Quantifying marine ectotherms vulnerability to climate warming

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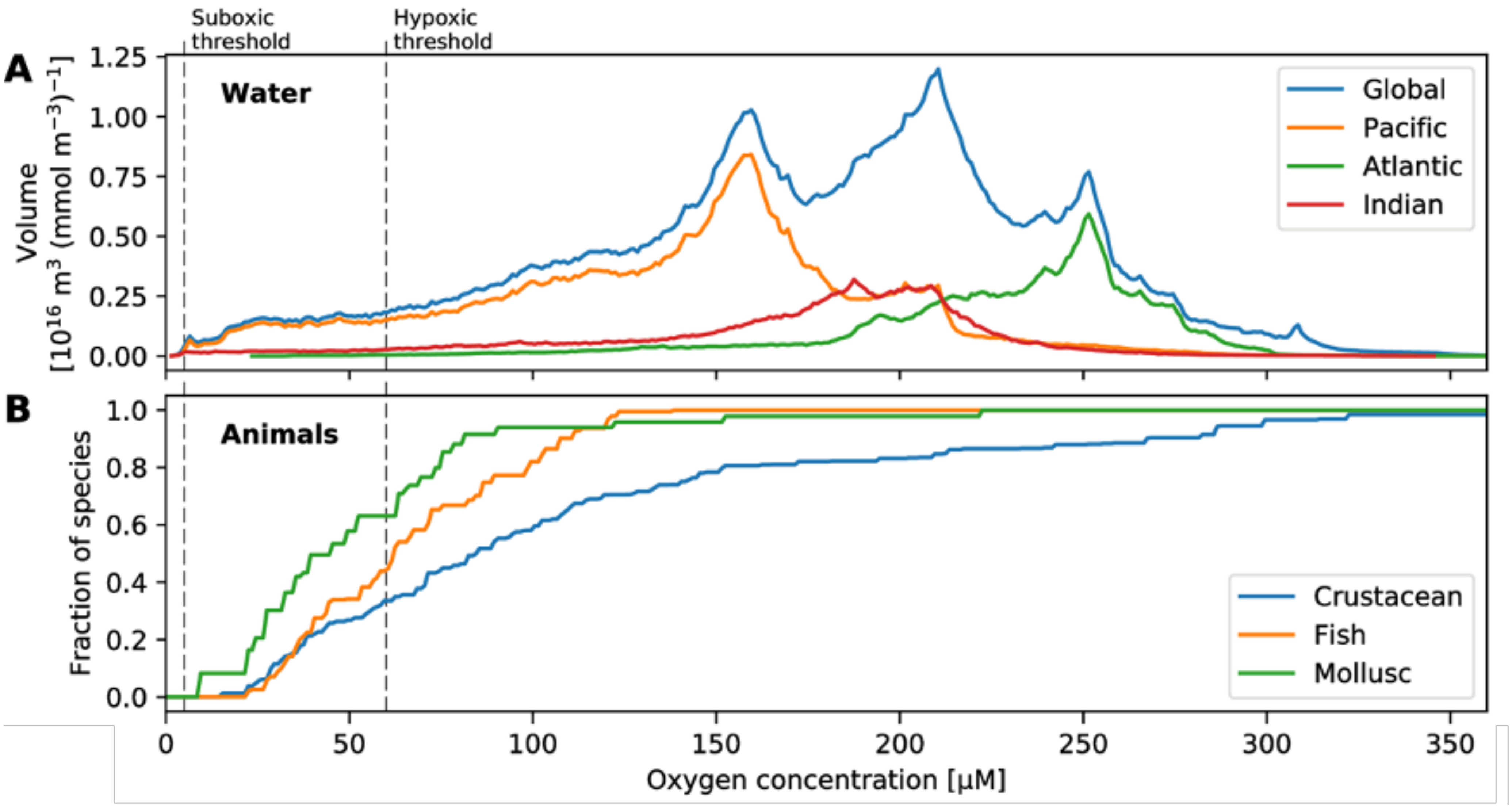
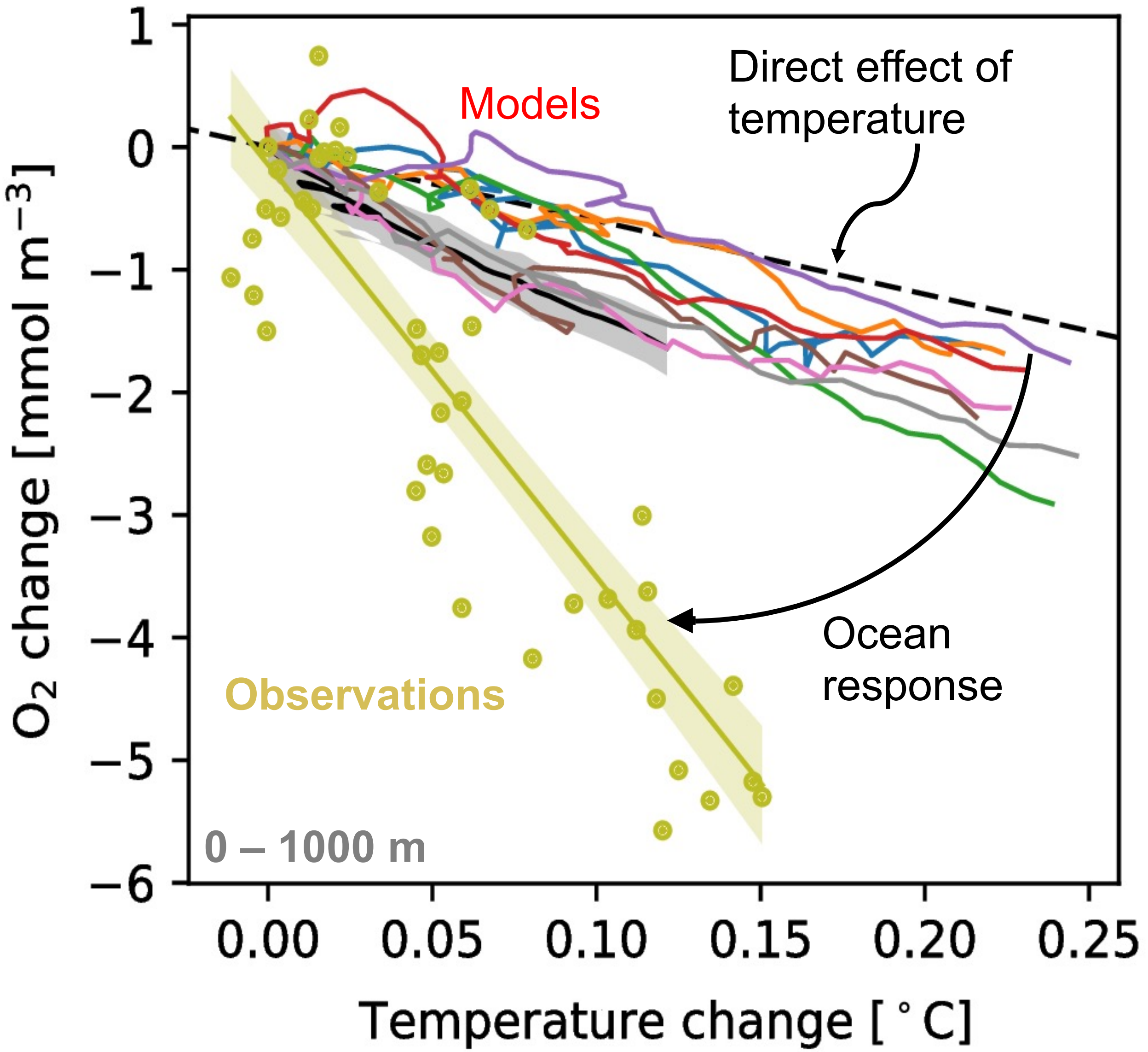
Dissolved oxygen heterogeneity plays a key role in setting marine habitat boundaries



