Using Genomics to Study Climate Change

Emma Strand

BIO 594: Ecological and Evolutionary Genomics

Lecture Lead

April 11th, 2019

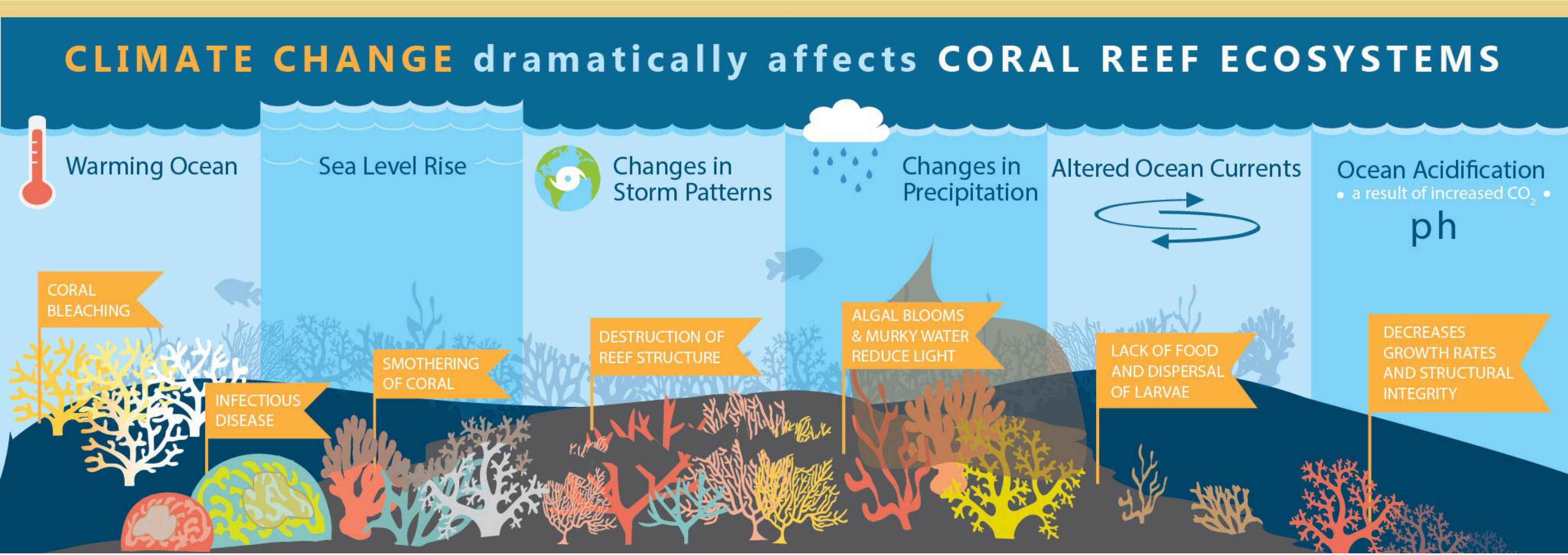
Outline

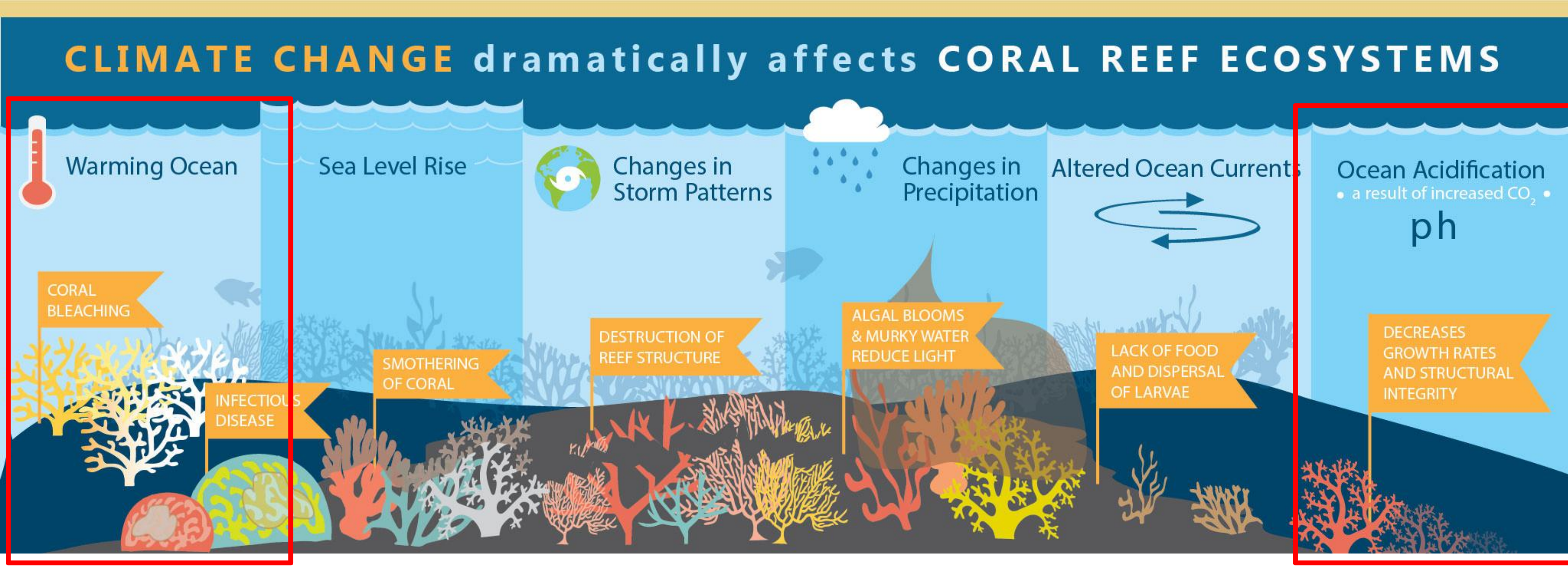
Climate Change
- Warming Waters
- Ocean Acidification

Effects on marine organisms

Major questions & knowledge gaps

Using modern-day genomics to answer those questions


CLIMATE CHANGE dramatically affects CORAL REEF ECOSYSTEMS
Warming Ocean
Sea Level Rise
Changes in Storm Patterns
Changes in Precipitation
Altered Ocean Currents
Ocean Acidification
• a result of increased CO_2 •
ph
CORAL BLEACHING
INFECTIOUS DISEASE
SMOTHERING OF CORAL
DESTRUCTION OF REEF STRUCTURE
ALGAL BLOOMS & MURKY WATER REDUCE LIGHT
LACK OF FOOD AND DISPERSAL OF LARVAE
DECREASES GROWTH RATES AND STRUCTURAL INTEGRITY



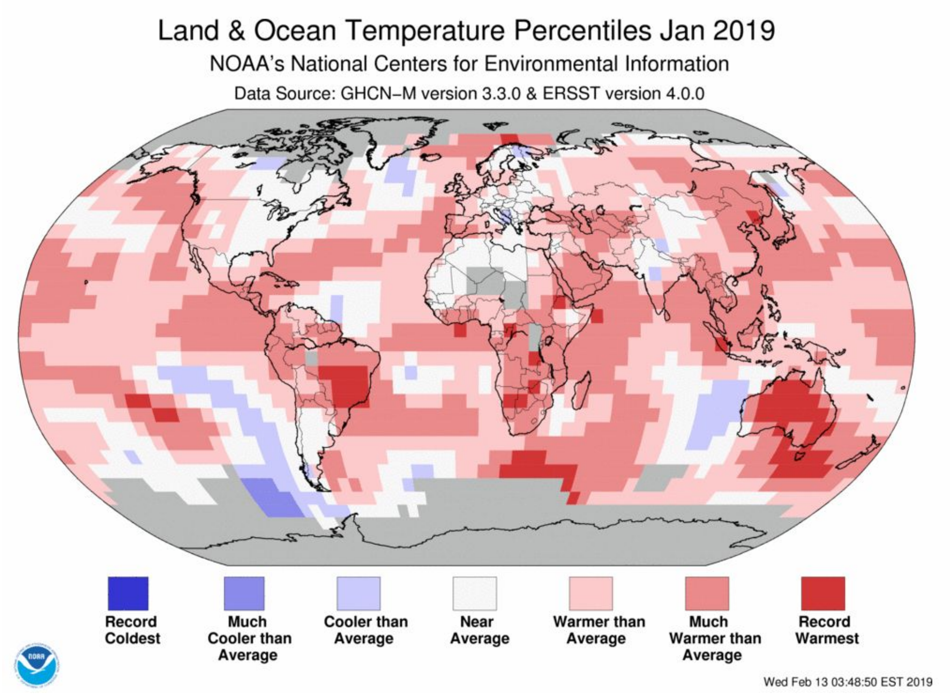
Warming Ocean:

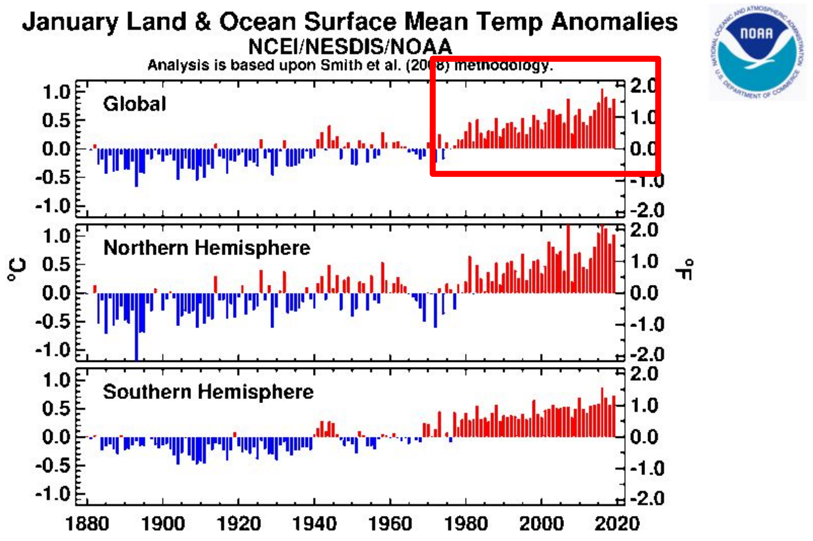
- Rising temperatures around the world
- Induced physiological response: coral bleaching

Ocean Acidification:

- Changing water chemistry that results in a drop in pH level because of excess CO_2

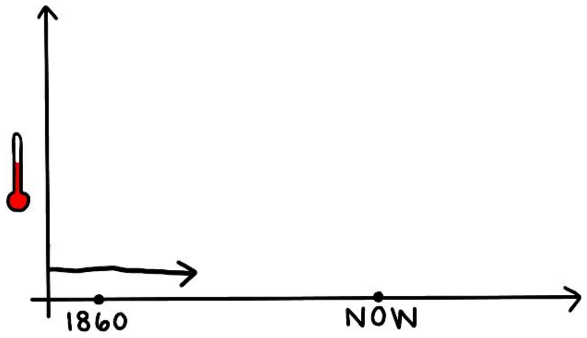
Warming Temperatures





Why Half a Degree of Climate Change Is a Big Deal

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



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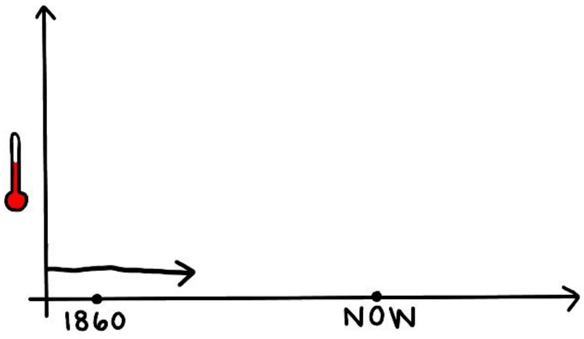
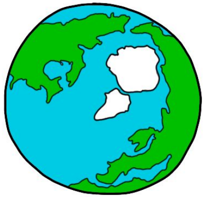


	1.5°C	2°C
Artic	Sea ice will remain during most summers	Ice-free summers are 10 times more likely
Extreme Heat	About 14% of world population	About 37% of world population



Will experience extreme heat waves every five years.

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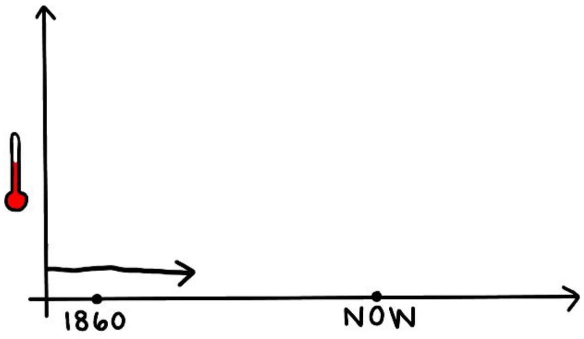
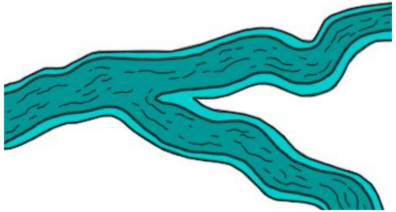
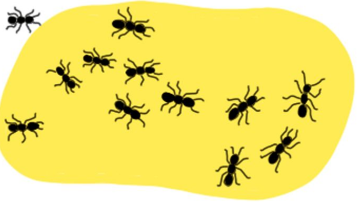


	1.5°C	2°C
Water	+350 million people worldwide	+411 million people worldwide
Plants and Animals	6% of insects 8% of plants 4% of vertebrates	18% of insects 16% of plants 8% of vertebrates





Will lose half of their habitat range.

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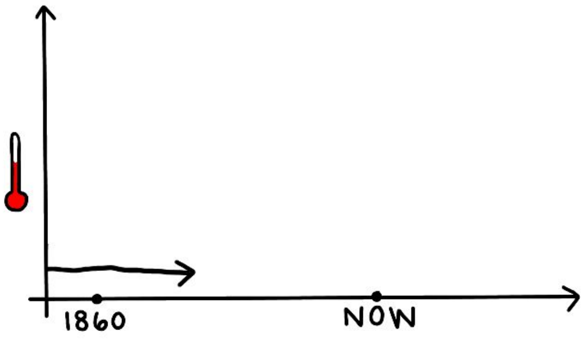

	1.5°C	2°C
Sea level rise	31 to 69 million people worldwide	32 to 80 million people worldwide

Exposed to severe flooding.
**Think about small islands & coastal cities.

Crops

Will be lower regardless.
Especially in sub-Saharan Africa, Southeast Asia, and Central and South America

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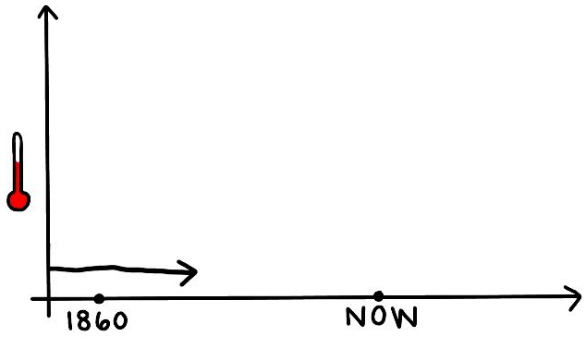


Small Change, Big Impact

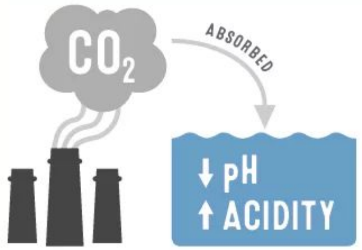
CORAL REEFS (!!)

1.5°C	2°C
Very frequent mass mortalities	Coral reefs mostly disappear worldwide.

CARBON DIOXIDE AND OCEAN ACIDIFICATION

Climate change is a much-discussed effect of rising carbon dioxide levels, but they can also affect our oceans. This graphic takes a look at how.

THE BASICS



Atmospheric carbon dioxide has increased by 40% from pre-industrial levels due to burning of fossil fuels and deforestation. Ocean acidification occurs when atmospheric carbon dioxide dissolves in seawater.

Acidity and alkalinity are measured on the logarithmic pH scale. A pH over 7 is alkaline; below 7 is acidic. A change of one unit represents a tenfold change in acidity or alkalinity. Seawater is alkaline, but average ocean surface pH has dropped by 0.1 since pre-industrial times, a 25% increase in acidity.

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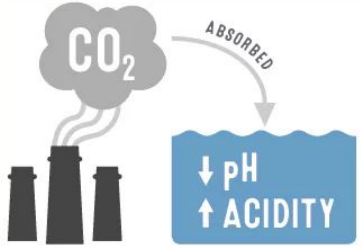

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PRE-INDUSTRIAL	2013	2100
pH 8.2	pH 8.1	pH 7.7
	25% MORE ACIDIC	(PROJECTED)

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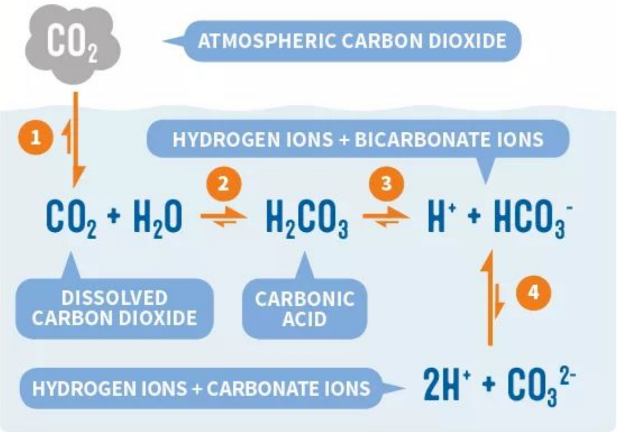
THE CHEMISTRY OF OCEAN ACIDIFICATION

Atmospheric carbon dioxide dissolves in seawater (1) and reacts with the water to form carbonic acid (2). Carbonic acid dissociates (splits up) into its ions (3); hydrogen ions produced by this dissociation increase acidity, lowering seawater pH. Increased atmospheric carbon dioxide ultimately produces more hydrogen ions, lowering pH further.



