Alfred-Wegener-Institut für Polar- und Meeresforschung in der Helmholtz-Gemeinschaft

Oxygen and capacity limitation of thermal tolerance (OCLT):

a matrix for integrating climate related stressor effects in marine ecosystems

Hans Pörtner

AWI NMR

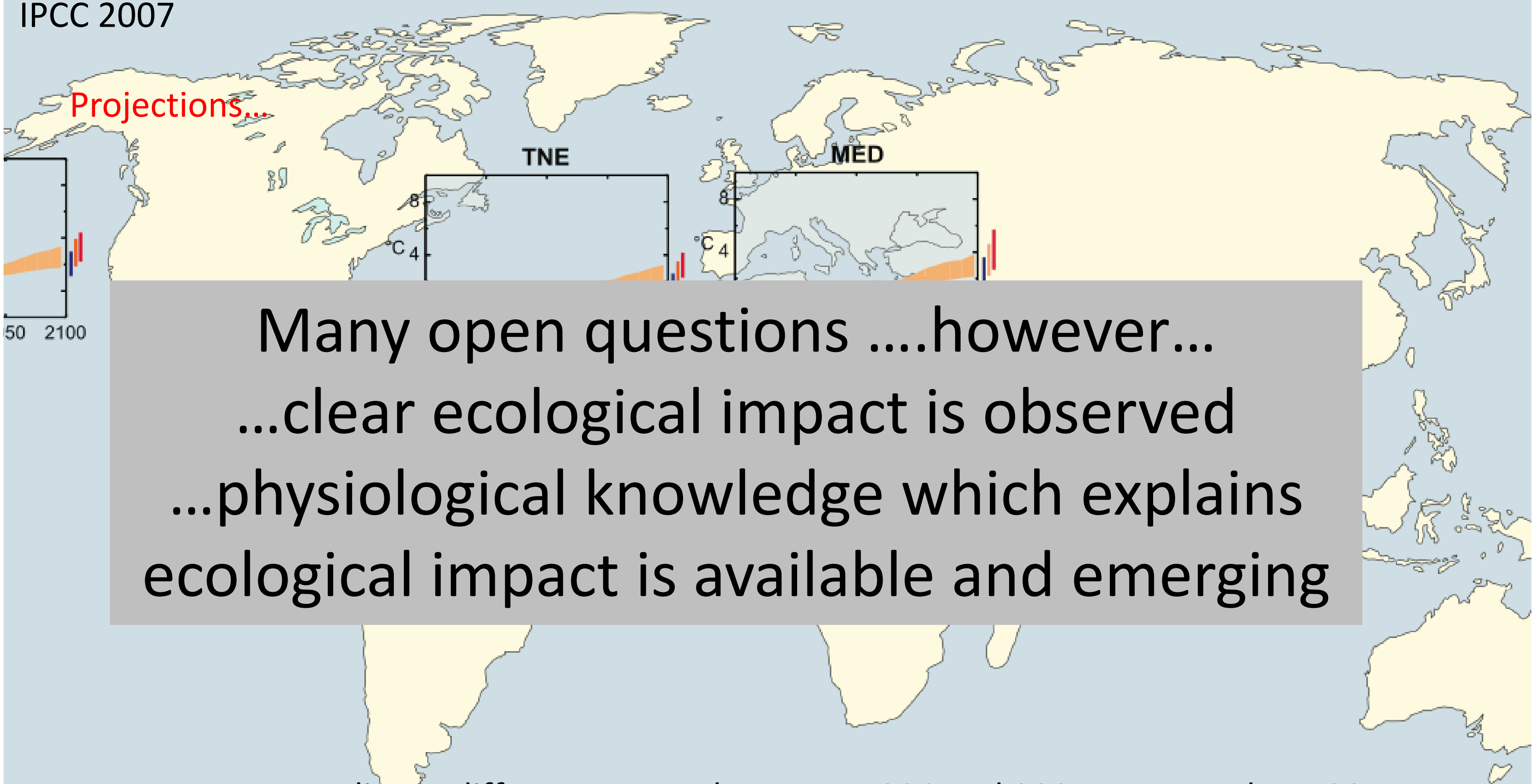
Physiological mechanisms linking climate
to ecosystem change

AWI ECOPHYSIOLOGY

Trends and projections of ocean warming:

IPCC 2007

Projections…



Many open questions ….however…
…clear ecological impact is observed
…physiological knowledge which explains ecological impact is available and emerging

Temperature anomalies in different oceans between 1906 and 2005 compared to 1901 to 1950. Projections until 2100 according to emission scenarios B1, A1B, A2.

The „emerging“ danger: Ocean Acidification (through CO_2 enrichment)…

...associated with a pH-decrement in surface water by 0.02 units per decade since 1980

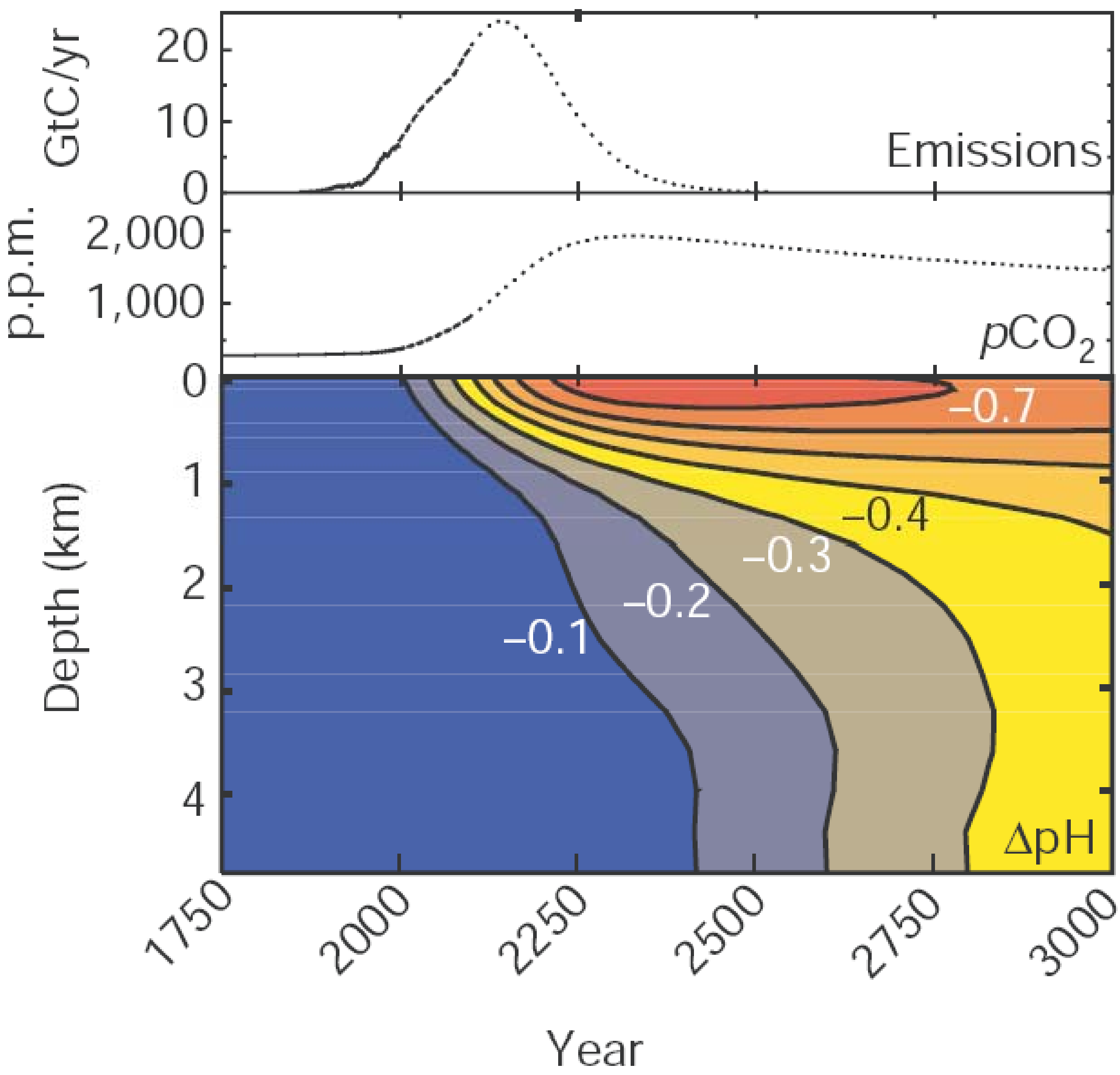
Even more questions….

…ecological impact setting in (calcification)

…emerging hypotheses and knowledge about physiological basis BEYOND calcification

RELEVANCE emphasized by:

- present atmospheric CO_2 accumulation beyond IPCC (2007) scenarios.
- possibility of coral reef marginalization by combined temperature and CO_2 (>350 ppm) effects.



Future scenario:
fossil fuel reserve:
5000 Gto C → 18 000 Gto CO_2

Pre-industrial

→ Today

ΔpH = - 0.12

→ 32 % more acidification

→ 2100

ΔpH = - 0.45

→2.8 fold more ….