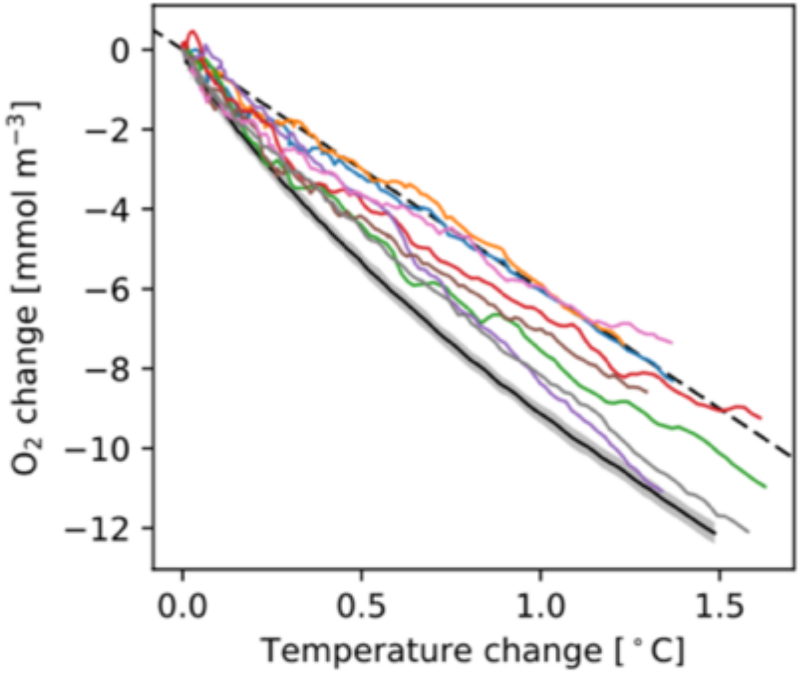
Long et al., 2019 Deutsch et al.,2020

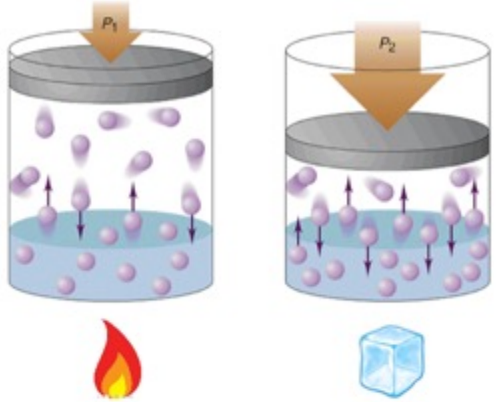
Ocean Deoxygenation

1970 - 2014



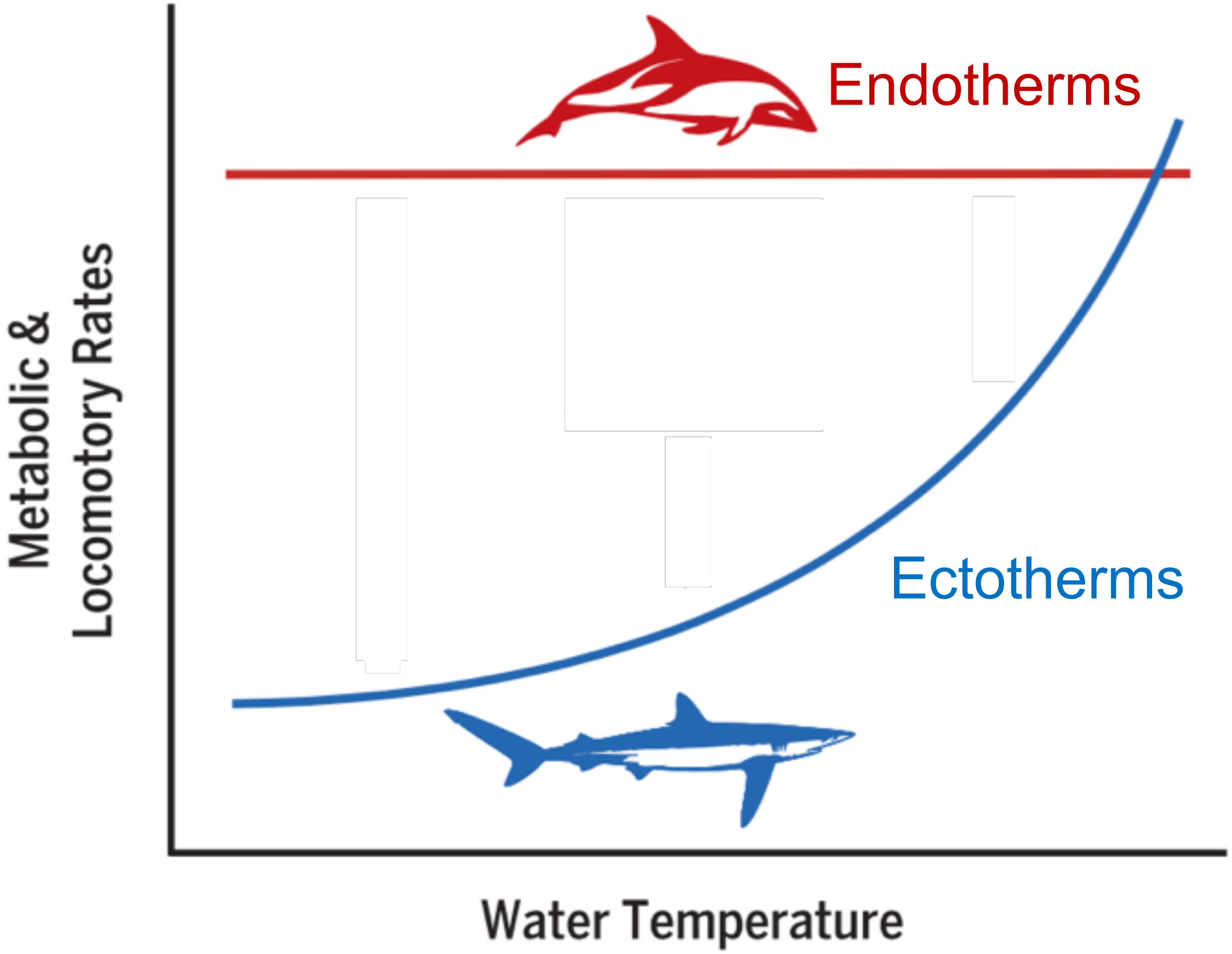
1970-2100





Long et al., 2019

Metabolic rates increase with temperature for Ectotherms



Grady et al., 2019

Metabolic theory

$S = \widetilde{\alpha^s} B^{\delta} pO_2$

$\widetilde{\alpha^s} = \alpha^s \exp\left[-\frac{E_s}{K_B}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$

Respiratory efficacy

$D = \alpha_D B^{\epsilon} \exp\left[-\frac{E_d}{K_B}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$

Metabolic demand

$\Phi = \frac{supply(S)}{demand(D)}$

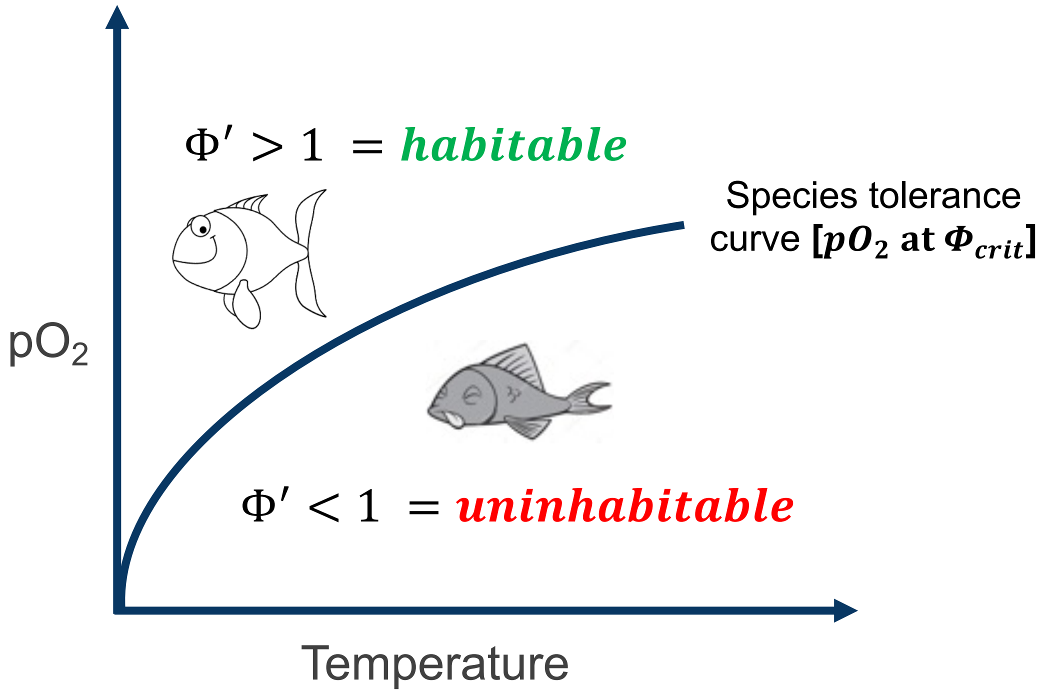
Metabolic index

$\Phi = A_o B^n pO_2 \exp\left[\frac{E_o}{K_B}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$

