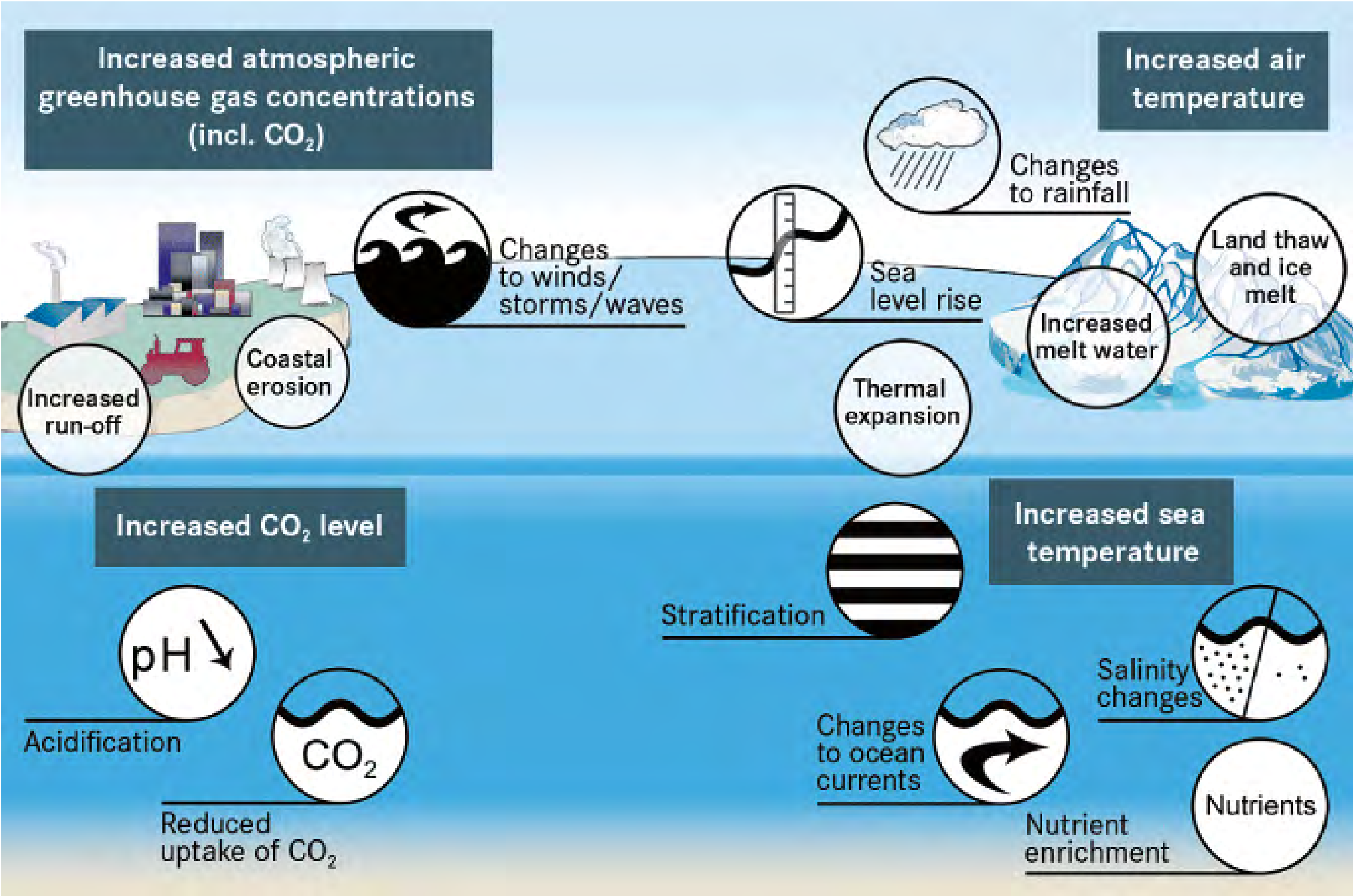
ARC Centre of Excellence Coral Reef Studies

Predicting evolutionary responses to climate change in the sea: progress and challenges

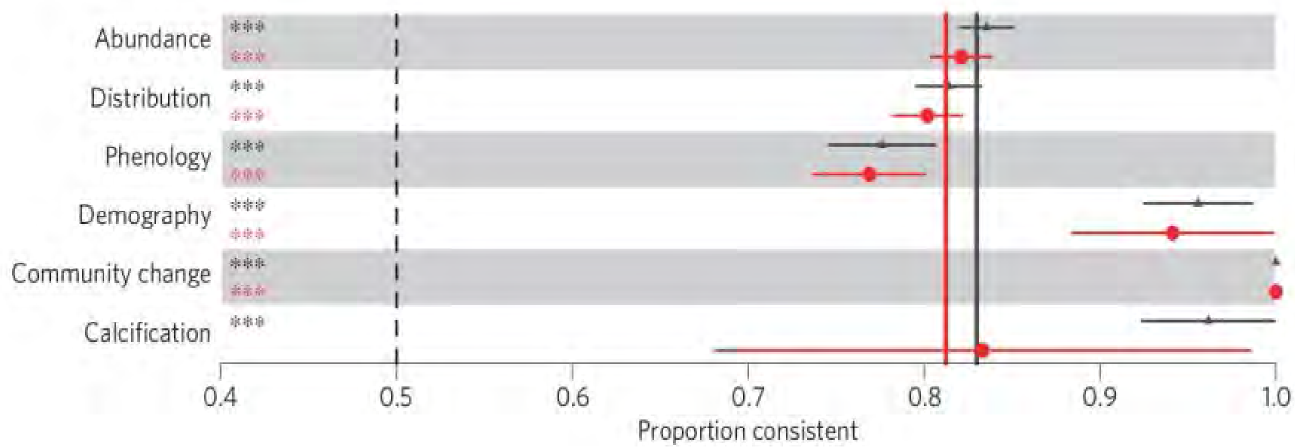
Philip Munday, James Cook University


Increased atmospheric greenhouse gas concentrations (incl. CO_2)
Increased air temperature
Changes to rainfall
Changes to winds/storms/waves
Sea level rise
Land thaw and ice melt
Increased melt water
Coastal erosion
Increased run-off
Thermal expansion
Increased CO_2 level
Increased sea temperature
Stratification
pH
Acidification
CO_2
Reduced uptake of CO_2
Salinity changes
Changes to ocean currents
Nutrients
Nutrient enrichment

Biological consequences

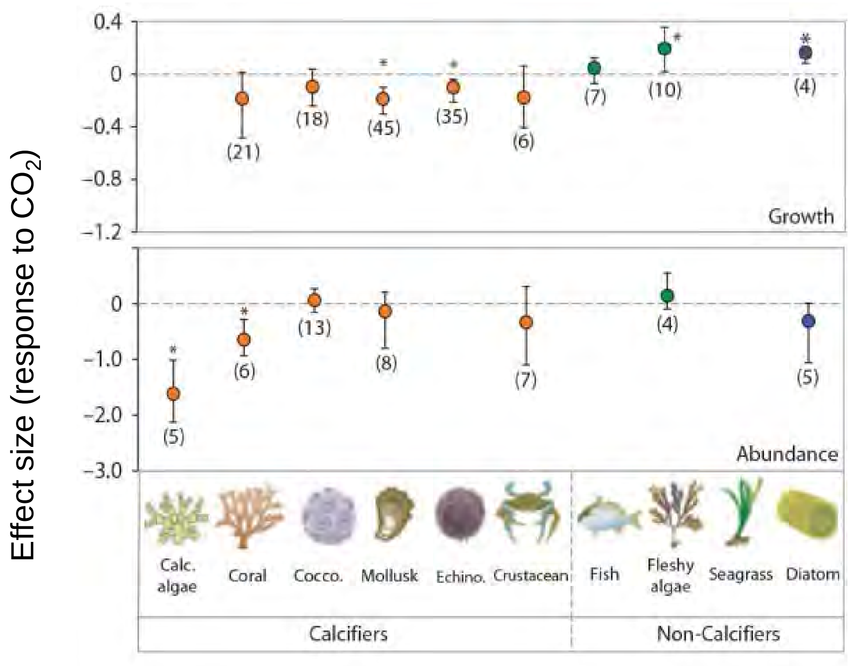
Observations

Poloczanska et al. 2013 NCC



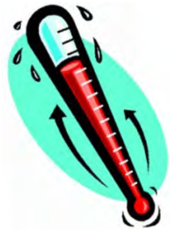
Experiments

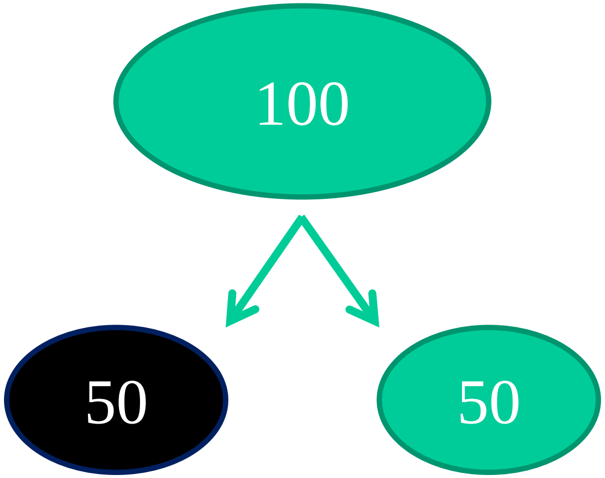
Kroeker et al. 2012 GCB



Evolutionary perspective

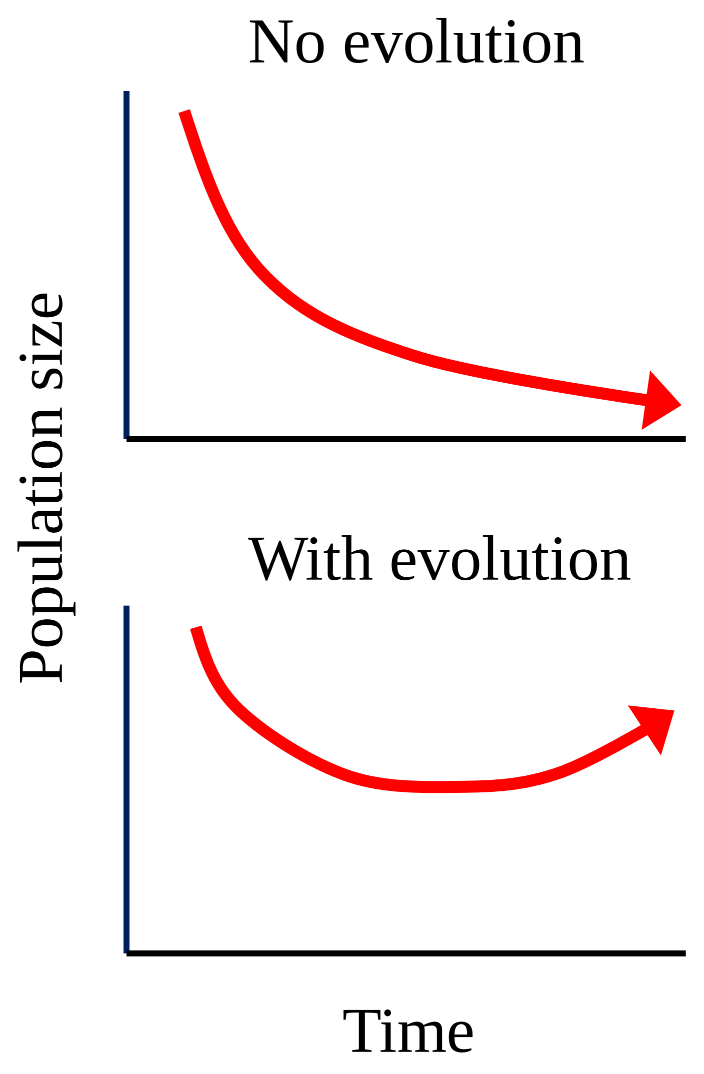
- Extrapolations from short-term experiments risk overestimating impacts

