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Integrating climate-related stressor effects on marine organisms:

…which proxies to use for climate sensitivity?
…physiological proxies?

Are there unifying principles (in animals)?...

AWI NMR

Hans Pörtner
(modified for the PICES website)

Physiological mechanisms linking climate to ecosystem change

AWI ECOPHYSIOLOGY

The marine realm: Multiple stressors in a climate context (changing concomitantly):

global: ocean warming, acidification, hypoxia…
local: eutrophication, pollution….

…with temperature presently being the predominant driver
…a challenge for experimental biology

What we need...

....(a) concept(s) explaining the physiological background of climate sensitivity

....(a) concept(s) integrating multiple environmental drivers

....(a) concept(s) leading and linking to ecologically relevant hypotheses:

e.g. climate effects on:

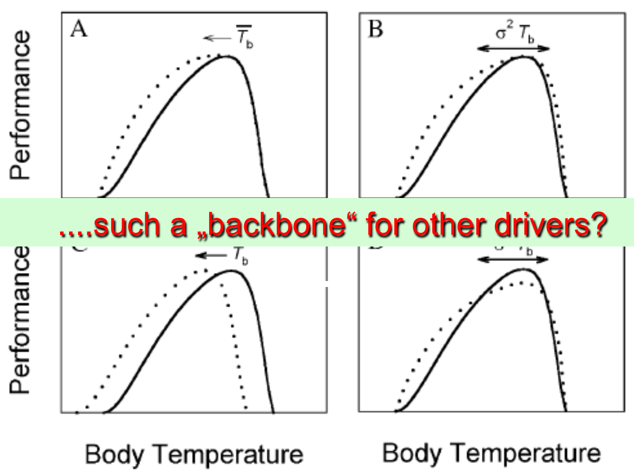
species abundance and distribution

community composition,

competitiveness,

predator prey relations

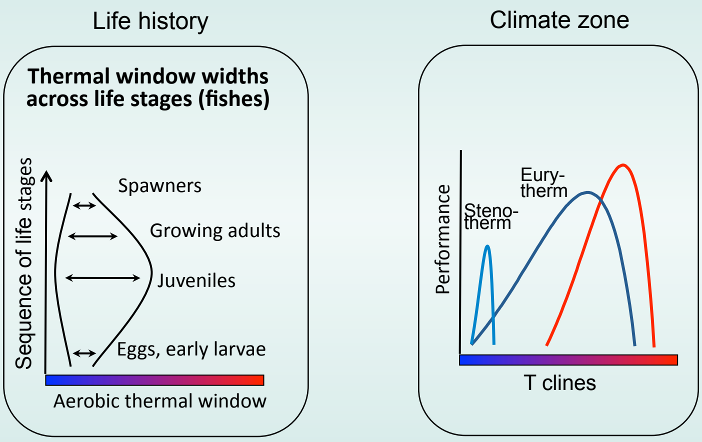
Thermal reaction norms: the „backbone“ of thermal responses and sensitivity



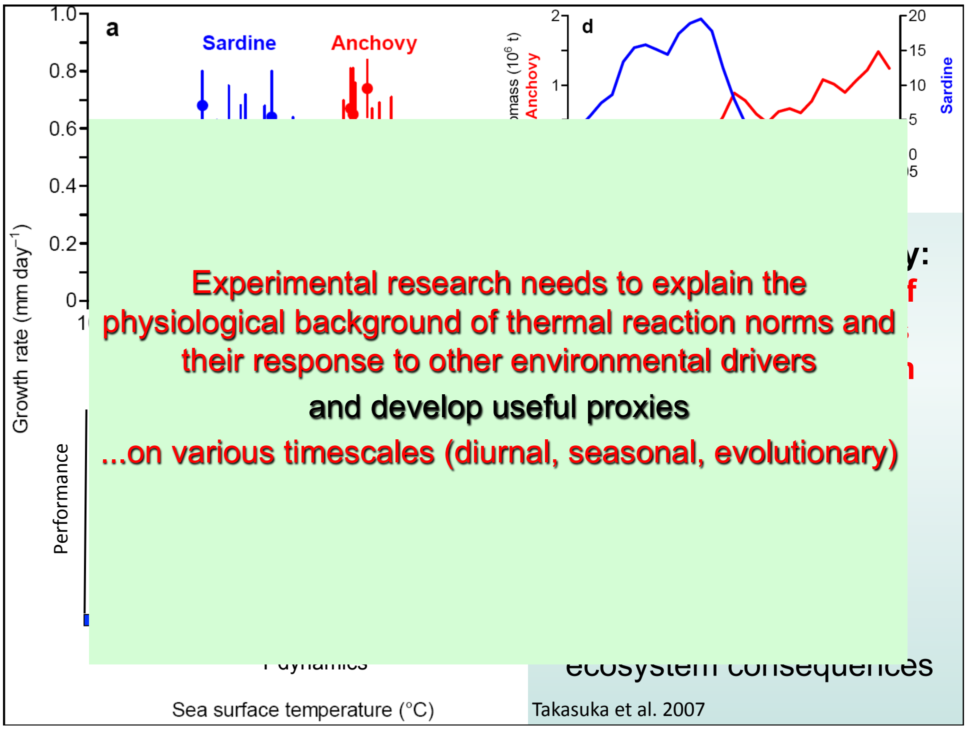
....such a „backbone“ for other drivers?

