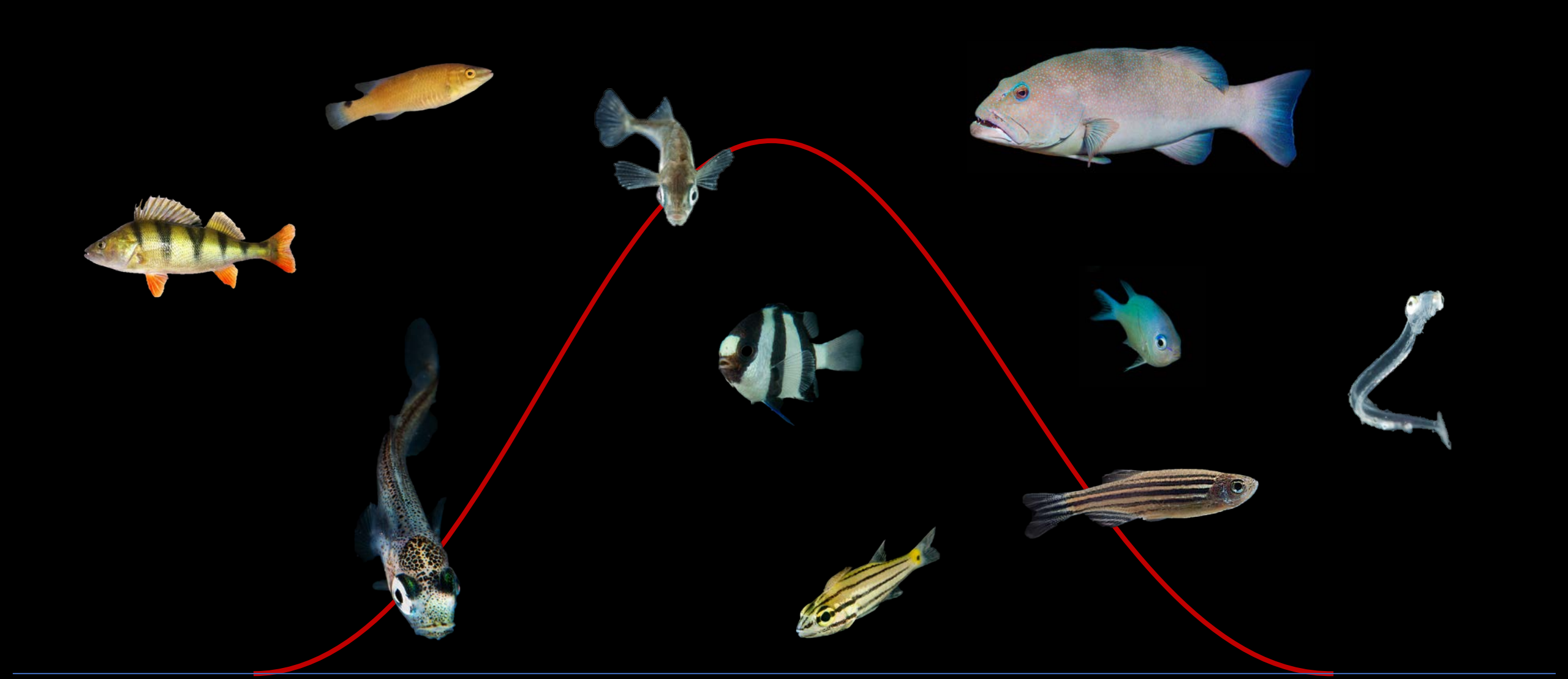
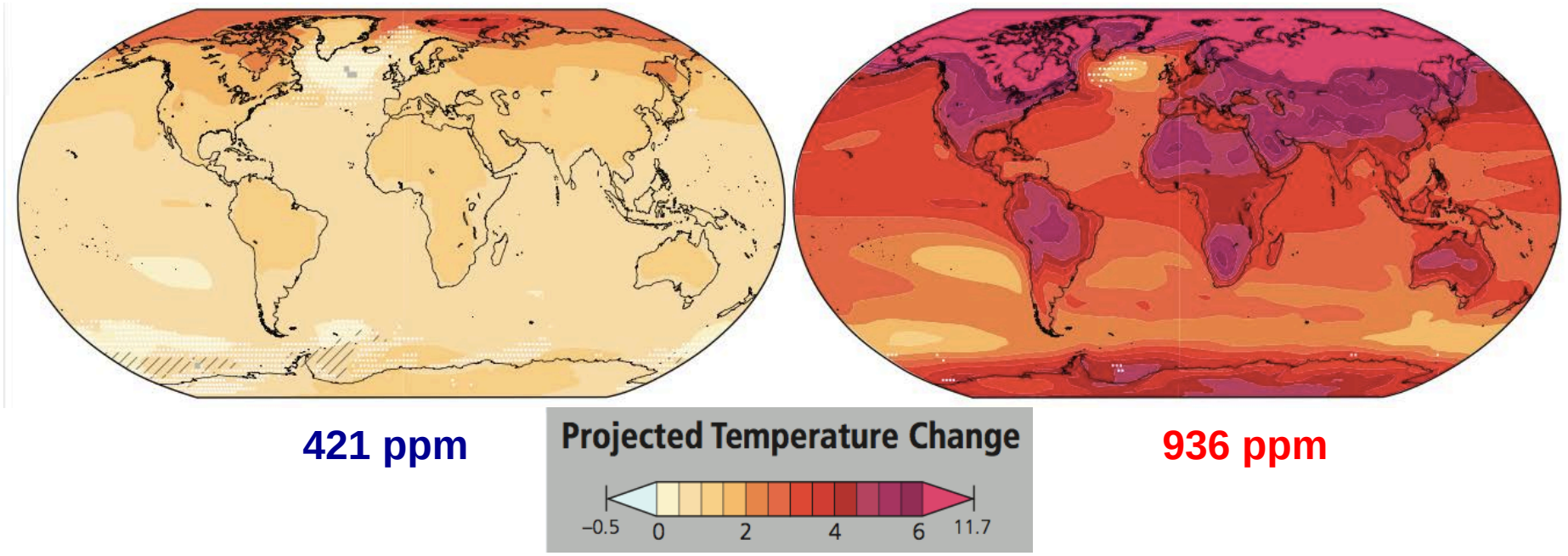


