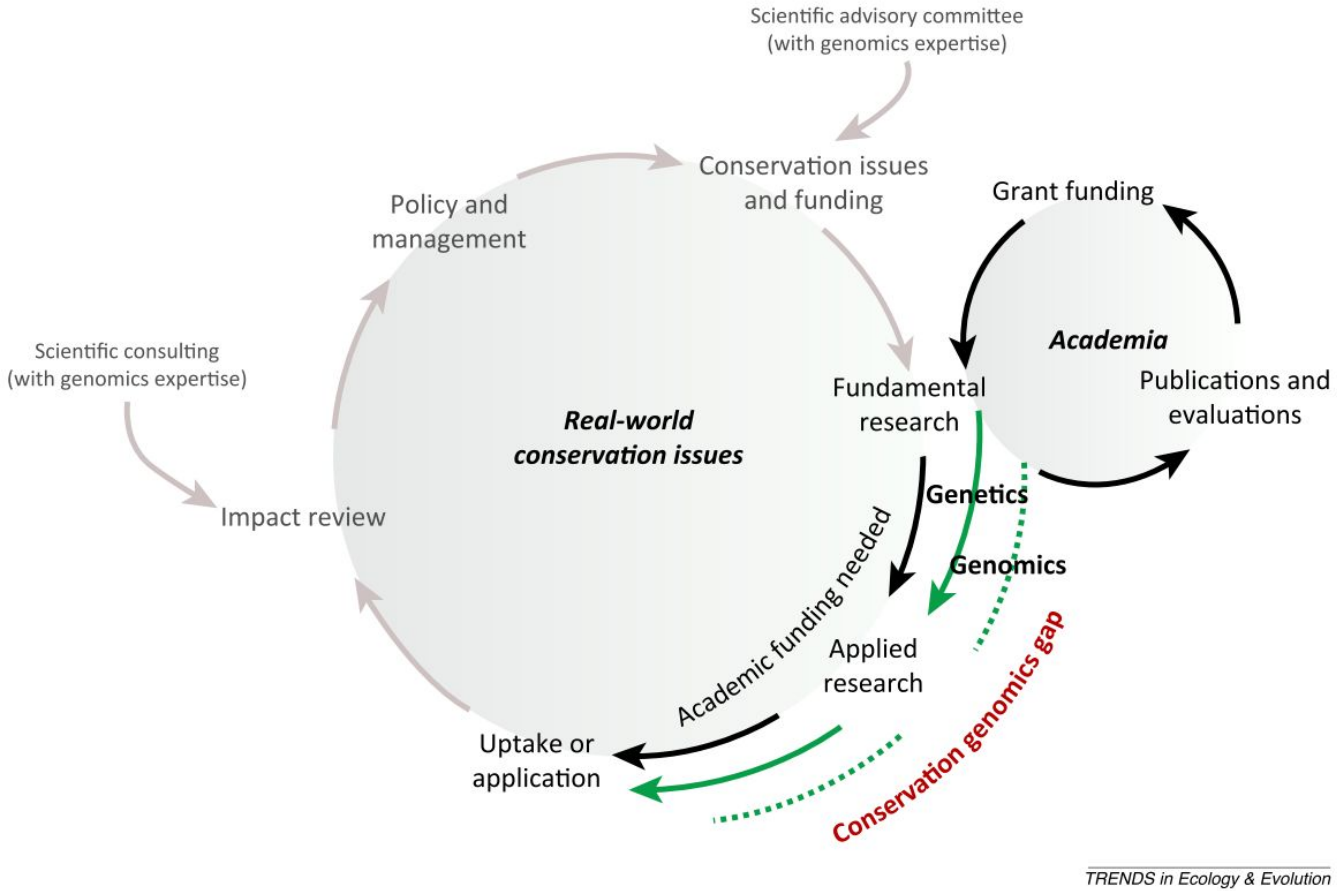
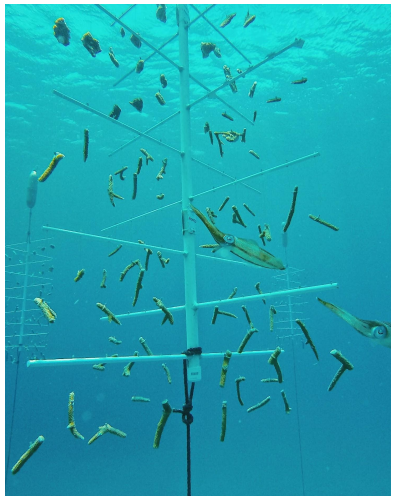
Current Conservation