Fig. 2. Hypothetical responses of performance functions to variation in the thermal environment (adapted from Huey and Kingsolver, 1993; *The American Naturalist*, © 1993

Not all thermal windows are the same:
Temporal dynamics and climate dependence



H.O. Pörtner and A.P. Farrell, *Science* 322, 690-692 (2008)



Experimental research needs to explain the physiological background of thermal reaction norms and their response to other environmental drivers

and develop useful proxies

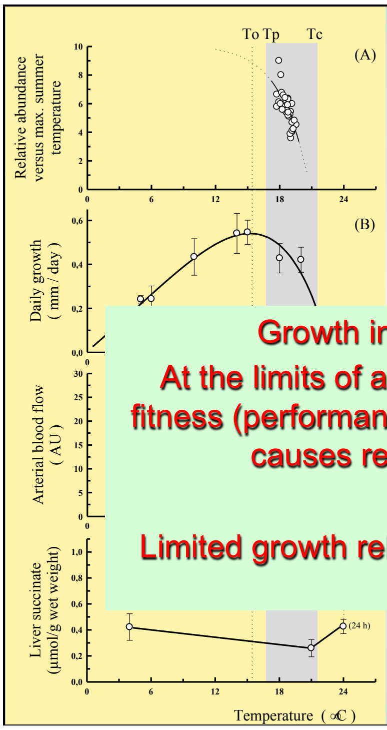
...on various timescales (diurnal, seasonal, evolutionary)

Addressing the why, how and when of thermal specialization...
Concept of **oxygen and capacity** limited thermal tolerance (OCLTT):

…confirmed in various animal phyla: sipunculids, annelids, molluscs (bivalves, cephalopods), crustaceans, insects (aquatic larvae), vertebrates, …..air breathers.

…provides access to the mechanistic underpinning

- of differences between climate zones (1997 onward)
- of climate sensitivity in the field (verified in 2007)
- of large scale biogeography (2001/8 onward)



Ecological calibration:
Climate effects in the field…..

Abundance

Eelpout

Growth

North Sea

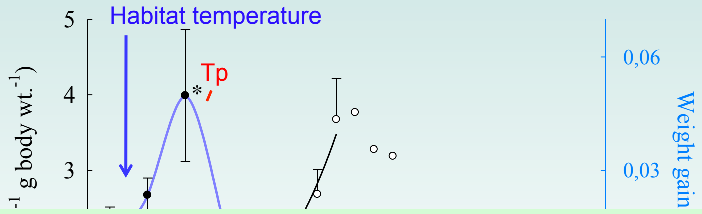
Growth includes acclimatization:
At the limits of acclimation capacity the loss of fitness (performance capacity) beyond pejus limits causes reduced field abundance!

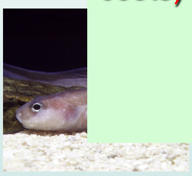
Limited growth relates to limited cardiocirculatory capacity

Pörtner and Knust, *Science*, 315, 95 – 97, 2007

Endogenous influences on growth performance?

Optimum growth found in range of low oxygen consumption (Antarctic eelpout)

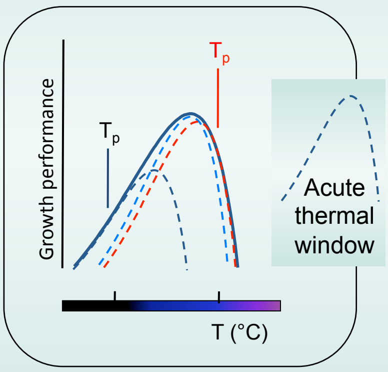




The temperature induced rise in oxygen consumption (indicating rising baseline energy costs) causes reduced growth performance capacity beyond pejus limits!