$A_c = Ao/\Phi_{crit}$

$\Phi' > 1 \ (\Phi > \Phi_{crit})$ and $\Phi' < 1 \ (\Phi < \Phi_{crit})$

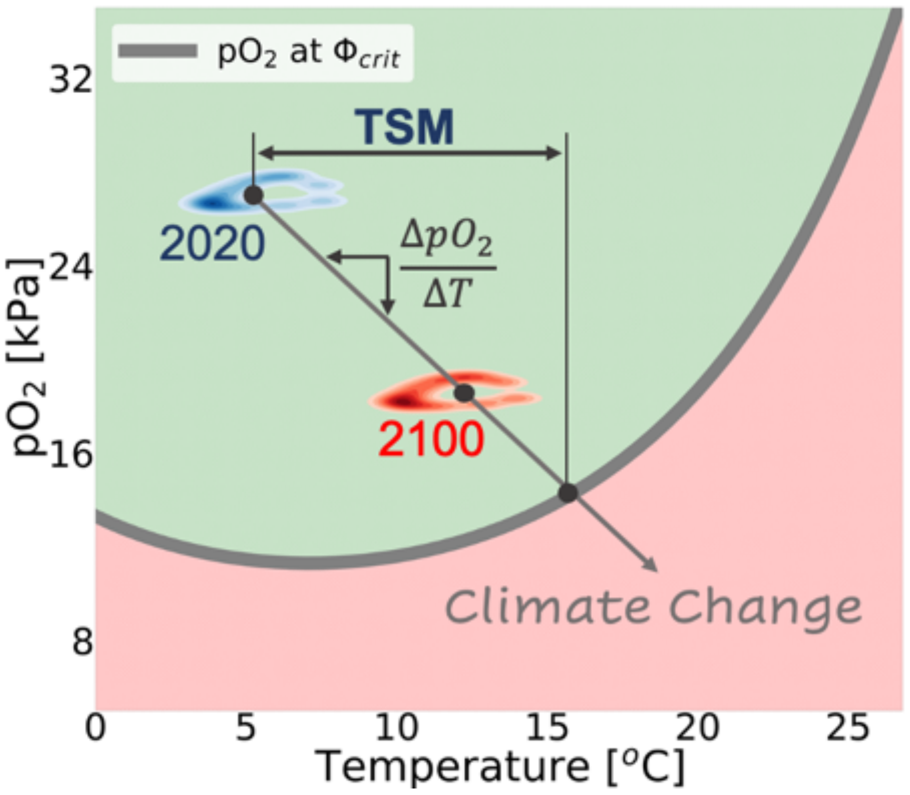
Organism metabolic constraints



- $\alpha_s = rate\ of\ gass\ transfer\ between\ water\ and\ organism$
- $\alpha_D = taxon\ specific\ basal\ metabolic\ rate$
- $A_c = \frac{\alpha_s}{\alpha_D}$ $(ecologoical\ hypoxic\ tolerance)$
- $k_B = Boltzman\ constant$
- $E_o = E_d - E_s\ (Activation\ energy)$
- $T = temperature$

Fry,1947; Portner and knust., 2007; Deutsch et al.,2015; 2020; Penn et al., 2018; Howard et al., 2020

Defining Organism's Thermal Safety Margin (TSM) in the context of climate change **[0 – 1000 m]**



