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

Ecosystem effects of ocean acidification in times of ocean warming: a physiologist's view

Physiological mechanisms linking climate to ecosystem change

Hans Pörtner

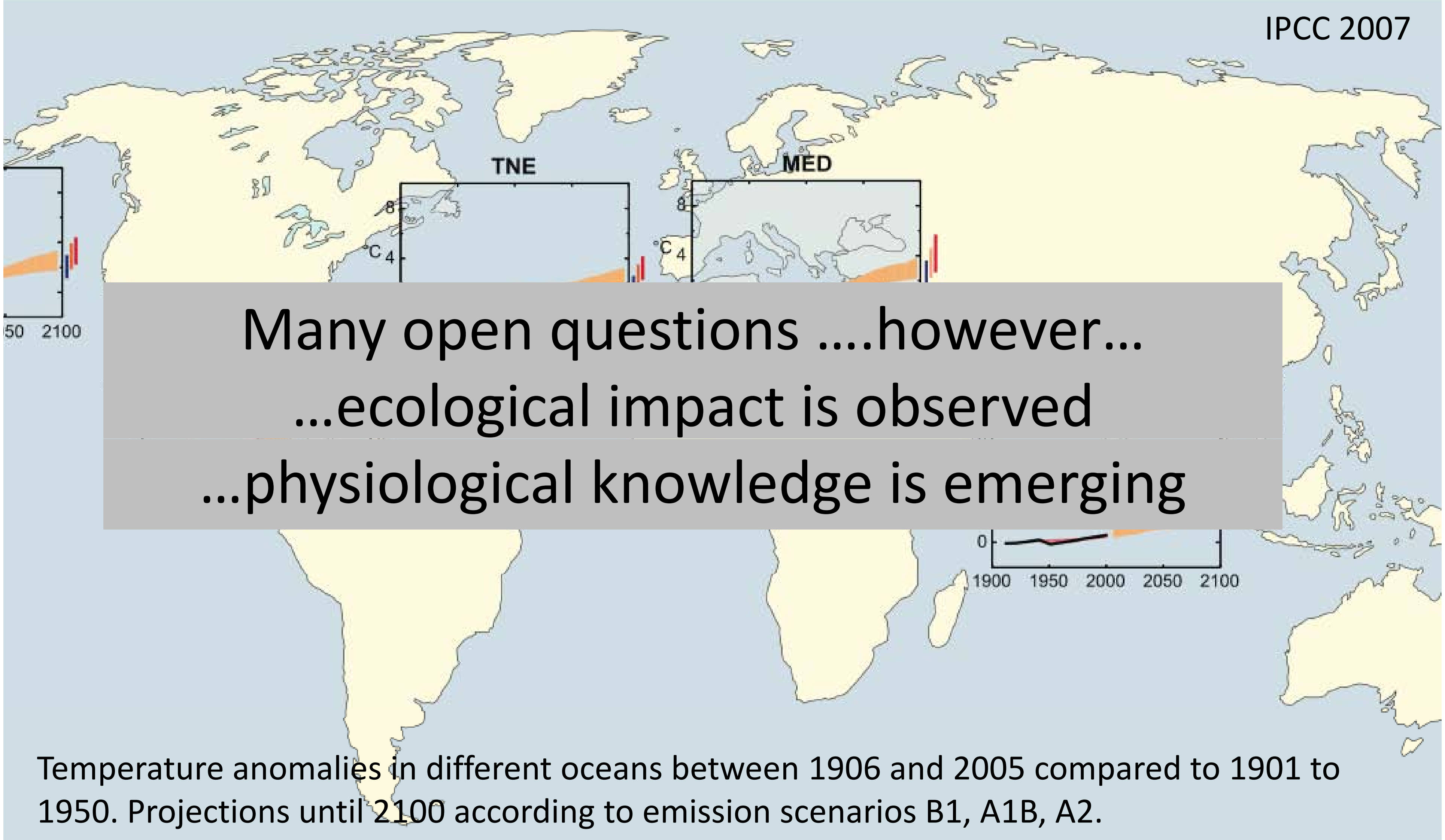
AWI NMR

Searching for unifying physiological principles in animal ecology and evolution

AWI Ecophysiology

Trends and projections of ocean warming:

IPCC 2007

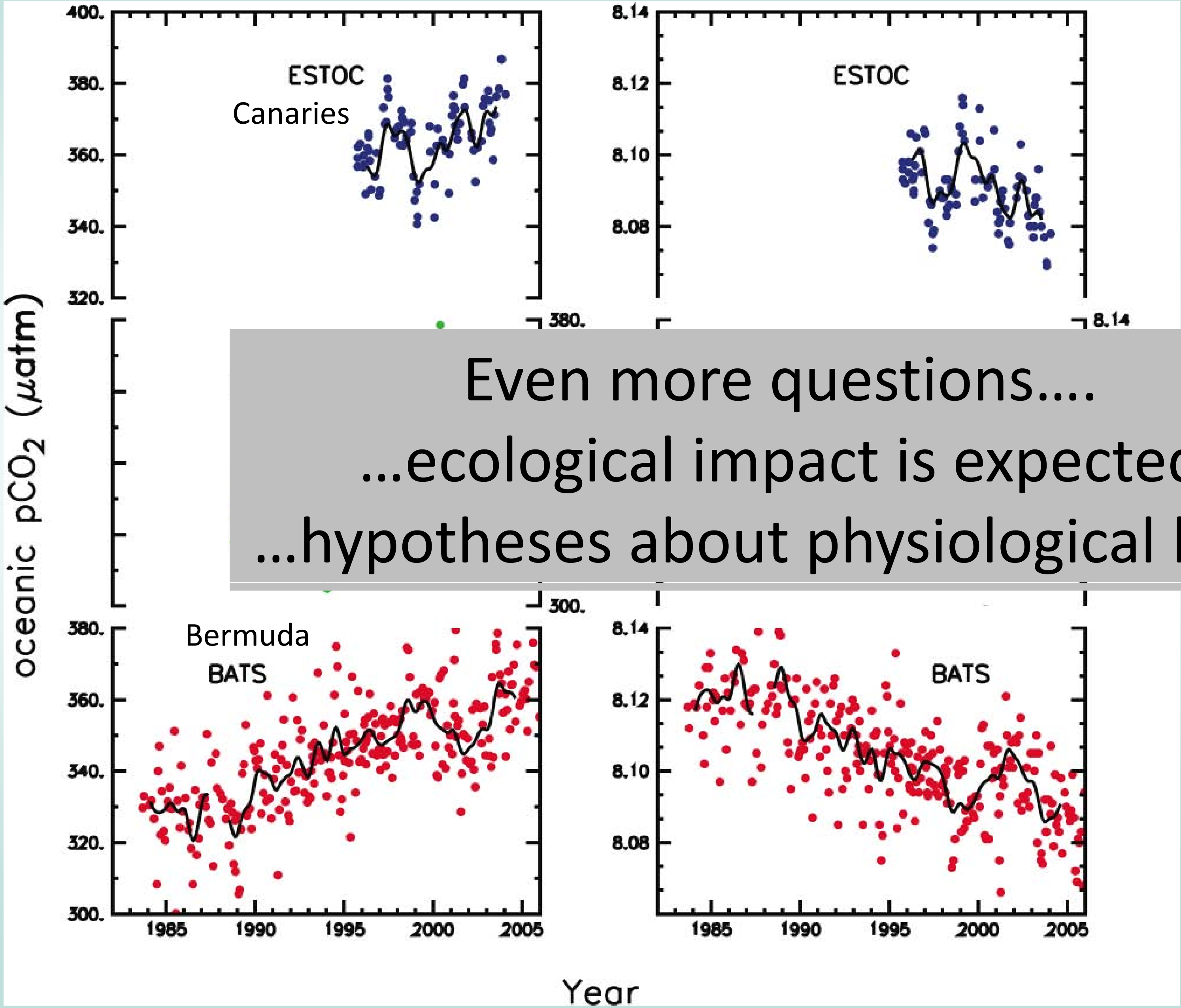


Many open questions ….however…
…ecological impact is observed
…physiological knowledge is emerging

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 is expected

…hypotheses about physiological basis

IPCC 2007

Analysing ecosystem effects of ocean acidification

…..against the background of ongoing change
- on species level
- on ecosystem level

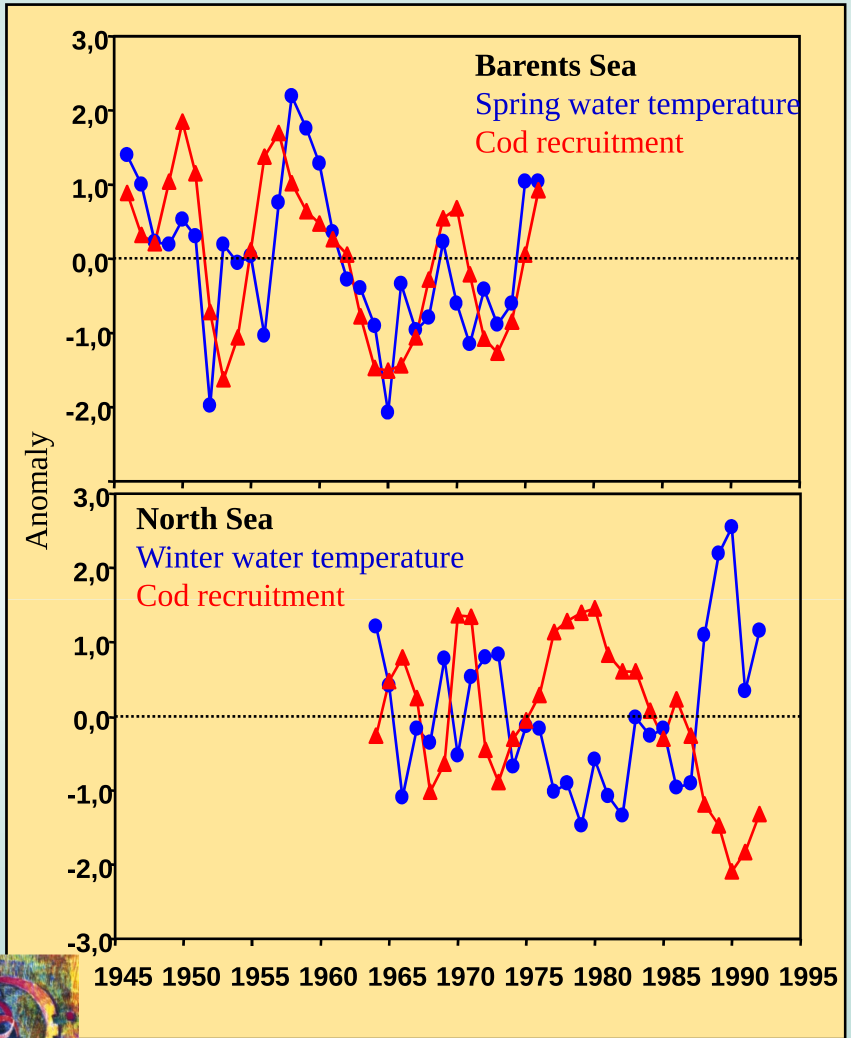
What do we need? To identify….