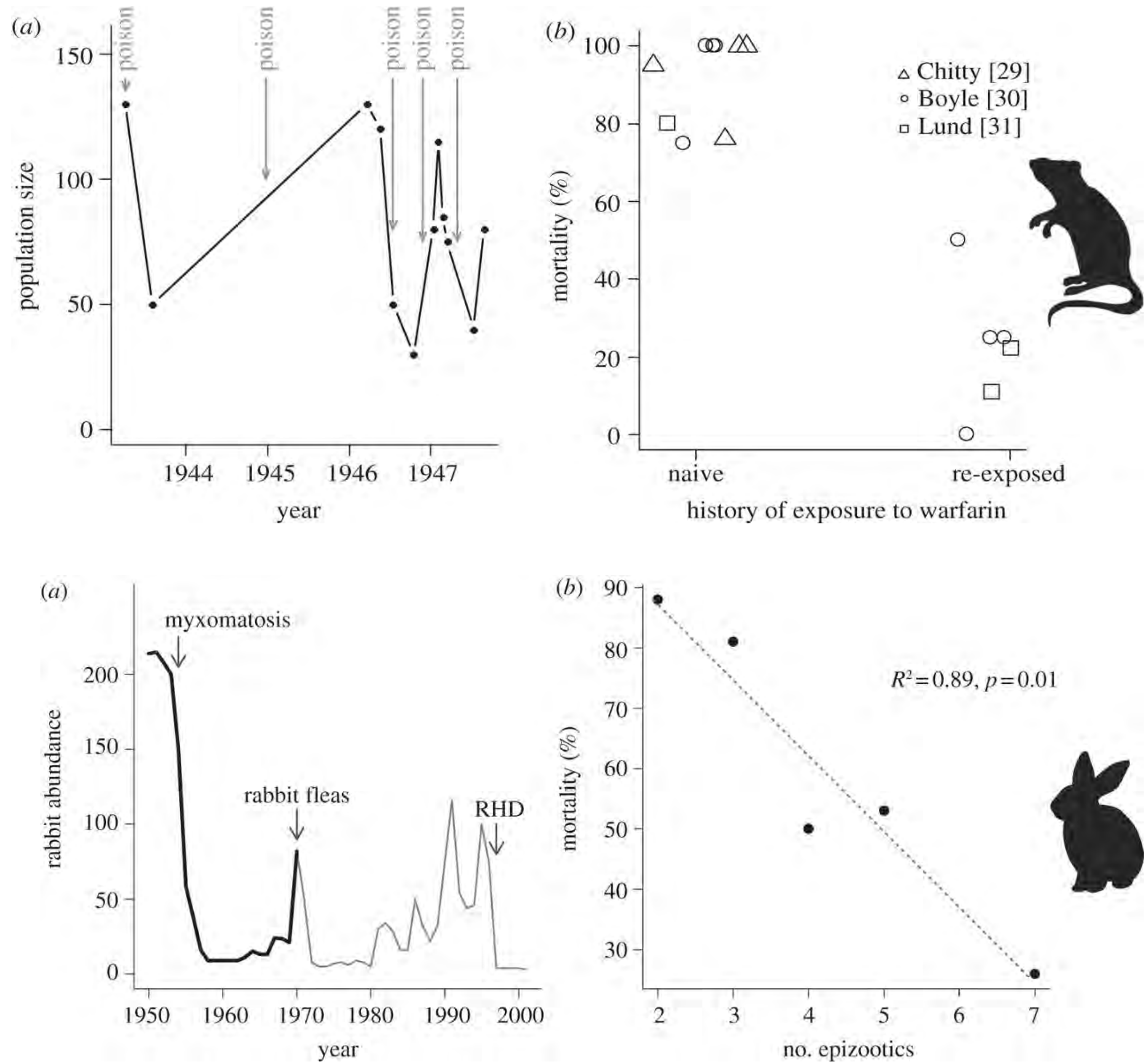




Evolutionary perspective

- Extrapolations from short-term experiments risk overestimating impacts
- Projections need to incorporate evolutionary potential
- Models that incorporate demographic effects of climate change and evolutionary potential

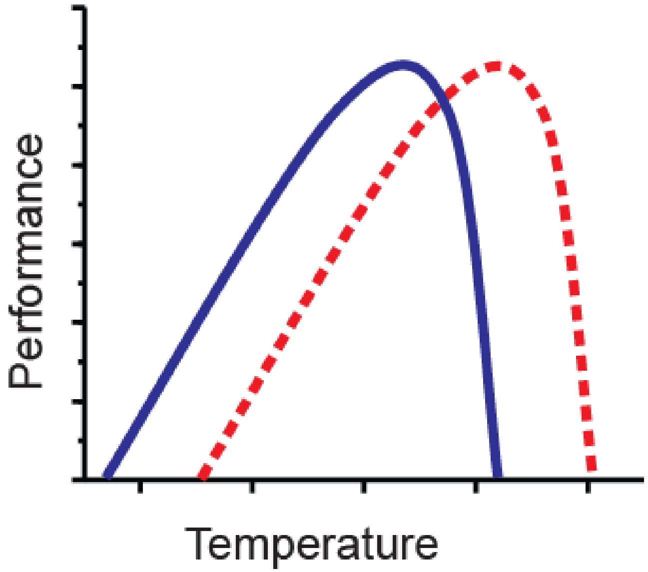




Vander Wal et al. Phil. Trans. R. Soc. B 2013;368:20120090

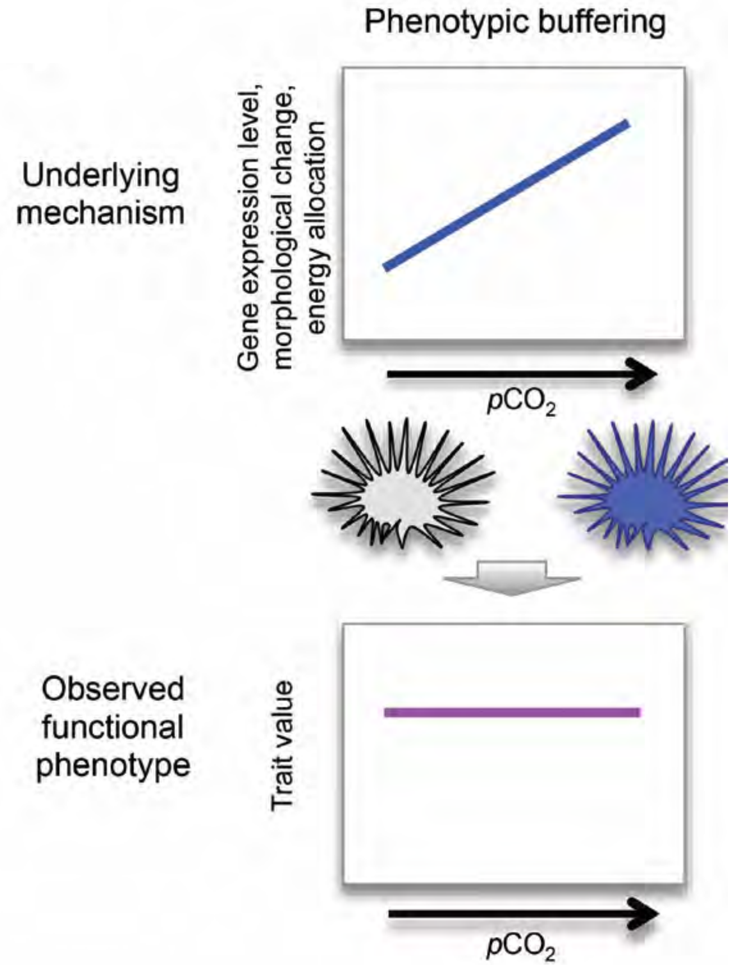
Acclimation and adaptation

- Acclimation(acclimatization)
  - Physiological, behavioural or morphological adjustment without genetic selection (plasticity)
- Genetic Adaptation
  - Selection on genetic variation that is inherited from one generation to the next



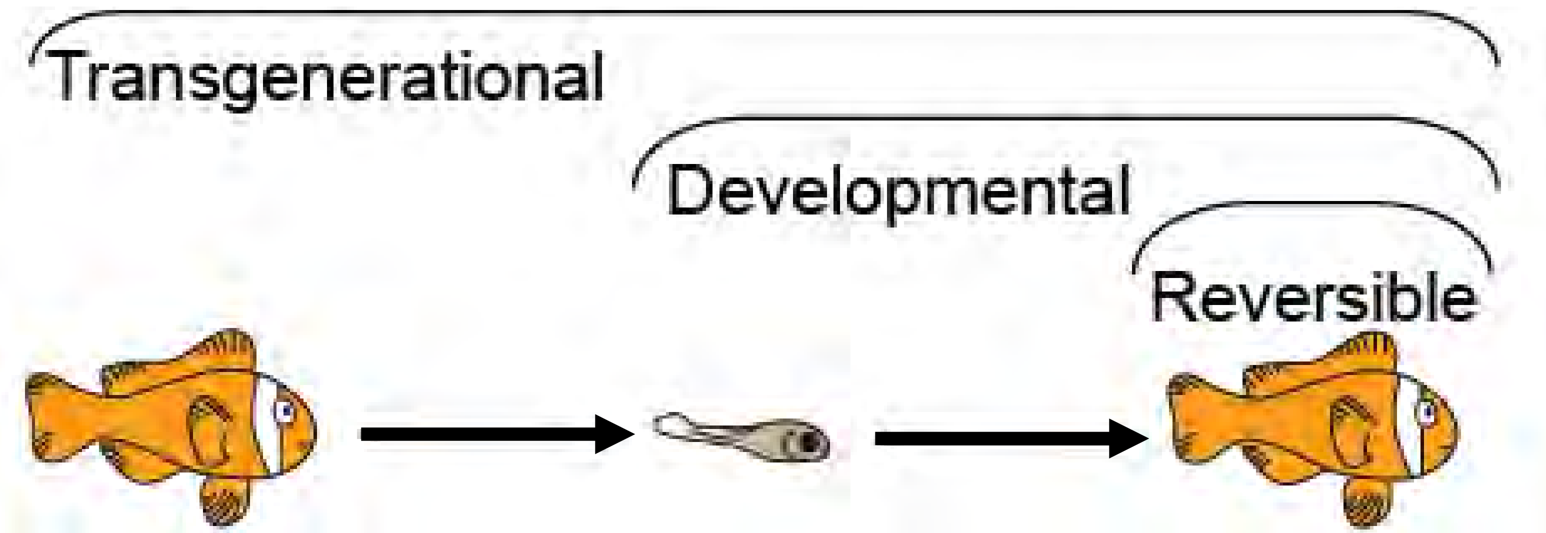
Acclimation

- Rapid phenotypic response to environmental change
- Improves performance in new environment
- Time for adaptation to catch up



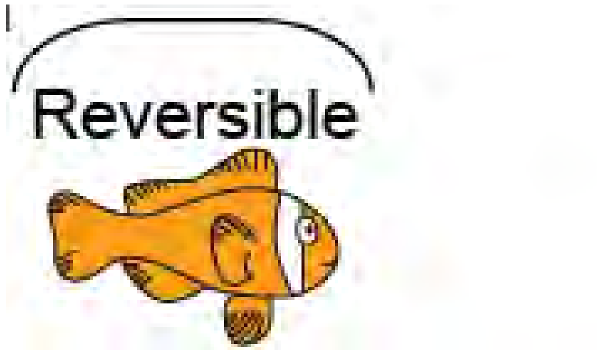
Sunday et al. 2014 *TREE, 29: 117-125*

Acclimation



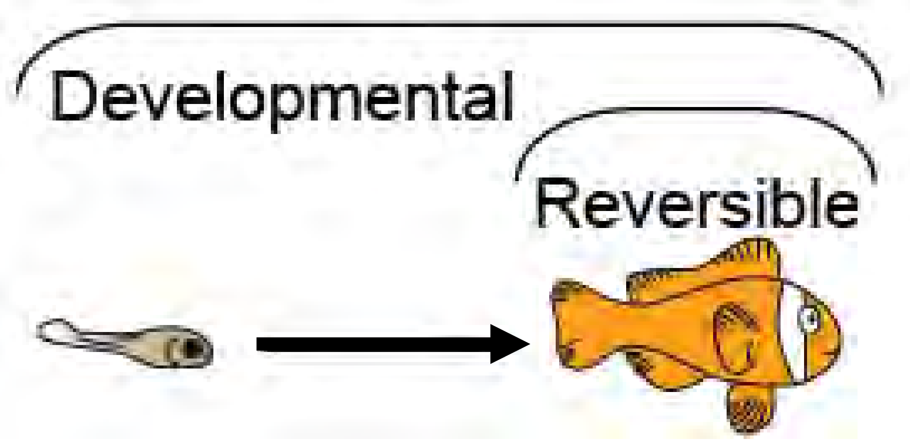
Sunday et al. 2014 *TREE, 29: 117-125*

Acclimation



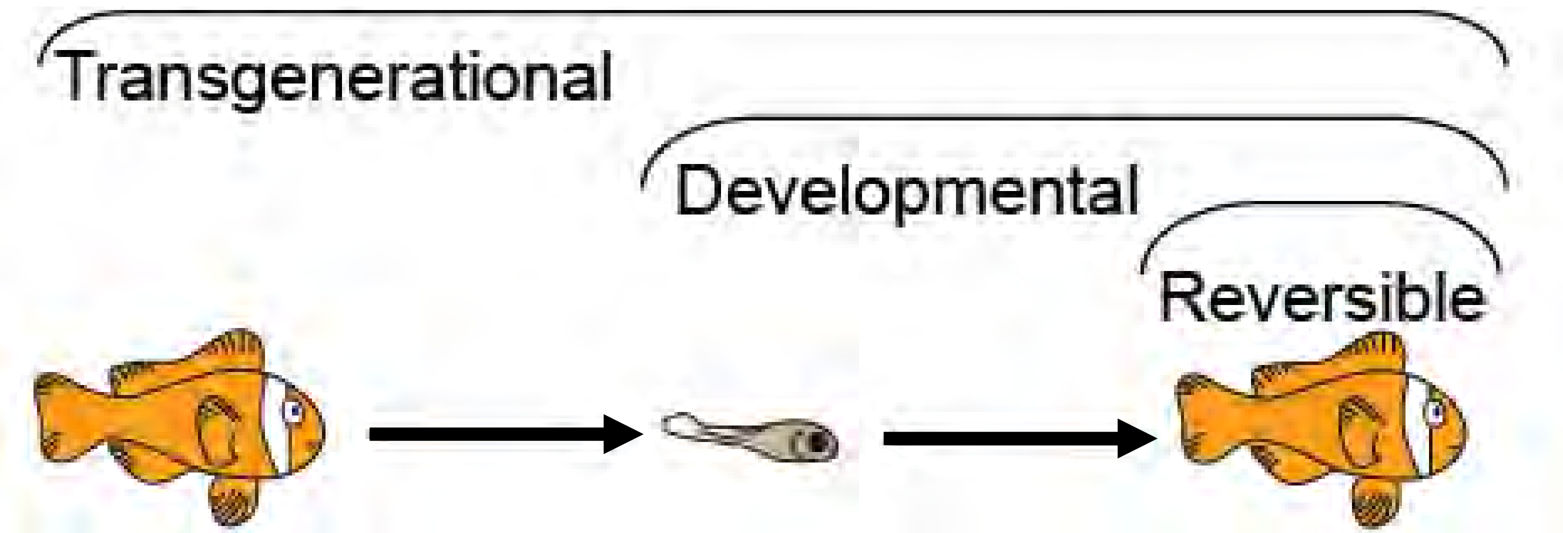
- Short-term regulated responses to environmental variation: e.g. diel & seasonal variation
- Species that live in variable environments

Acclimation



- Irreversible response to environmental conditions experienced during ontogeny
- Influences response of later life stages