How will ocean warming and acidification impact fish?

Fredrik Jutfelt
Associate professor
Norwegian University of Science and Technology, Trondheim
@FredrikJutfelt

Climate change projections



Strategies for survival



- **Migrate**
- **Stay (↓fitness)**
- **Acclimate**
- **Adapt (Evolve)**
- **Die**

(IPCC 2014, WGII Ocean systems TA)

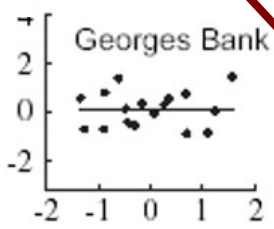
Population effects of warming

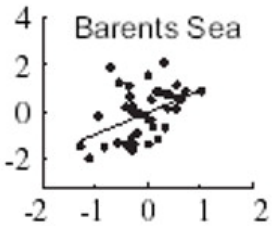
Recruitment plotted against temperature anomaly

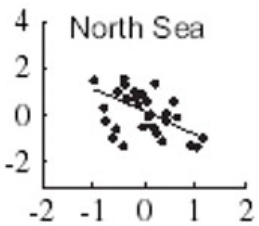
Increasing fitness

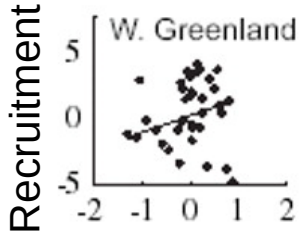
Decreasing fitness

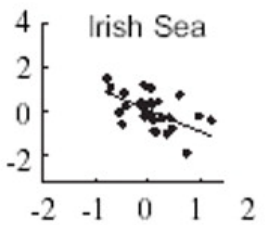












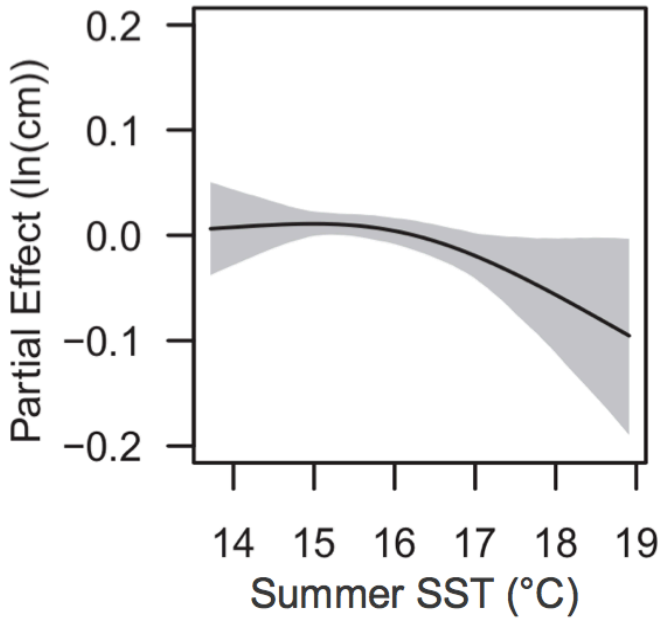


Atlantic cod
(*Gadus morhua*)

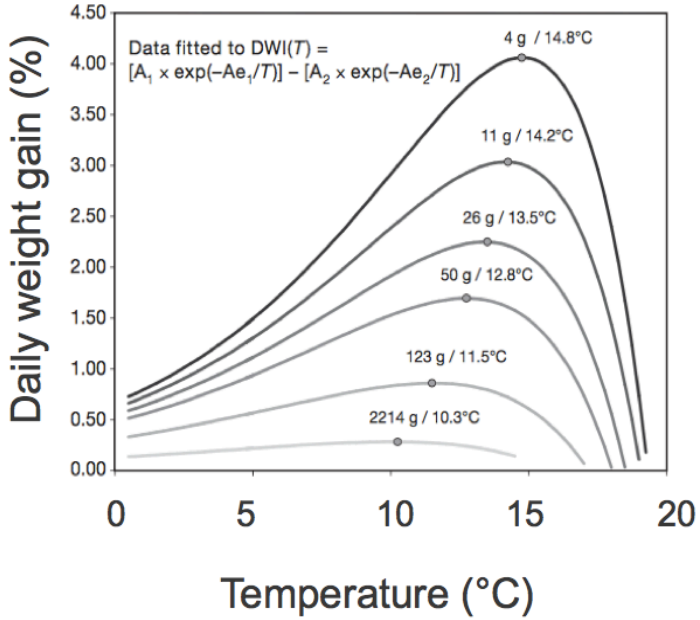
Drinkwater ICES JMS (2005) 62.