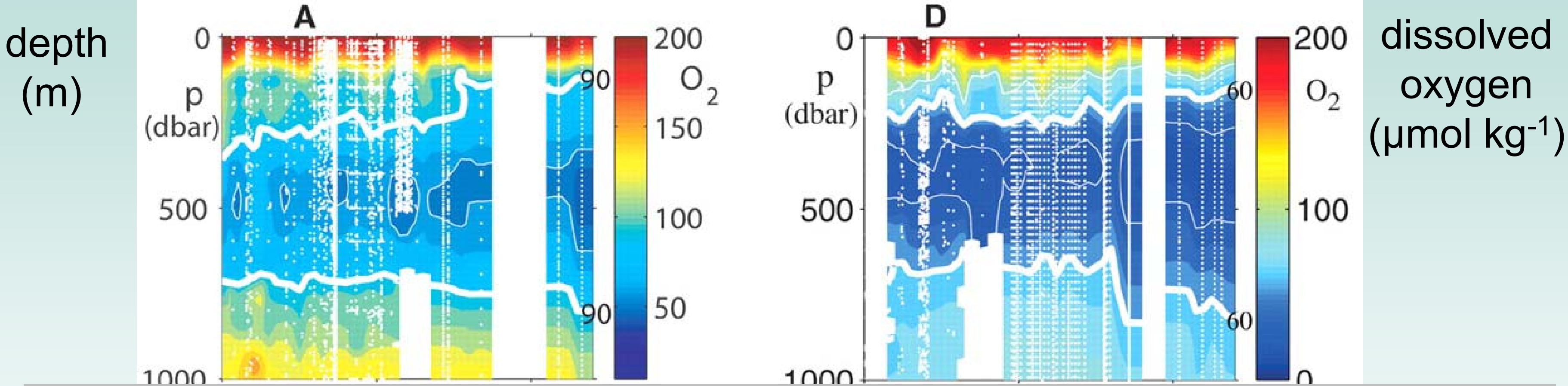
→ 2300

ΔpH = - 0.77

→5.9 fold more …

Caldeira and Wickett, 2003, 2005

Expanding oxygen minimum layers



Hypoxia effects….

…ecological impact setting in (...dead zones)

...combined with CO_2 effects

…some knowledge about physiological basis

Unifying principles in ecosystem effects of ocean warming, acidification, hypoxia?

L. Stramma et al., *Science* 320, 655 -658 (2008)

Physiology and climate change:

(Quantitative) evidence linking physiological responses to ecosystem change in various climate scenarios is scarce

Solutions?

Patterns identified by long-term Field data (!), Macrophysiology, Meta-Analyses using **statistical tools**....

However,......this remains insufficient…

To be complemented by:

…. mechanism based projections linking physiological and ecological processes.

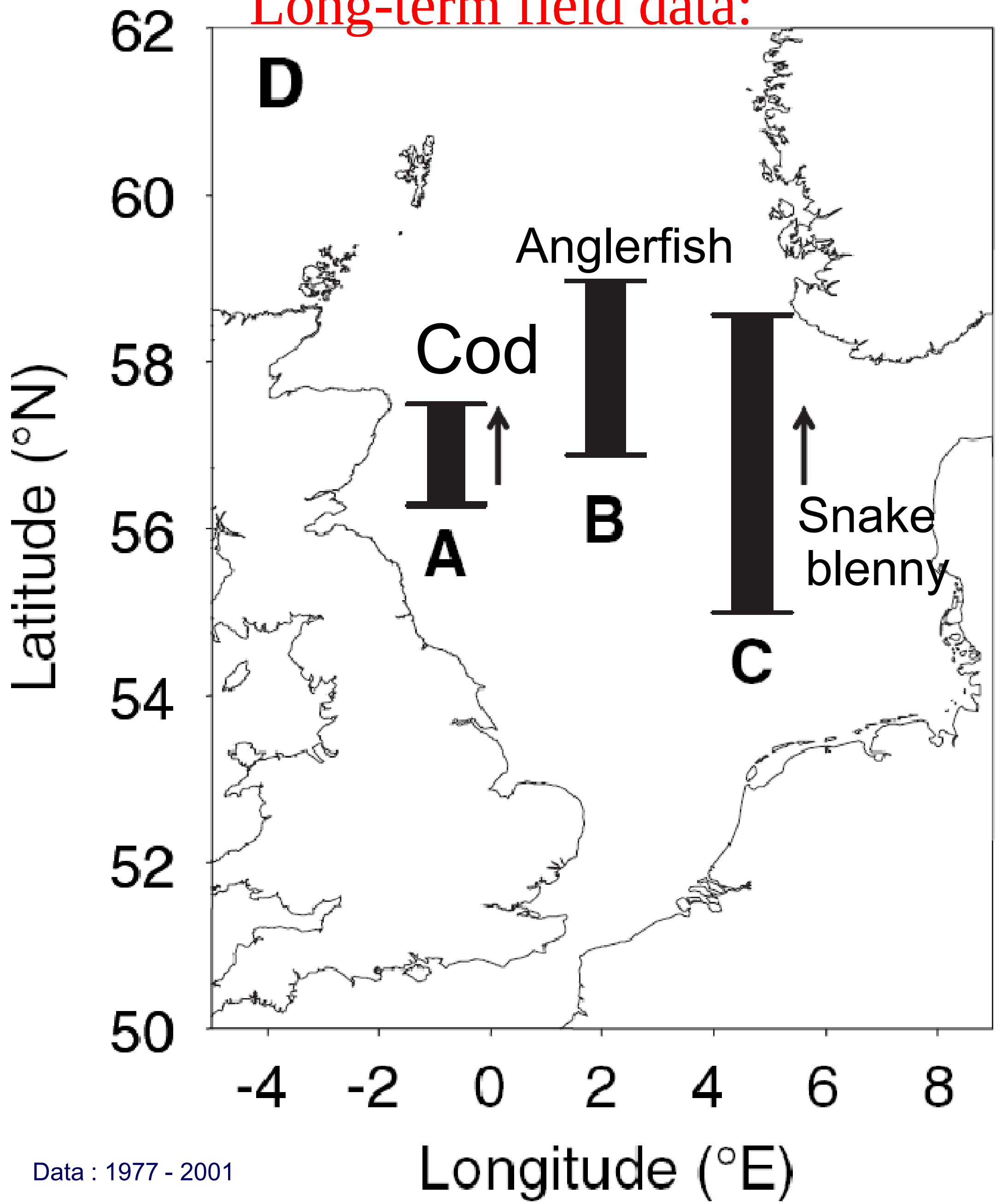
What would we need? To develop….

- an integrative understanding of the **mechanisms, benefits, functional tradeoffs** of adaptation
- an understanding of the **interdependence of mechanisms at various levels of biological organisation**, molecular to whole organism and.... ecosystem
- an integrative picture of **synergistic or antagonistic effects** of abiotic and biotic factors

Expected result:

- Reliable **projections** of ecosystem change
- High **predictive power** for realistic scenarios

Long-term field data:



Data : 1977 - 2001

Current ecological phenomena:

East Atlantic species are moving North

…..to various degrees (!)