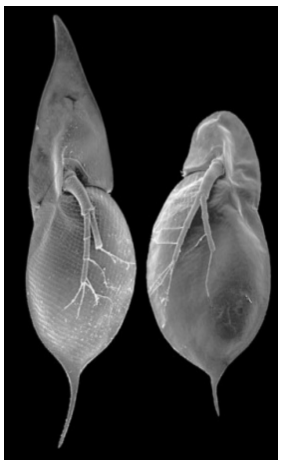
Acclimation

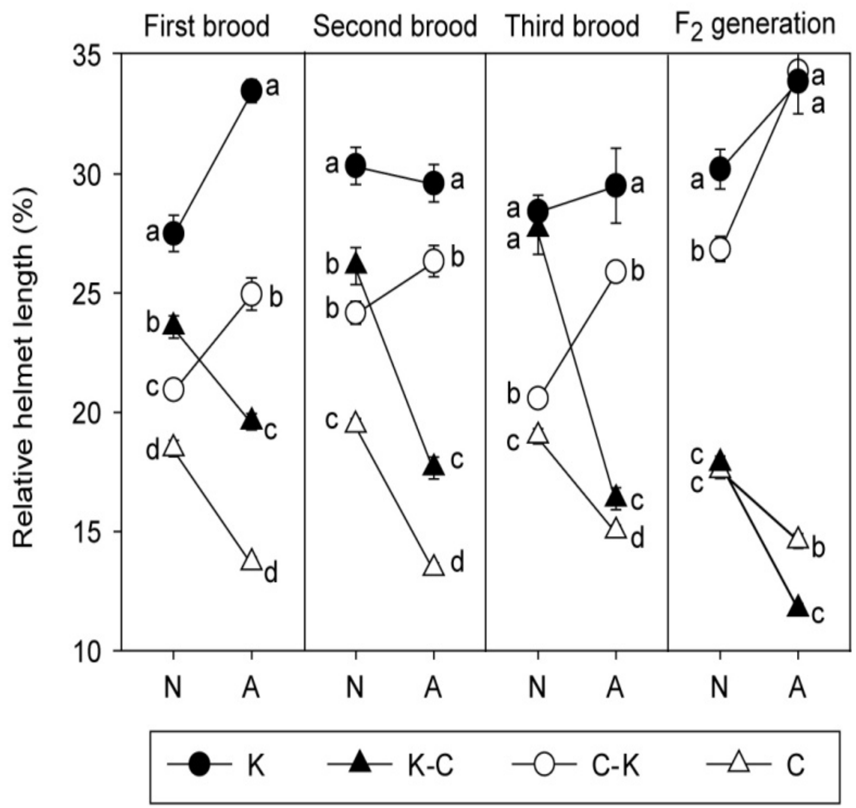


- Environment experienced by the parents (or earlier generations) influences the offsprings' response to environmental conditions

Transgenerational Acclimation

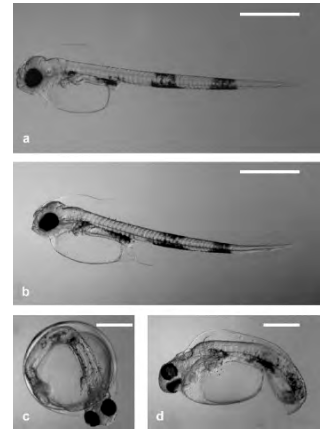
Daphnia (waterflea) response to predator chemical cues

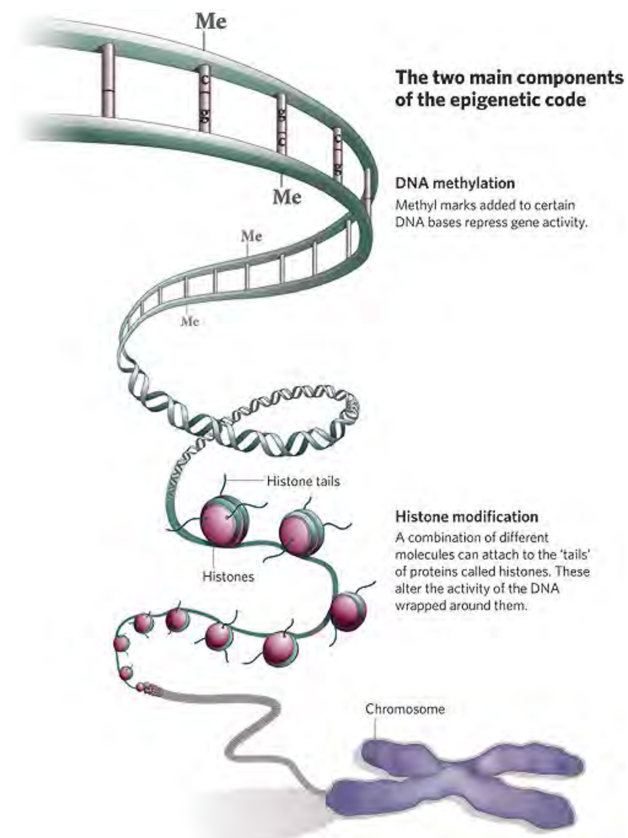




Argrawal et al. 1999 Nature

- Nutrients
  - Yolk
- Somatic factors
  - Hormones and proteins
- Epigenetic state
  - DNA methylation
  - Chromatin structure
  - Modify the activation of genes
  - Influenced by the environment
  - Heritable!





Transgenerational Acclimation

- Limited capacity for reversible acclimation
- + 1.5- 3°C affects:
  - growth, reproduction, aerobic performance
- Rearing fish over multiple generations
  - Developmental
  - Transgenerational

Spiny damselfish

Experimental design

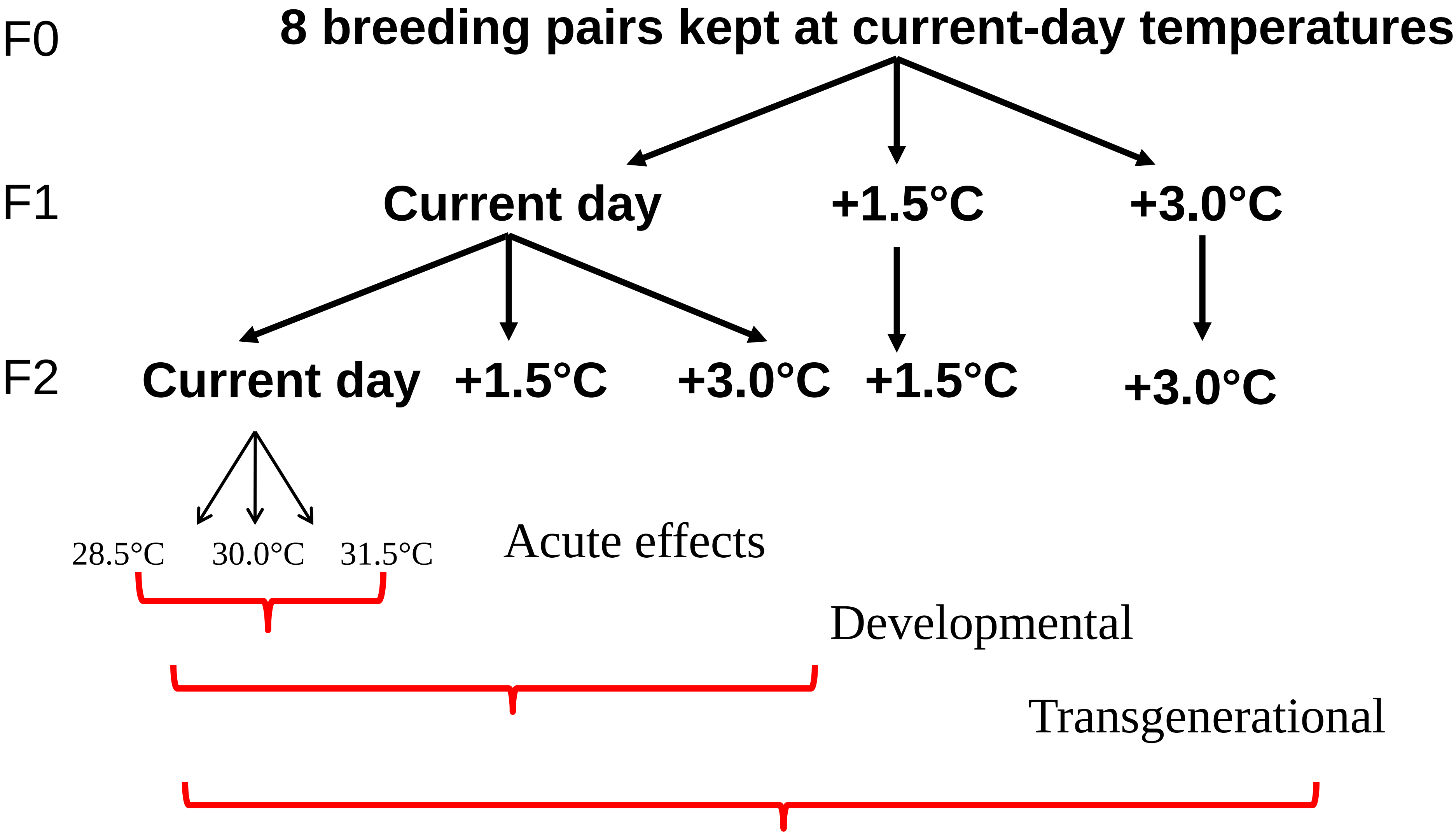
F0 **Breeding pairs kept at current-day temperatures**

F1 **Current day** **+1.5°C** **+3.0°C**

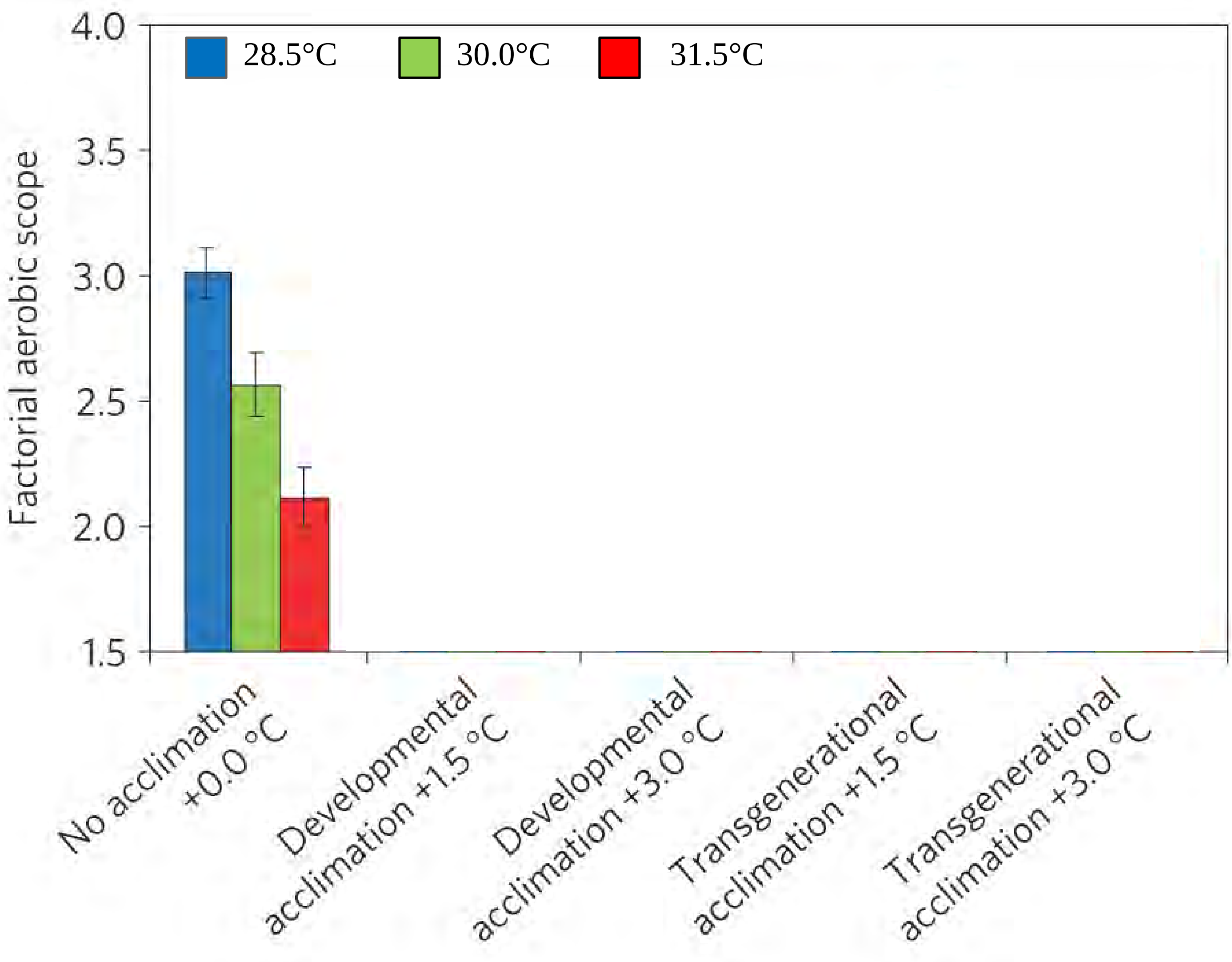
F2 **Current day** **+1.5°C** **+3.0°C** **+1.5°C** **+3.0°C**