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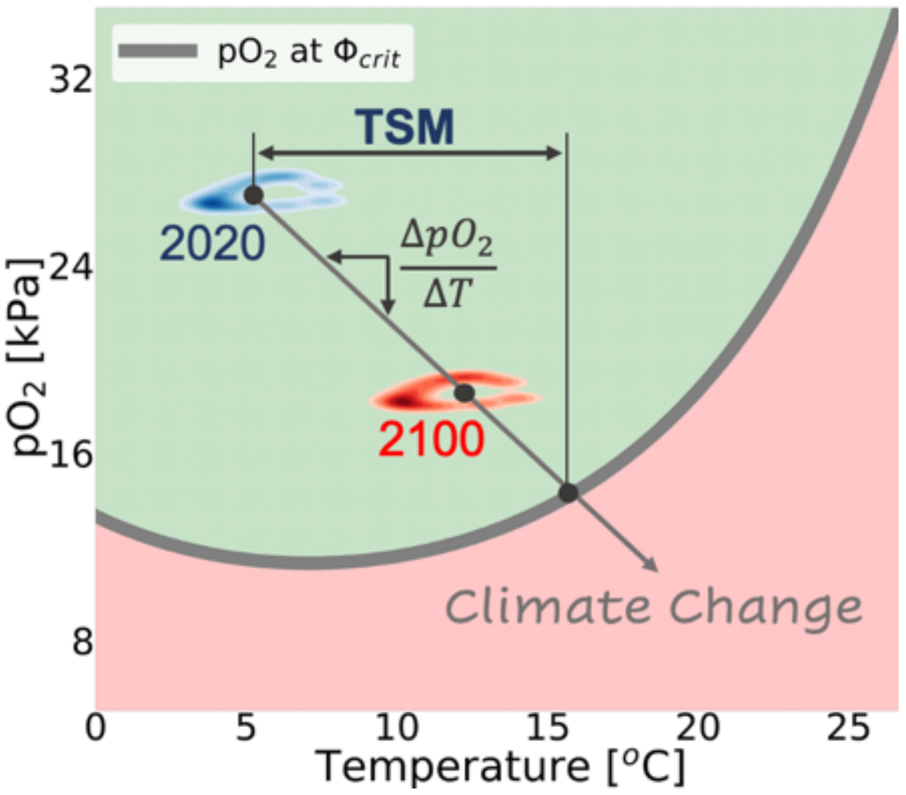