Shifting biogeographies

~ Different thermal sensitivities

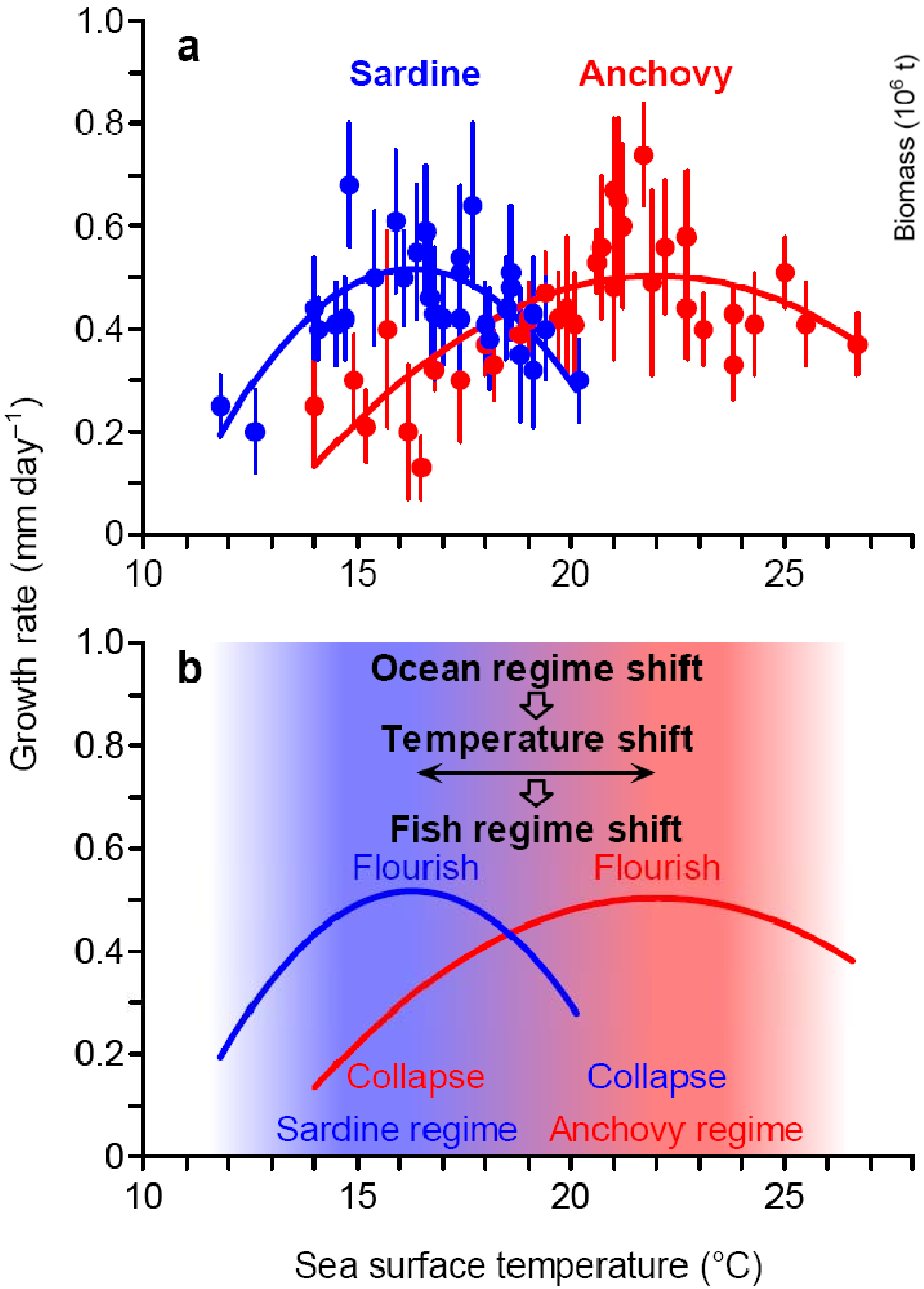
→ Changes in community composition

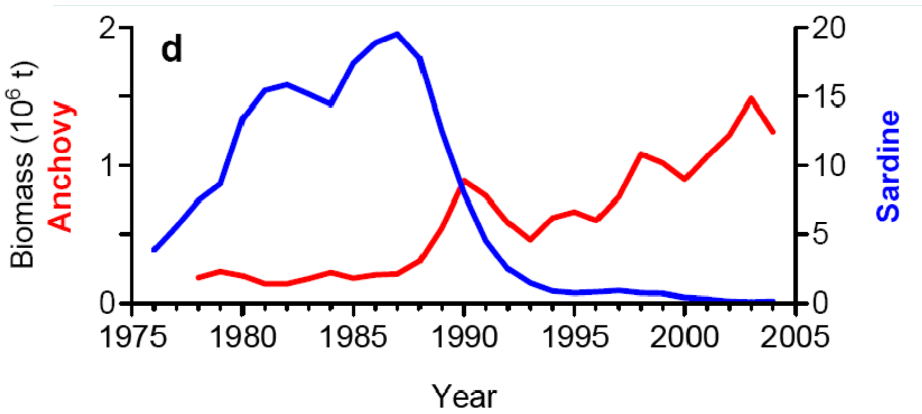
Cod
(*Gadus morhua*)

Anglerfish
(*Lophius piscatorius*)

Snake blenny
(*Lumpenus lampretaeformis*)

Perry A.L. *et al.*, 2005



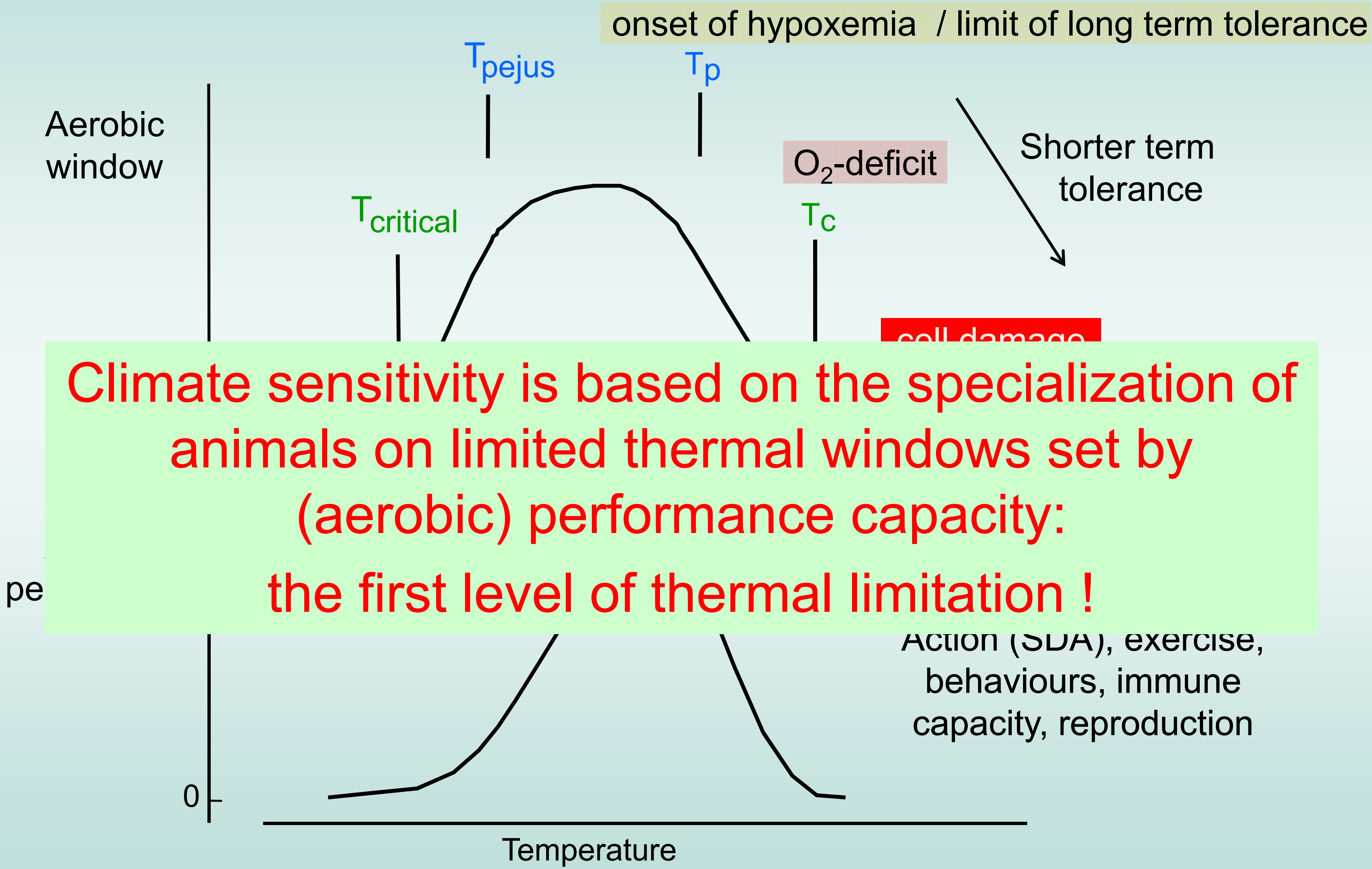


Thermal specialization explaining sensitivity, productivity and ecological phenomena?

The climate-induced "regime shift" from sardines to anchovies (Japanese Sea) is linked to the **thermal windows** of growth of the two species.

Takasuka et al. 2007

Explaining climate specialization from (animal) physiology: Concept of oxygen and capacity limited thermal tolerance (OCLT)



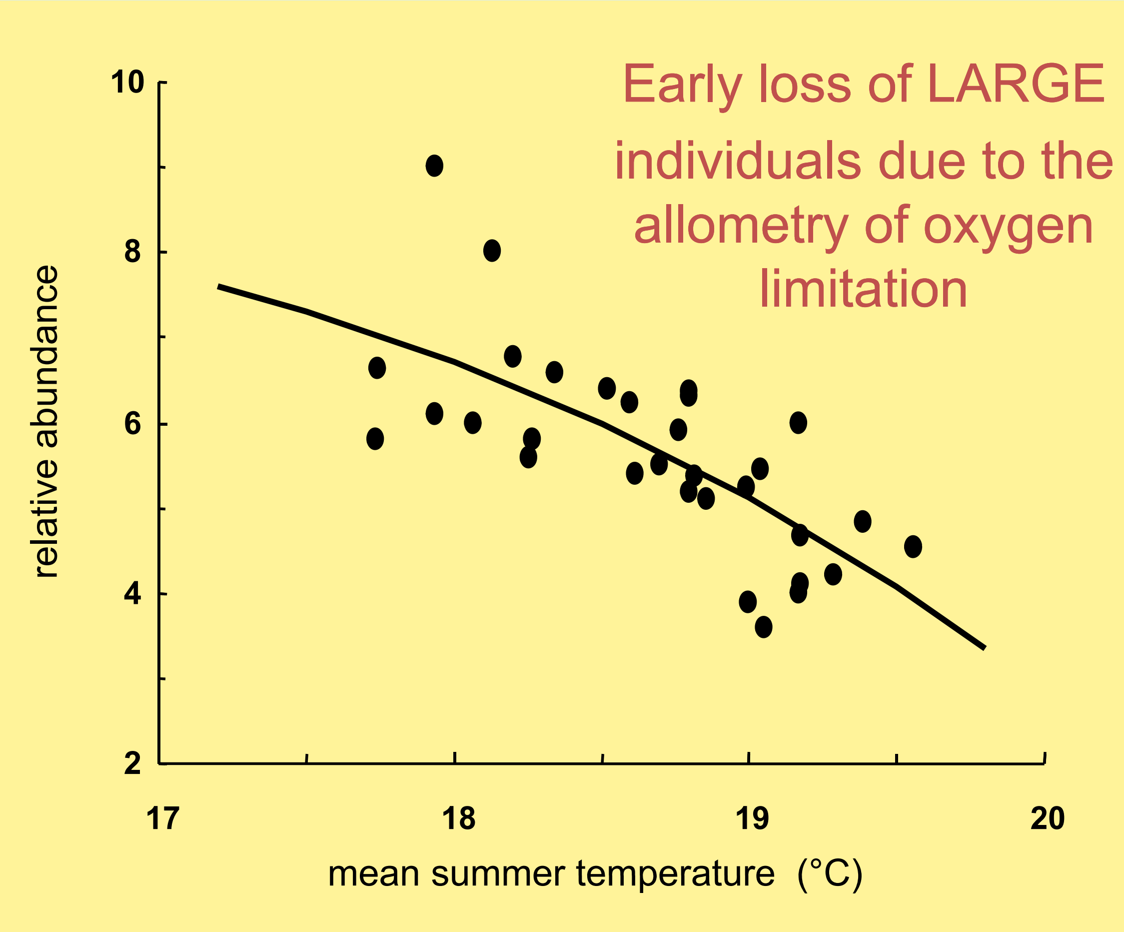
Climate sensitivity is based on the specialization of animals on limited thermal windows set by (aerobic) performance capacity:

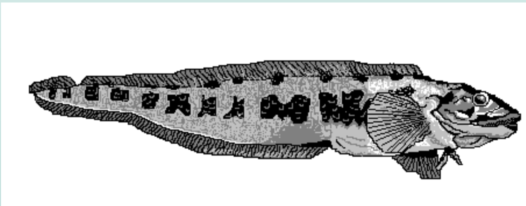
the first level of thermal limitation !