28.5°C 30.0°C 31.5°C

Experimental design

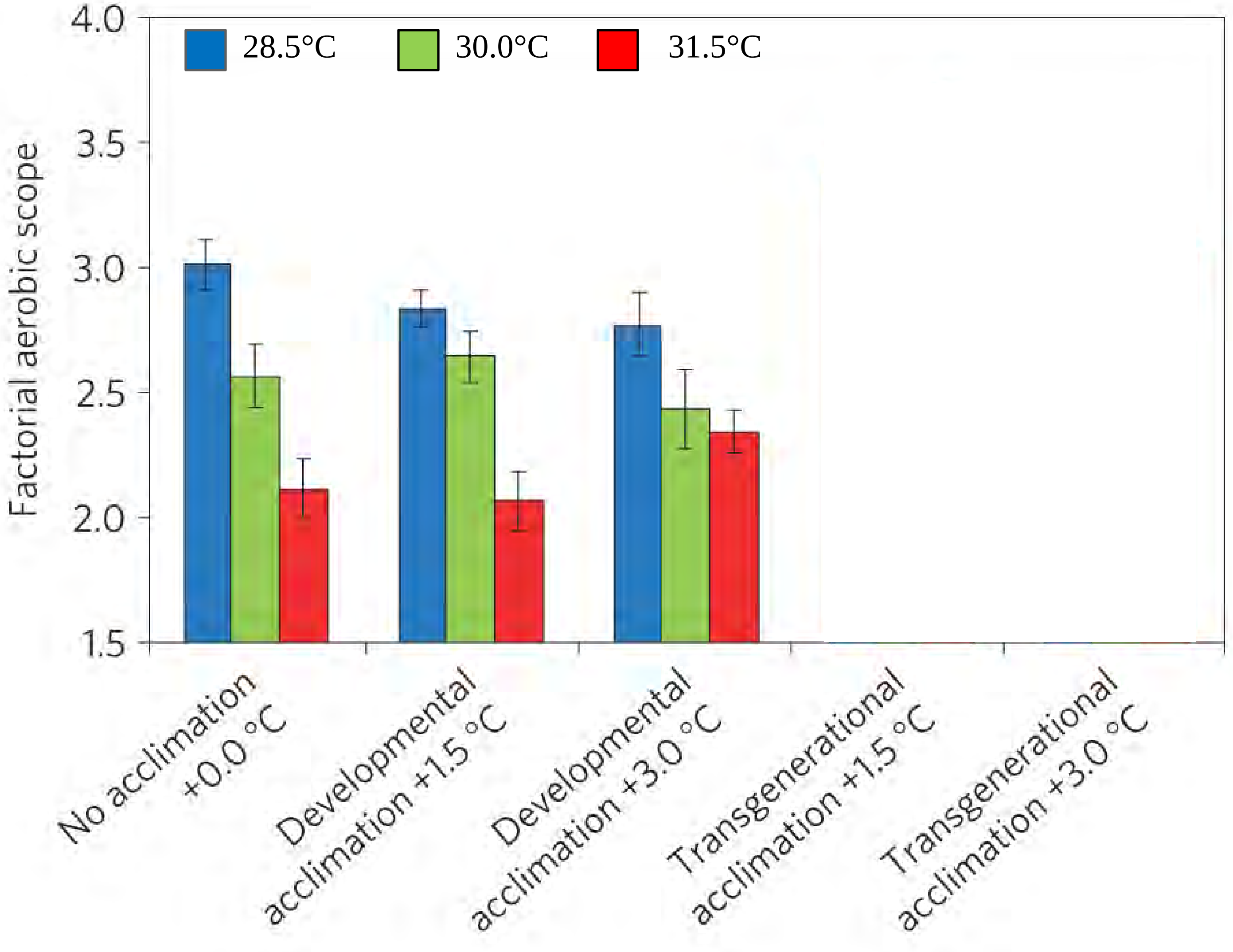


Acute effects



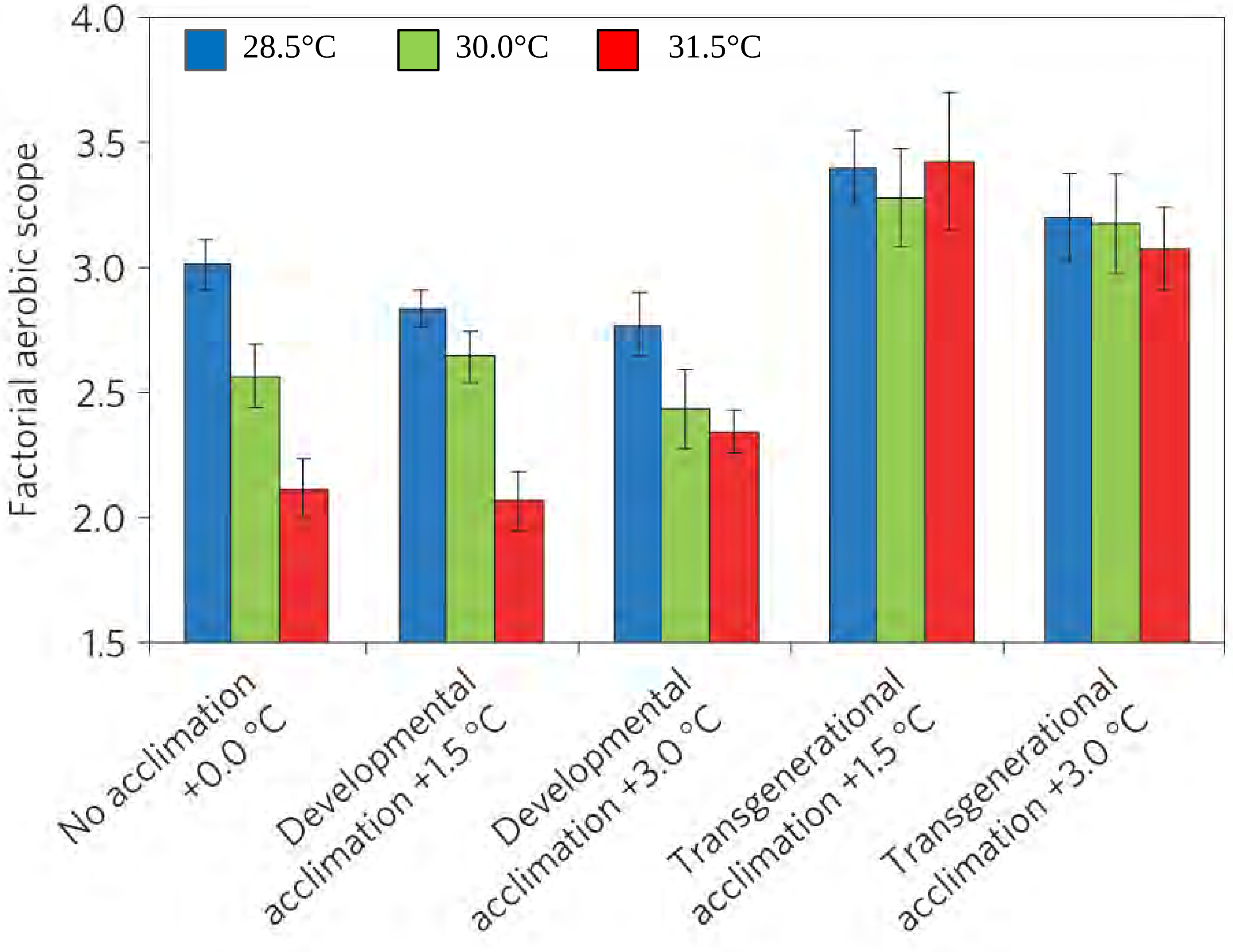
Donelson et al. 2012 *Nature Climate Change* 2: 30-32

Developmental acclimation



Donelson et al. 2012 *Nature Climate Change* 2: 30-32

Transgenerational acclimation



Donelson et al. 2012 *Nature Climate Change* 2: 30-32

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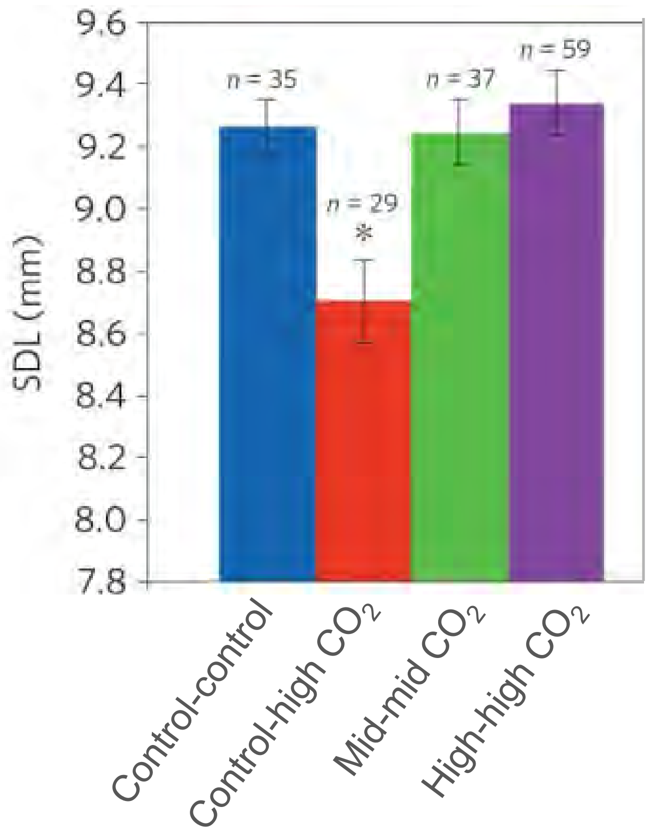
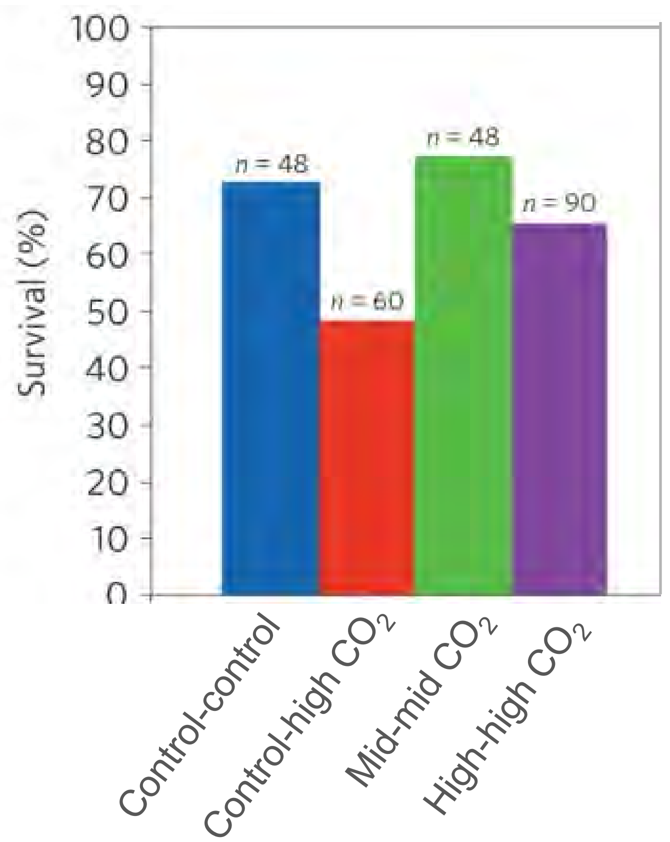
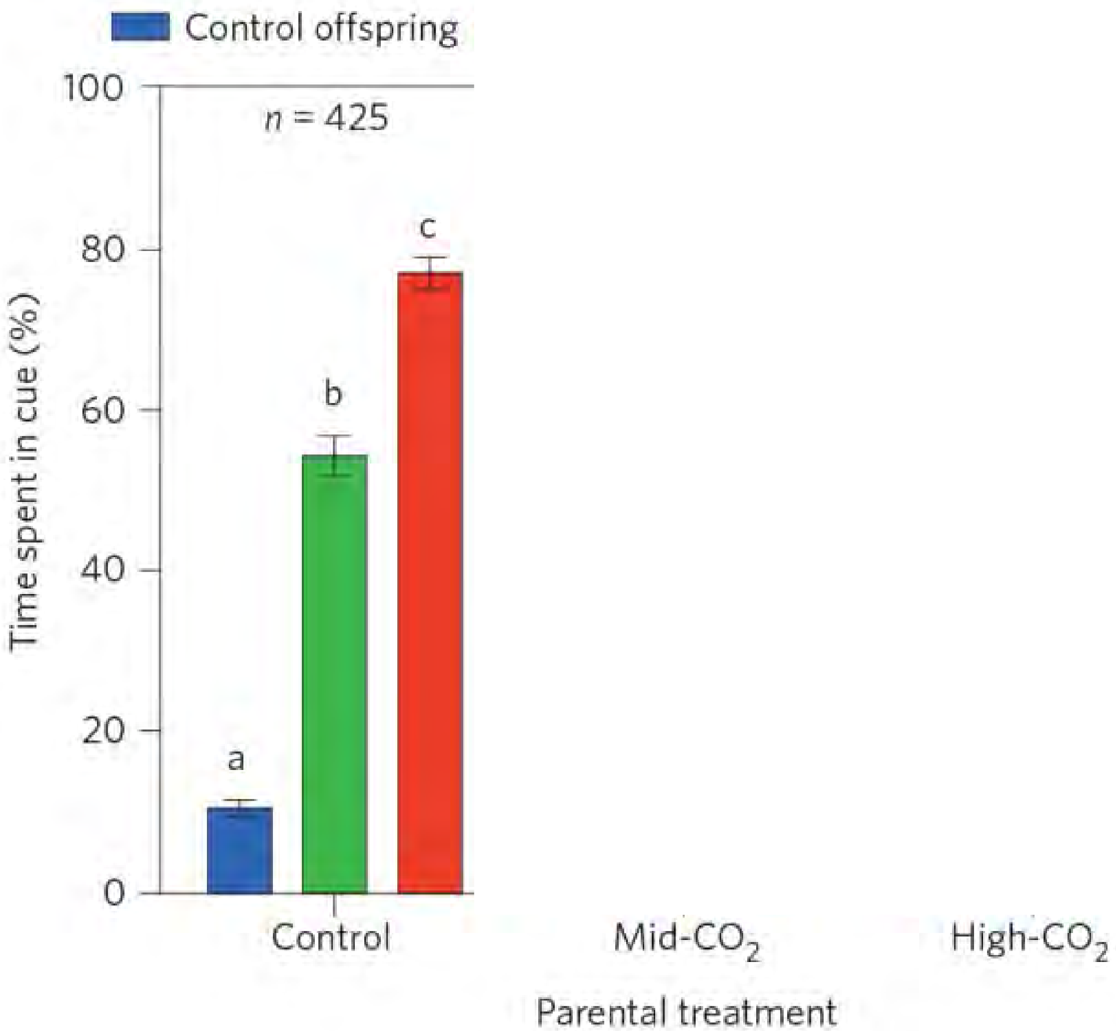