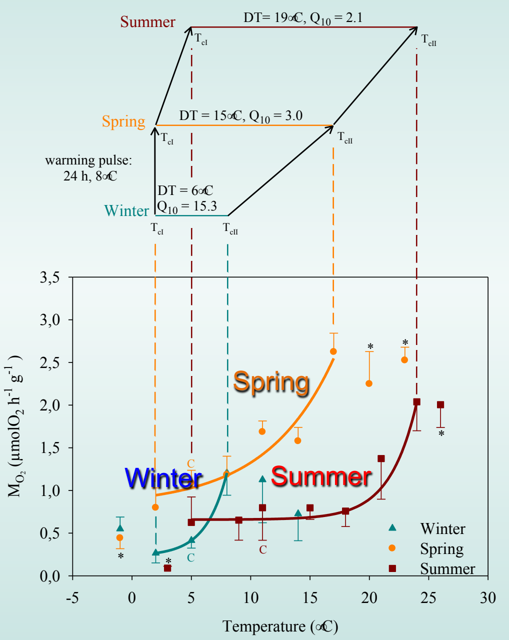
Brodte et al. 2006, Mark et al., 2002

Acclimation capacity causes shifts in acute thermal windows within the thermal niche: tradeoffs in energy budget

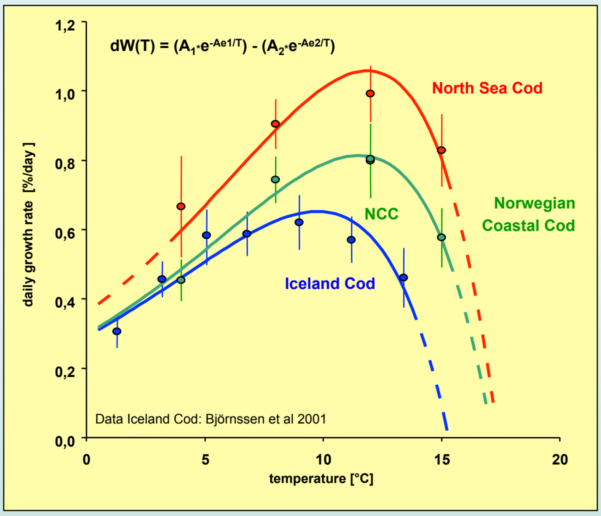


(after Lannig et al. 2005, Brodte et al. 2006 Wittmann et al. 2008, Schroer et al. 2009)

Seasonal acclimation in temperate lugworms

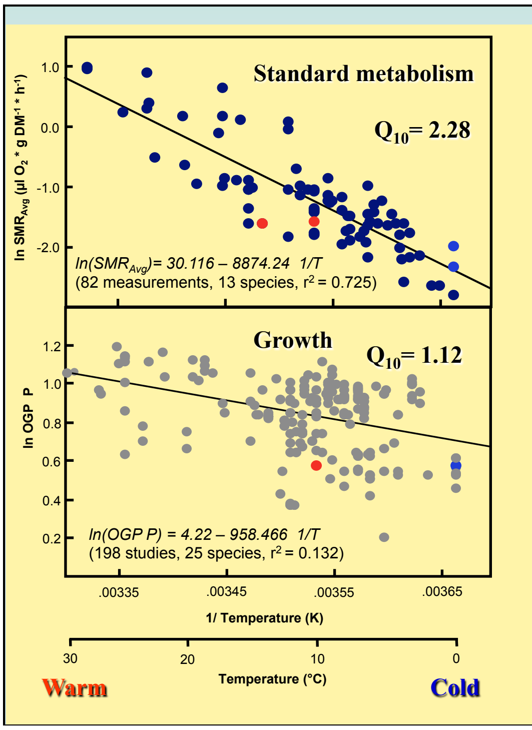


Climate dependent specialization in East Atlantic cod (*Gadus morhua*) populations results in limited and different thermal windows of growth performance
...due to tradeoffs in energy budget?