Hydrogencarbonate ions can dissociate further to form carbonate ions (4) but this is less favoured. Consequently hydrogencarbonate ions are the most abundant form of inorganic carbon in the oceans. Calcium carbonate can also react with dissolved carbon dioxide in seawater to form more hydrogencarbonate ions (5).

5 $CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-$

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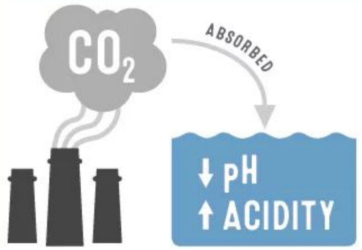

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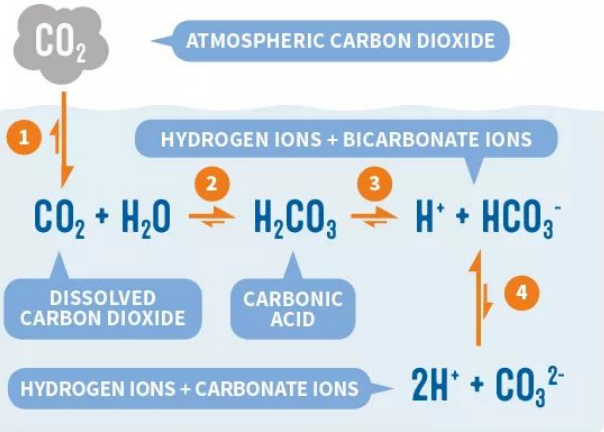

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THE EFFECTS OF OCEAN ACIDIFICATION

1 EFFECT ON CALCIFYING ORGANISMS AND CORAL

As ocean pH drops, hydrogen ions react with carbonate ions. Calcifying organisms such as clams, oysters and crustaceans use the carbonate ions from seawater to make shells. When calcium carbonate is undersaturated in seawater, their shells can start dissolving. Coral skeletons can also be affected.

2 EFFECT ON FOOD WEBS AND FISHING

Calcifying organisms are at the root of a number of marine food webs. Negative effects on their population could have a knock-on effect on species that feed on them, impacting fishing industries.

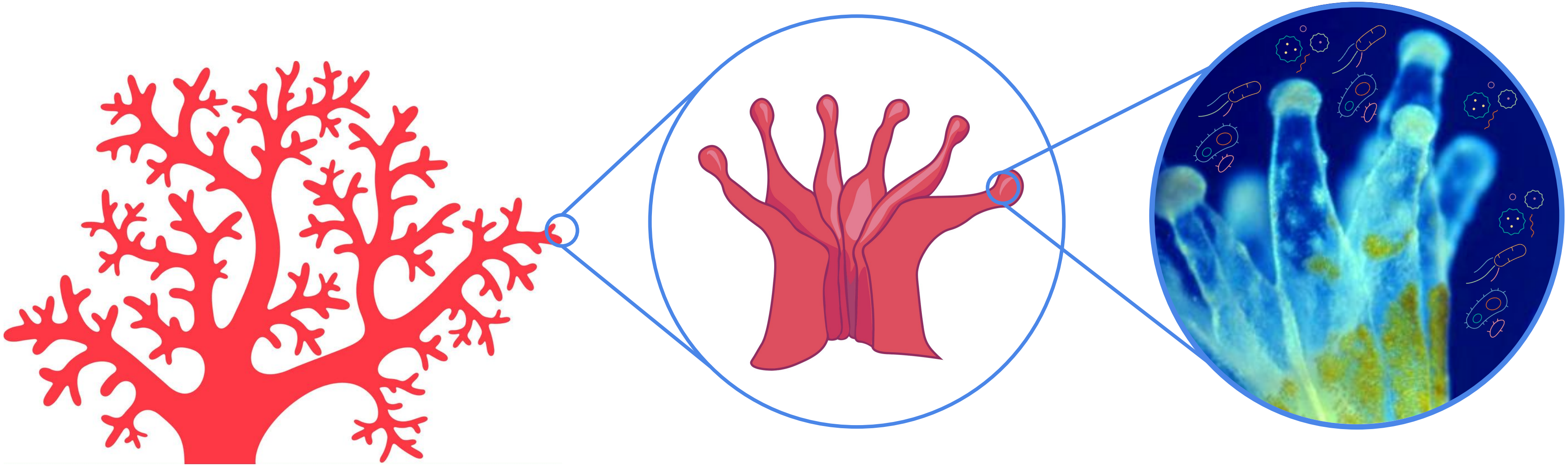
3 EFFECTS ON ANIMAL CHEMICAL SIGNALLING

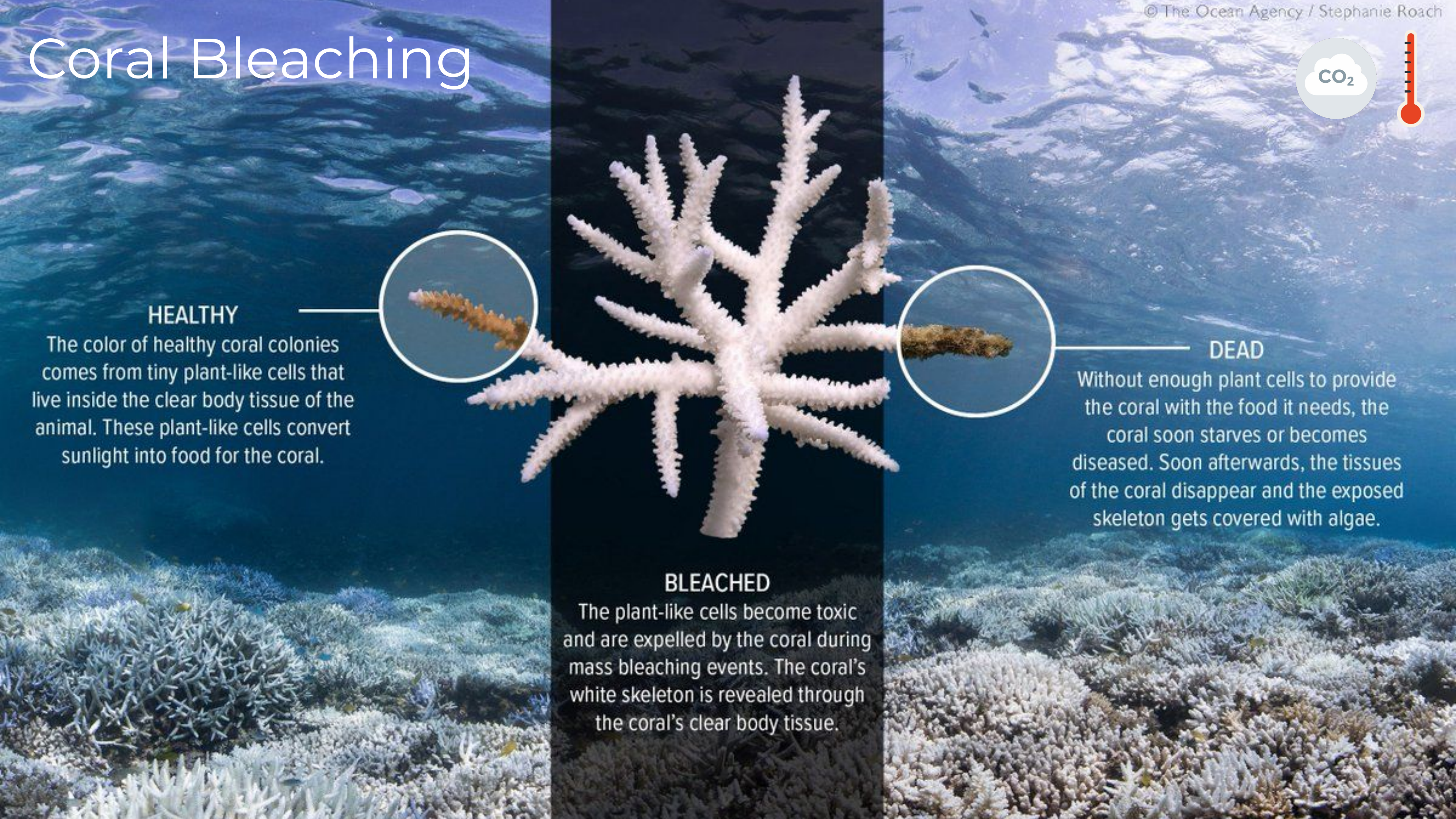
Many marine species use chemical signals for detecting predators, settlement, and reproduction. Ocean acidification can alter signalling molecules, which could in turn have potentially detrimental effects on a number of different species.