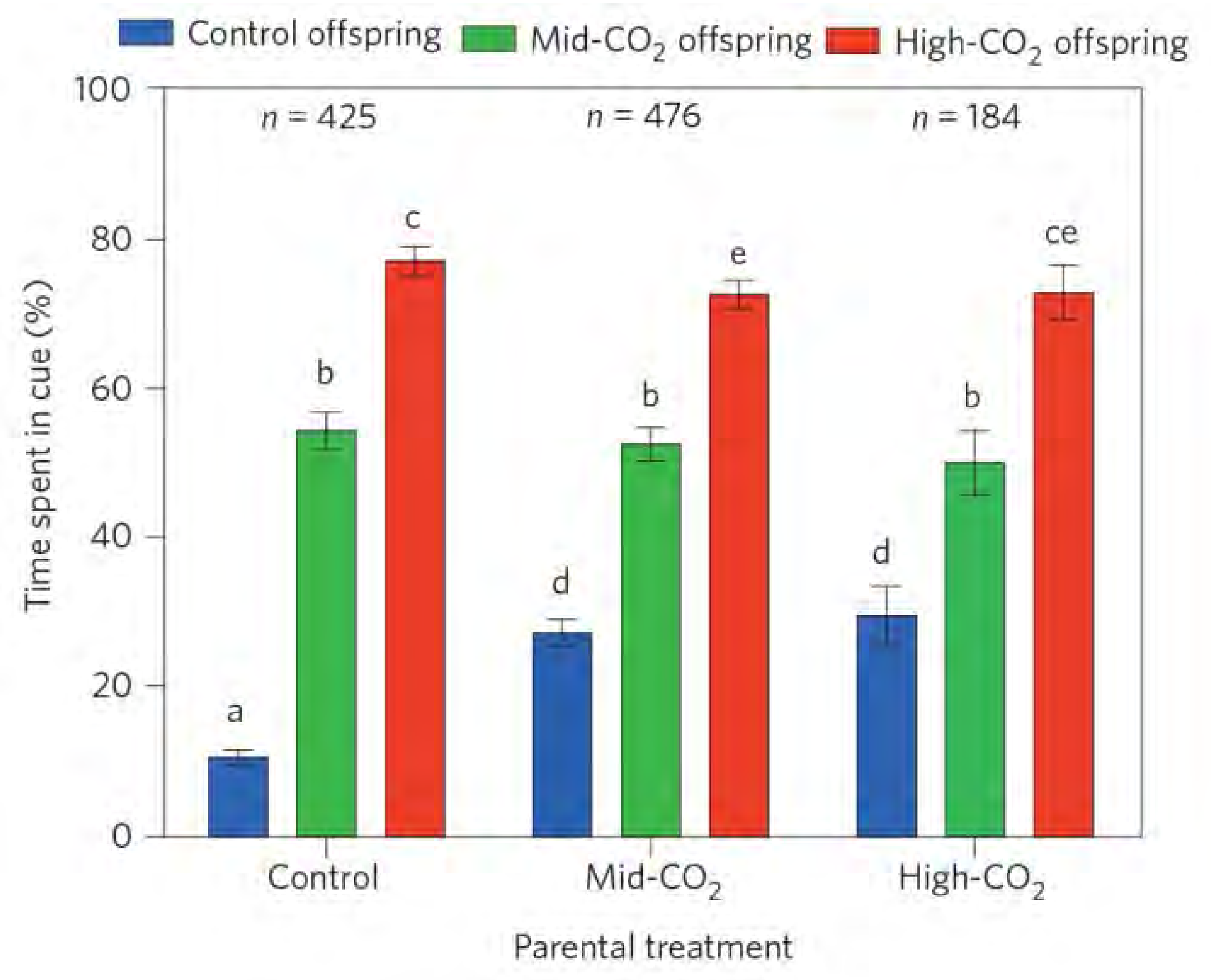
Miller et al. 2012. *Nature Climate Change*, 2: 858-861

No transgenerational acclimation



Welch et al. 2014. *Nature Climate Change*, 4: 1086-1089

No transgenerational acclimation



Welch et al. 2014. *Nature Climate Change*, 4: 1086-1089

Summary

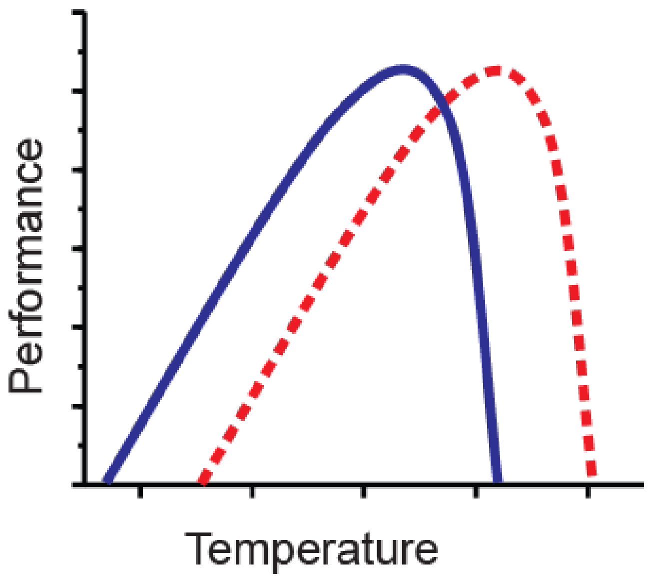
- Transgenerational acclimation is a powerful mechanism by which populations can adjust to rapid climate change
- May take several generations for full acclimation potential to be expressed
- Not all traits acclimate across generations

Future directions

- Will short-term acclimation translate to long-term persistence?
- What are the costs or trade-offs?
- Does acclimation affect genetic adaptation?
  - Retard by shifting phenotype without selection?
  - Accelerate by genetic assimilation?

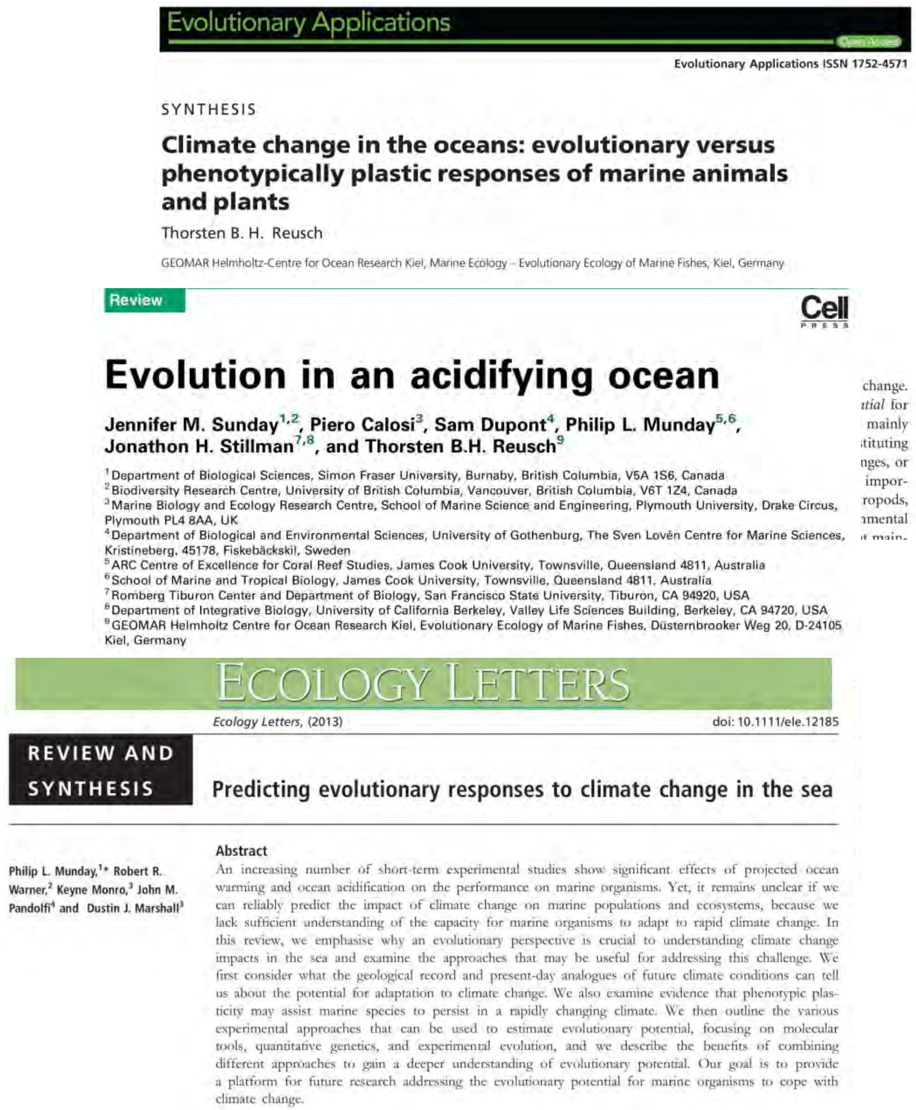
Adaptation

- Acclimation
  - Physiological, behavioural or morphological adjustment without genetic selection (plasticity)
- Genetic Adaptation
  - Selection on genetic variation that is inherited from one generation to the next



Assessing evolutionary potential

- Field studies
- Experimental evolution
- Quantitative genetics
- Molecular approaches
- Combined



Evolutionary Applications

Evolutionary Applications ISSN 1752-4571

SYNTHESIS

Climate change in the oceans: evolutionary versus phenotypically plastic responses of marine animals and plants

Thorsten B. H. Reusch

GEOMAR Helmholtz-Centre for Ocean Research Kiel, Marine Ecology – Evolutionary Ecology of Marine Fishes, Kiel, Germany

Review

Cell PRESS

Evolution in an acidifying ocean

Jennifer M. Sunday[1,2], Piero Calosi[3], Sam Dupont[4], Philip L. Munday[5,6], Jonathon H. Stillman[7,8], and Thorsten B.H. Reusch[9]

[1] Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, V5A 1S6, Canada
[2] Biodiversity Research Centre, University of British Columbia, Vancouver, British Columbia, V6T 1Z4, Canada
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[5] ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia
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[7] Romberg Tiburon Center and Department of Biology, San Francisco State University, Tiburon, CA 94920, USA
[8] Department of Integrative Biology, University of California Berkeley, Valley Life Sciences Building, Berkeley, CA 94720, USA
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ECOLOGY LETTERS

Ecology Letters, (2013) doi: 10.1111/ele.12185

REVIEW AND SYNTHESIS

Predicting evolutionary responses to climate change in the sea

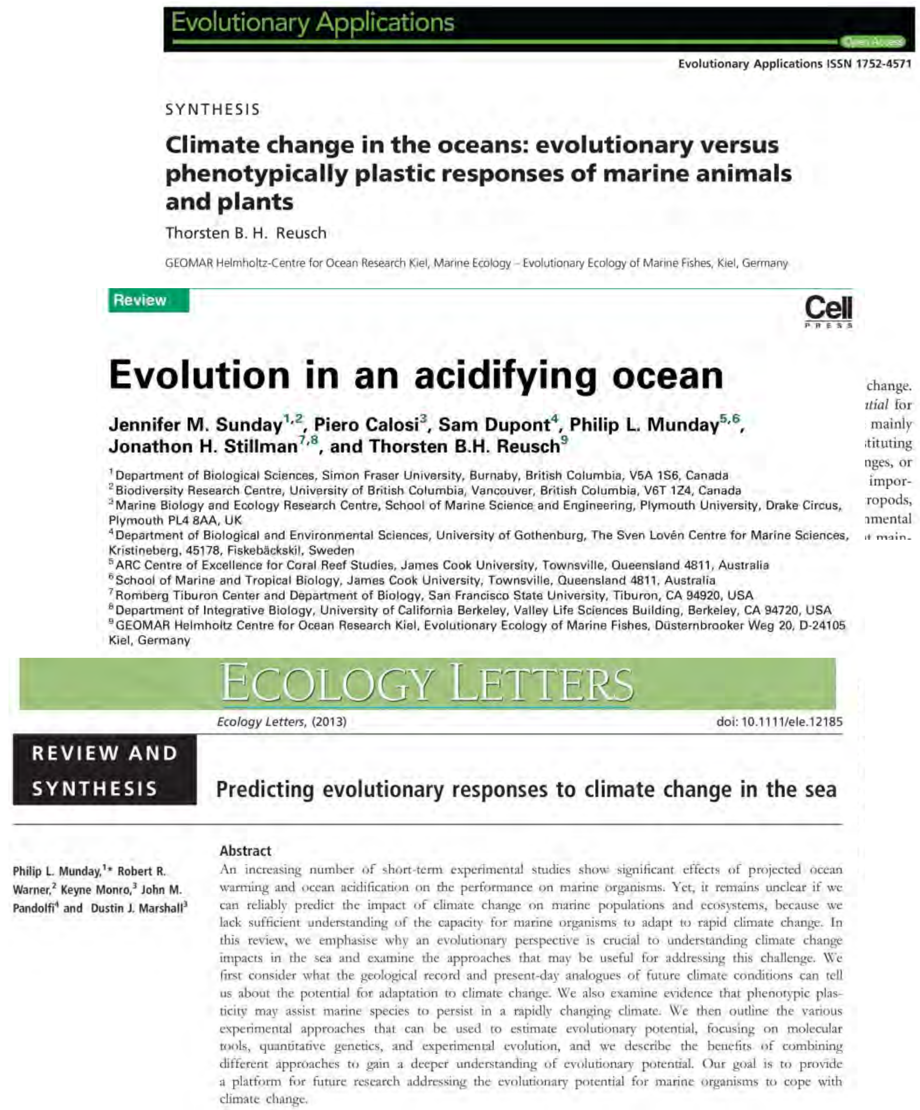
Philip L. Munday,[1]* Robert R. Warner,[2] Keyne Monro,[3] John M. Pandolfi[4] and Dustin J. Marshall[3]

Abstract

An increasing number of short-term experimental studies show significant effects of projected ocean warming and ocean acidification on the performance on marine organisms. Yet, it remains unclear if we can reliably predict the impact of climate change on marine populations and ecosystems, because we lack sufficient understanding of the capacity for marine organisms to adapt to rapid climate change. In this review, we emphasise why an evolutionary perspective is crucial to understanding climate change impacts in the sea and examine the approaches that may be useful for addressing this challenge. We first consider what the geological record and present-day analogues of future climate conditions can tell us about the potential for adaptation to climate change. We also examine evidence that phenotypic plasticity may assist marine species to persist in a rapidly changing climate. We then outline the various experimental approaches that can be used to estimate evolutionary potential, focusing on molecular tools, quantitative genetics, and experimental evolution, and we describe the benefits of combining different approaches to gain a deeper understanding of evolutionary potential. Our goal is to provide a platform for future research addressing the evolutionary potential for marine organisms to cope with climate change.