Current Conservation

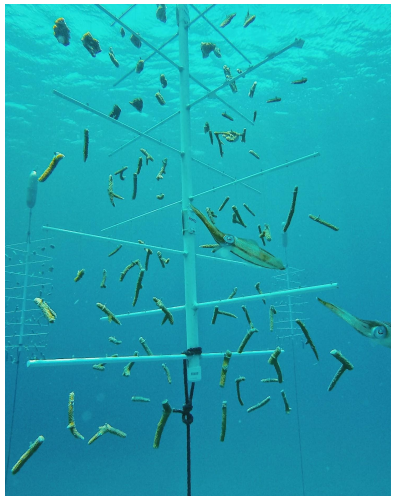
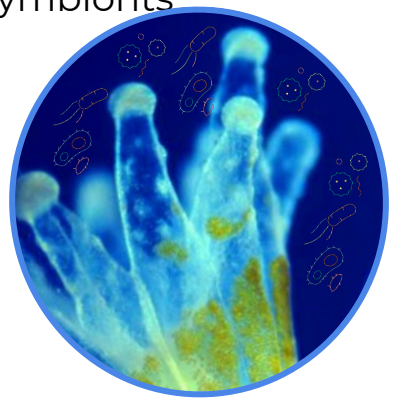
Intensity of Intervention

Approaches	Restoration Trees & Gardens	Induce Acclimatization
Actions		Pre-conditioning generations of natural stocks to various environmental conditions

Modified from van Oppen et al 2015

Current Conservation

Intensity of Intervention

Approaches	Restoration Trees & Gardens	Induce Acclimatization	Modification of Microbial Symbiont Communities
Actions		Pre-conditioning generations of natural stocks to various environmental conditions	Inoculate Early Coral Life Stages with Stress-tolerant Microbial Symbionts 

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Current Conservation

Intensity of Intervention →

	Selective Breeding	Evolution of *Symbiodiniaceae*
Approaches		
Actions	Select stocks using ambient environment, genetic markers or species ID; Cross stocks	Mutagenesis and Selection through Experimental Evolution; Inoculate Coral Early Life Stages

Modified from van Oppen et al 2015

Current Conservation

Intensity of Intervention

Approaches	Selective Breeding	Evolution of *Symbiodiniaceae*	Gene Editing
Actions	Select stocks using ambient environment, genetic markers or species ID; Cross stocks	Mutagenesis and Selection through Experimental Evolution; Inoculate Coral Early Life Stages	CRISPR/Cas-9 intervention in either the coral host or the symbiont

Modified from van Oppen et al 2015

Current Conservation

Restoration Trees & Gardens

Induce Acclimatization

Modification of Microbial Symbiont Communities

Assisted Evolution: Selecting for a successful phenotype

- Scaling up to ecological level?
- Financial support?
- Ethical debate?