Performance decline
Growth

In the wild



In the laboratory



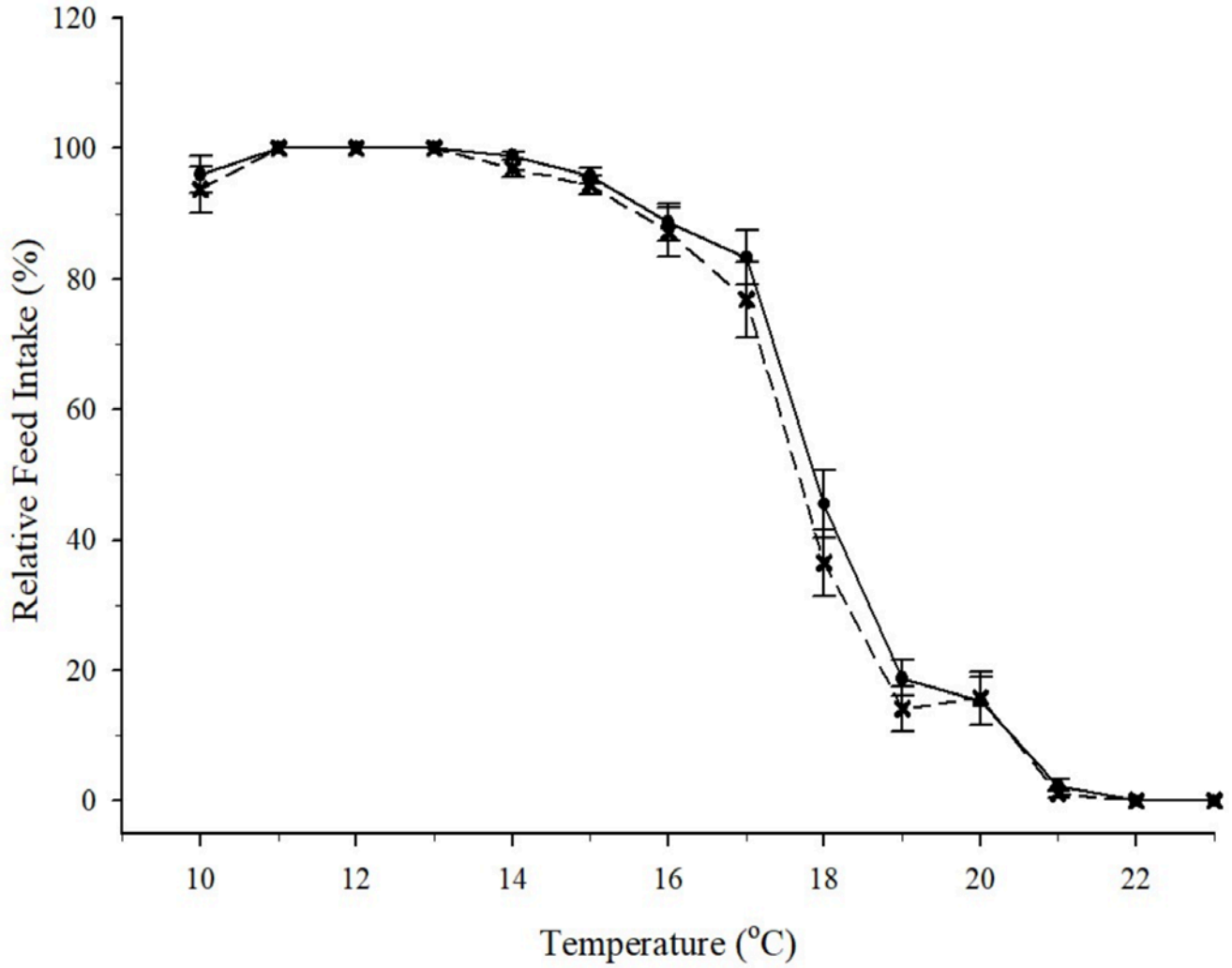


Atlantic cod
(*Gadus morhua*)

Rogers et al. PNAS. (2011) 108.

Björnsson et al. Aquaculture. (2007) 271.