Assessing evolutionary potential

- Field studies
- Experimental evolution
- Quantitative genetics
- Molecular approaches
- Combined
  - molecular & field or experimental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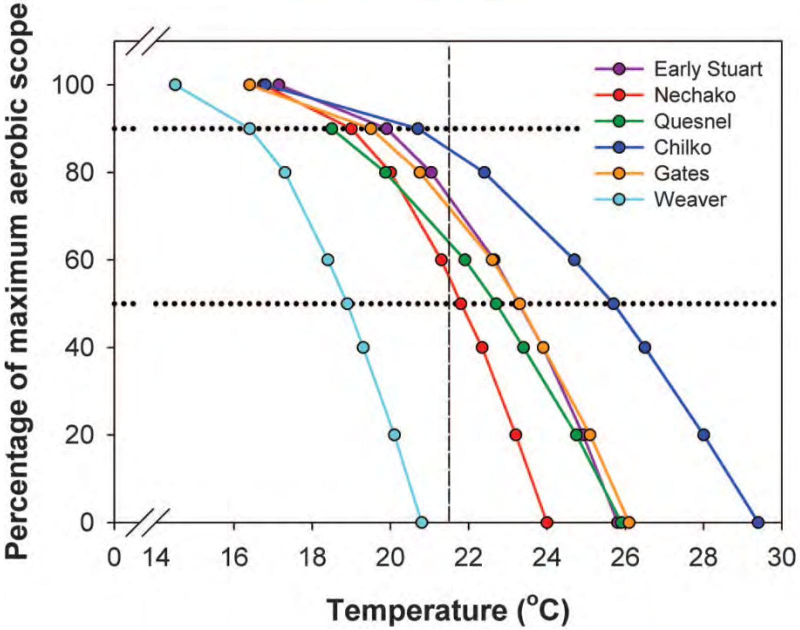
Field studies

- Population comparisons
  - environmental gradients
  - analogue environments
- Evidence for adaptation
- Distinguishing plasticity vs genetic adaptation
- Time frame unknown

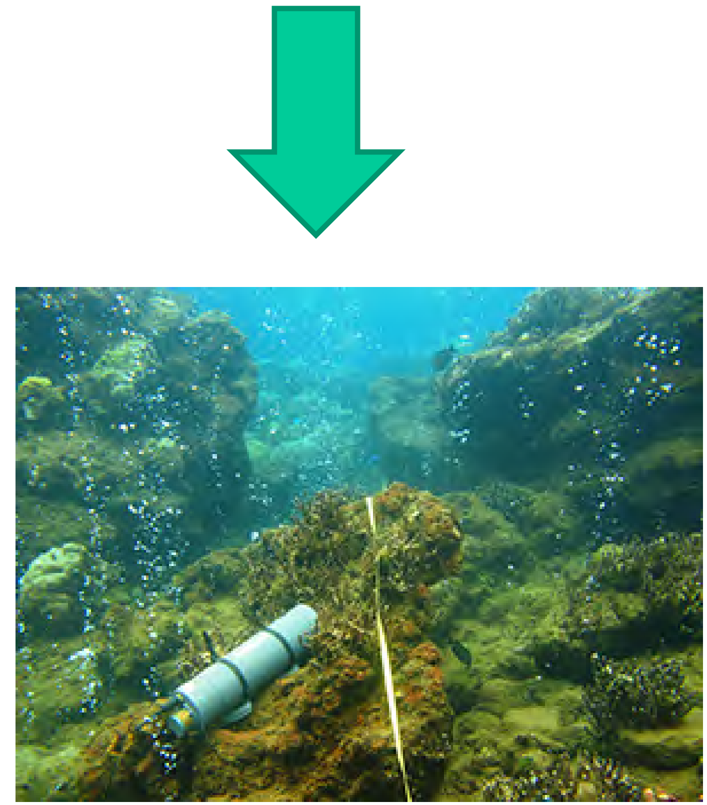


Eliason et al. 2011. *Science* 332: 109-112

Field studies

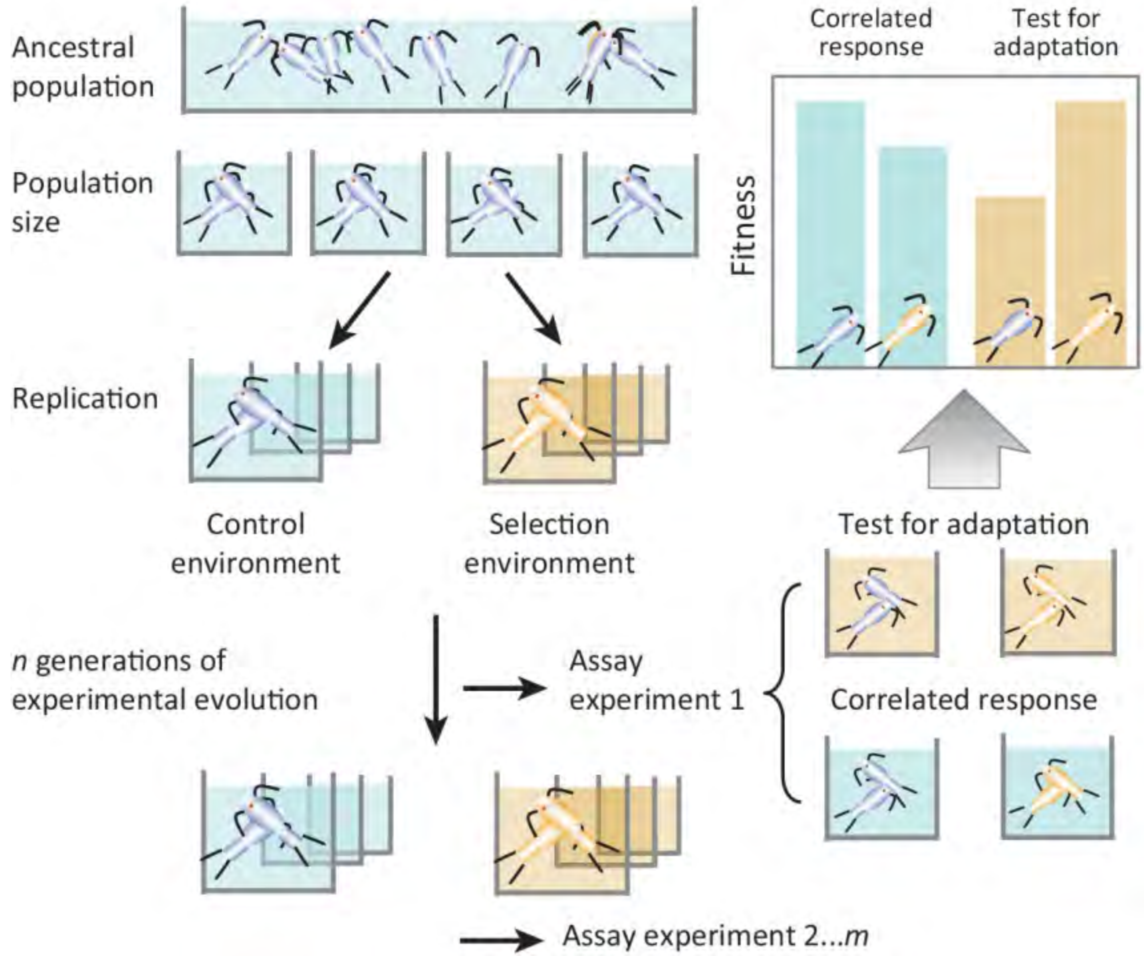
- Analogue environments
  - e.g. upwelling zones or natural CO_2 seeps
- Confounding factors
  - e.g. nutrients or temperature
- Spatial extent vs scale of population connectivity
- Genetic migration load

external larval supply



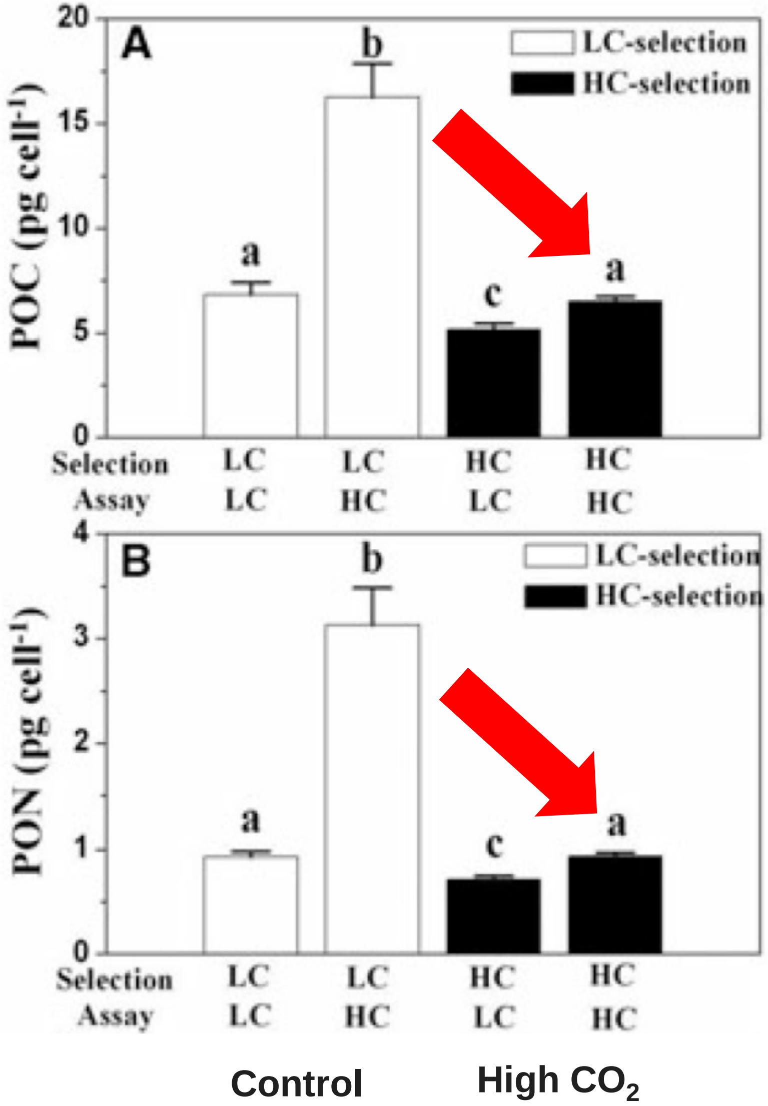
Experimental evolution

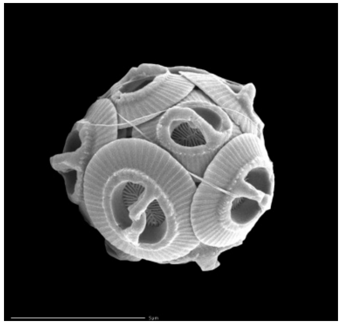
- Rear for many generations under selection
- Realised evolution
- Best suited to small, short-lived organisms that can be cultured (e.g. algae, plankton)