After Pörtner, 2001, 2002, Pörtner et al., 2005, Pörtner and Knust, Science 2007

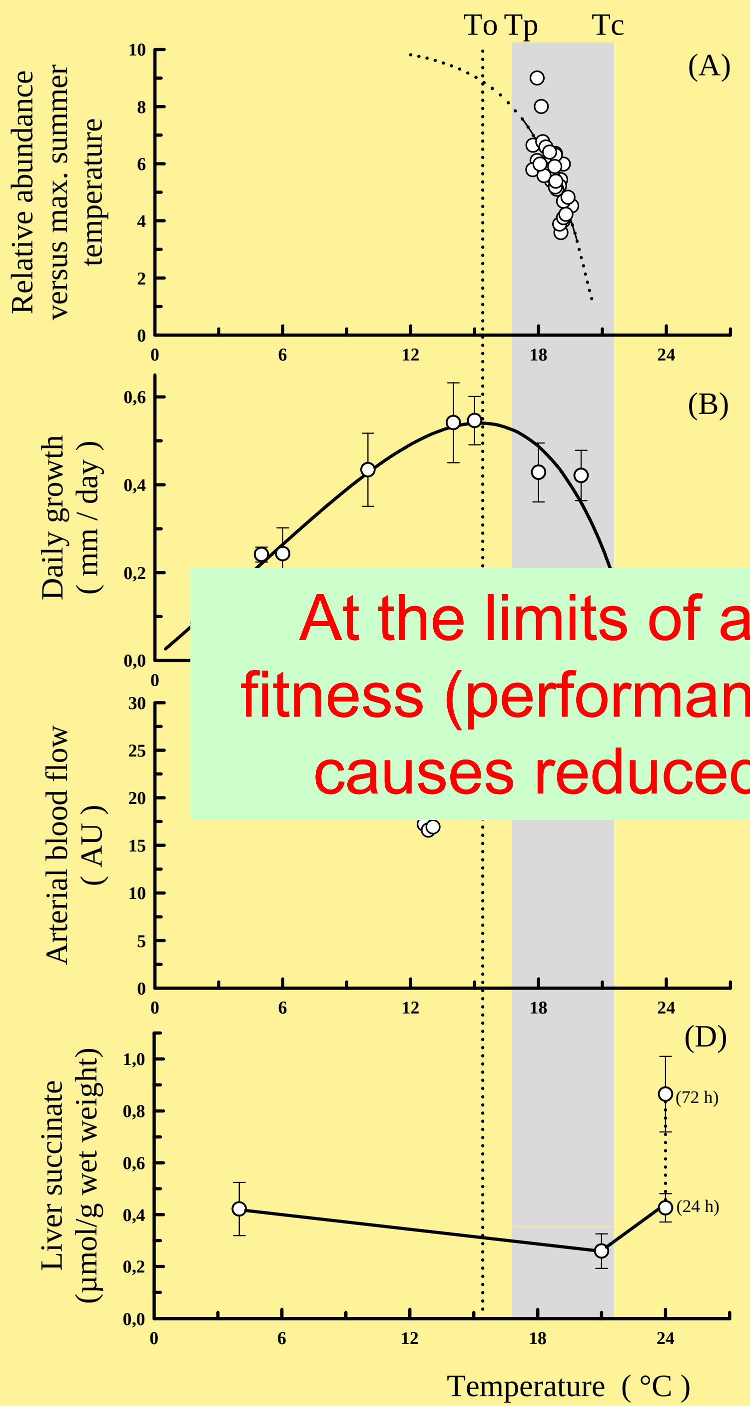
Are these physiological principles suitable to explain ecological phenomena?

Eelpout (*Zoarces viviparus*) abundance in the German Wadden Sea falls at high summer mean temperatures





Climate effects in the field…..



Abundance

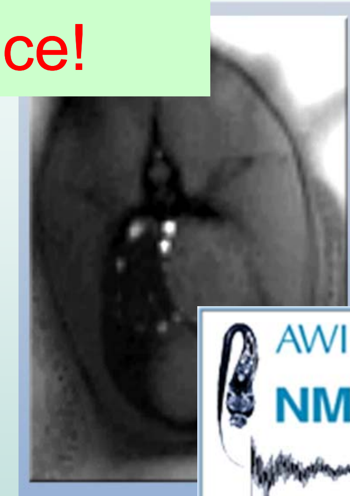
Eelpout

Growth

North Sea

ns

At the limits of acclimation capacity the loss of fitness (performance capacity) beyond pejus limits causes reduced growth and field abundance!



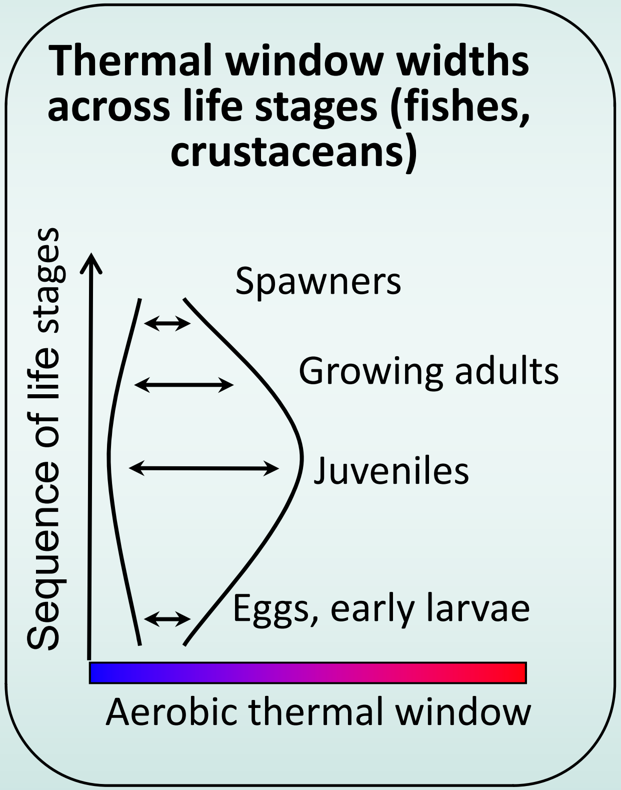
Blood flow

O_2-deficit

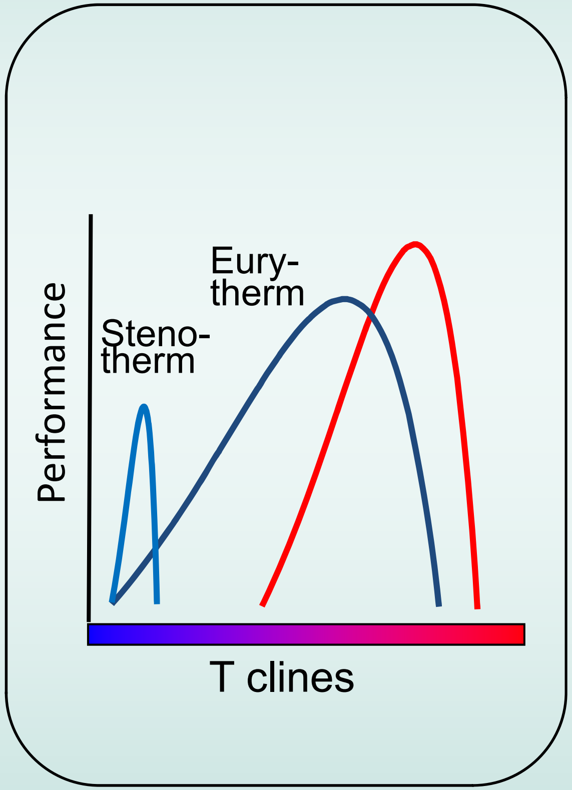
Pörtner and Knust, *Science*, 315, 95 – 97, 2007