.....lower growth in Northern cod (*Gadus morhua*) populations (juvenile cod ~ 500 g) confirmed by field data

Pörtner et al. 2008



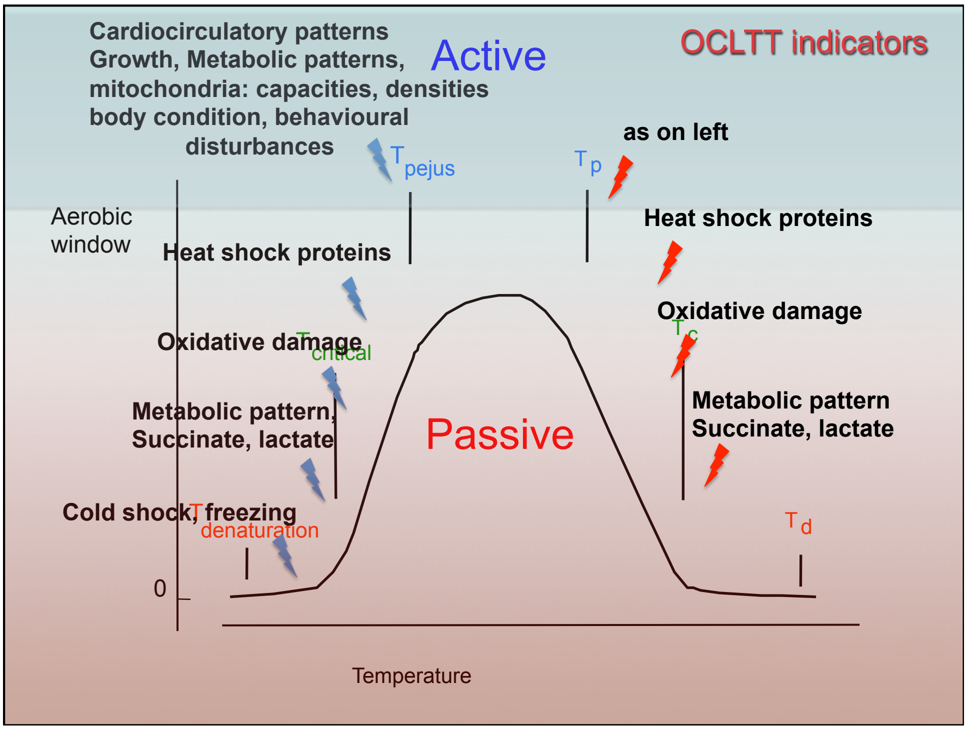
Changing performance towards high latitudes: constraints in energy budget

Elevated growth (of pectinids) in relation to metabolic rate in the cold:

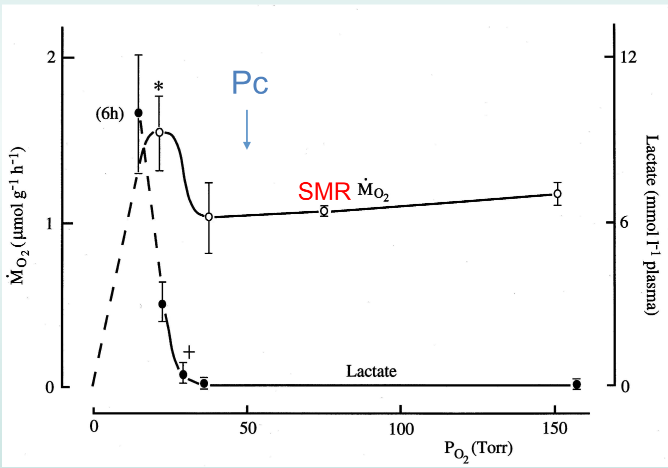
Increased energy efficiency supports growth performance at high latitudes

Less energy available for reproduction, development, ... wide thermal windows, resistance to multiple stressors