Atlantic cod food intake at different temperatures

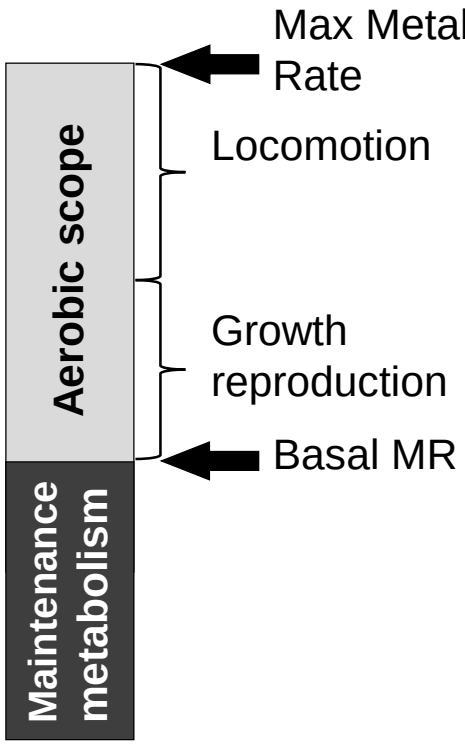


Aerobic Scope Model

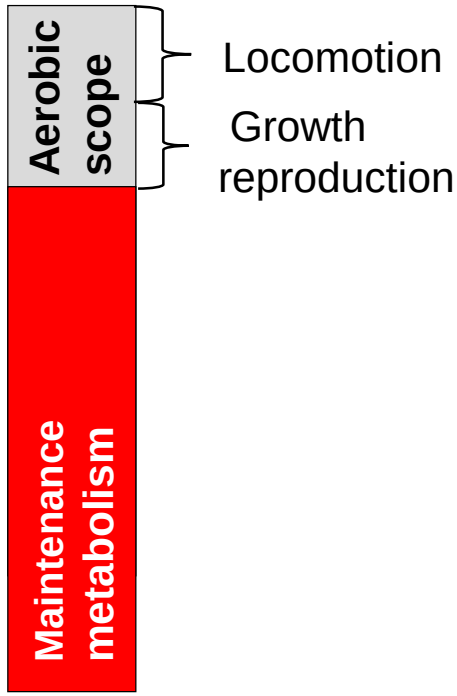
“Energy tank”