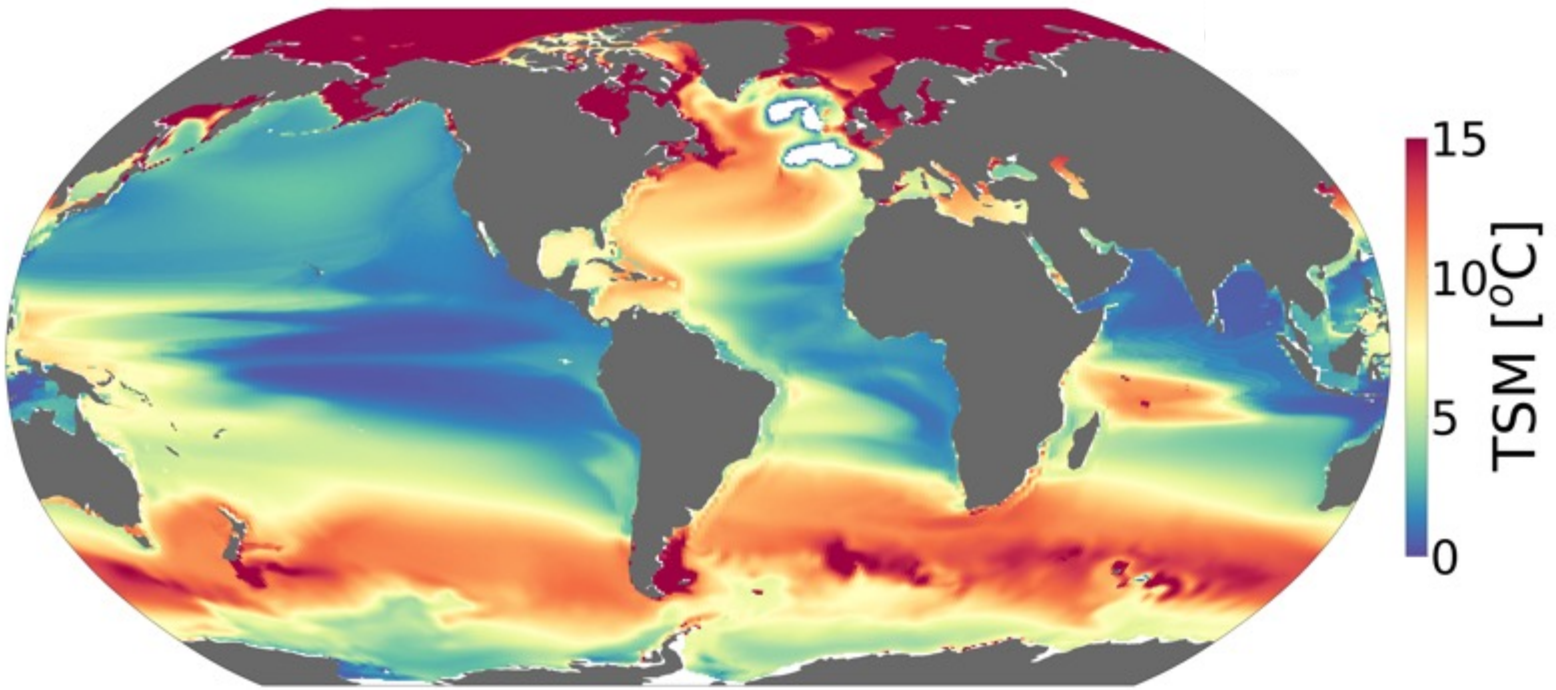
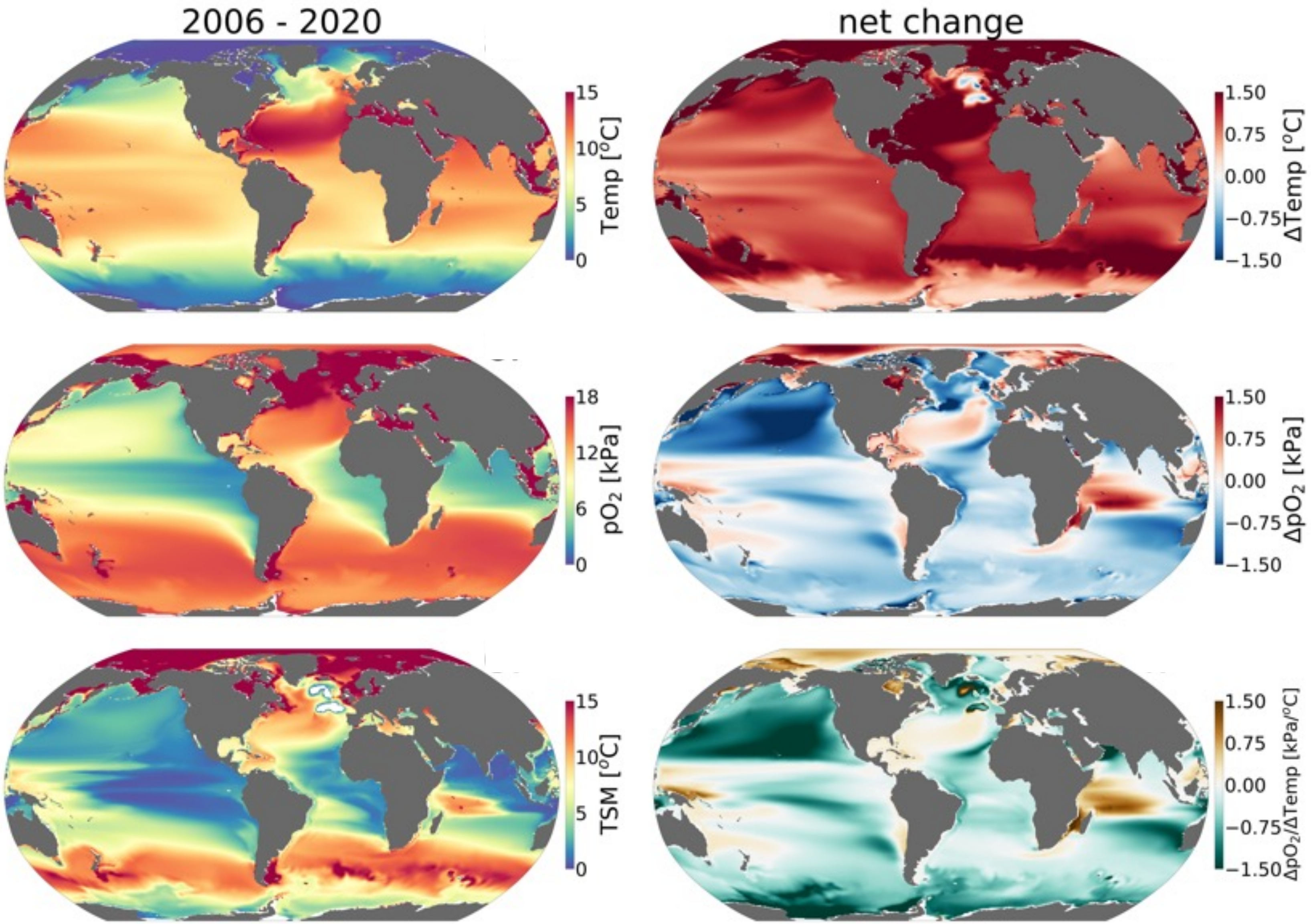