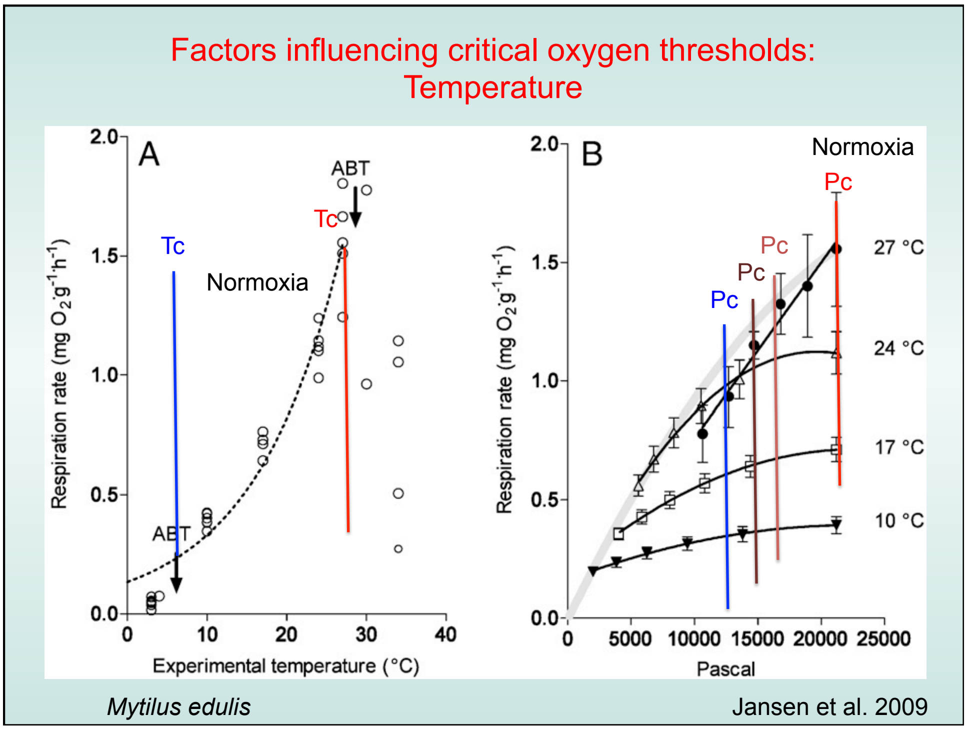
Heilmayer et al. 2004

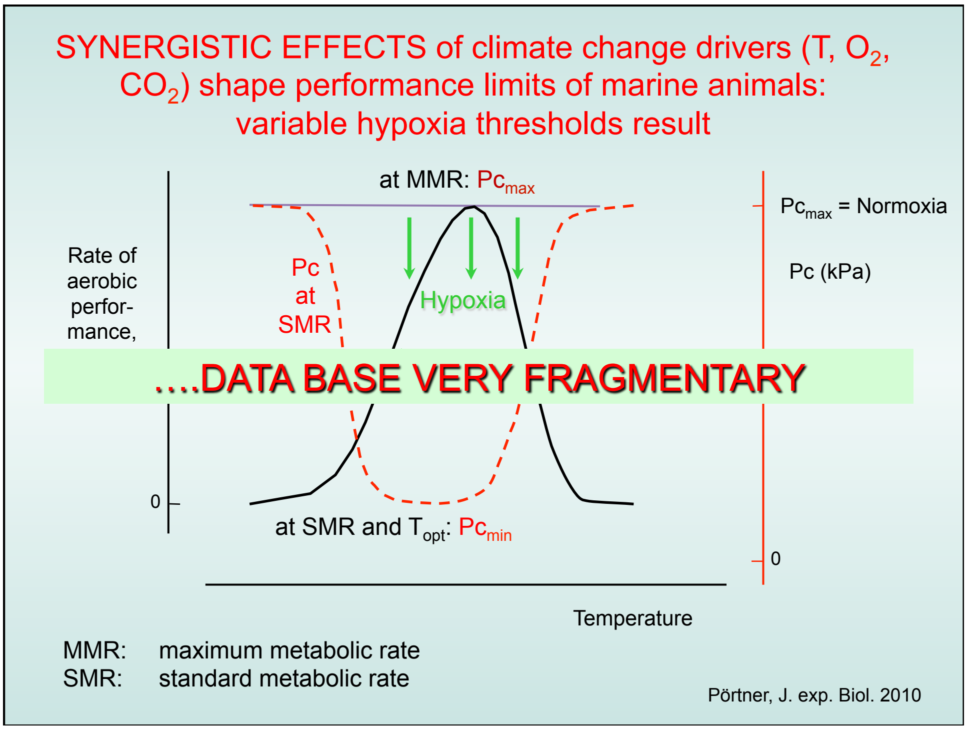


Quantifying hypoxia tolerance
Patterns of critical Po_2 at standard metabolic rate (SMR):
Transition to anaerobic metabolism characterizes Pc
in toad *Bufo marinus*
in oxyregulating shrimp (*Palaemon elegans*)