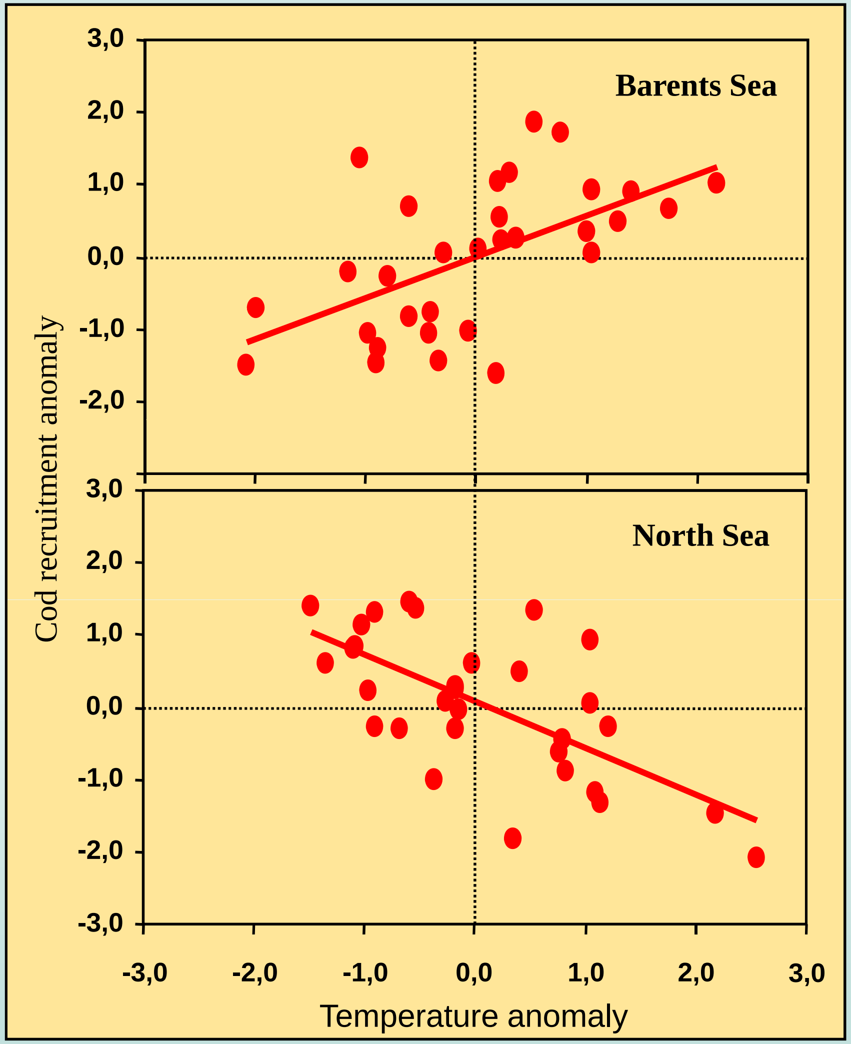
- Physiological mechanisms: …for a cause and effect understanding!
- Response of those mechanisms to various levels of OA!
- Thresholds and time scales of effects: …at species & ecosystem levels!
- Realistic scenarios: …on top of ongoing change!

↔ Learning from thermal ecology and physiology

Species specific thermal windows behind ecological phenomena:

Cod recruitment closely follows temperature reflecting upper and lower thermal limits

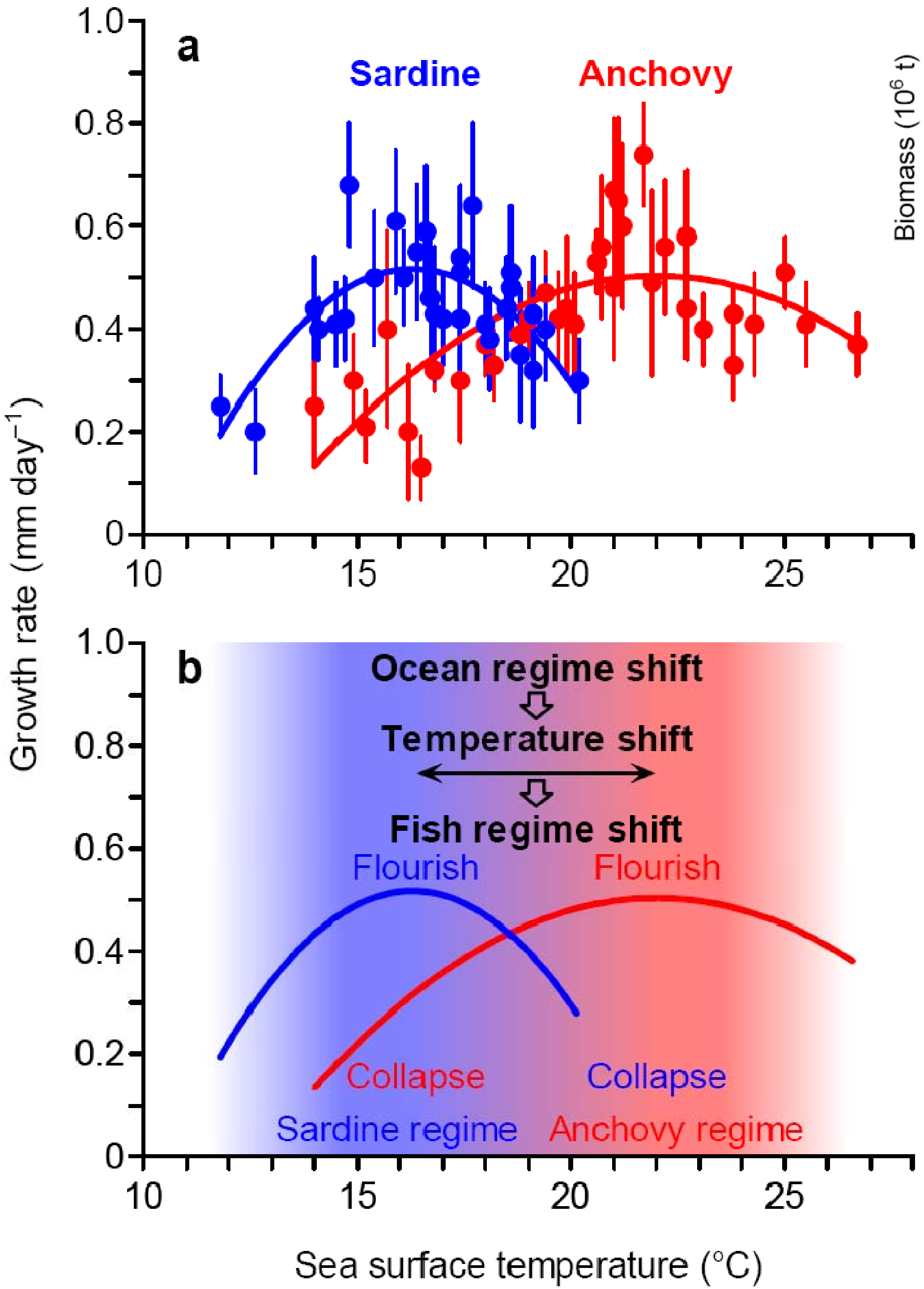


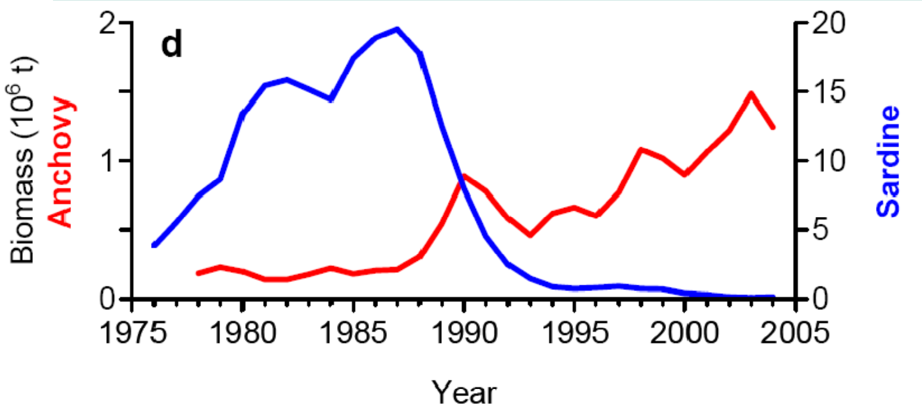


La Sapienza

Colosimo et al. 2003

Cooperation with Institut für Ostseeforschung, Warnemünde, F.R.G.





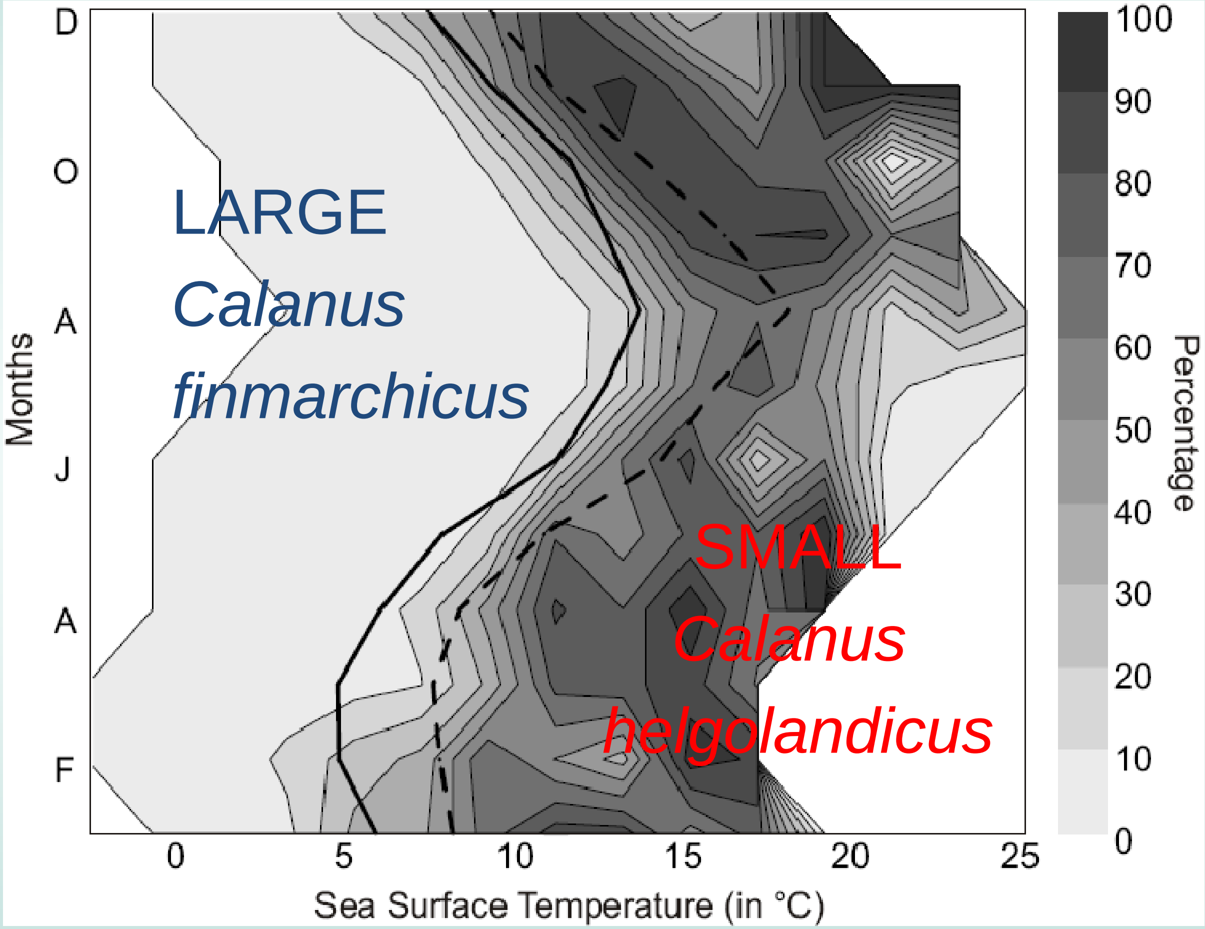
Thermal windows explaining ecological phenomena?