Effects on Marine Organisms

The Coral Holobiont

- Coral Host + Symbiodiniaceae + Microbiome




Coral Bleaching
© The Ocean Agency / Stephanie Roach
CO2
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.

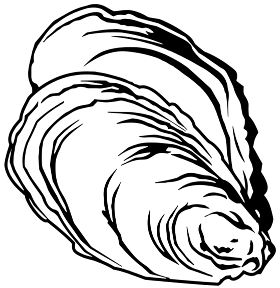
Effects on Marine Organisms

Ocean Acidification & Calcifying Organisms

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

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

$\downarrow$ pH



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Hydrogen & bicarbonate ions

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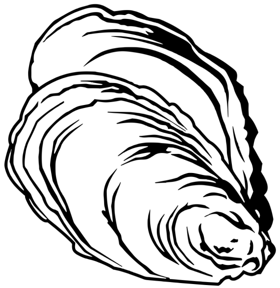
$$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$$

Calcium carbonate



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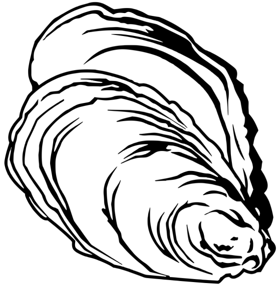
CO_3^{2-} + Ca^{2+} → $CaCO_3$

Calcium carbonate



$CaCO_3 + CO_2 + H_2O$

$\downarrow\uparrow$ Carbonate dissolution

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

Major Questions / Concerns

How do these stressors impact the organism’s functions?

- How much does climate change threaten ecosystems?

Do organisms have the potential to survive?

- Can they acclimatize and/or adapt?
- If so, how can they do that? What are the underlying mechanisms?

Are there strategies we can use to help these organisms survive their rapidly changing conditions?

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Potential for Survival

Options / Responses:

- Move physically to another environment (migrate)
- Acclimatize
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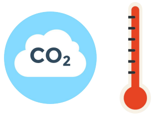
Migration:

- Population genomics
- Genetic connectivity among populations



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- **Adapt**
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Acclimatization

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

Wilmer et al 2005

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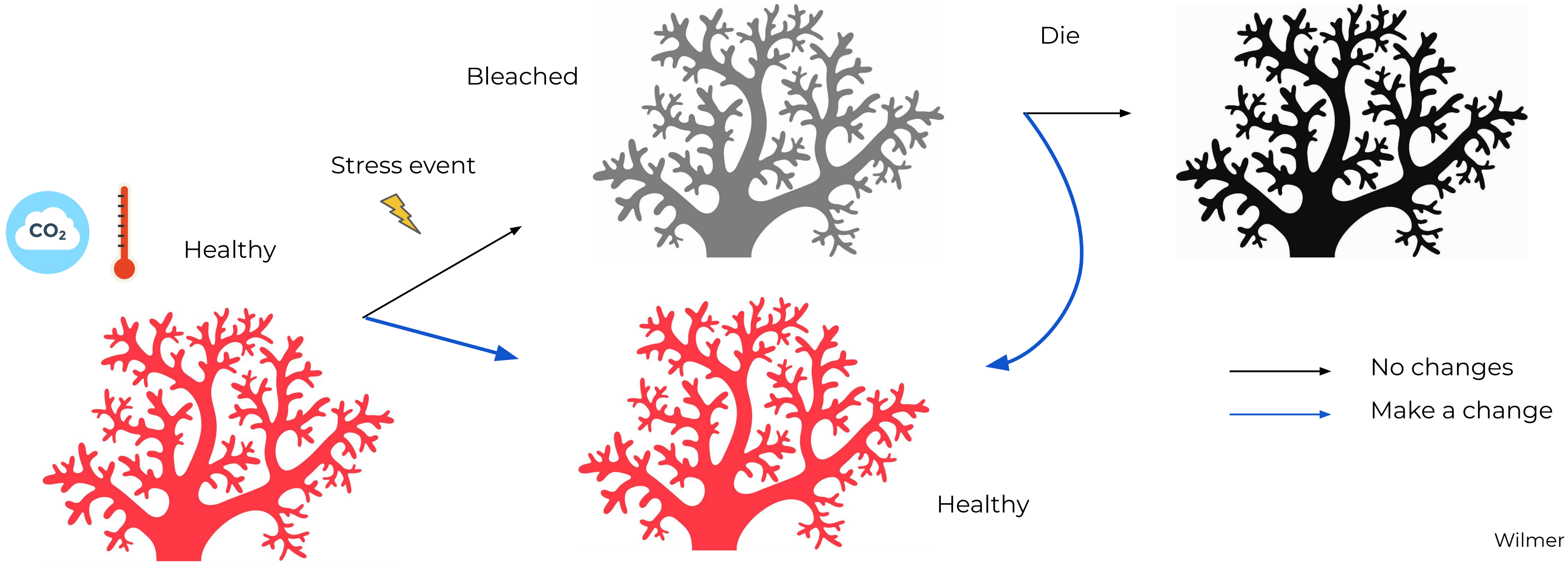

Wilmer et al 2005

Acclimatization & Phenotypic Plasticity

Phenotypic Plasticity:
Ability of an organism to express different phenotypes depending on the biotic or abiotic environment

- Short-term compensatory changes in response to environmental disturbance

Wilmer et al 2005

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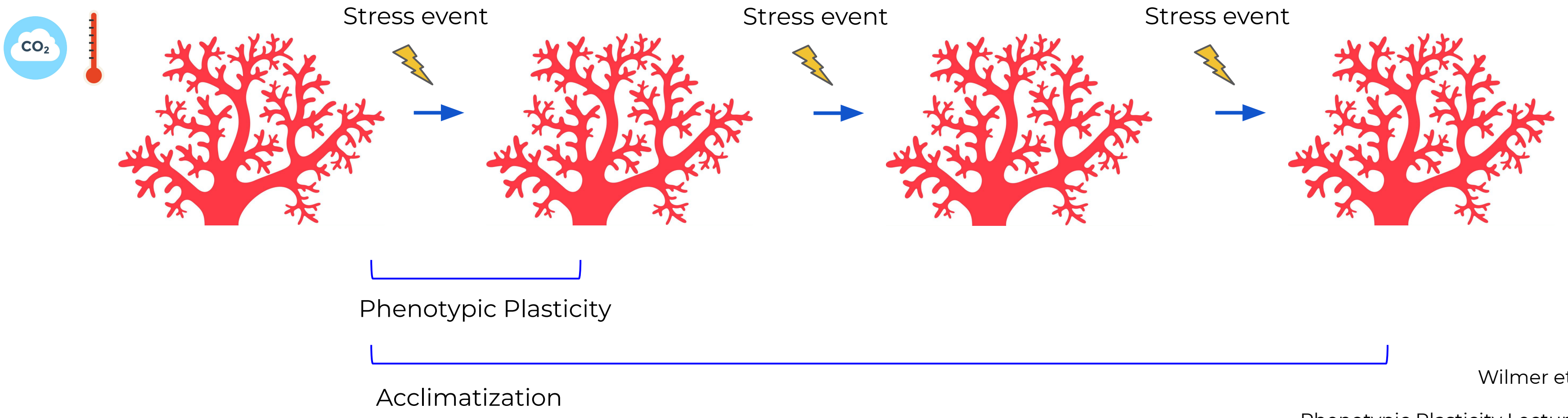

Wilmer et al 2005

Adaptation

Process by which natural selection adjusts the frequency of alleles in the population

- Requirements: over several generations and genetic change

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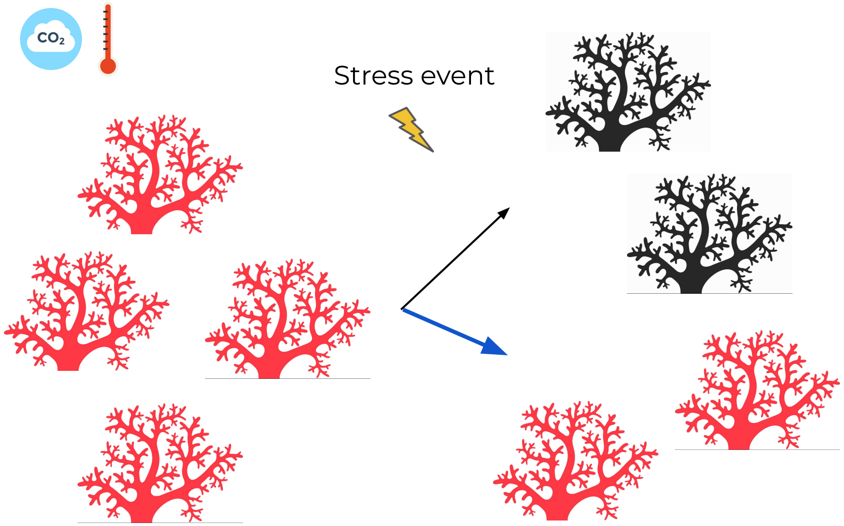