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

Life history



Climate zone

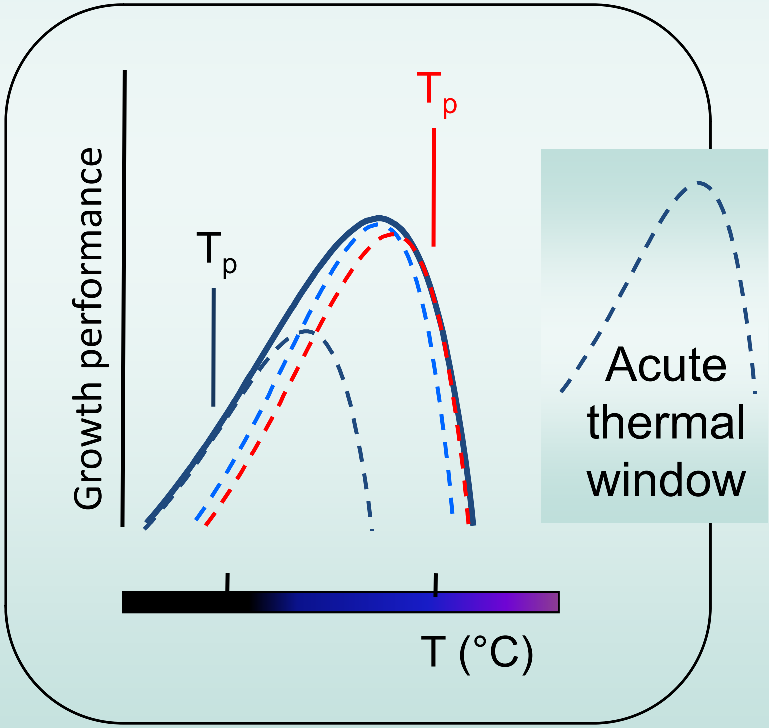


There are metabolic and functional consequences of adaptation to various climate regimes:

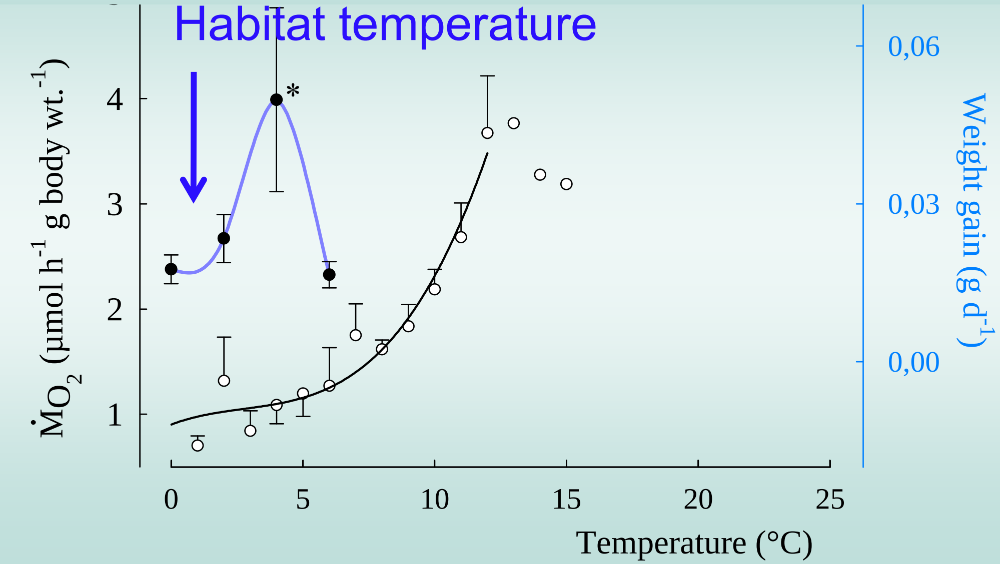
Co-defining sensitivity to CO_2, hypoxia…. and vice versa ?

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

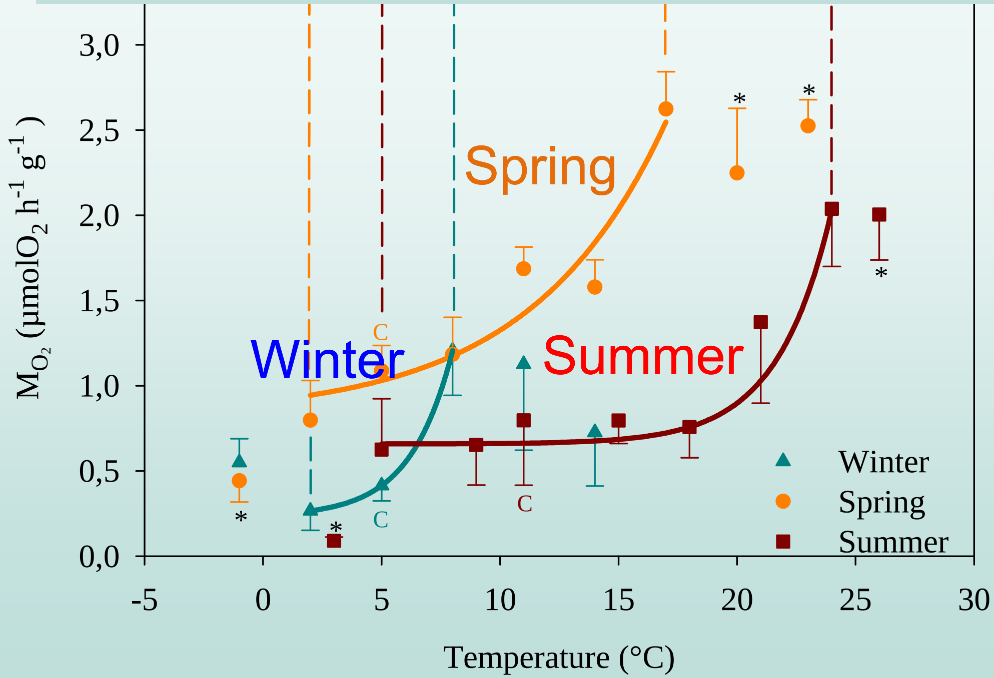
Acclimation capacity differs between species according to climate zones: defining the thermal niche



Warm acclimation in Antarctic fish



Seasonal acclimation in temperate lugworms

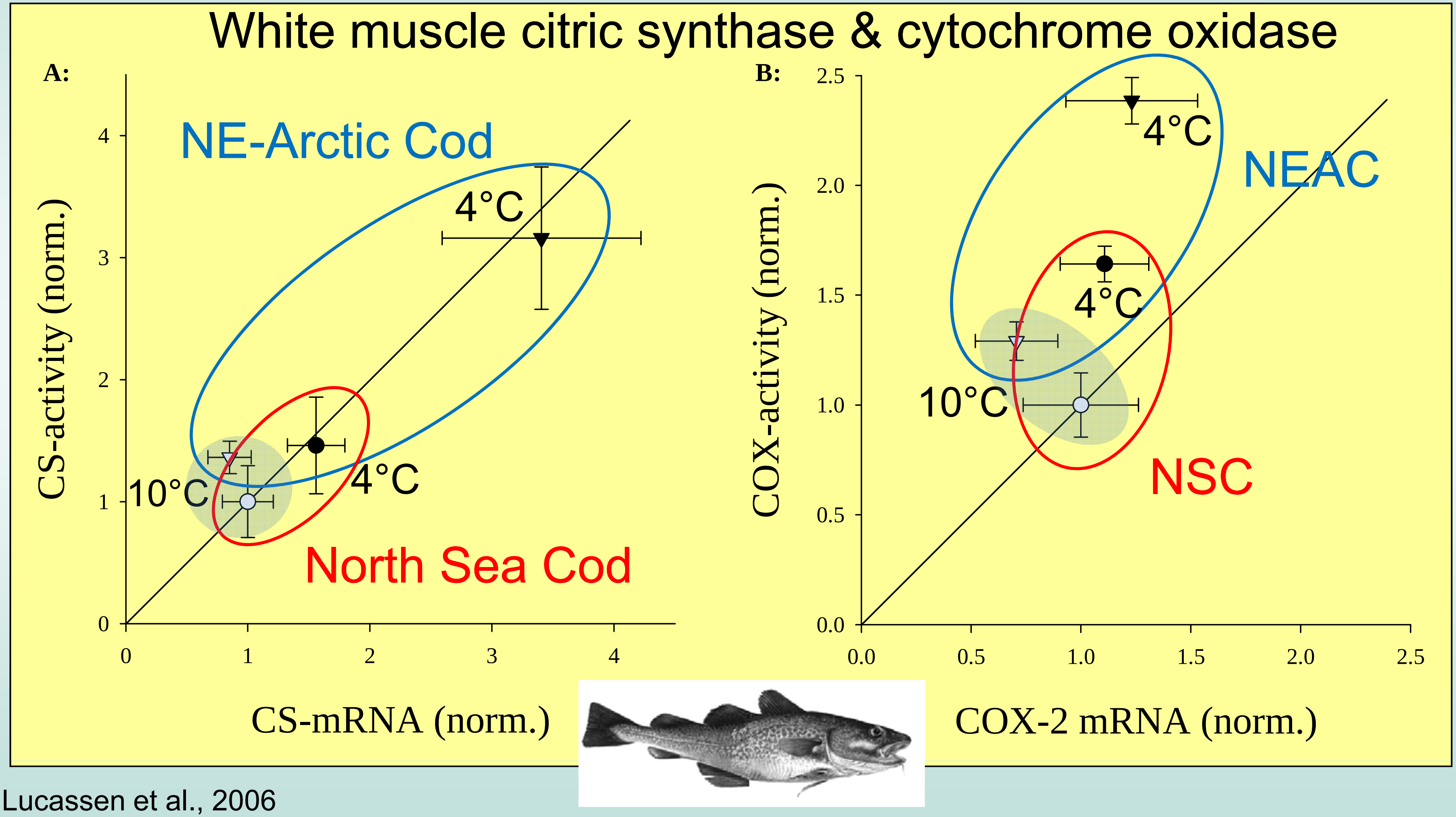


(after Lannig et al. 2005, Brodte et al. 2006
Wittmann et al. 2008, Schroer et al. 2009)