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

Climate induced changes in the food web

Regime shift from LARGE to SMALLer copepods in the North Sea…… driven by warmer temperatures.



Percentage of *C. helgolandicus* in total *Calanus*

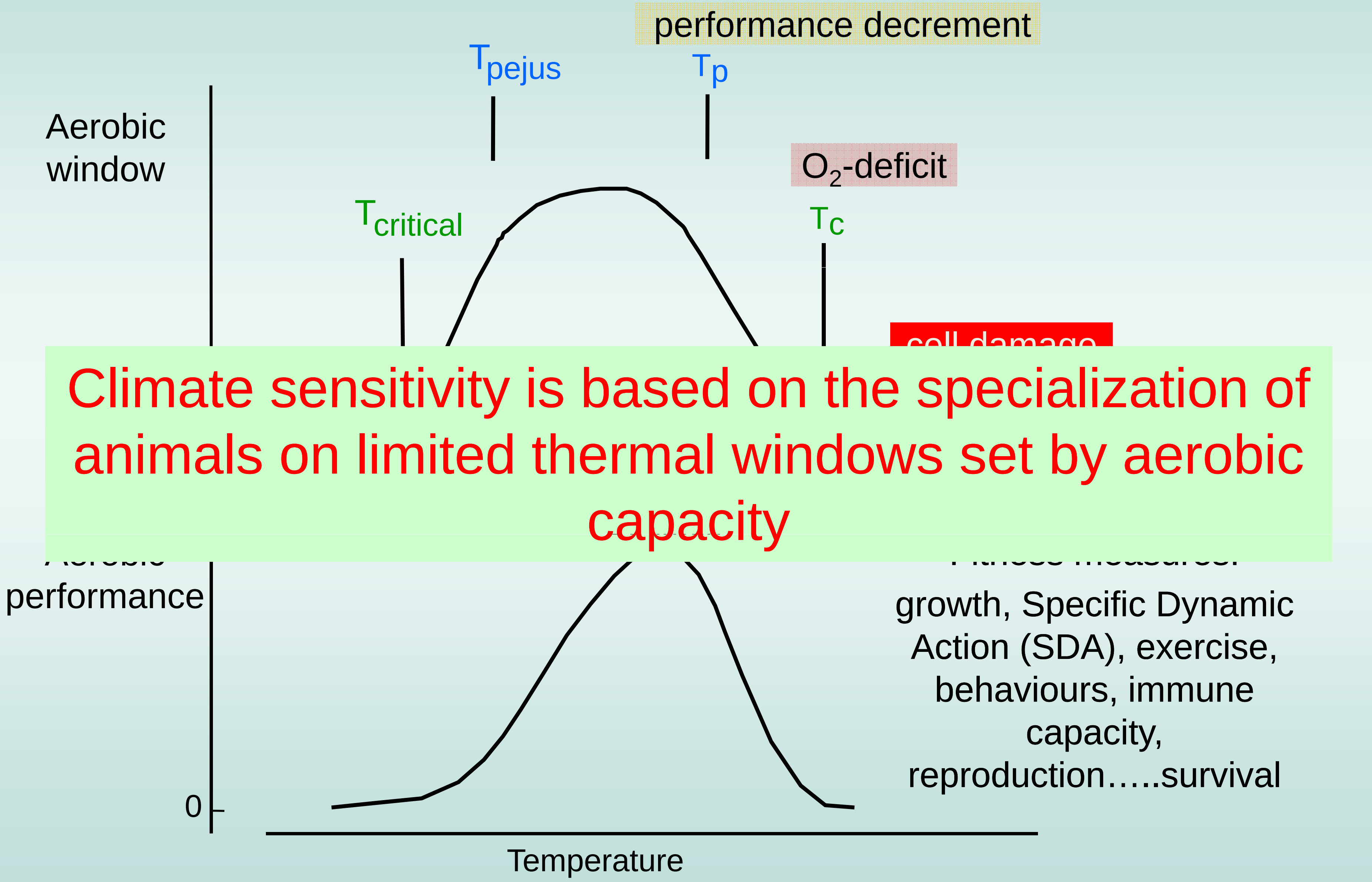
(Beaugrand et al., 2003
Helaouët and Beaugrand, 2007)

Different thermal windows of predator and prey organisms co-define prey availability:

Affecting food web structure

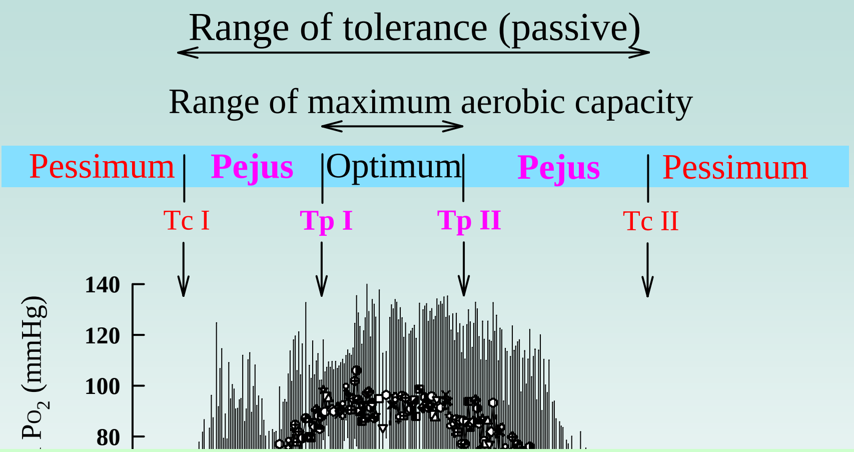
Smaller food items contributing to the decline of cod stocks in the North Sea?

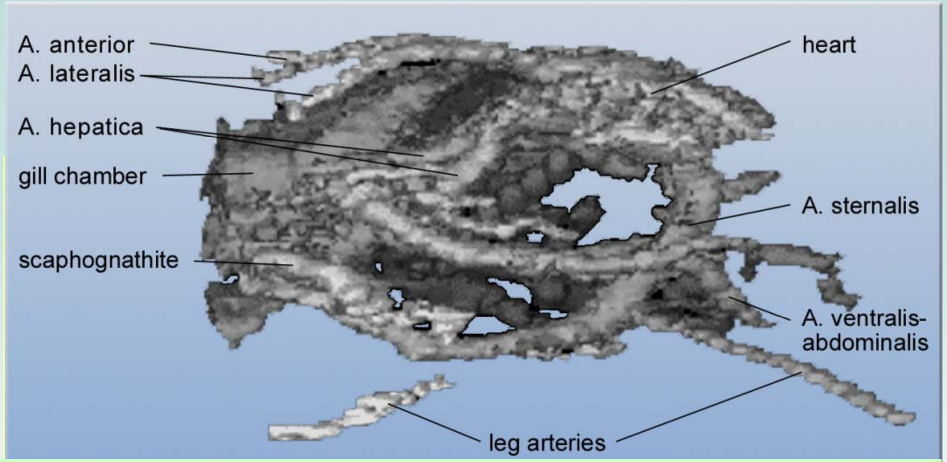
Explaining thermal windows from animal physiology: Concept of oxygen and capacity limited thermal tolerance



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

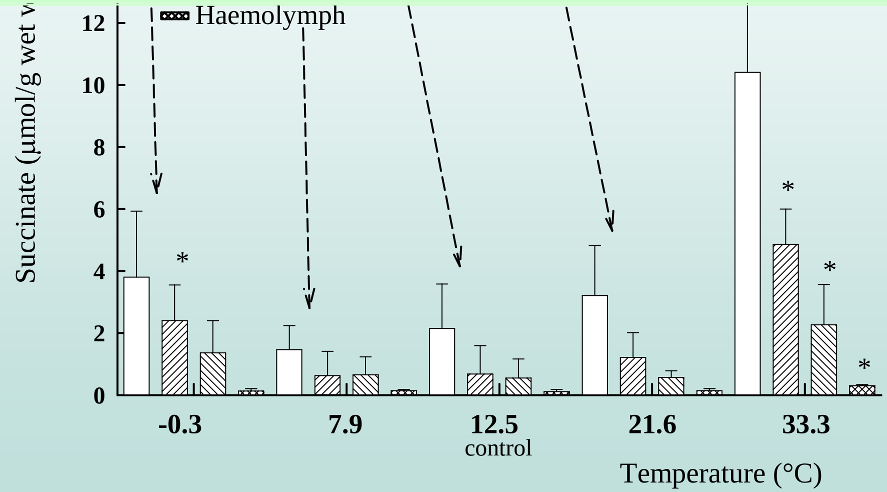
After Pörtner, 2001, 2002, Pörtner et al., 2005, Pörtner and Knust, Science 2007





Concept of oxygen and capacity limited thermal tolerance supported by data from various animal phyla:

sipunculids, annelids, molluscs (bivalves, cephalopods), crustaceans, vertebrates, …..air breathers