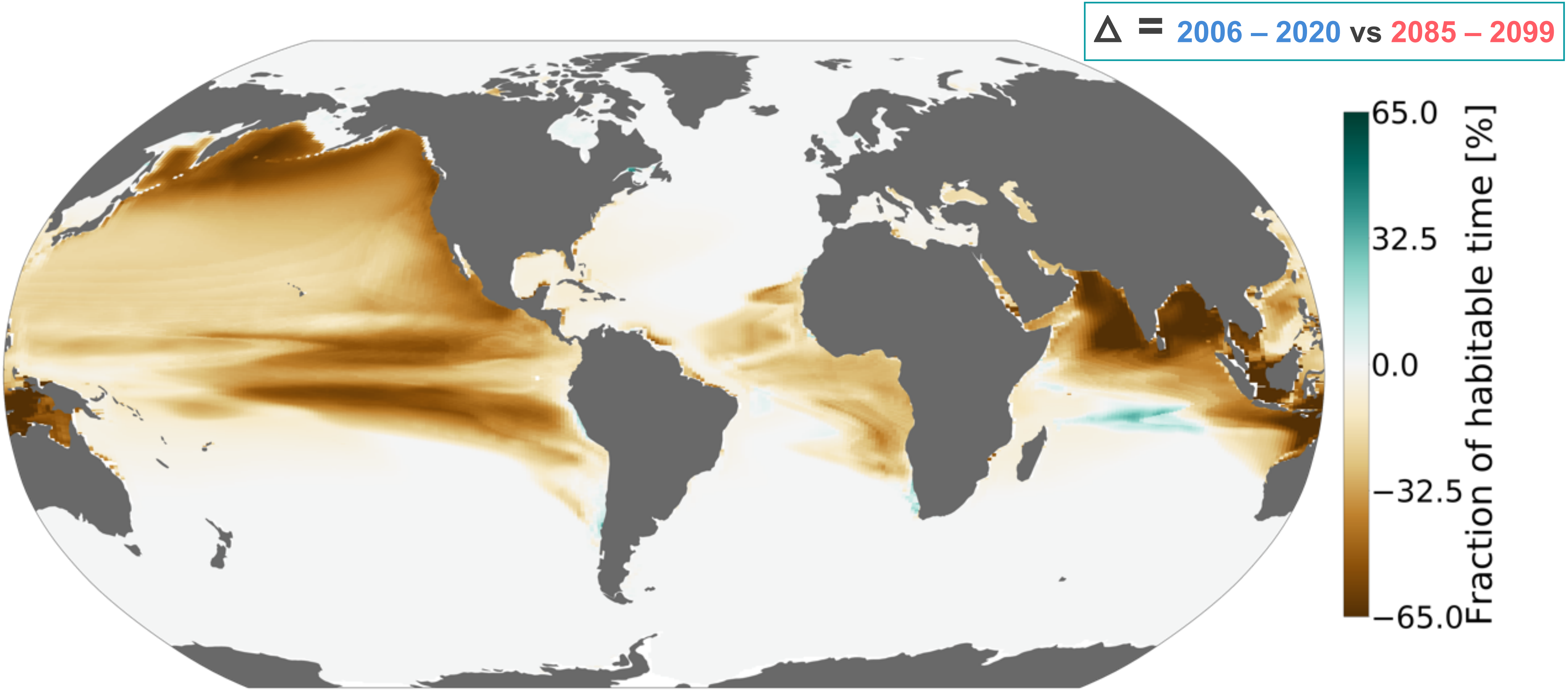
Organismic anthropogenic TSM are set by both present climate state and net long-term changes in pO_2 and temp [0 – 1000 m, CESM1-LE]



Δ = 2006 – 2020

vs 2085 – 2099

Marine ectotherms vulnerability to extirpation increase the largest in the tropical regions and North Pacific [0 – 1000 m, CESM1-LE]