Genomic basis : (Cold) acclimation capacity even differs between populations

Less in temperate eurythermal North Sea cod (NSC)

than in cold eurythermal Barents Sea cod (NEAC)

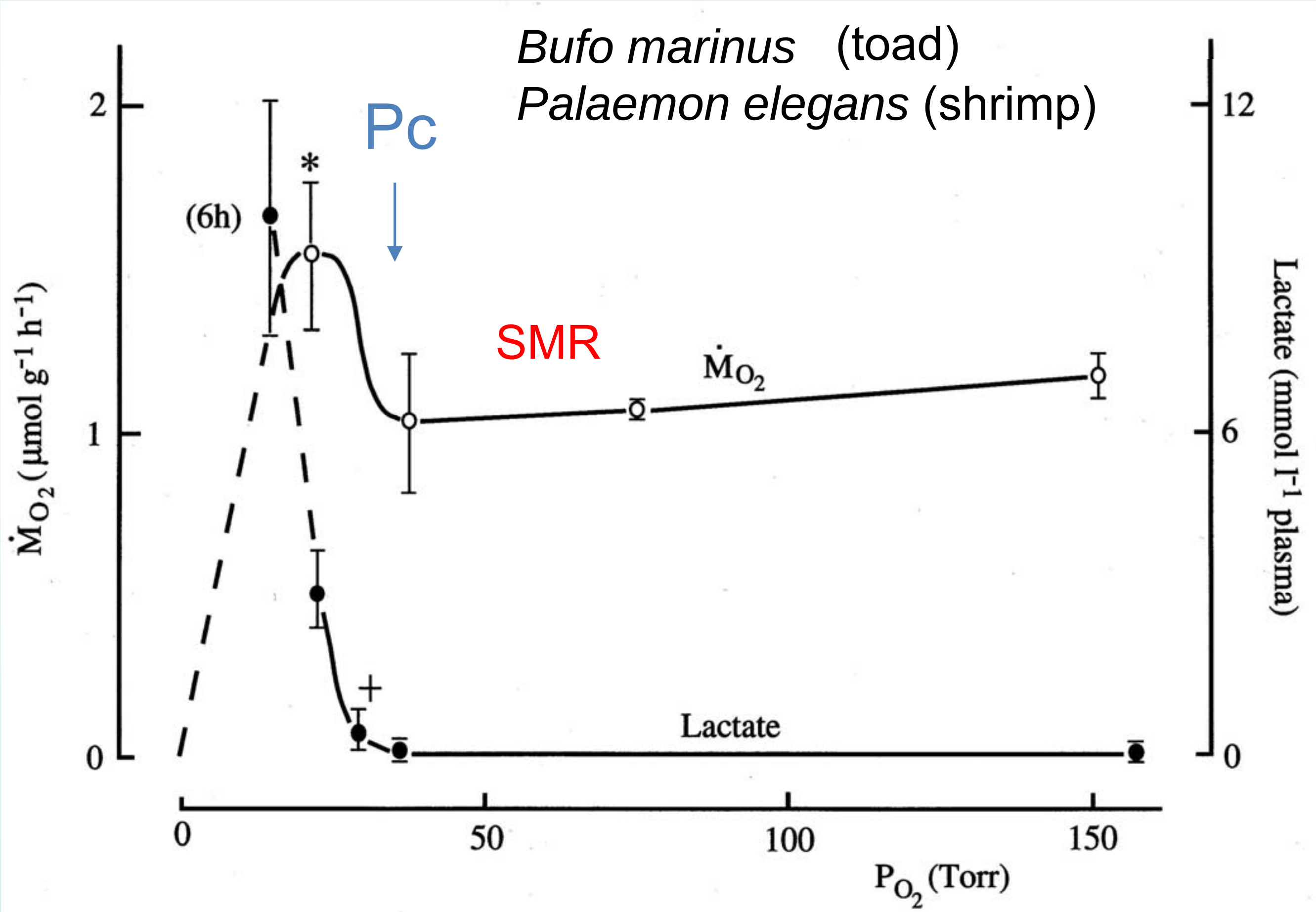


Lucassen et al., 2006

Tradeoff: High cost of eurythermal cold adaptation causing lower growth

Integrating hypoxia sensitivity into thermal tolerance
Patterns of critical Po_2 at standard metabolic rate (SMR):

Transition to anaerobic metabolism characterizes Pc in oxyregulators, may cause metabolic stimulation in hypoxia

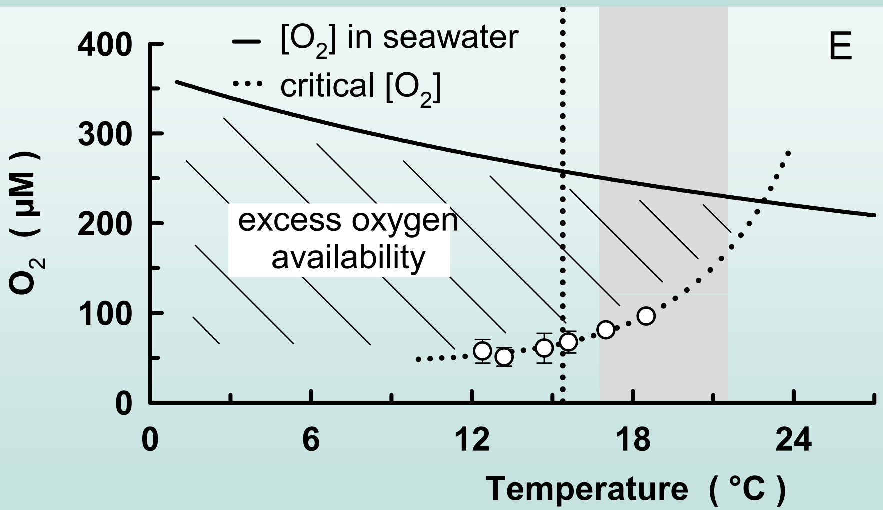


Pörtner et al. 1991

A different look at Pc:

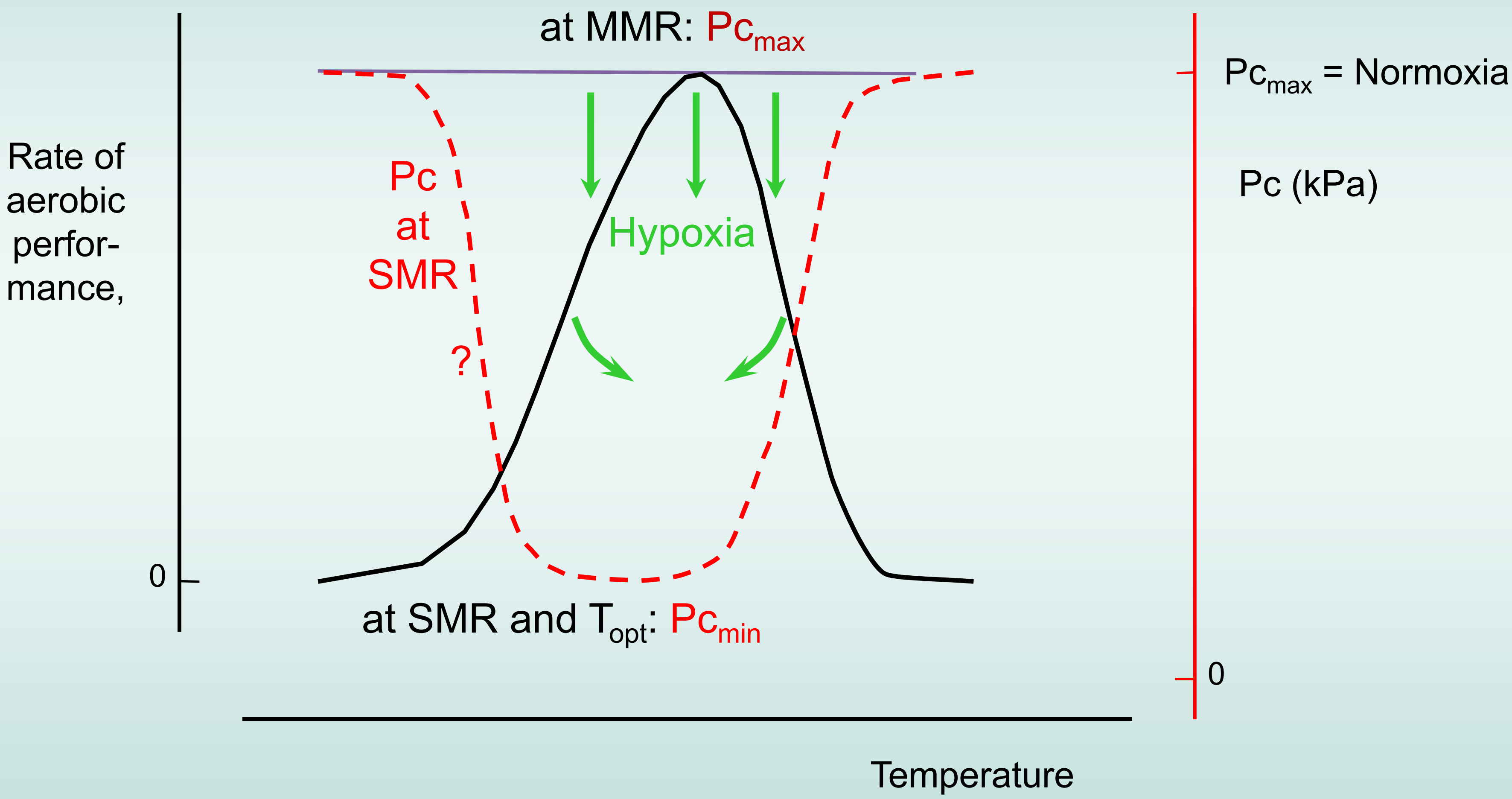
Upon warming (and cooling) the level of excess oxygen availability shrinks from supporting aerobic scope to setting thermal limits.