Frederich and Pörtner, AJP 2000

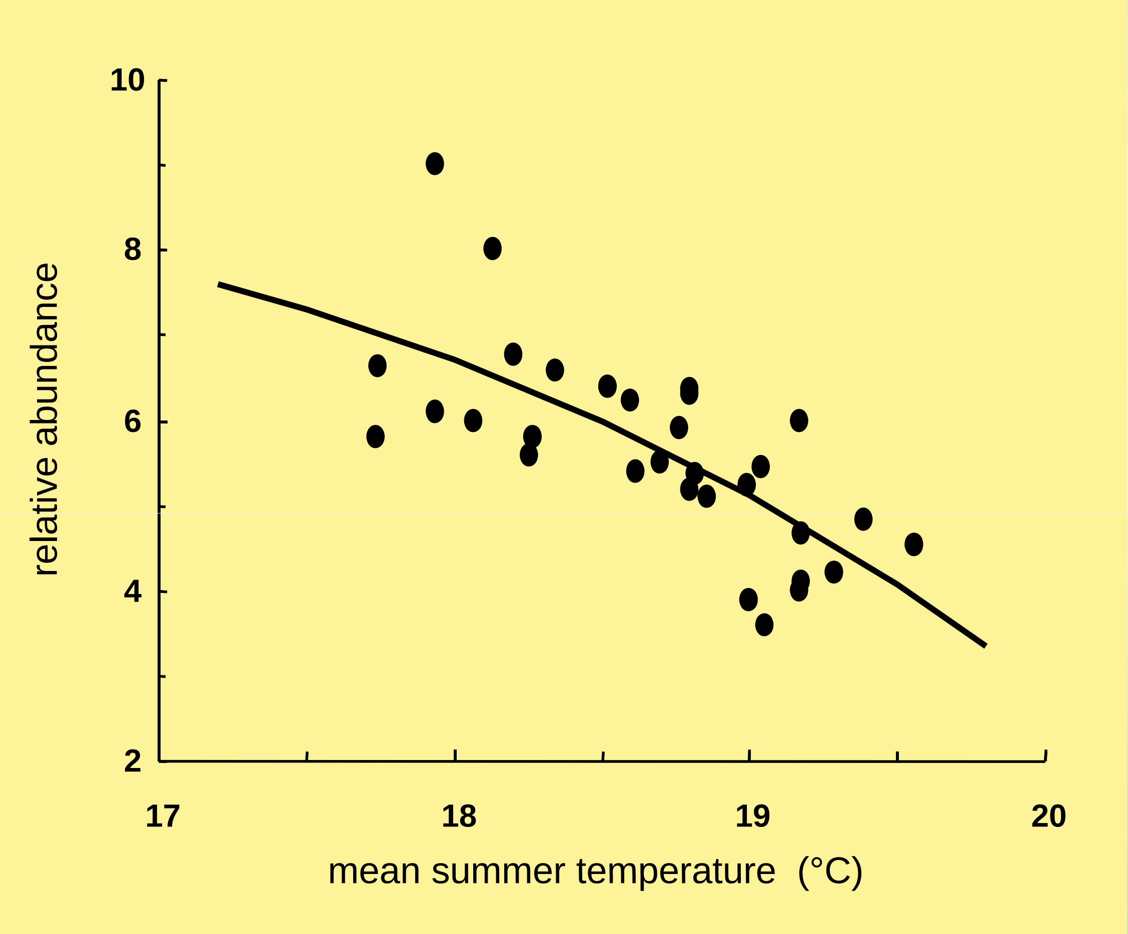
Tp: pejus temperature,
onset of limited aerobic scope

(pejus: getting worse)

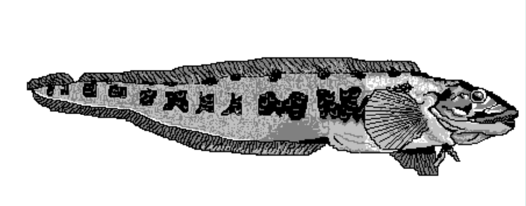
Tc: critical temperature,
loss of aerobic scope,
onset of anaerobic metabolism

Are these physiological findings suitable to explain ecological phenomena?

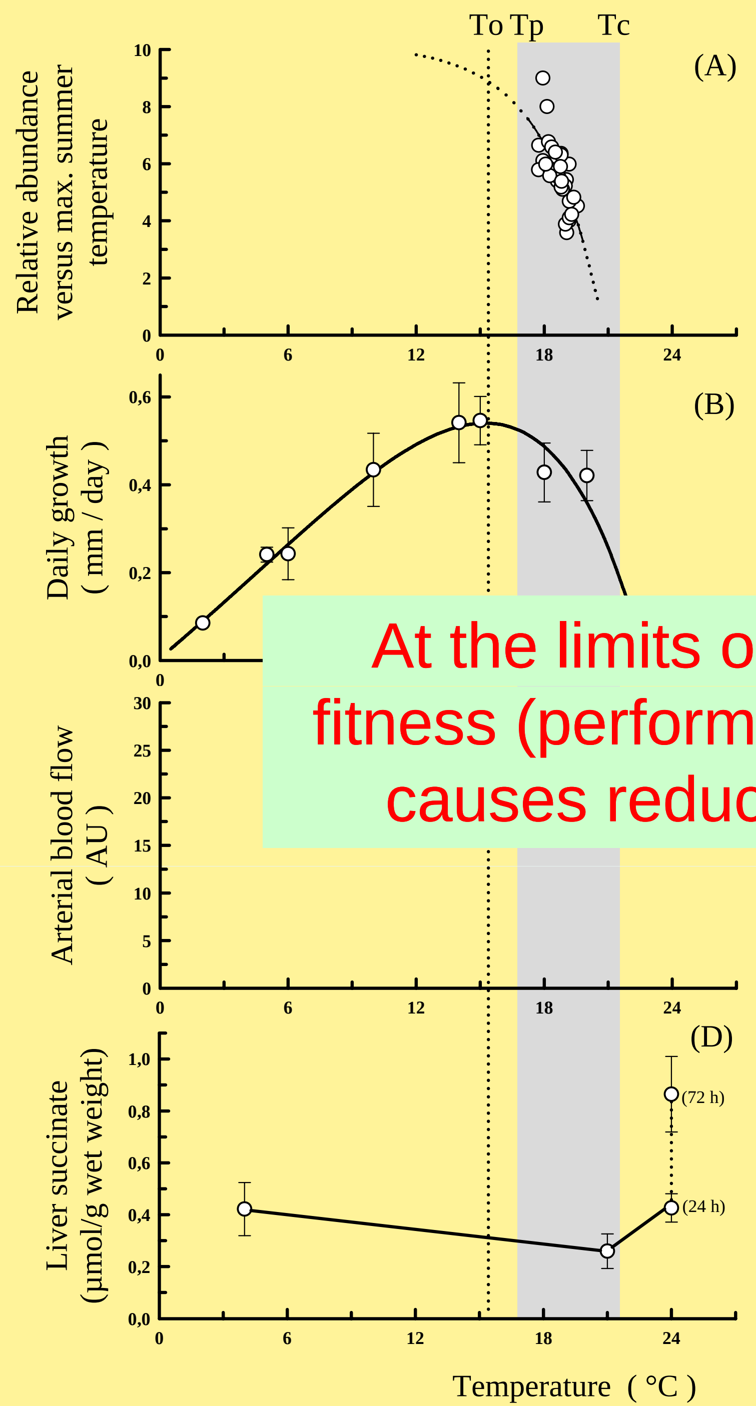
Eelpout (*Zoarces viviparus*) abundance in the German Wadden Sea falls at high summer mean temperatures



Early loss of LARGE individuals due to the allometry of oxygen limitation



Climate effects in the field…..



Abundance

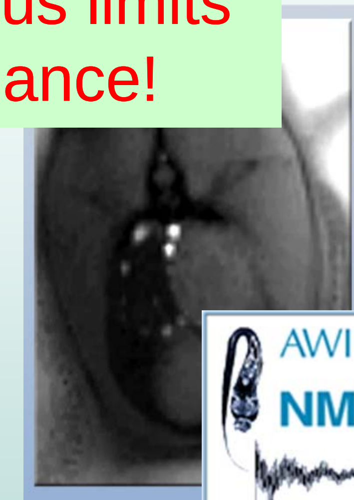
Eelpout

North Sea

Growth

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

Blood flow

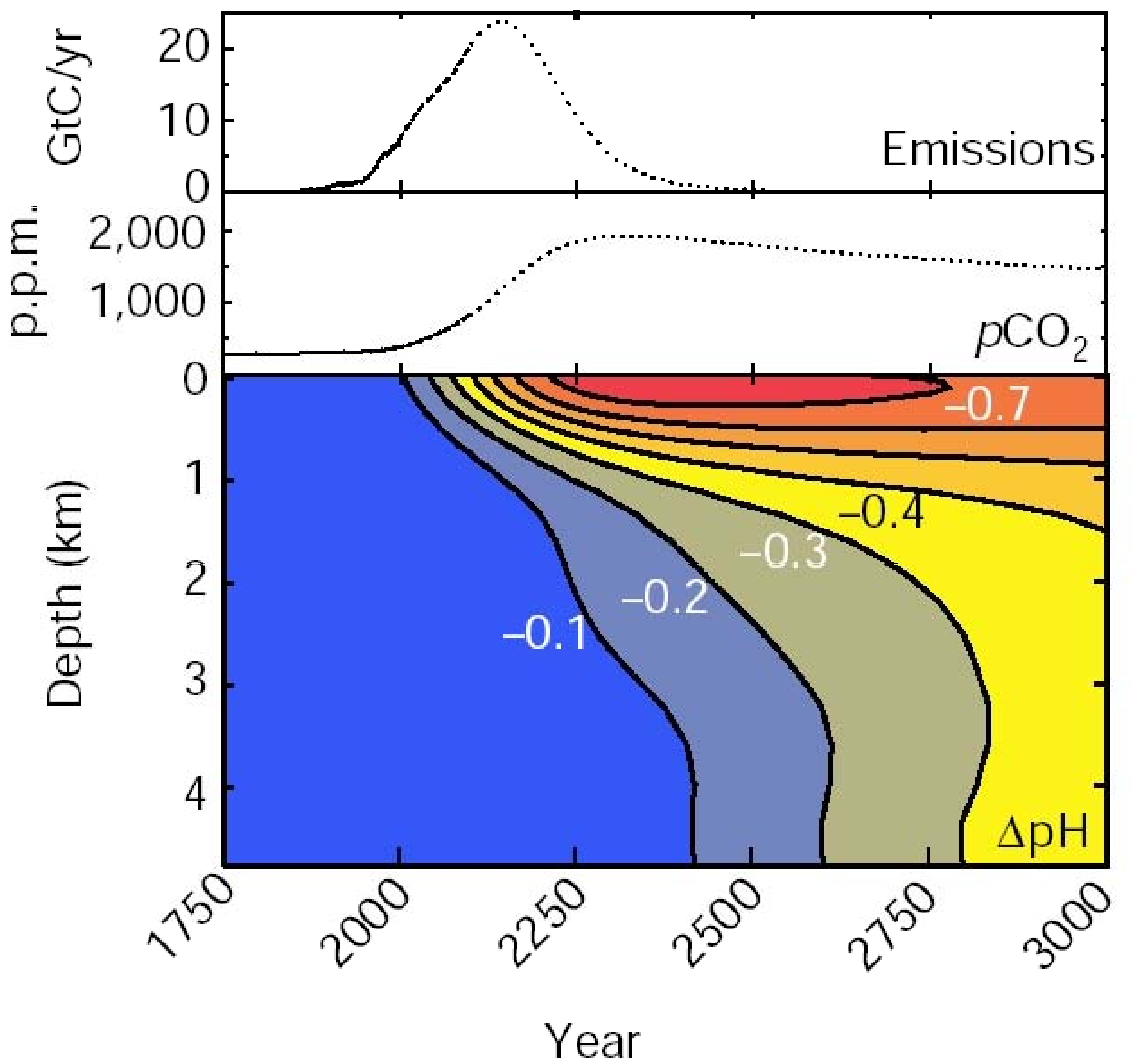


AWI NMR

O_2-deficit

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

Ocean acidification: The superimposed problem



Caldeira & Wickett 2003

The future ocean (e.g. in 2100)