F1 generation F1 generation

Wilmer et al 2005

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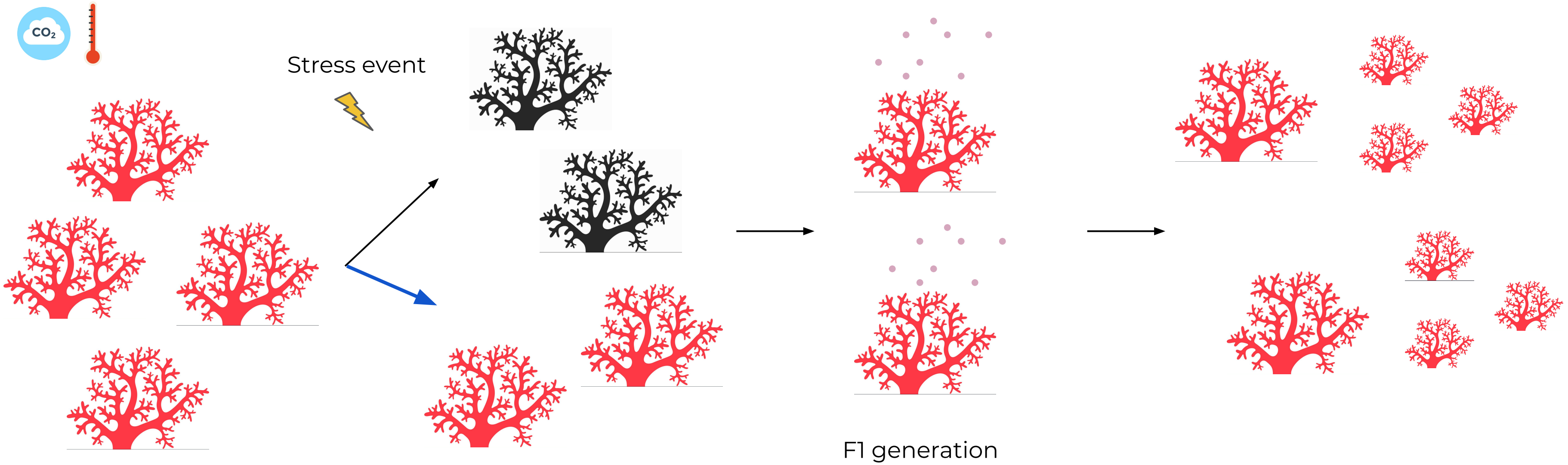

F1 generation

F1 generation

change in frequency of alleles

Wilmer et al 2005

Potential for Survival

Acclimatization: long-term changes that allow an organism to survive changing environmental conditions

- Mechanisms: Phenotypic plasticity
- Acclimation: this process seen in a lab setting

Adaptation: natural selection that occurs over several generations and requires a genetic change

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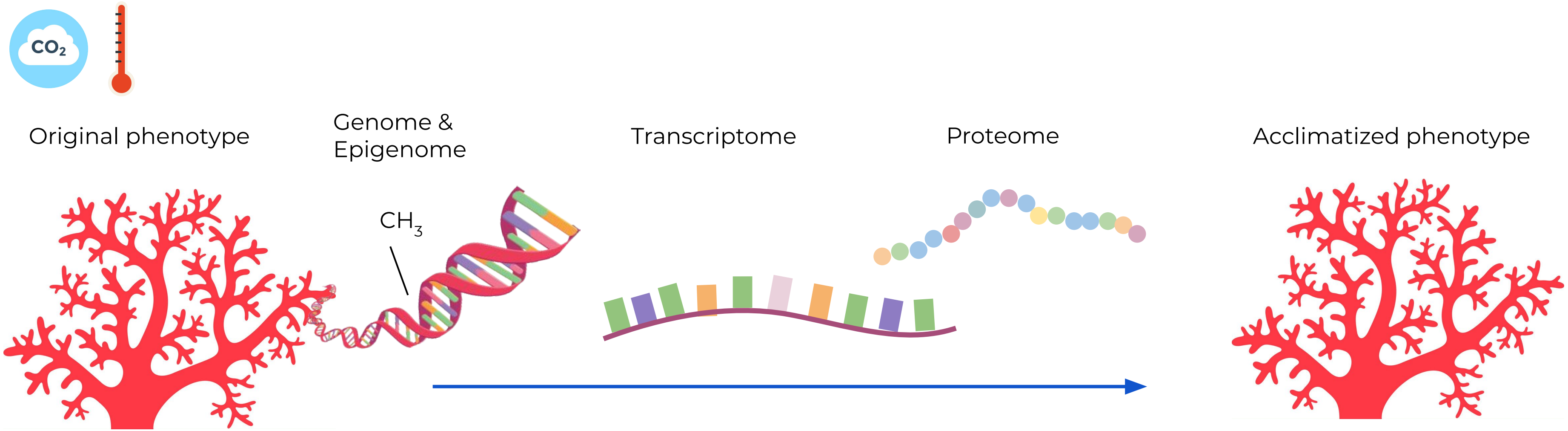
Adaptation: natural selection that occurs over several generations and requires a genetic change

The mechanisms of acclimatization in an organism and adaptation in a population are **genomic changes**

Genomic changes underlying acclimatization

Acclimatization requires a change in phenotype in response to the changing environment

Changes in phenotype require changes at genomic levels



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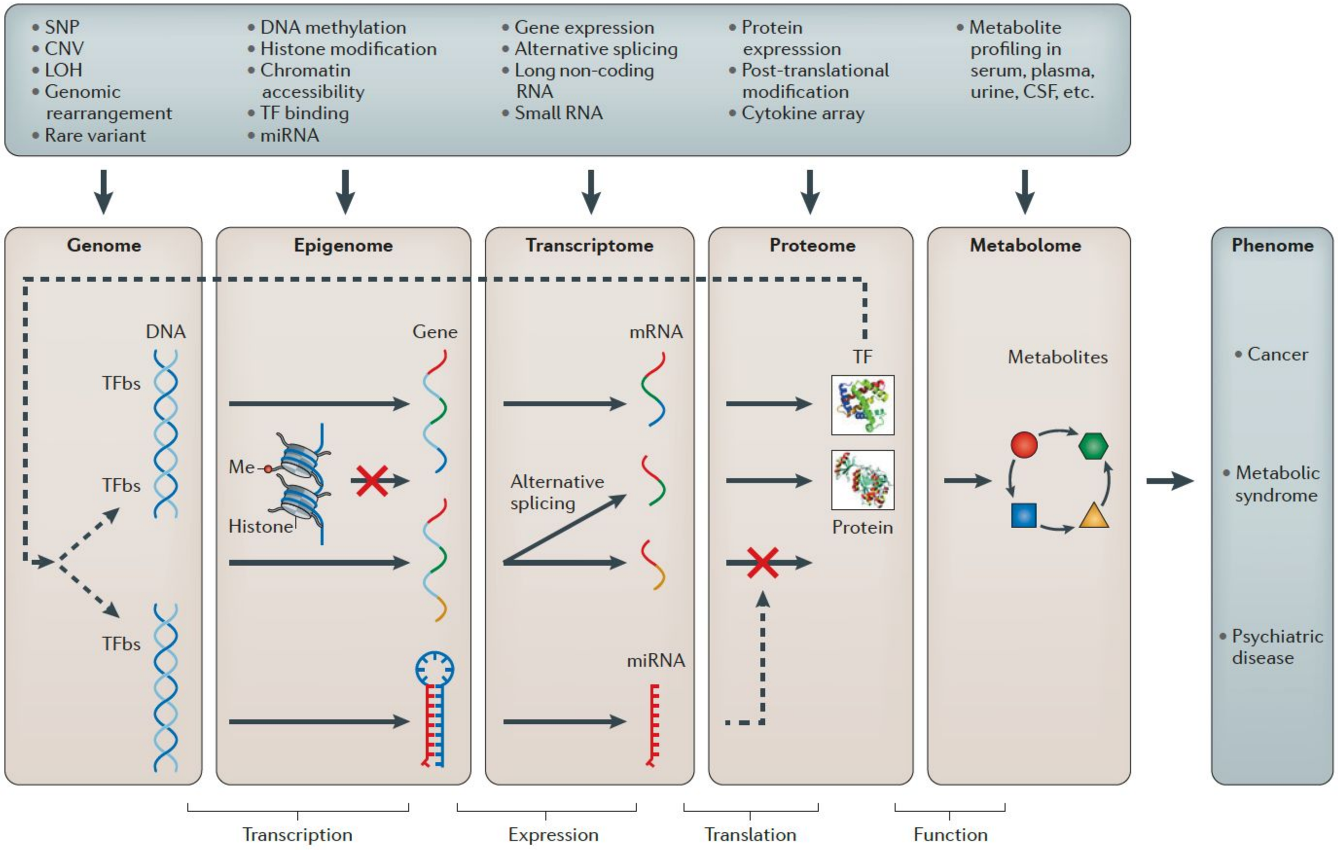
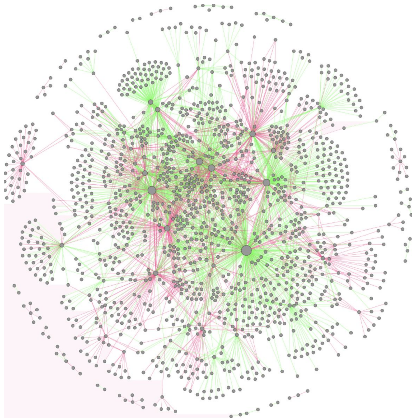