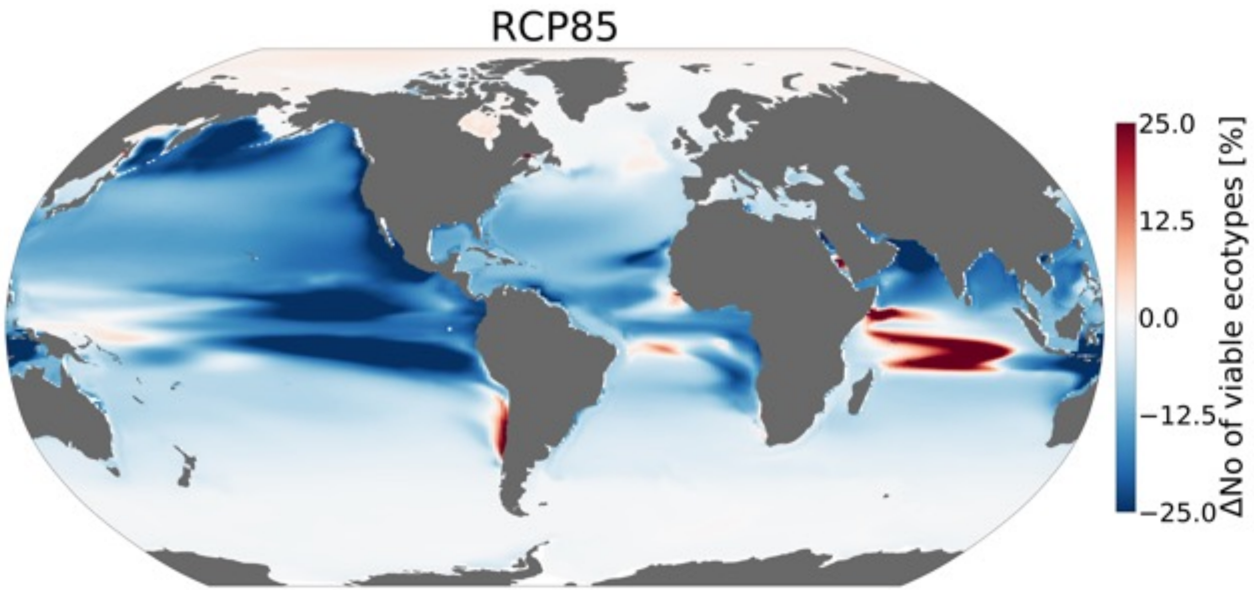
Summary

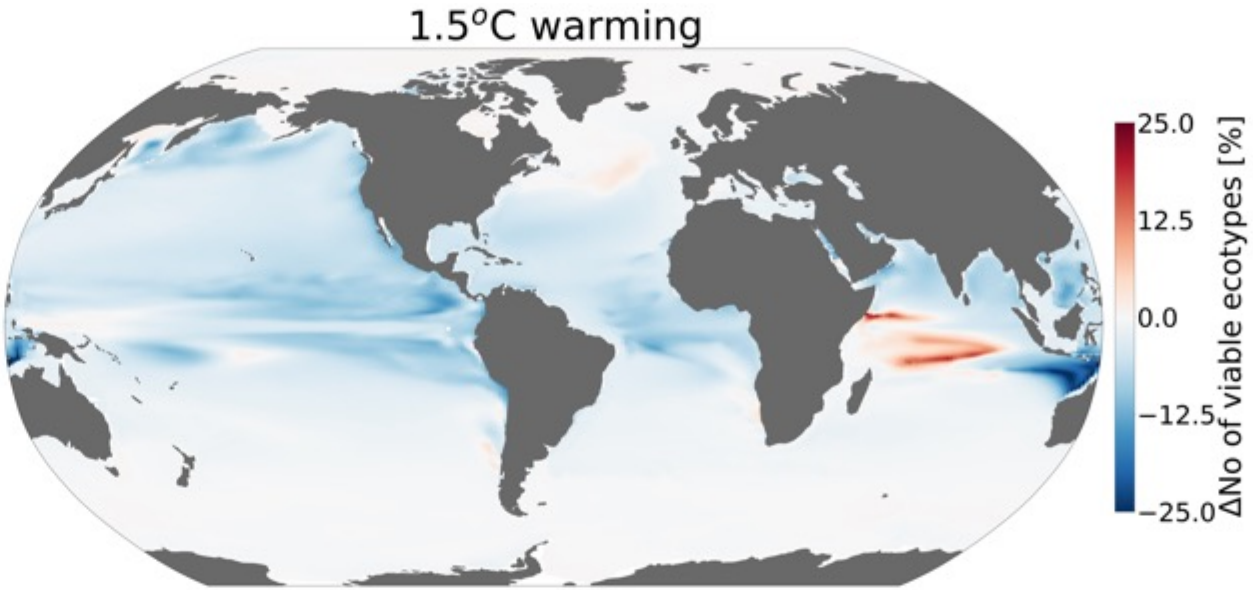
- Warming and deoxygenation projected over the next several decades will yield a reduction in thermal safety margins for some organisms, curtailing the volume of viable habitat for some sensitive ecosystems.
- Our results demonstrate that in many regions, organisms will be pushed closer or beyond their physiological limits leaving the ecosystem more vulnerable to extreme events.
- We find that the fraction of habitable time for an average locally adapted ecotype decreases by over 50% in the tropical oxygen minimum zones and North Pacific basin by the end of the century.
- Long-term oxygen gain in the Arctic Ocean helps more organisms meet their metabolic demand in the future, while oxygen abundance prohibits habitat loss in the Southern Ocean.