- warmer, more stratified
- less oxygen in the deep
- more acidified

Modified water chemistry (surface)

Pre-industrial → Today

ΔpH = 0.12

Today → 2100

ΔpH = 0.45

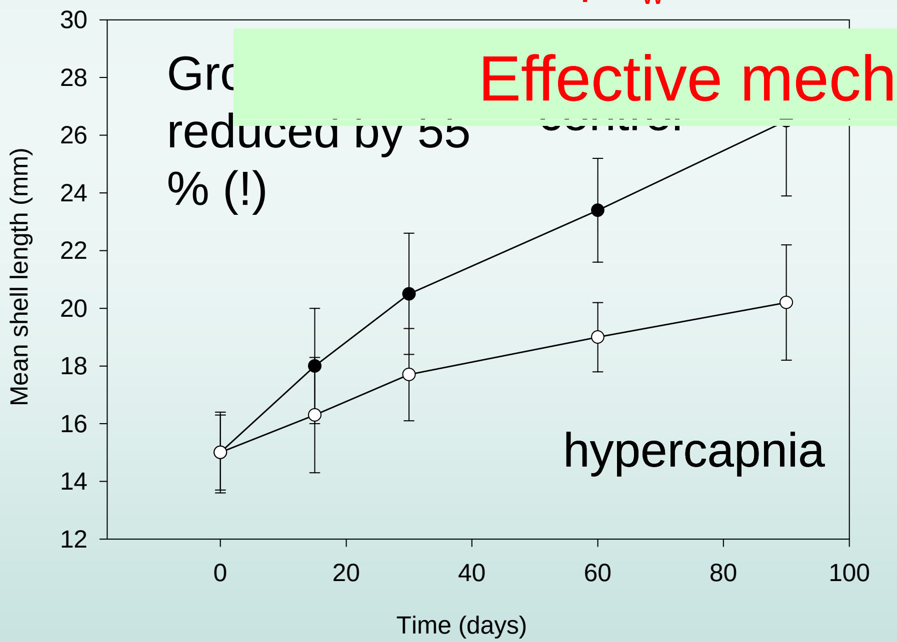
Current research focuses on specific CO_2 effects e.g. on growth performance

Mediterranean mussels *Mytilus galloprovincialis*

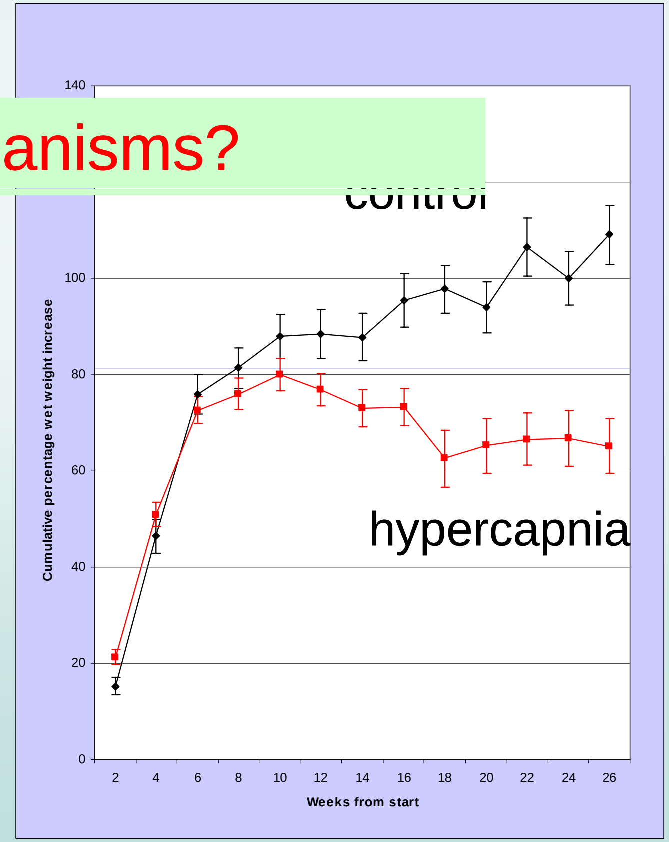
Pacific sea urchin *Hemicentrotus pulcherrimus*

560 ppm CO_2

pH_w 7.3

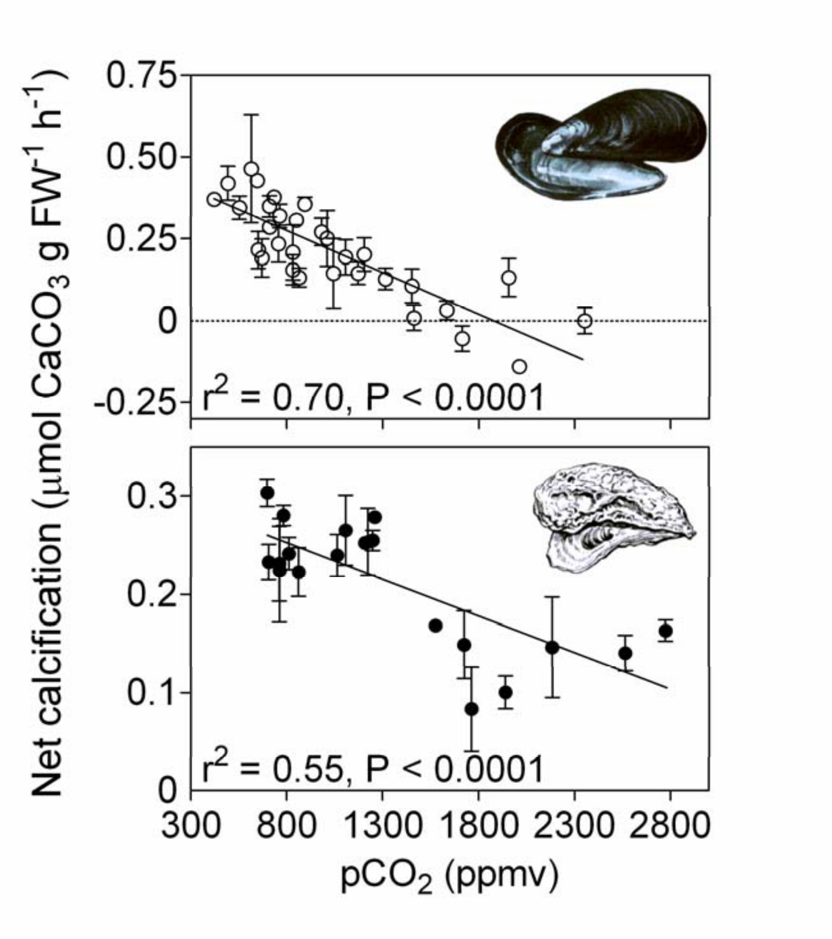


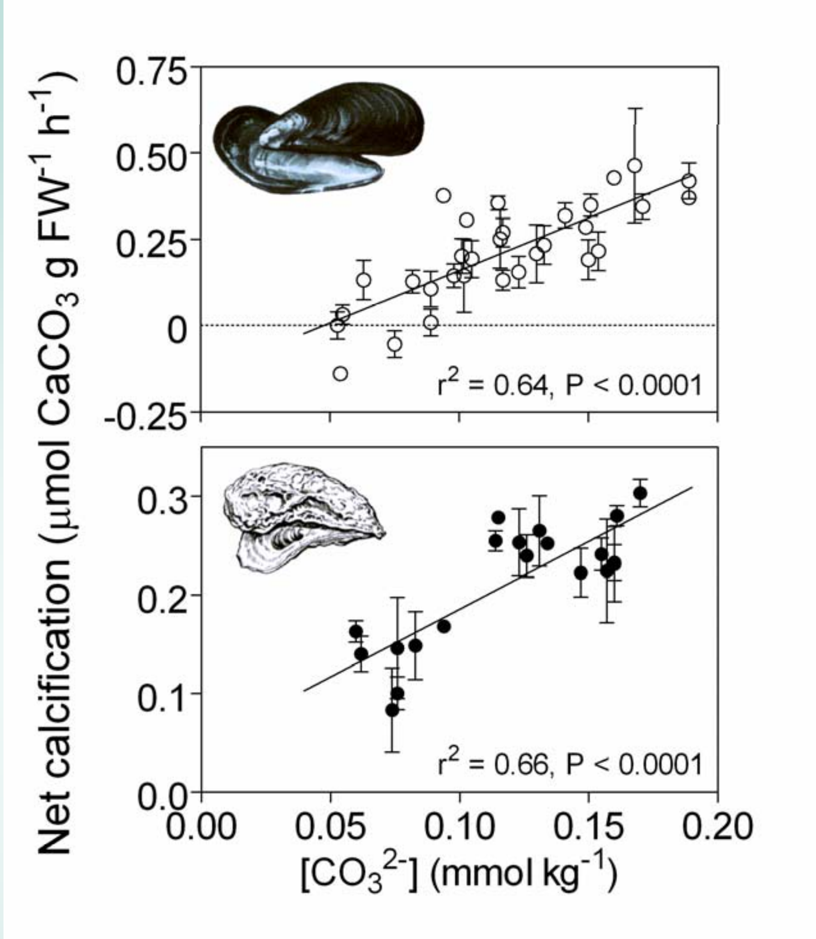
Effective mechanisms?