Sunday et al. 2014 *TREE, 29: 117-125*

Experimental evolution

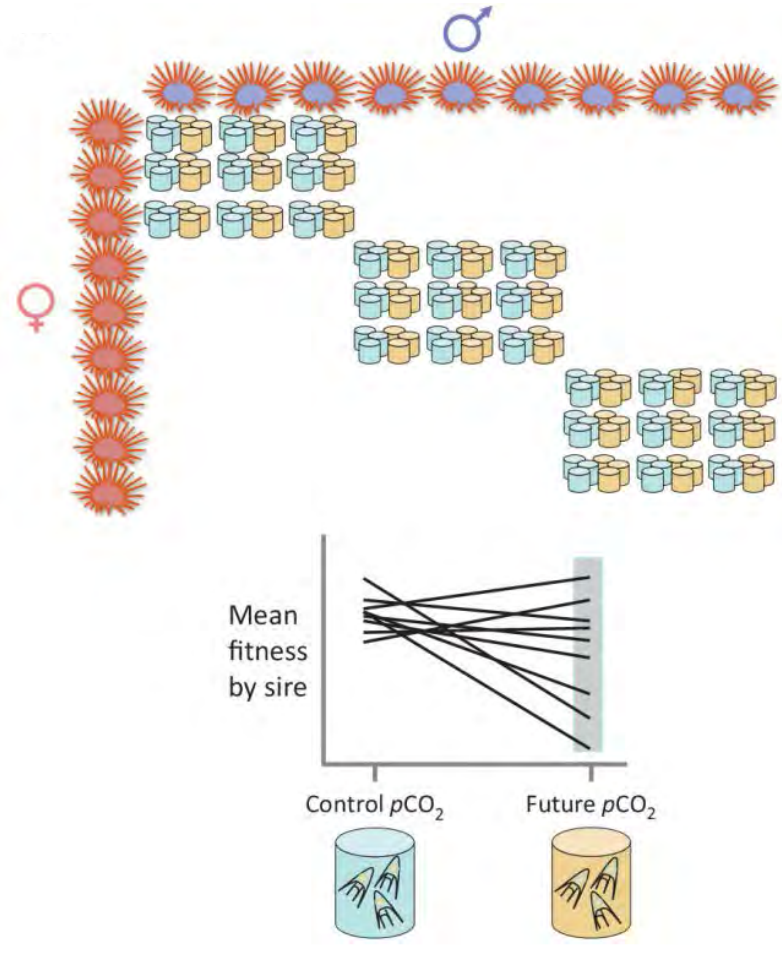




Jin et al. 2013 *Evolution*: 1869-1878

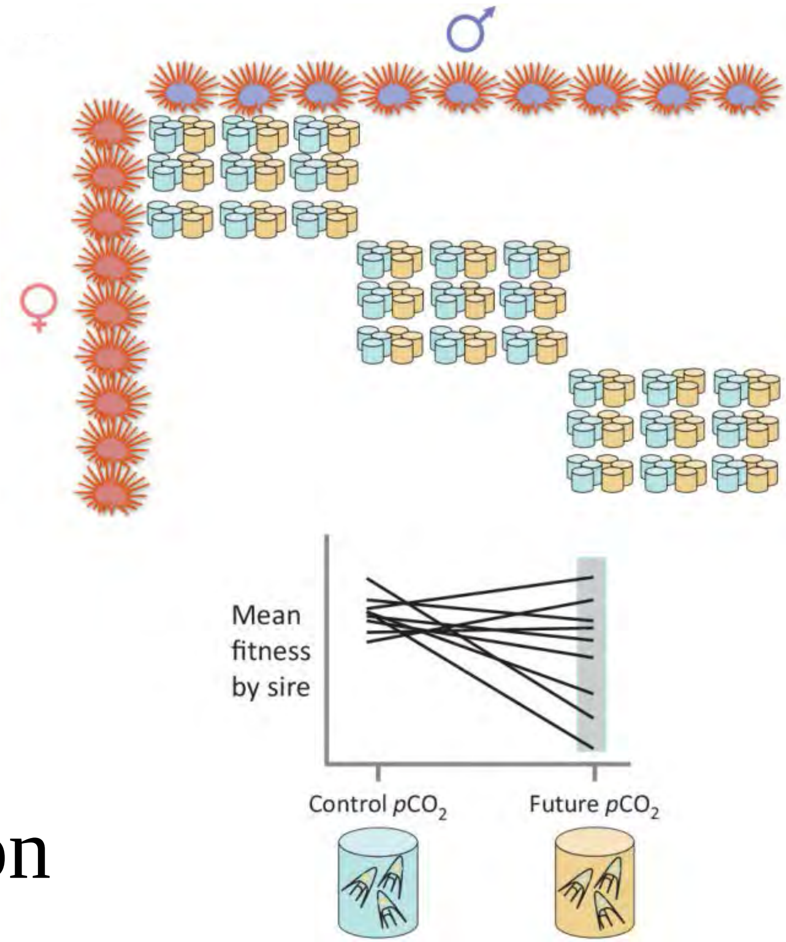
Quantitative genetics

- Parent-offspring correlations
- Pedigree mapping
- Breeding designs



Quantitative genetics

- Parent-offspring correlations
- Pedigree mapping
- Breeding designs
  - partition phenotypic variation
    - fathers
    - mothers
    - fathers*mothers
    - environment
- Heritable genetic variation



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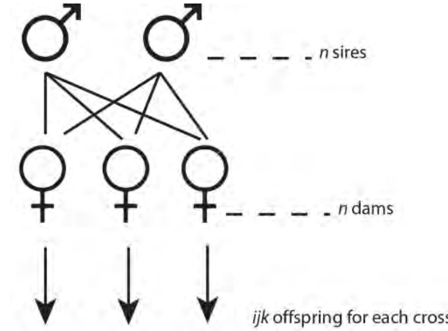


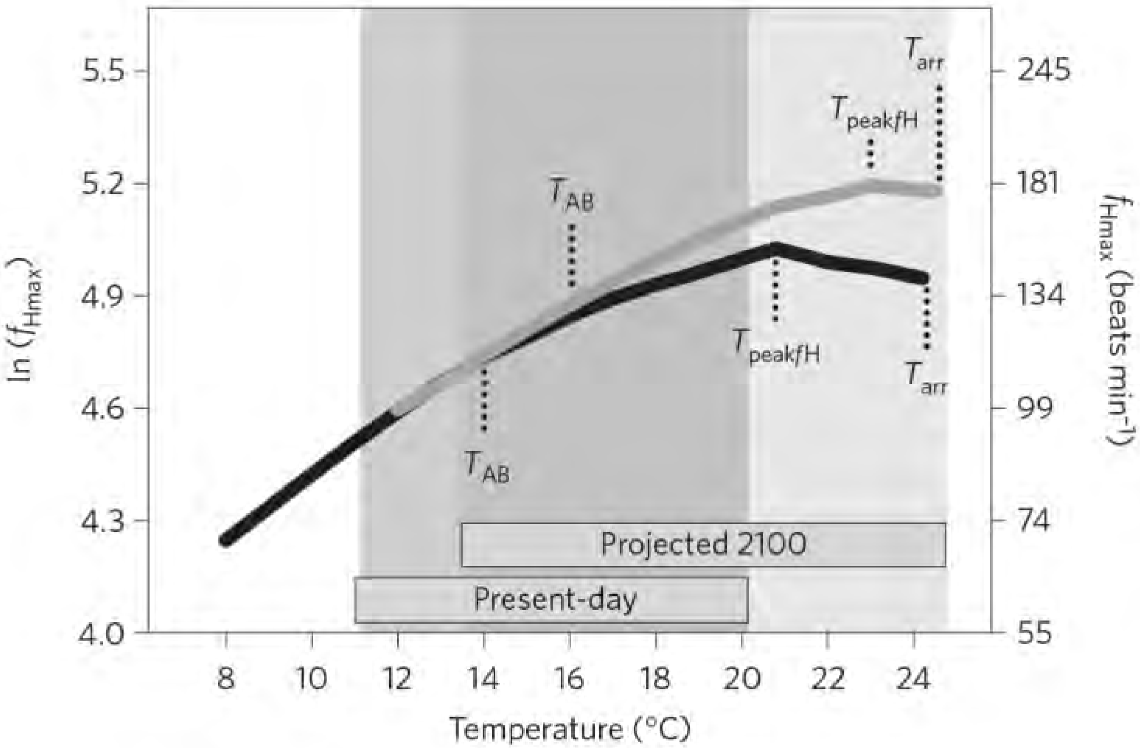
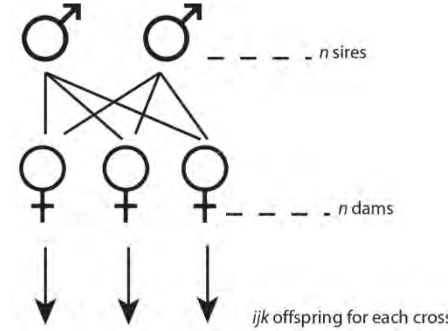


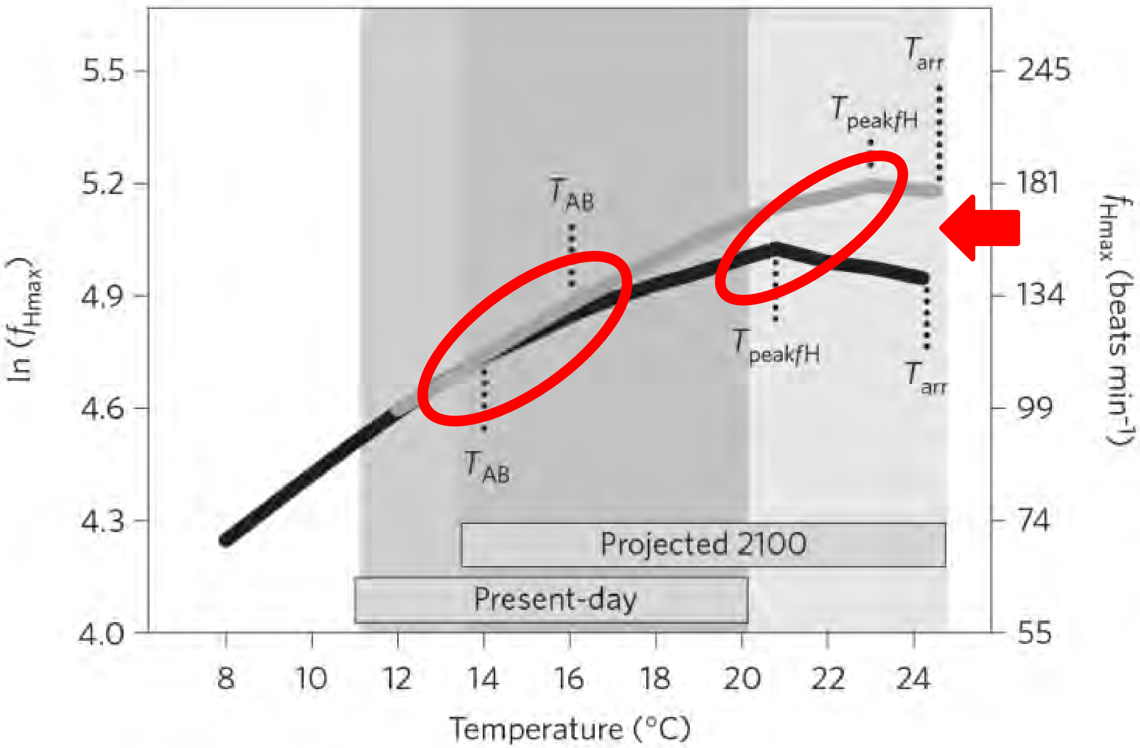
Table 1 | The plastic and genetic effects contributing to cardiac performance and thermal tolerance in Quinsam River chinook salmon (*O. tshawytscha*).

	DF	SS	*F*	*P*	σ^2	% phenotypic var
T_{AB}						
Treatment	1	235	267	<0.001	0.84	Plastic 42
Dam	4	3.04	0.87	0.485	0.01	
Sire	4	12.3	3.49	0.009	0.04	Additive 9
Sire × Dam	4	3.99	1.14	0.340	0.01	
Treatment × Dam	4	7.26	2.07	0.086	0.03	
Treatment × Sire	4	8.19	2.33	0.057	0.03	
Residual	260	228			0.82	
T_{peakfH}						
Treatment	1	101.6	26.9	<0.001	0.36	Plastic 7
Dam	4	30.0	1.98	0.098	0.11	
Sire	4	23.4	1.54	0.191	0.08	
Sire × Dam	4	9.37	0.62	0.650	0.03	
Treatment × Dam	4	7.24	0.48	0.752	0.03	
Treatment × Sire	4	5.83	0.38	0.819	0.02	
Residual	260	985			3.52	
T_{arr}						
Treatment	1	2.30	0.68	0.411	0.01	
Dam	4	35.2	2.59	0.037	0.13	Maternal 4
Sire	4	24.1	1.77	0.134	0.09	
Sire × Dam	4	6.70	0.49	0.740	0.02	
Treatment × Dam	4	1.47	0.11	0.980	0.01	
Treatment × Sire	4	9.66	0.71	0.585	0.03	
Residual	260	882			3.15	

Munoz et al. 2013 *Nature Climate Change*, 5: 163-166

Quantitative genetics





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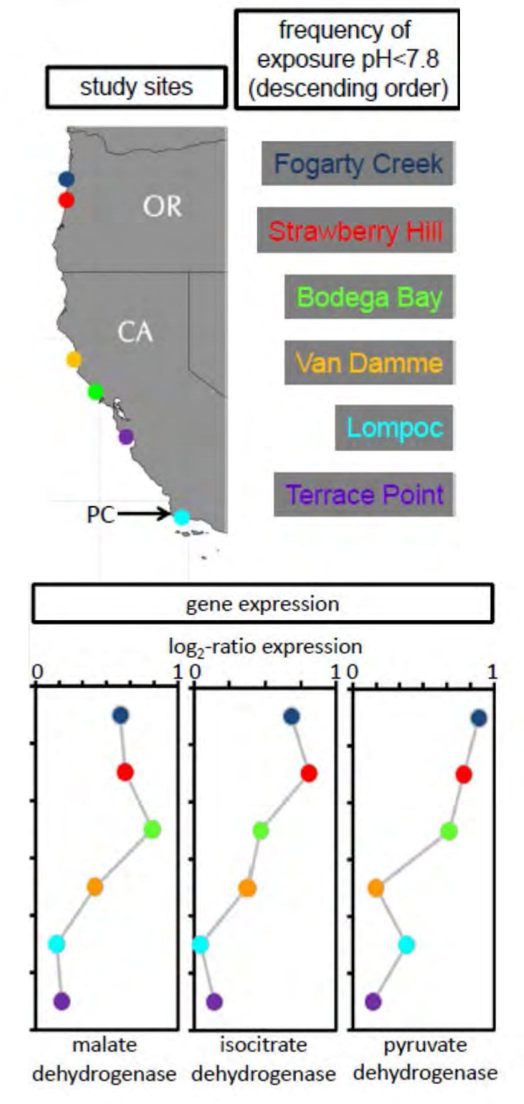
Dam	4	35.2	2.59	0.037	0.13	Maternal	4
Sire	4	24.1	1.77	0.134	0.09		
Sire × Dam	4	6.70	0.49	0.740	0.02		
Treatment × Dam	4	1.47	0.11	0.980	0.01		
Treatment × Sire	4	9.66	0.71	0.585	0.03		
Residual	260	882			3.15		