Thank You

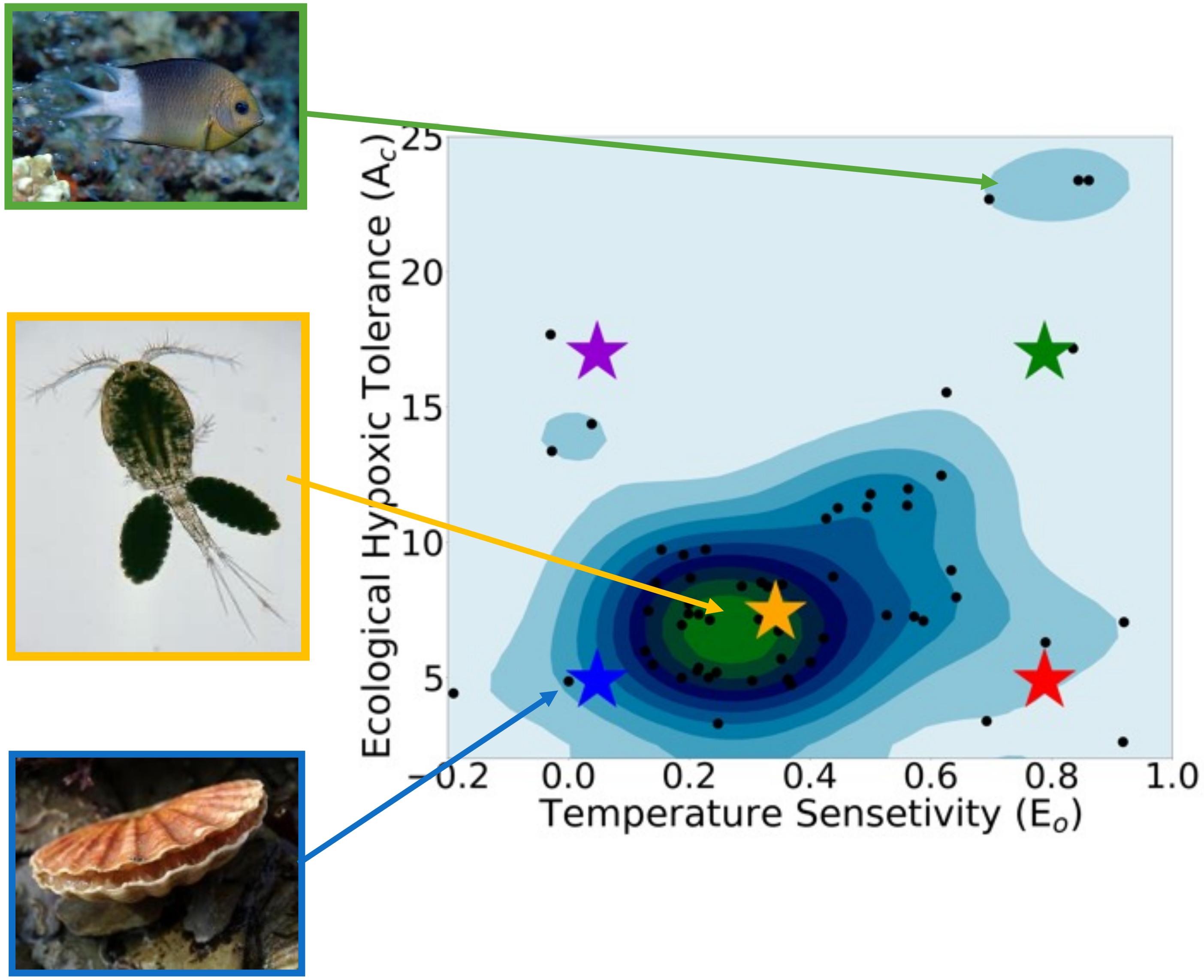
Habitat loss is reduced by almost 50% in the ***1.5°C warming*** vs. ***RCP85 scenario***

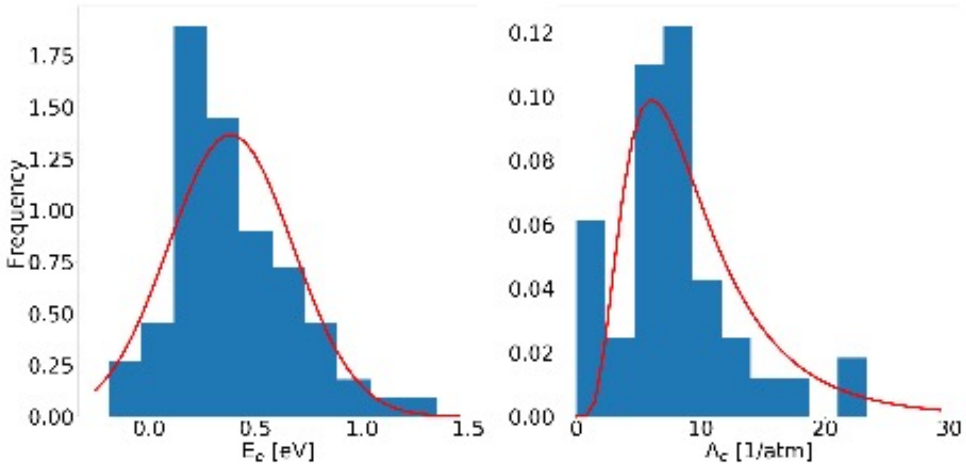
[0 – 1000 m, CESM1-LE]





Organism’s physiological constraints





Locally adapted ecotype

Ac = 2.5:30 (N = 40)

Eo = -0.3:1.5 (N = 40)

} **1600 Ecotypes**

freq_Ac = Fitted lognormal function (red curve)

freq_Eo = Fitted normal function (red curve)

$$Ac_{locally\ adapted} = \frac{\sum(A_c \times freq_{Ac})}{\sum(freq_{Ac})}$$

$$Eo_{locally\ adapted} = \frac{\sum(E_o \times freq_{Eo})}{\sum(freq_{Eo})}$$