Michaelidis et al. (2005)

Data courtesy: Y. Shirayama





Water physicochemistry

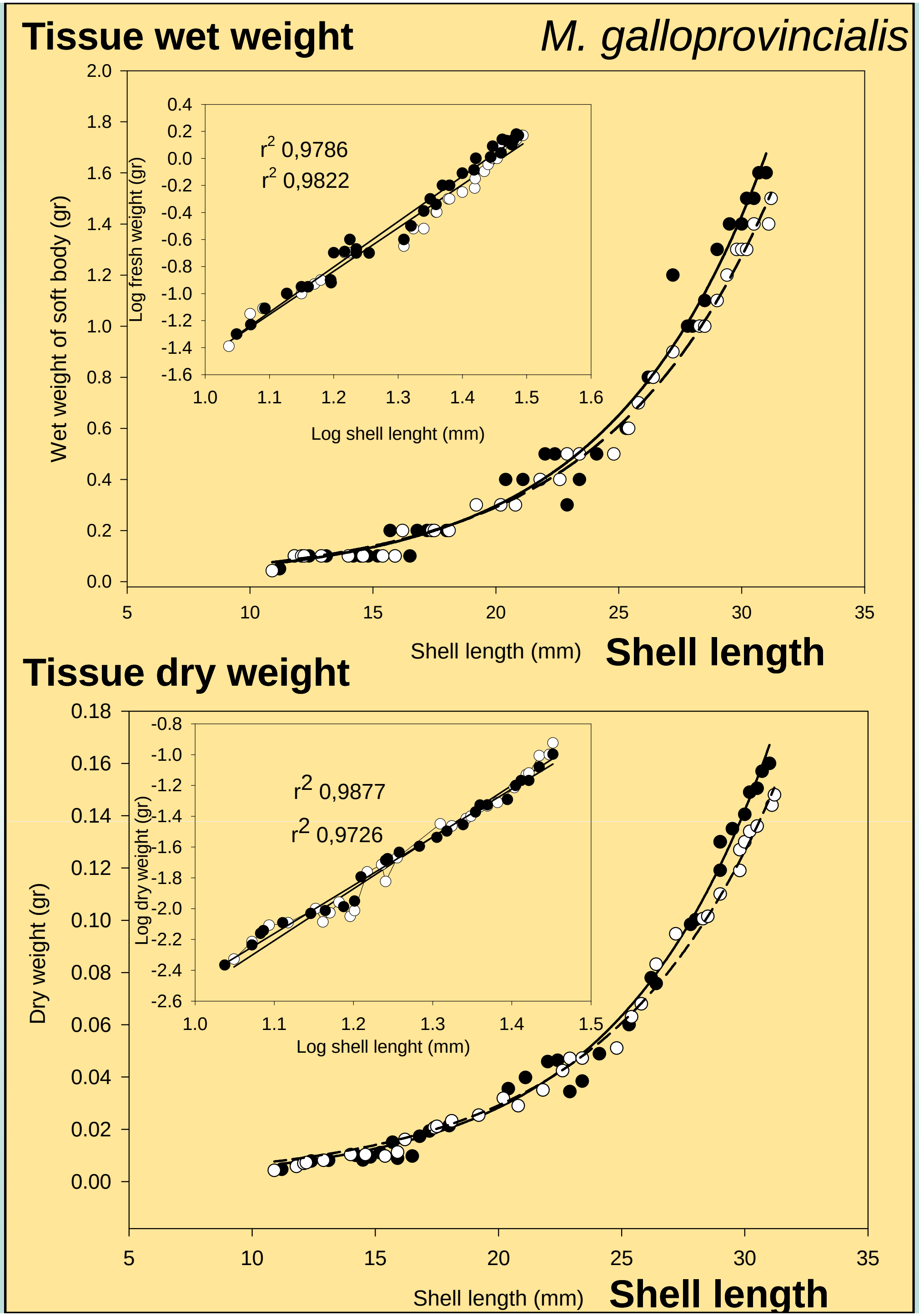
Gazeau et al., 2007

Doubling of present day $P\text{CO}_2$: acutely (!) reduced calcification

→ 30% ↓ of calcification in mussels (*M. edulis*)

→ 15% ↓ of calcification in oysters (*C. gigas*)

Effective mechanisms?



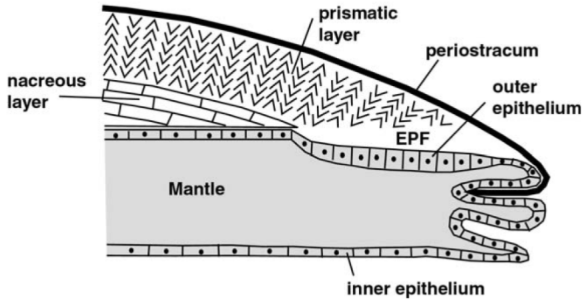
Searching for mechanisms:

Close coordination in the reduction of tissue dry / wet weight and shell length

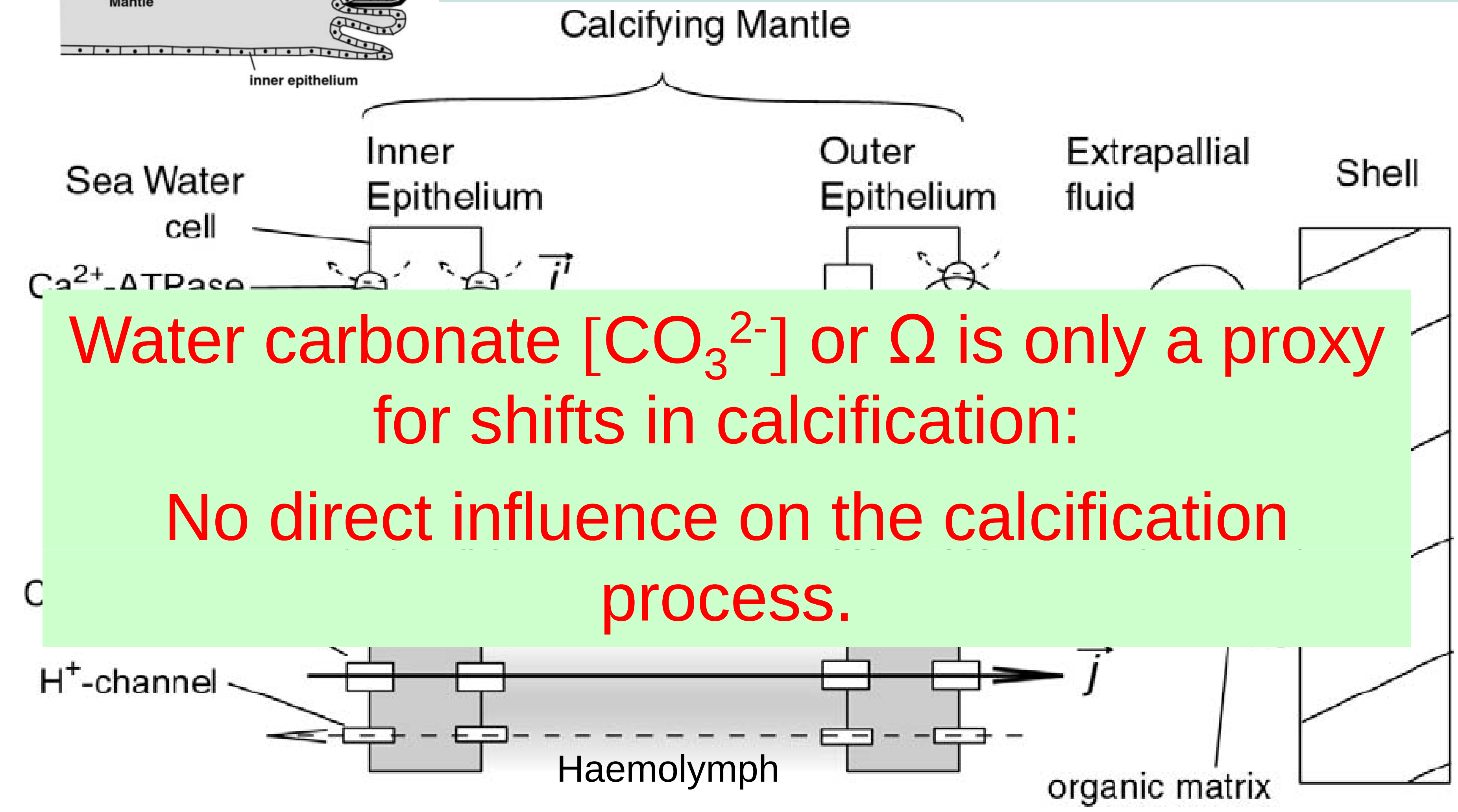
↓

Which parameter is setting BOTH soft body growth and calcification rates?

Michailidis et al. (2005)



Four membranes crossed from sea water to extrapallial fluid

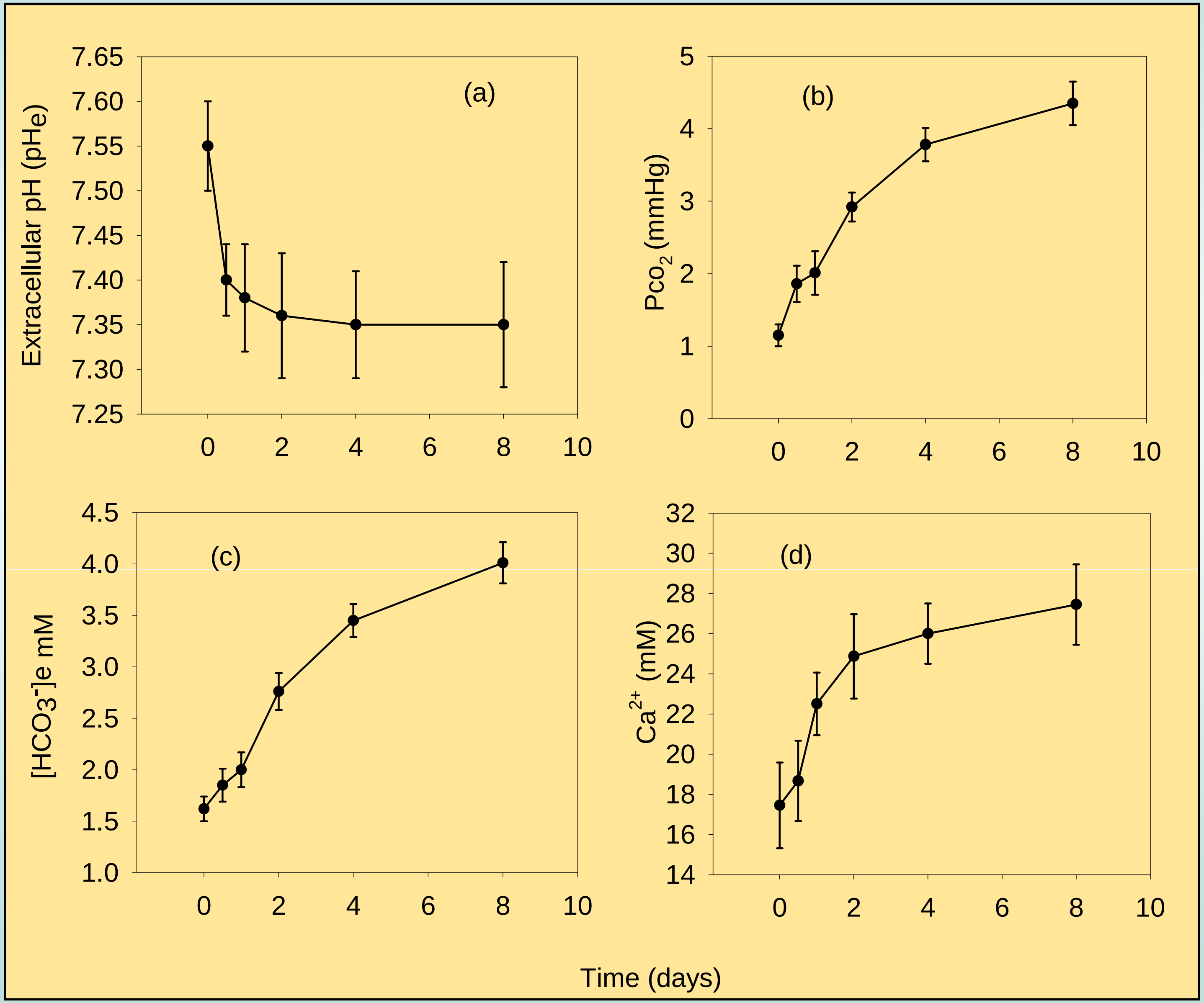


Water carbonate [CO_3^{2-}] or Ω is only a proxy for shifts in calcification:

No direct influence on the calcification process.

Schematic calcification model for marine bivalve shells (Carre et al., 2006):

Partially compensated extracellular acidosis in haemolymph of *Mytilus galloprovincialis*

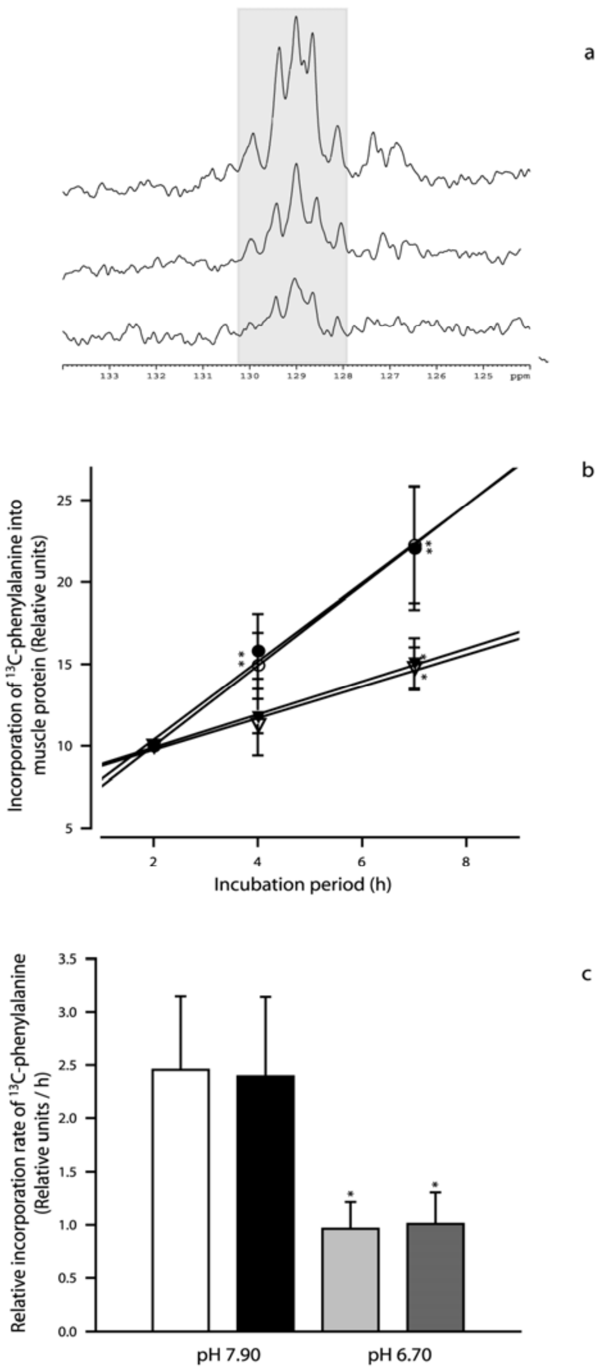


Hypercapnia (pH 7.3) causes

- lowered pH_e
- elevated P_{CO_2}
- bicarbonate accumulation
- Ca^{2+} accumulation

in haemolymph.

Michailidis et al. (2005)

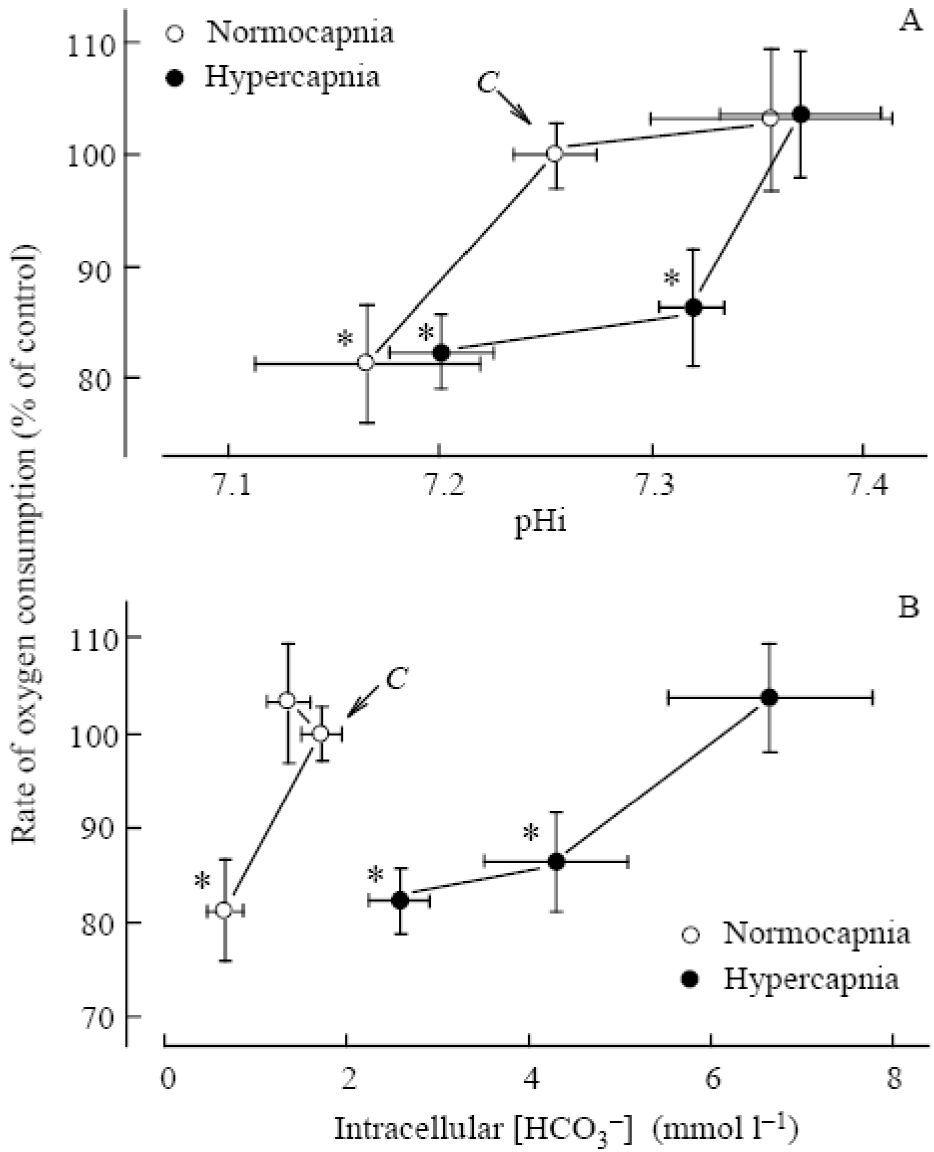


Reduced cellular protein synthesis during acidosis associated with reduced metabolic rates

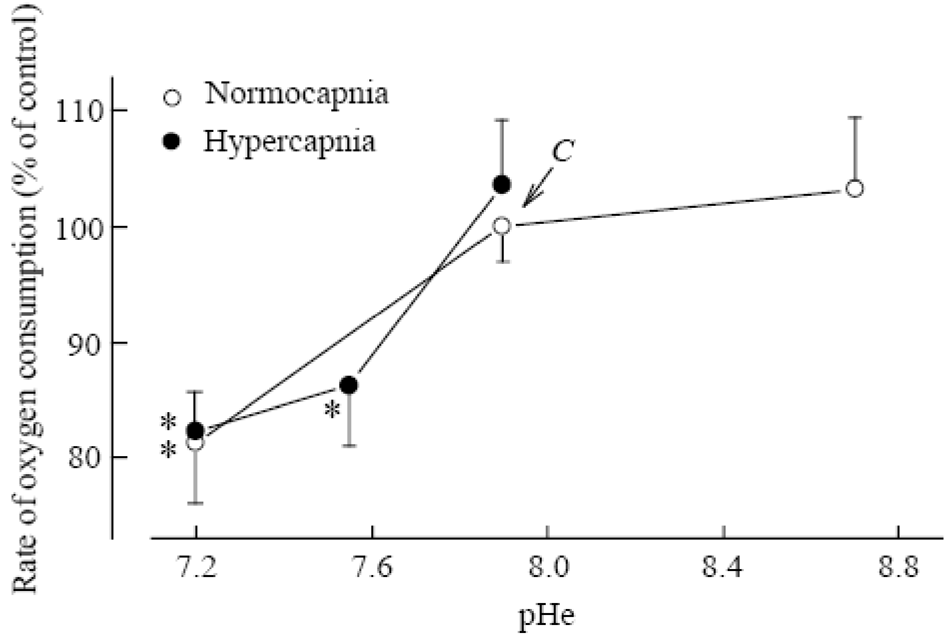
….likely causing reduced growth rates

Langenbuch et al. 2006

Disentangling effective acid-base parameters by experiments manipulating acid-base status under normo- and hypercapnia.