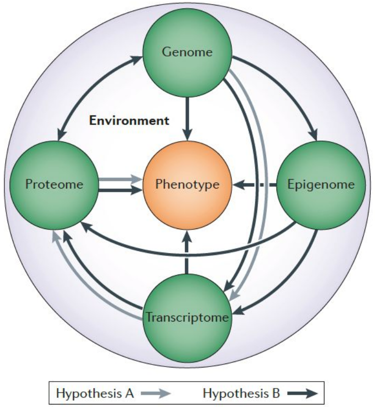
Ritchie et al 2015

Genomic changes underlying acclimatization

The connection between genotype and phenotype is complex and involves systems like gene regulatory networks (GRNs)

Many times a change in phenotype requires a change in thousands of genes that are a part of a GRN





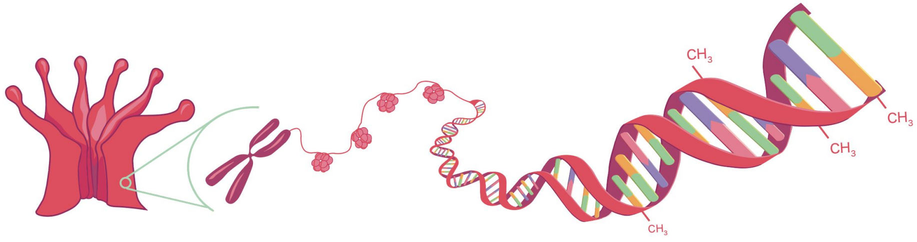
Ritchie et al 2015
Gene Regulatory Networks Lecture (Jennifer)

Epigenetics

Potentially heritable changes in gene expression that occur without changes in DNA sequence

Affects accessibility of genes for transcription

DNA Methylation
Histone Modifications



Bollati and Baccarelli 2010
Epigenetics Lecture (Kevin)

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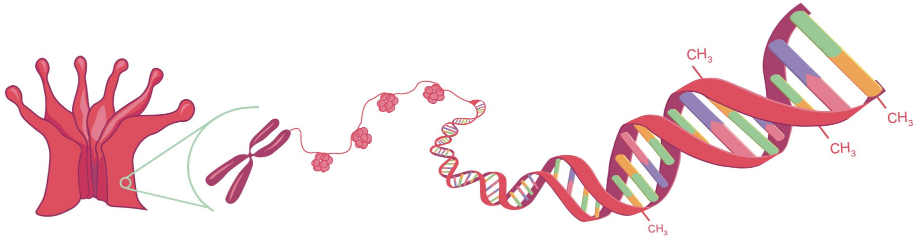
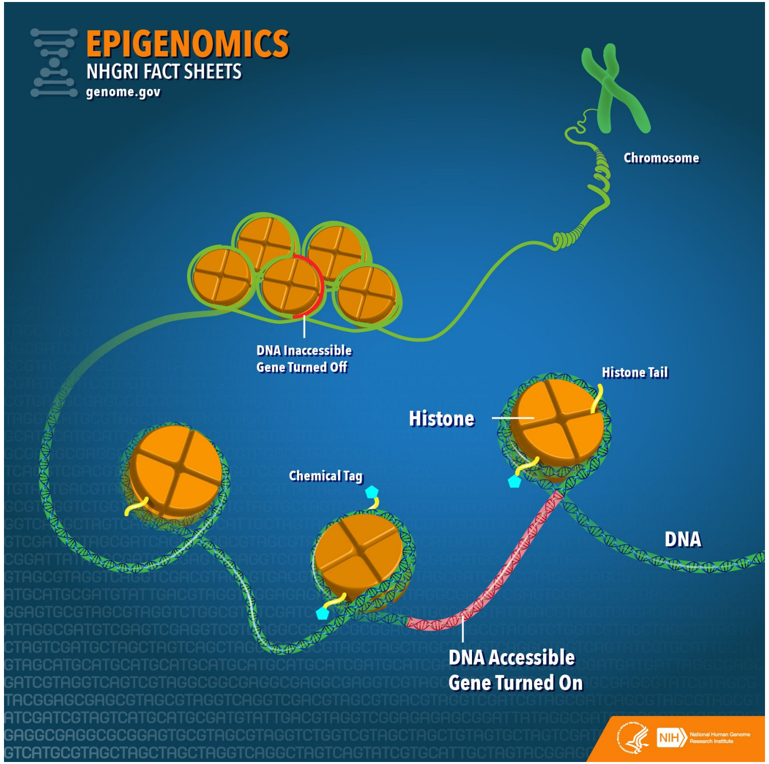
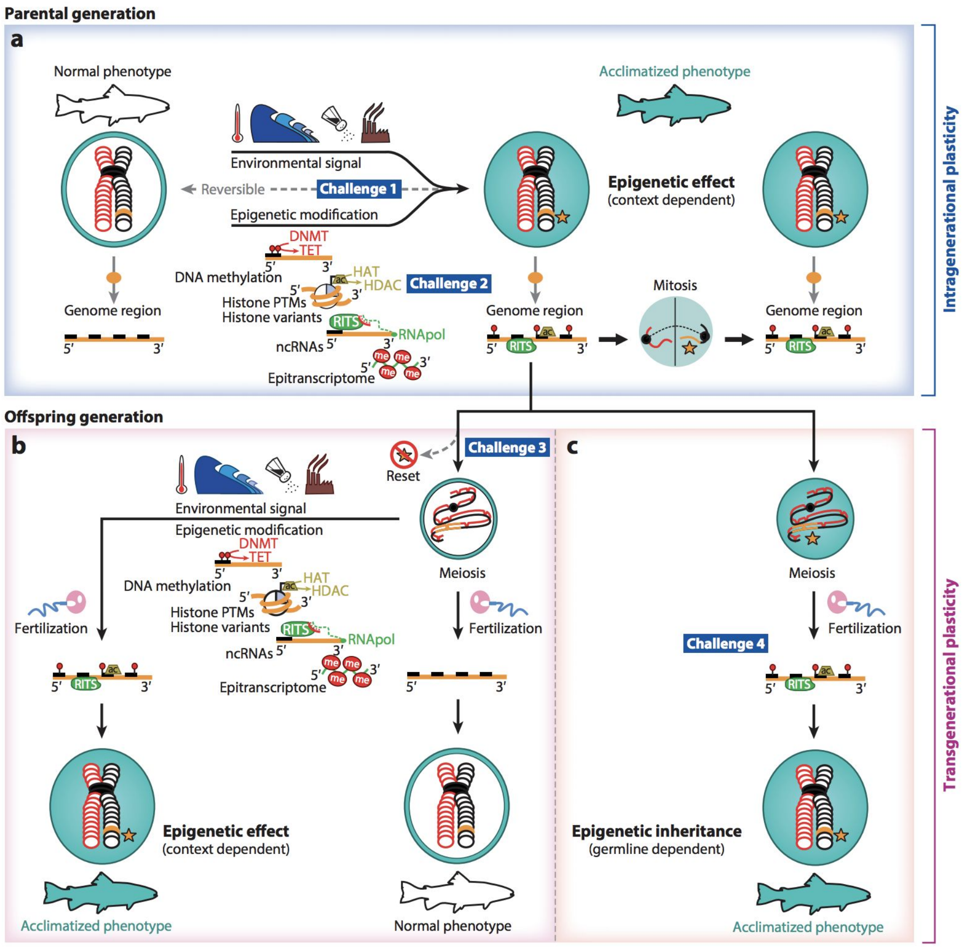




Bollati and Baccarelli 2010
Epigenetics Lecture (Kevin)