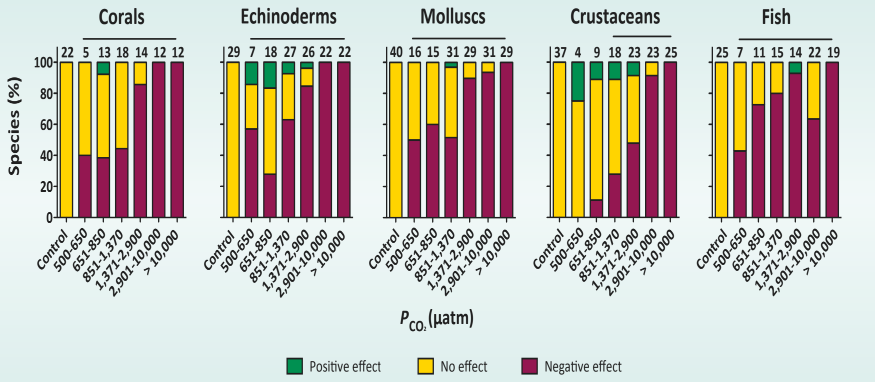
Pörtner et al.1991


Factors influencing critical oxygen thresholds:
Temperature
A
Normoxia
Tc
Tc
ABT
ABT
Respiration rate (mg O2·g-1·h-1)
Experimental temperature (°C)
B
Normoxia
Pc
Pc
Pc
Pc
27 °C
24 °C
17 °C
10 °C
Pascal
Mytilus edulis
Jansen et al. 2009


SYNERGISTIC EFFECTS of climate change drivers (T, O2, CO2) shape performance limits of marine animals: variable hypoxia thresholds result
at MMR: Pcmax
Rate of aerobic perfor- mance,
Pc at SMR
Hypoxia
Pcmax = Normoxia
Pc (kPa)
....DATA BASE VERY FRAGMENTARY
at SMR and Topt: Pcmin
Temperature
MMR: maximum metabolic rate
SMR: standard metabolic rate
Pörtner, J. exp. Biol. 2010

How to integrate CO_2 sensitivity (ocean acidification)?

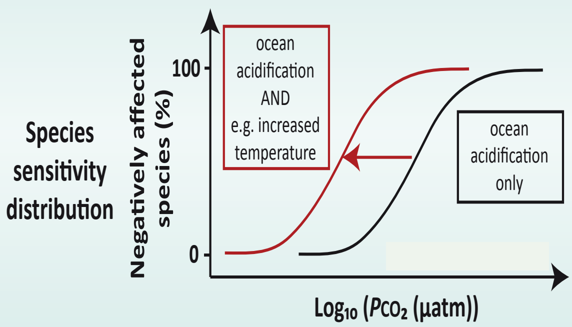
Sensitivity distribution across animal phyla:
a metaanalysis



Crustaceans less sensitive than corals, echinoderms, molluscs,,,,fishes?

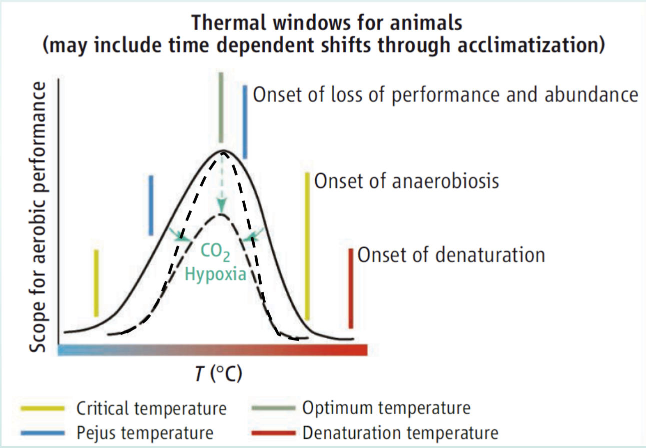
A. Wittmann & H.O. Pörtner, Nature Climate Change 2013

Synergism of multiple stressors:
sensitivity distribution shifted to lower values of P_{CO_2}



A. Wittmann, H.O. Pörtner, 2013

SYNERGISTIC EFFECTS:
Ocean acidification constrains
thermal windows
Implications: ....biogeography, species interactions



high CO_2 decreases functional capacity, causing a narrowing of thermal windows

....a pattern first seen in decapod crustaceans (Metzger et al., 2007, Walther et al., 2009)

H.O. Pörtner and A.P. Farrell, *Science* 322, 690-692 (2008)

A suggestion:

…bring (apparently isolated) effects of various drivers together using temperature relations as a matrix

…the same fitness proxies can be used