Pc equals normoxic Po_2 at high (and low?) Tc‘s



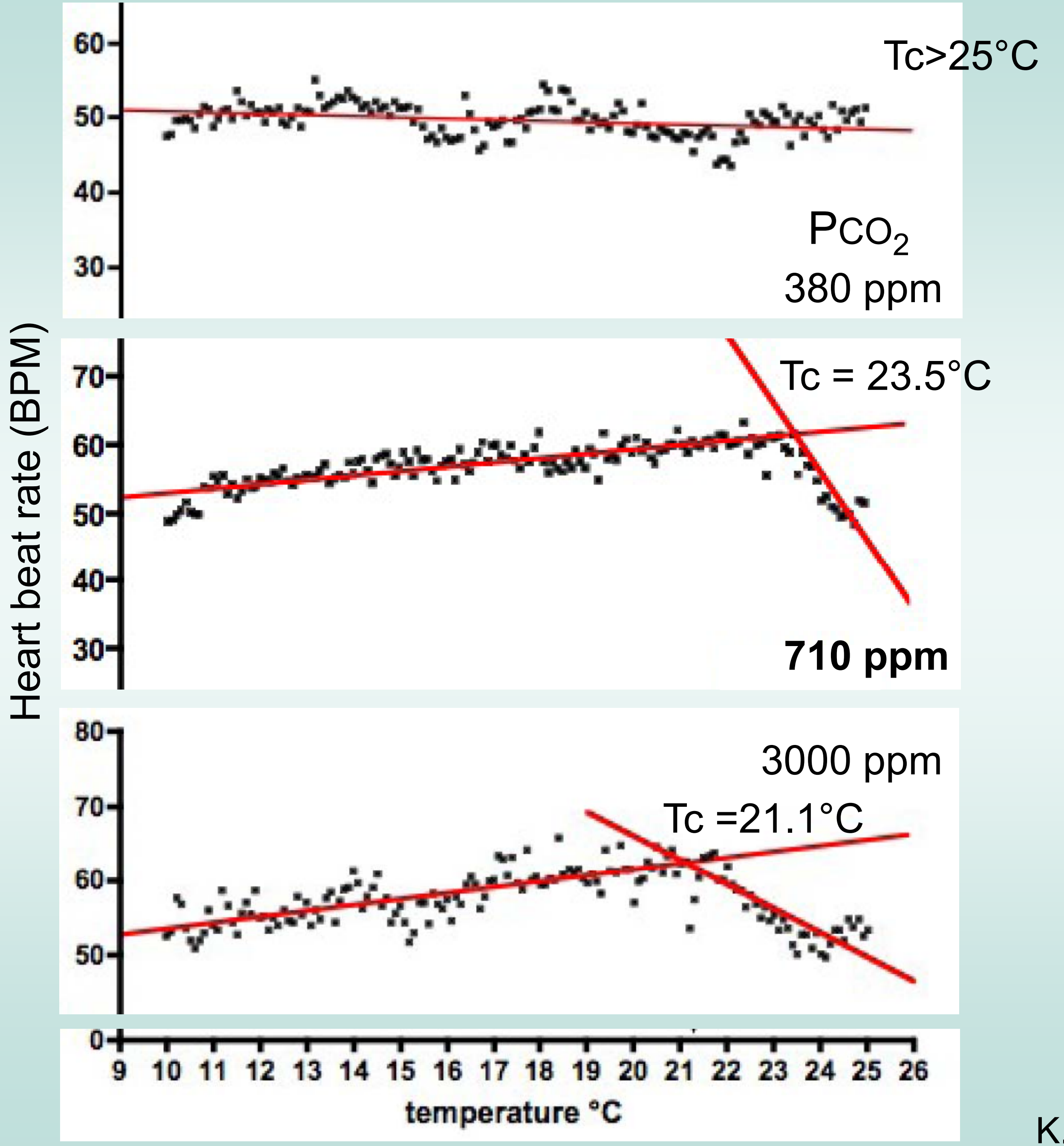
(Zakhartsev et al. 2003, Pörtner and Knust 2007)

Integrating hypoxia effects into O_2 limited thermal tolerance:



MMR: maximum metabolic rate
SMR: standard metabolic rate

Pörtner, J. exp. Biol. 2010



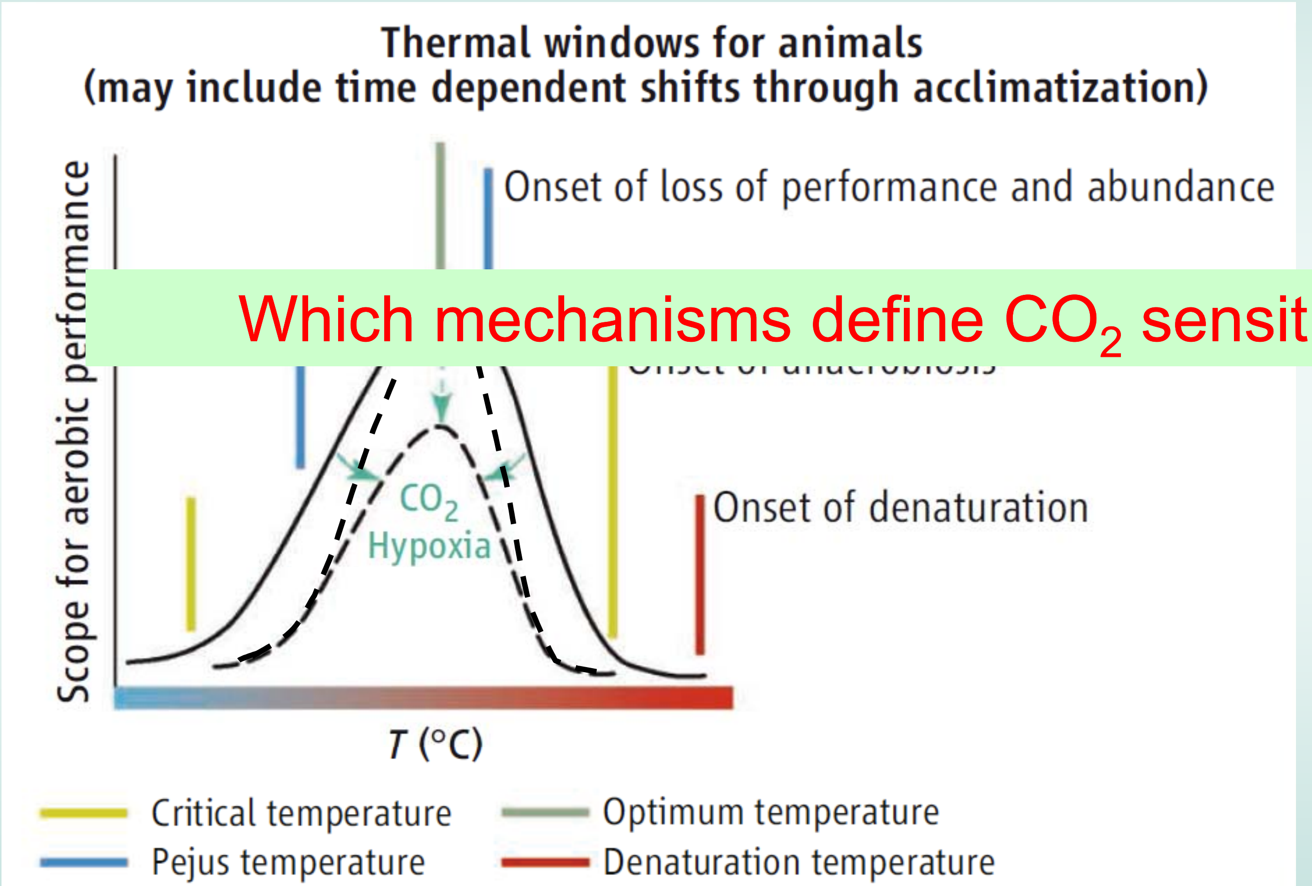
Leftward shift of upper Tc sets in under expected CO_2 accumulation scenarios:

Highest CO_2 sensitivity at thermal extremes,
→ Narrowing of thermal windows

K. Walther et al. 2009.

CO_2 causes enhanced hypoxemia at thermal extremes

BUT not necessarily lower performance optima, e.g. in fish
(Melzner et al. 2009)