Munoz et al. 2013 *Nature Climate Change*, 5: 163-166

Molecular approaches

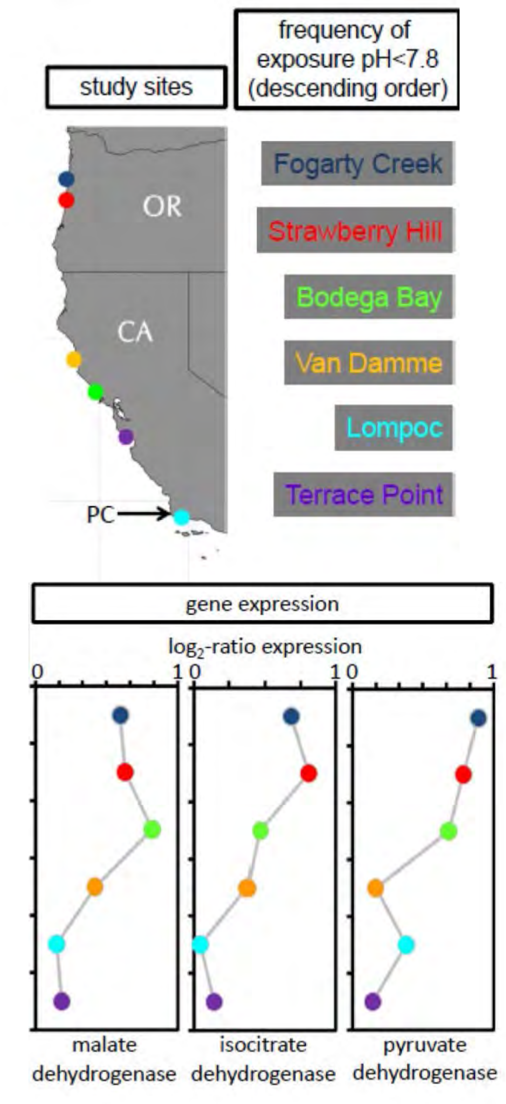
- Survey genetic variation (e.g. alleles)
- Identify genetic selection
- Insight to mechanisms (e.g. transcriptome)
- Alone do not predict evolutionary potential
- Genotype-to-phenotype map is weak



Evans et al. 2015 *Comparative Biochem & Physiol*

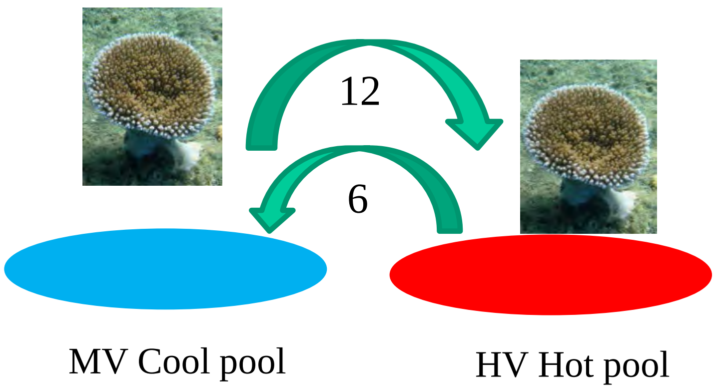
Molecular approaches

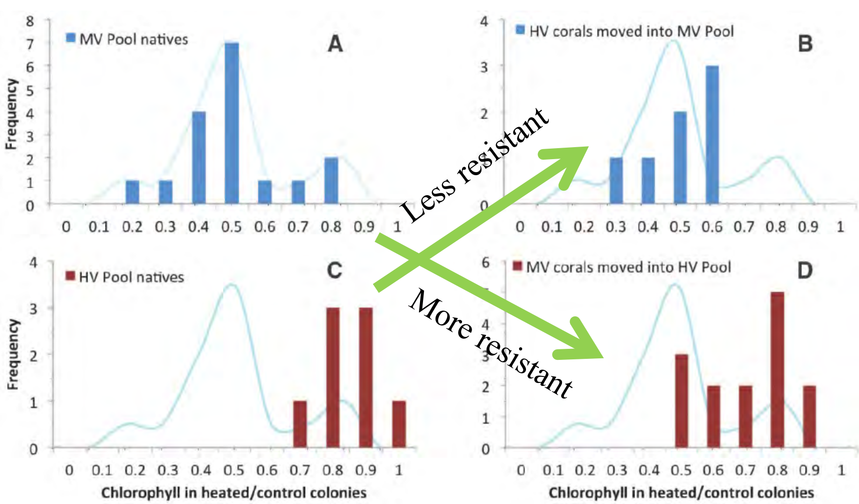
- Survey genetic variation (e.g. alleles)
- Identify genetic selection
- Insight to mechanisms (e.g. transcriptome)
- Alone do not predict evolutionary potential
- Most powerful with field studies or experiments



Evans et al. 2015 *Comparative Biochem & Physiol*

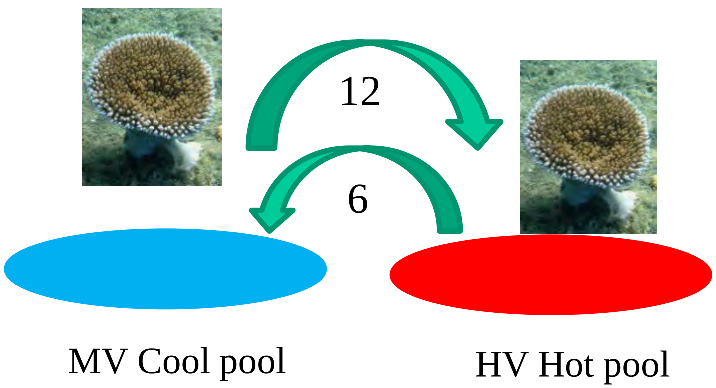
Molecular approaches



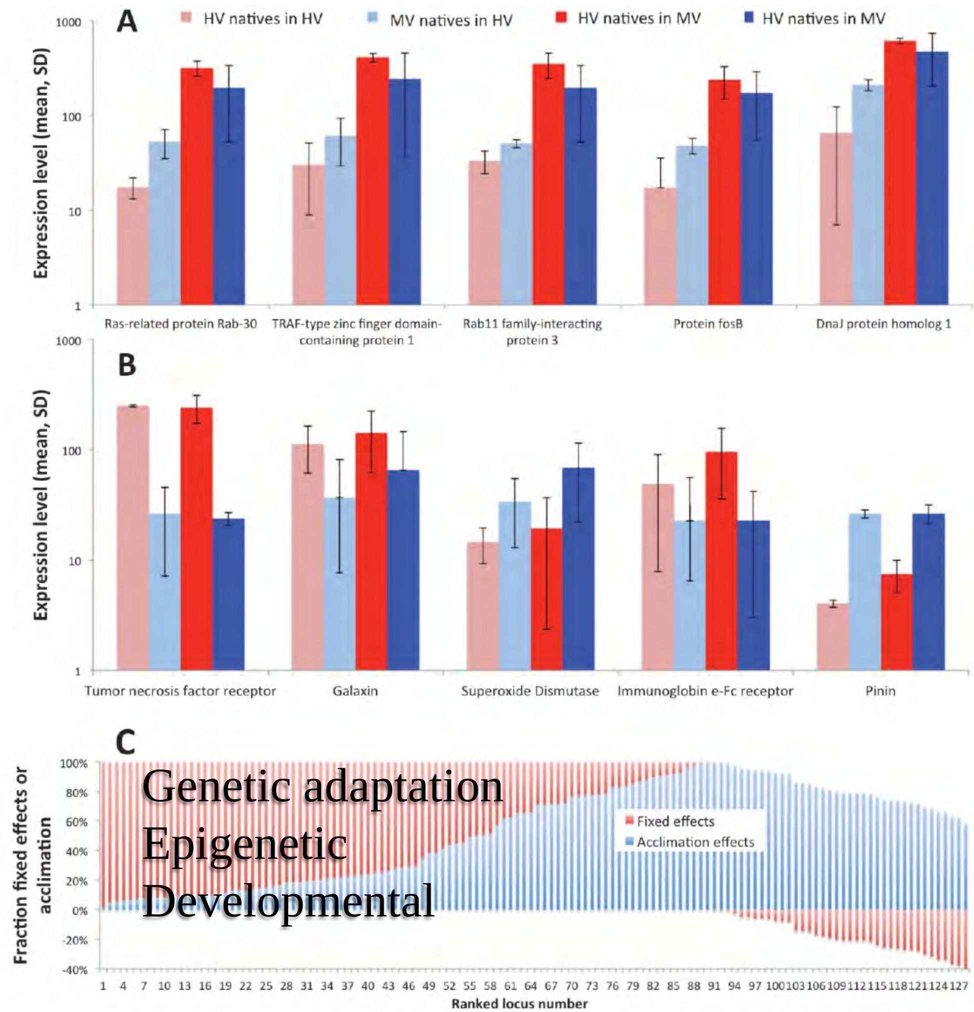


Palumbi et al. 2014 *Science, 344: 895-898*

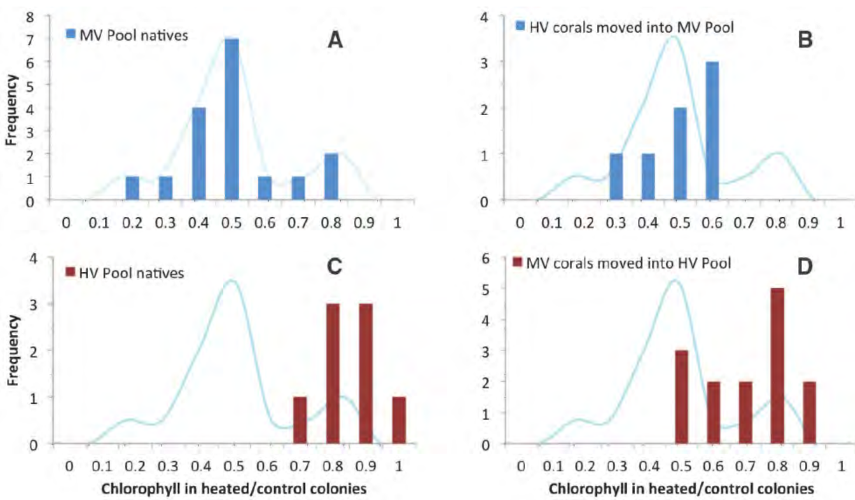
Molecular approaches



74 transplant 71 pool



Genetic adaptation
Epigenetic
Developmental



Palumbi et al. 2014 *Science, 344: 895-898*

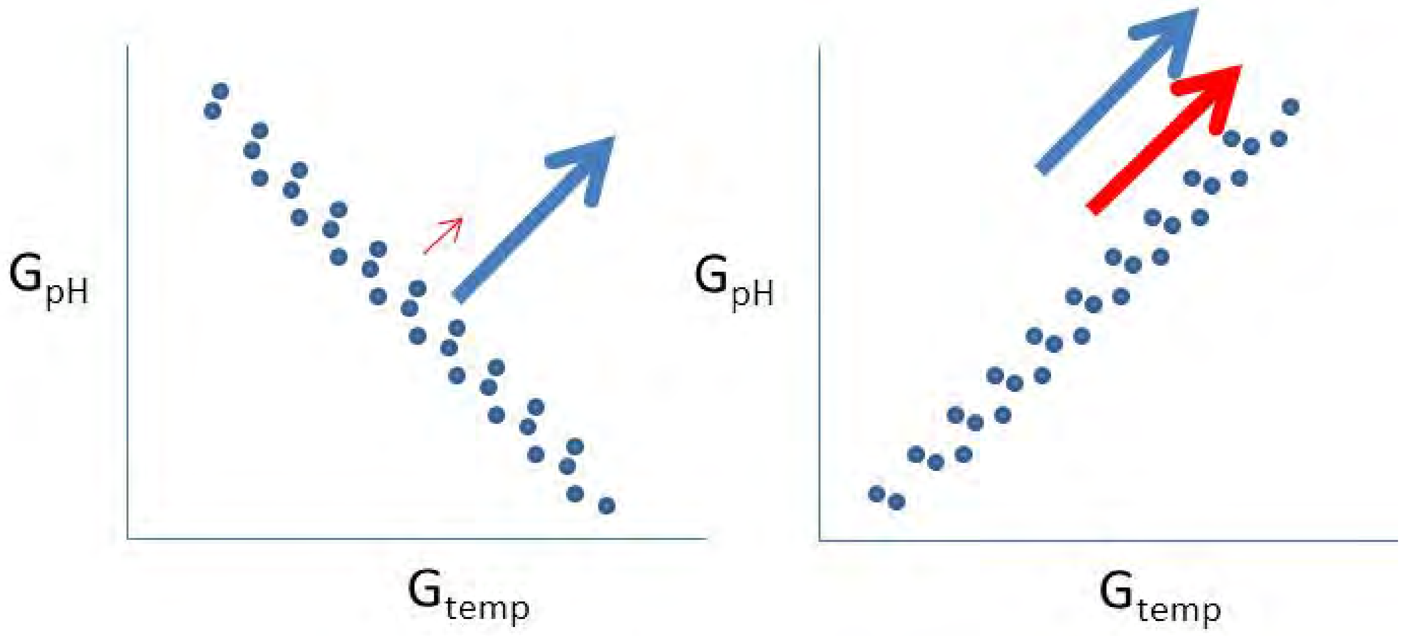
50:50 “fixed” and acclimation

Summary

- Increasing evidence for evolutionary potential
- Range of techniques and approaches available
- Experimental approaches that examine heritability and evolution of phenotypic traits
- Need to test for acclimation and adaptation
- Acclimation may be especially important in buffering populations against climate change

Future directions

- Genetic correlations between traits



Future directions

- Genetic correlations between traits
- Testing interaction between acclimation and genetic adaptation
- Include evolutionary potential in demographic models (evolutionary rescue)
- Community level models?

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