Integrating climate-related stressor effects on marine organisms:

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

Are there unifying principles (in animals)?

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

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


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

Growth

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

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

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

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

Seasonal acclimation in temperate lugworms

Temperature (°C)
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.

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.

\[ \text{ln} \left( \frac{\text{OGP}}{P} \right) = 4.22 - 958.466 \frac{1}{T} \]

\[ (198 \text{ studies, 25 species, } r^2 = 0.132) \]

\[ \ln(\text{SMR}_{avg}) = 30.116 - 8874.24 \frac{1}{T} \]

\[ (82 \text{ measurements, 13 species, } r^2 = 0.725) \]

\[ Q_{10}^{10} = 2.28 \]

\[ Q_{10}^{11} = 1.12 \]
Quantifying hypoxia tolerance
Patterns of critical \( \text{Po}_2 \) at standard metabolic rate (SMR):
Transition to anaerobic metabolism characterizes \( \text{Pc} \)
in toad *Bufo marinus*
in oxyregulating shrimp (*Palaemon elegans*)

\[
\text{M}_{\text{O}_2}(\text{mmol g}^{-1} \cdot \text{h}^{-1})
\]

\[
\text{Pc}
\]

\[
\text{SMR M}_{\text{O}_2}
\]

\[
\text{Lactate}
\]

\[
\text{P}_\text{O}_2(\text{Torr})
\]

Pörtner et al. 1991
Factors influencing critical oxygen thresholds: Temperature

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

...DATA BASE VERY FRAGMENTARY

Pörtner, J. exp. Biol. 2010

MMR: maximum metabolic rate
SMR: standard metabolic rate
How to integrate CO₂ sensitivity (ocean acidification)?

Sensitivity distribution across animal phyla: a metaanalysis

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

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 CO₂

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)

A suggestion:
...bring (apparently isolated) effects of various drivers together using temperature relations as a matrix

...the same fitness proxies can be used