Epigenetics

Potential for transgenerational effects



Eirin-Lopez and Putnam 2019

Epigenetics

CpG O/E

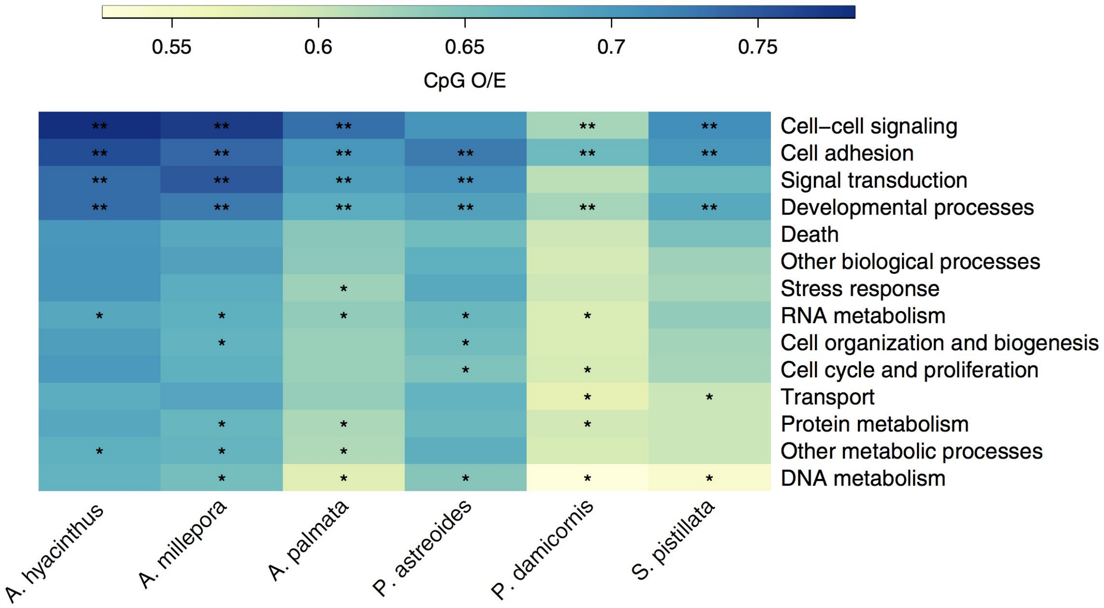
- Measure of historical methylation
- O/E = observed/expected

High CpG O/E

- Lower methylation

Low CpG O/E

- Higher methylation



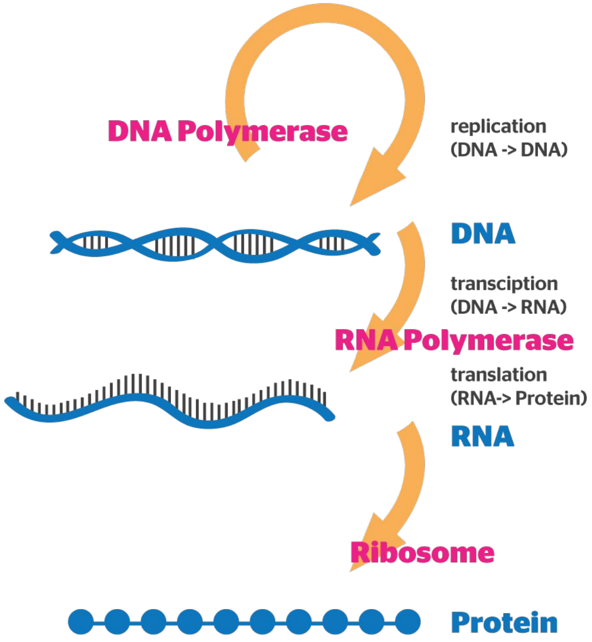
Dimond and Roberts 2015

Gene Expression & Transcriptomics

Identifying what genes are involved in overall stress response

Changes in gene expression that correlate with changes in phenotype/fitness in response to stress

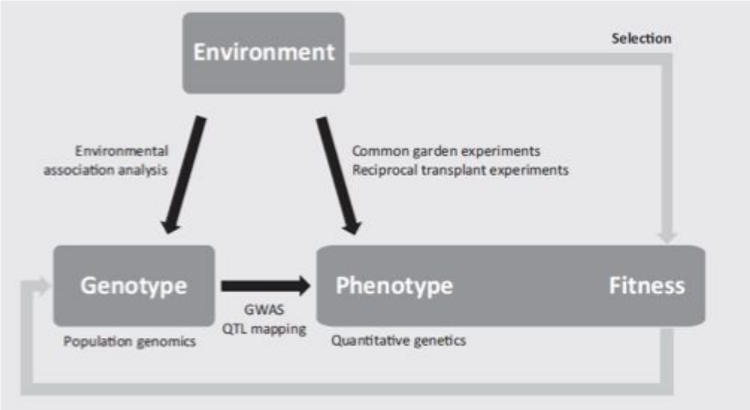
Methods:
RNAseq



Adaptive Potential

Identifying genes involved in **local adaptation**

- Top-down approaches
  - Genome-wide association studies (GWAS)
  - Quantitative trait locus mapping (QTL)
- Bottom-up approaches
  - **Landscape/seascape Genomics**



Rellstab et al 2015
Seascape/Landscape Genomics Lecture (Amy)

Adaptive Potential

Local adaptation

- Environmental pressures shaping a local population’s tolerance

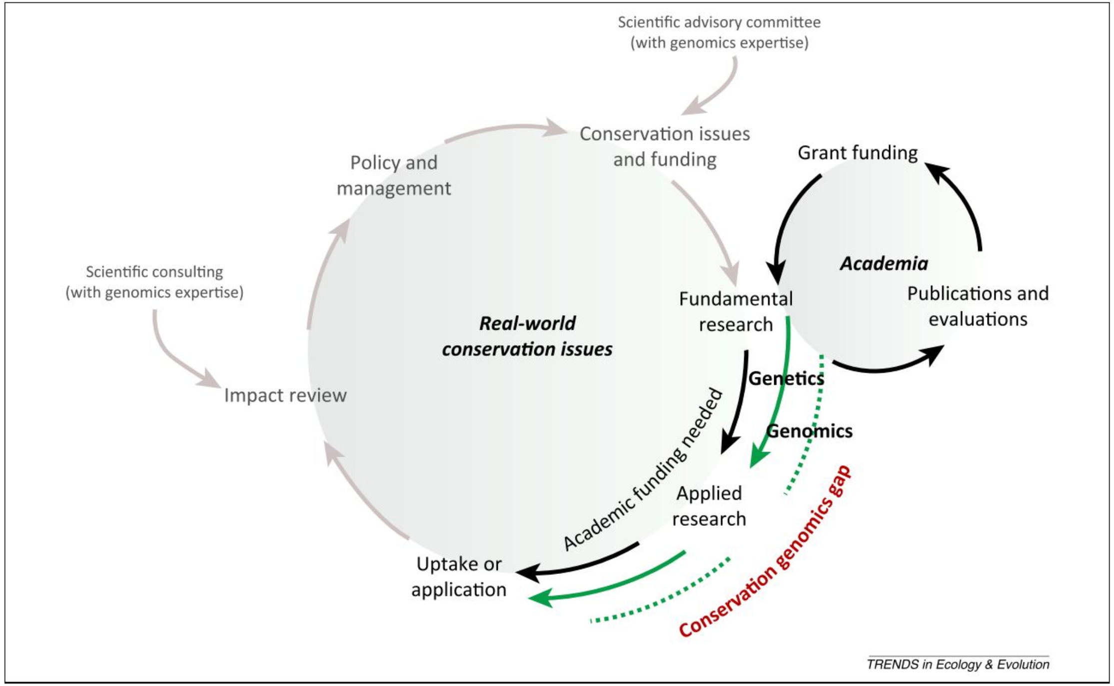
Identifying putatively adaptive loci, and alleles associated with the presence of a climate change stressors

Population structure and genetic diversity to evaluate a population’s potential to respond quickly enough

- Jordan et al 2017
- Bay et al 2018

Conservation Genomics

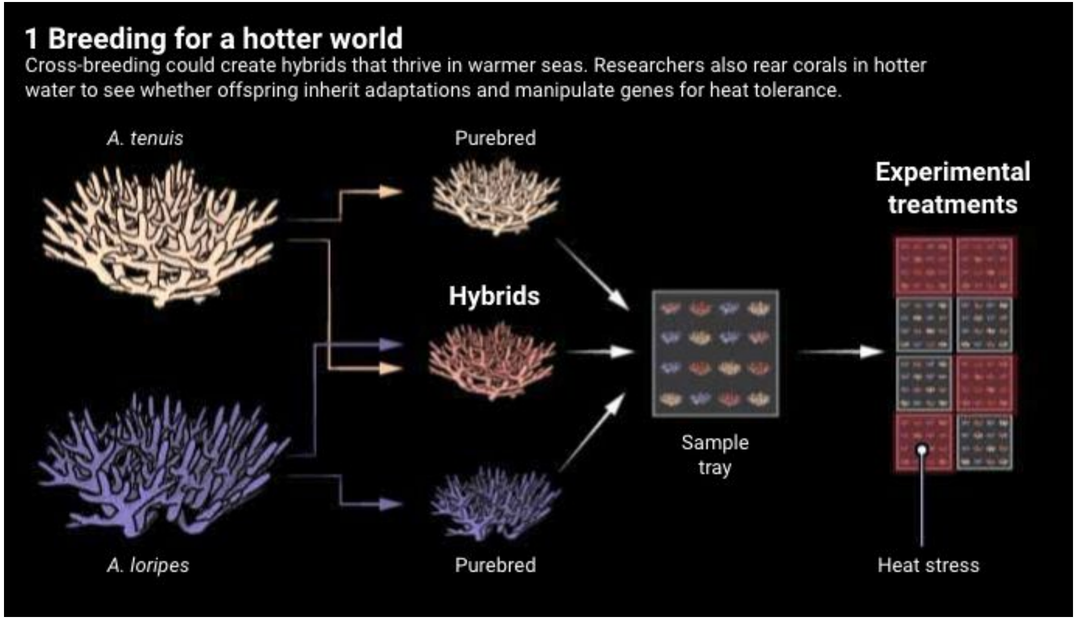
How can we use genomic methods to make predictions about an individual or population’s ability to withstand climate change?