Selective Breeding

Evolution of *Symbiodiniaceae*

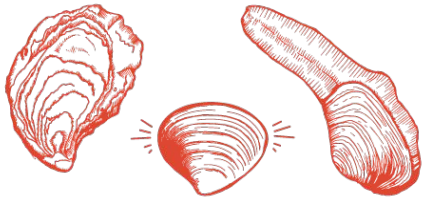
Gene Editing

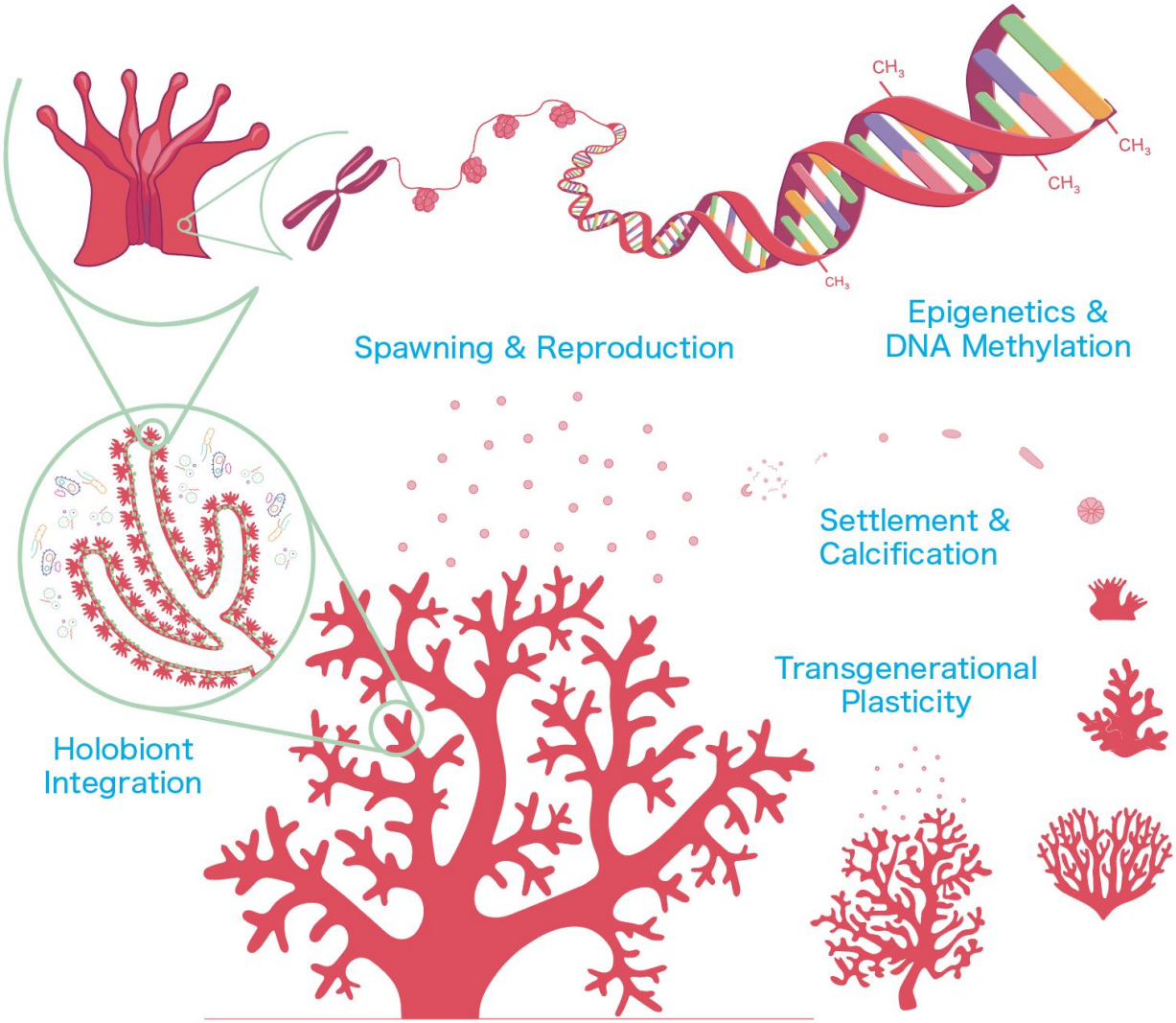
Modified from van Oppen et al 2015

PUTNAM LAB

THE UNIVERSITY OF RHODE ISLAND

Marine Invertebrate Physiology & Epigenetics Stress Responses to Climate Change





THANK YOU

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Adam Helbig
Chris Suchoki, M.Sc.
Maddie Sherman
Alexa Farraj
Ana McMenamin
Emma Ferrante

In Memory of Dr. Ruth Gates

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