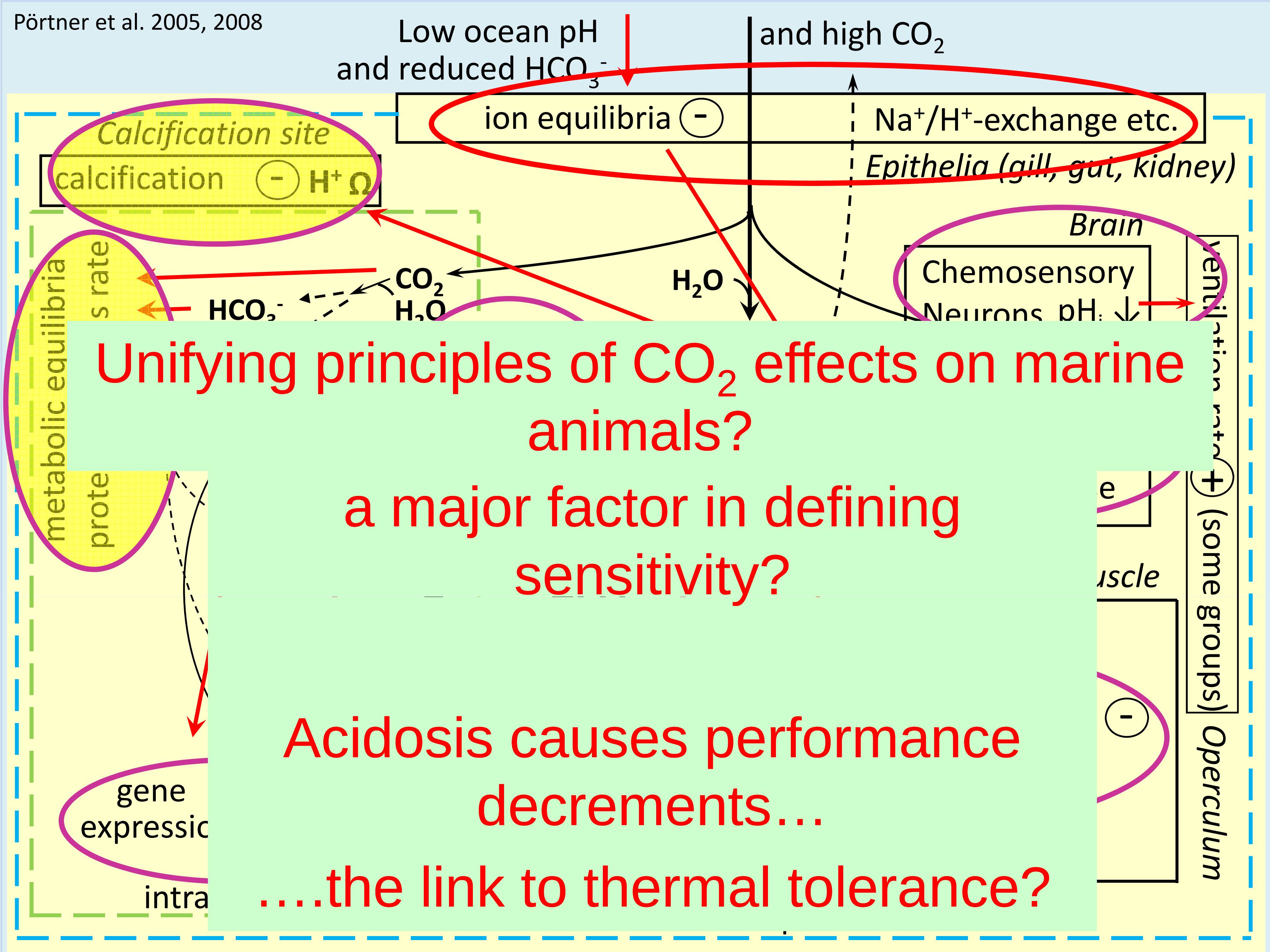


Effects on metabolic rate, *S. nudus* muscle



Extracellular pH only is consistently related to metabolic rate.

Reipschläger and Pörtner, 1996



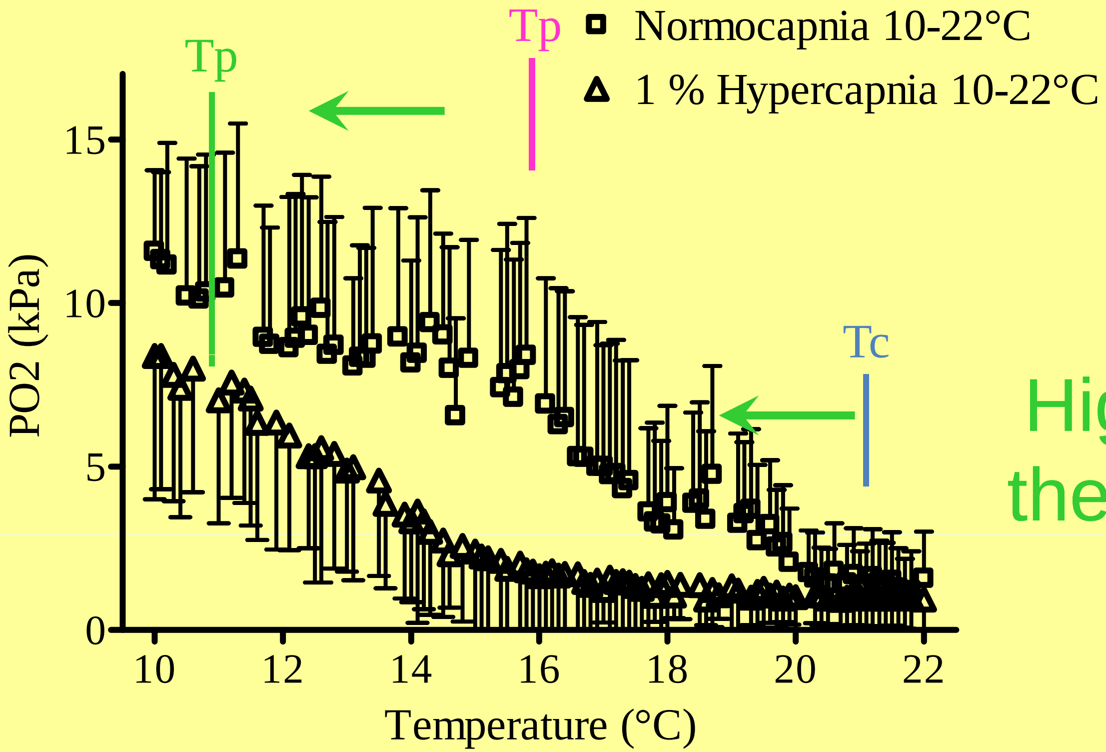
Unifying principles of CO_2 effects on marine animals?

a major factor in defining sensitivity?

Acidosis causes performance decrements…

….the link to thermal tolerance?

CO_2 induced loss in performance enhances thermal stress



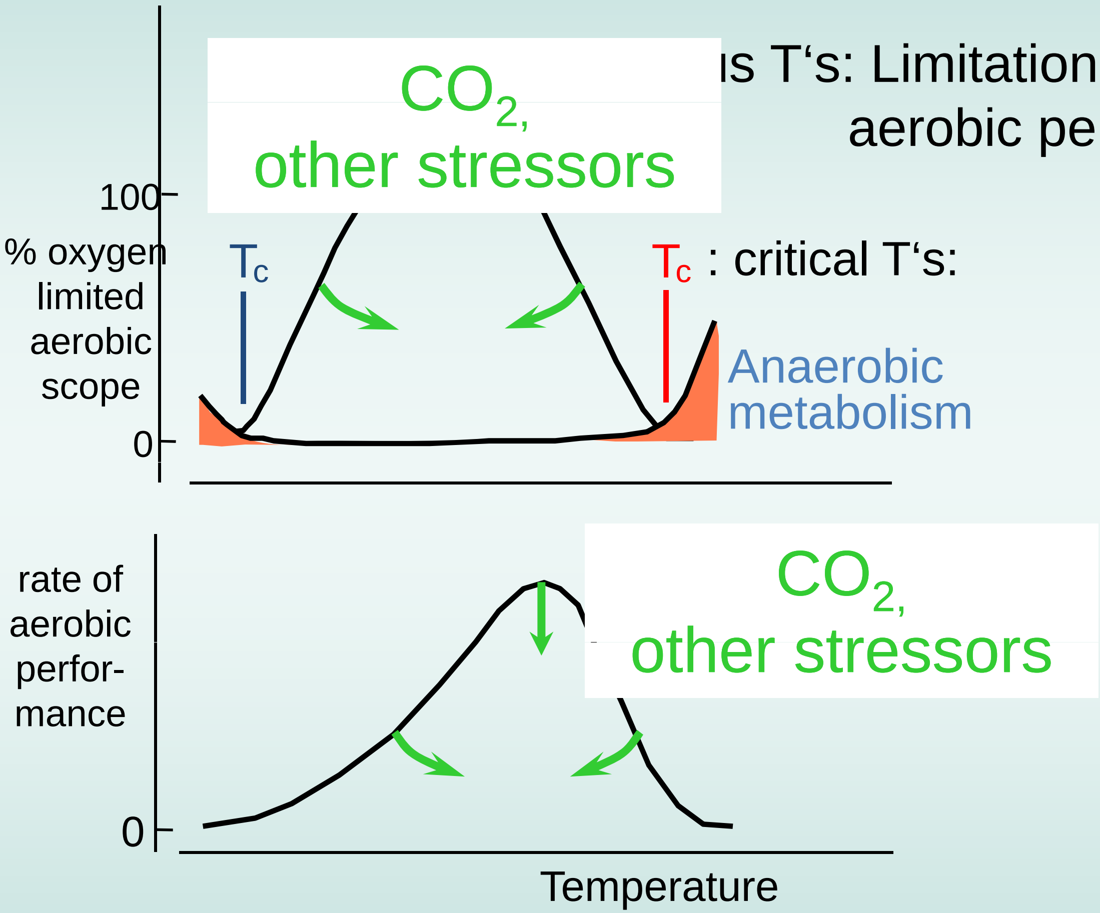
Δ~ 4-5°C:

High sensitivity of thermal thresholds to CO_2

Similar pattern during cooling (S. Baumgartner et al. unpubl.)

Metzger et al., 2007

Hypothesis: Through decrements in extracellular pH……
CO_2 causes a narrowing of thermal windows and influences species and their interactions



…is T's: Limitation of aerobic performance → Effects on behaviour, growth, reproduction, ….fitness

T_c : critical T's:

Shifts in:

- geographical distribution
- Species interactions
- ….food web structure

Pörtner et al, 2005, JGR Oceans, Metzger et al. 2007

Addressing CO_2 effects and sensitivities in warming oceans, hypotheses

First lines of CO_2 sensitivity (with ecological relevance) likely depend on

- CO_2 effects on temperature dependent performance in rel. to compensation capacity for extracellular acid-base status.
- This includes disturbance of calcification through extracellular acidification.

Implications to be considered:

- seasonal shifts in performance windows
- climate dependent functional specialization
- temperature dependent biogeography
- climate dependent growth, fecundity
- synergistic interactions with factors in addition to temperature (hypoxia, pollutants, …)

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

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