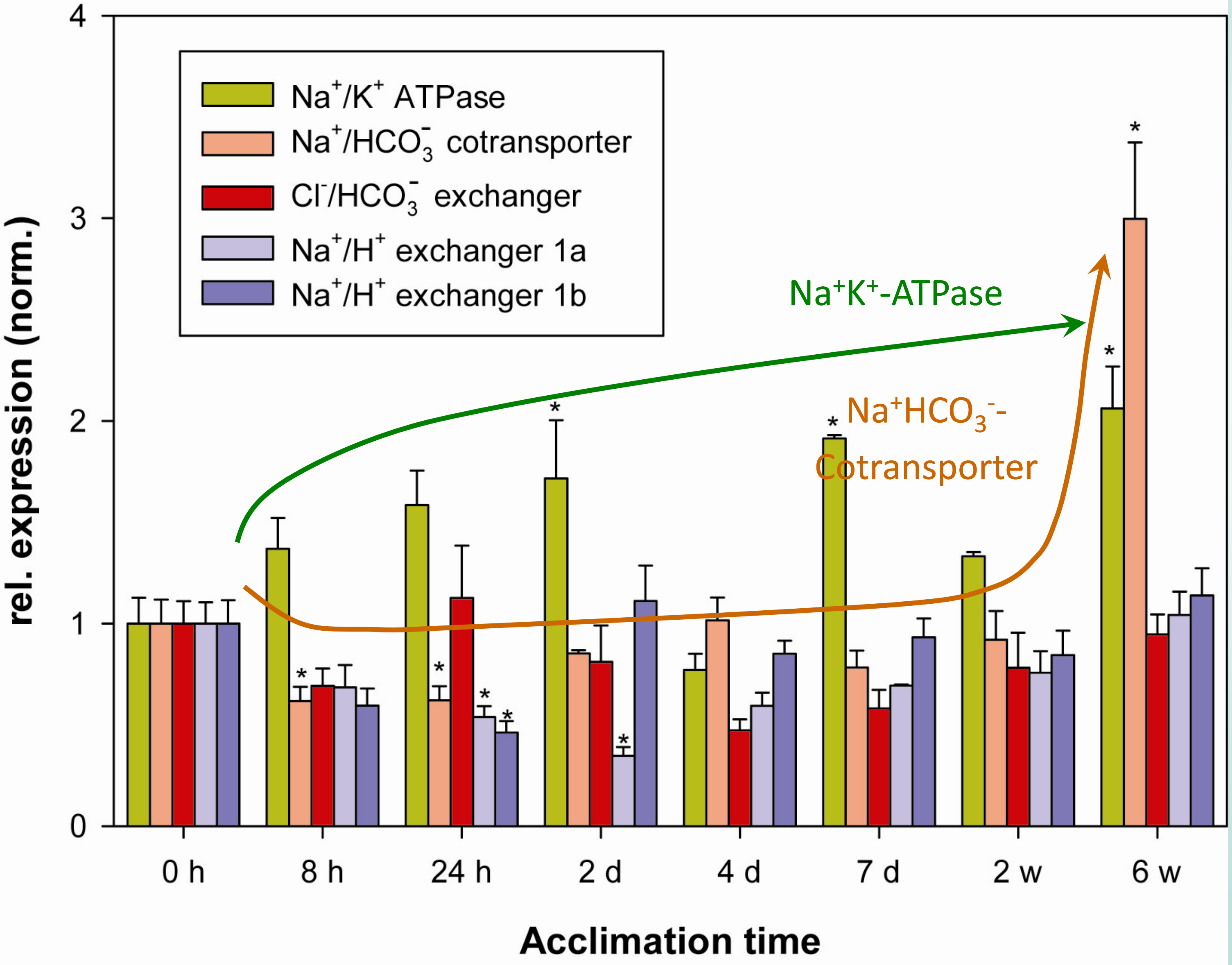


Which mechanisms define CO_2 sensitivity?

Hypothesis confirmed in Crustaceans (… et al. 2007, Walther et al. 2009), coral reef fishes (Munday et al. 2009)

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

Acclimation to high CO_2 tensions occurs via gene expression of pH–regulation mechanisms in fish gills, ….alleviating sensitivity in apparently insensitive fish?



Eelpout
(*Z. viviparus*)

Expression studied by real-time PCR

6 weeks

Deigweiher et al. 2008

At high CO_2 levels (>3000 ppm) uncompensated acidosis and me… …rates

…contribu… calcificati… and enha… time scale…

Compe… and, th… …h
…contrib… …nce.

Regulation of extracellular acid-base status as a major factor in defining different sensitivities?

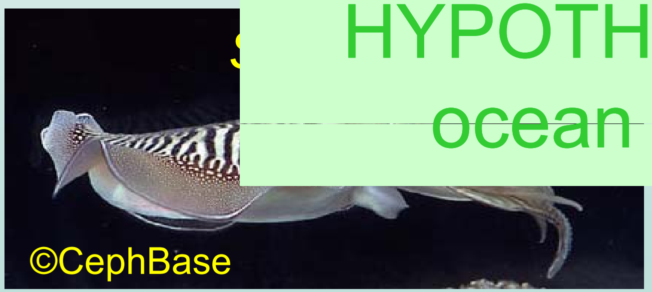
Acidosis causes performance decrements…

….a link to modulating thermal tolerance?

HYPOTHESES to be tested under ocean acidification scenarios

Atlantic cod

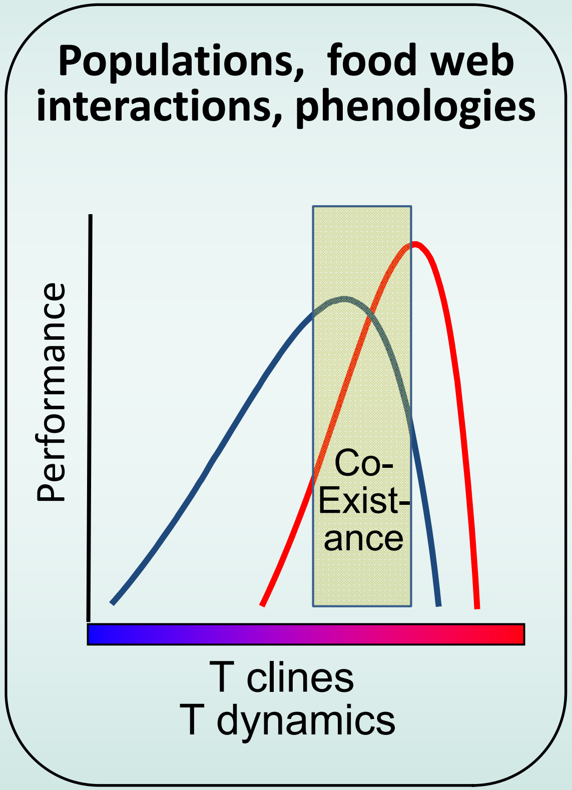
…tes:
…e and

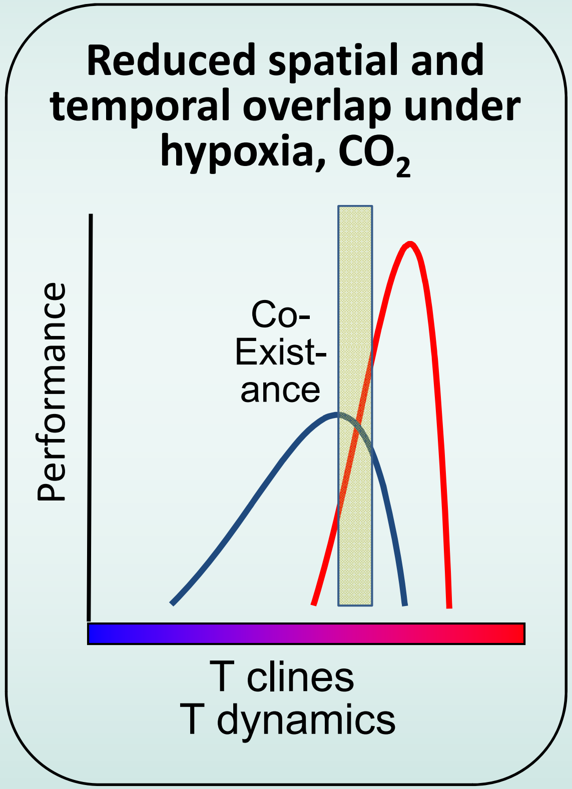


Pörtner 2008

Mechanism based projections of ecosystem implications:

CO_2 (and hypoxia) affect species interactions due to differential sensitivities





Differential sensitivities

Relative changes in performance:

- **Δ competition**
- **Δ susceptibility to predation**

THERMAL WINDOWS as defined by the OCLT concept: a suitable matrix for understanding changes in food web dynamics and ecosystem functioning

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

Addressing CO_2 and hypoxia effects in warming oceans, hypotheses

First lines of sensitivity (with ecological relevance) likely depend on

- effects on OCLT (oxygen and capacity limited thermal tolerance)
- compensation capacity for extracellular acid-base status in relation to levels of CO_2 accumulation and OA.

Implications to be considered:

- seasonal shifts in performance windows
- climate dependent functional specialization
- temperature dependent biogeography
- climate dependent growth, fecundity
- synergistic interactions with further factors in addition to temperature, hypoxia, CO_2 (e.g. various pollutants, …)
- effects on biogeography and species interactions

EPOCA European Project on OCean Acidification ⟺ BIOACID Germany ⟺ NATURAL ENVIRONMENT RESEARCH COUNCIL United Kingdom

CLICOFI

Effects of climate induced temperature change on marine coastal fishes

EU PROJECT ENV4-CT-0596

SCAR: EASIZ, EVOLANTA, EBA

CLIMATE CHANGE, THERMAL LIMITS and ADAPTATION, ENERGY BUDGETS , OCEAN ACIDIFICATION

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