Need for intervention?

Assisted evolution:

- Stress conditioning
- Assisted gene flow
- Hybridization
- Modifications of algal symbiont communities
- Manipulations of other microbes like bacteria



Need for intervention?

Assisted evolution:
- Stress conditioning
- Assisted gene flow
- Hybridization
- Modifications of algal symbiont communities
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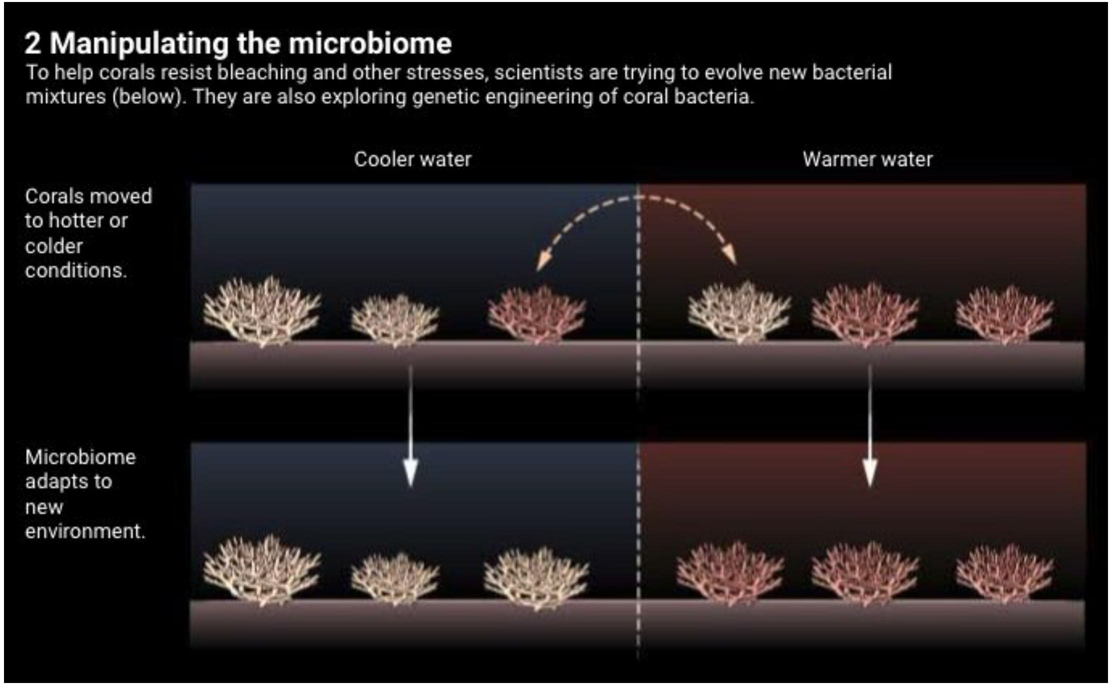

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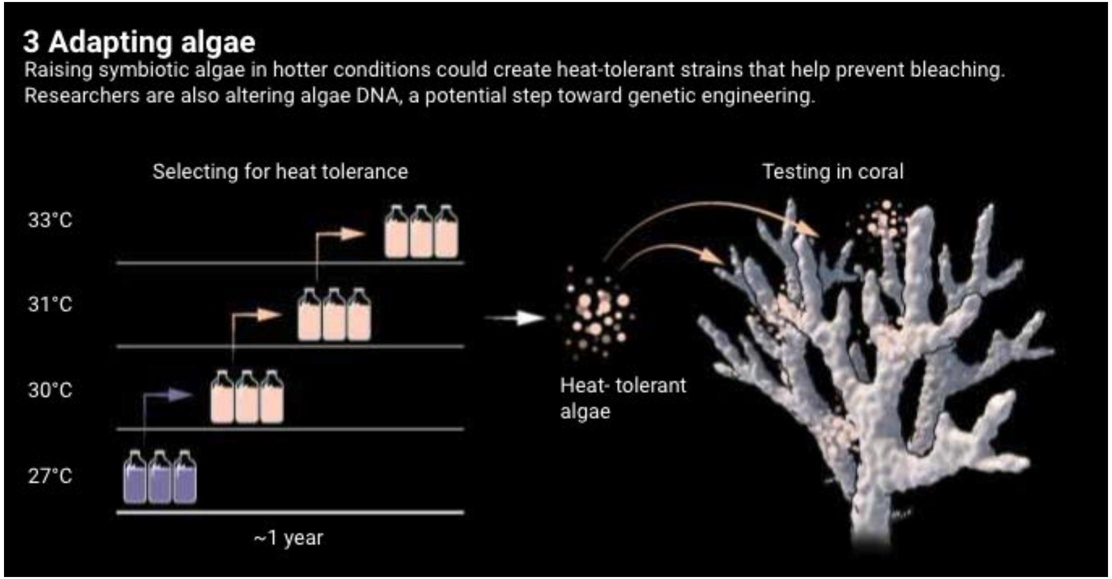
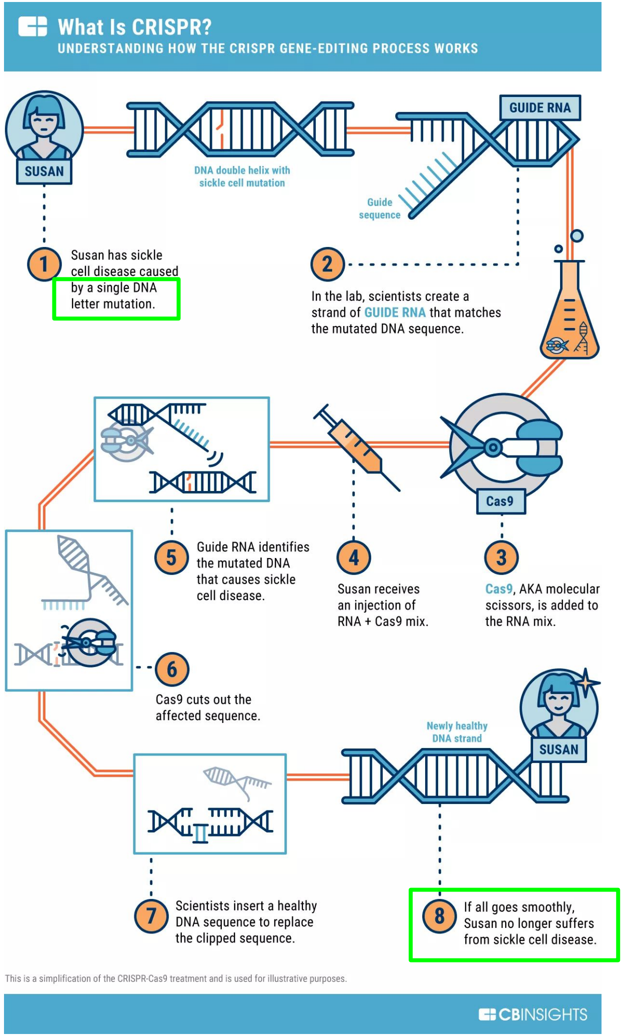


Need for intervention?

Gene-editing potential:

- CRISPR/Cas-9
- iRNA
- Morpholinos

New technology and still needs a vast amount of research before implementing



Conclusions

Climate change (i.e. warming waters and ocean acidification) is forcing organisms to respond by either: migrating, acclimatizing, or adapting.

Genomics can be used to investigate the underlying mechanisms of a phenotypic change that may (or may not) allow the organism to acclimatize.

- i.e. Genetics, epigenetics, transcriptomics, proteomics

Genomics can be used to evaluate a population’s adaptive potential

- i.e. Landscape/seascape genomics