Optimal temperature

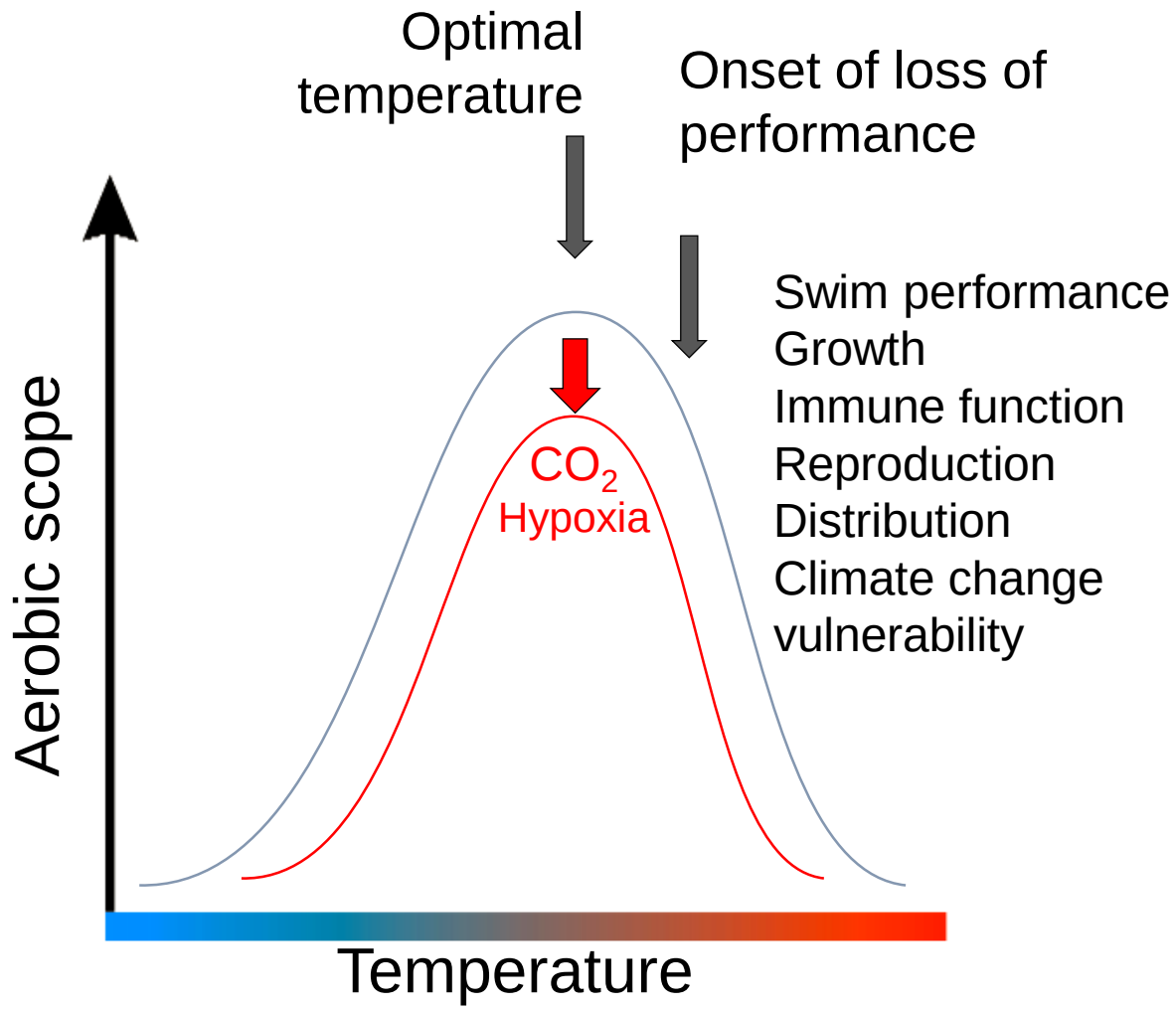


Acute warm



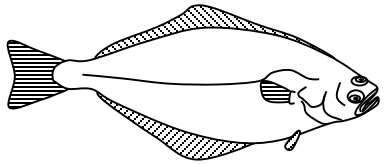
Thermal physiology and the OCLTT hypothesis

(Oxygen and Capacity Limited Thermal Tolerance)

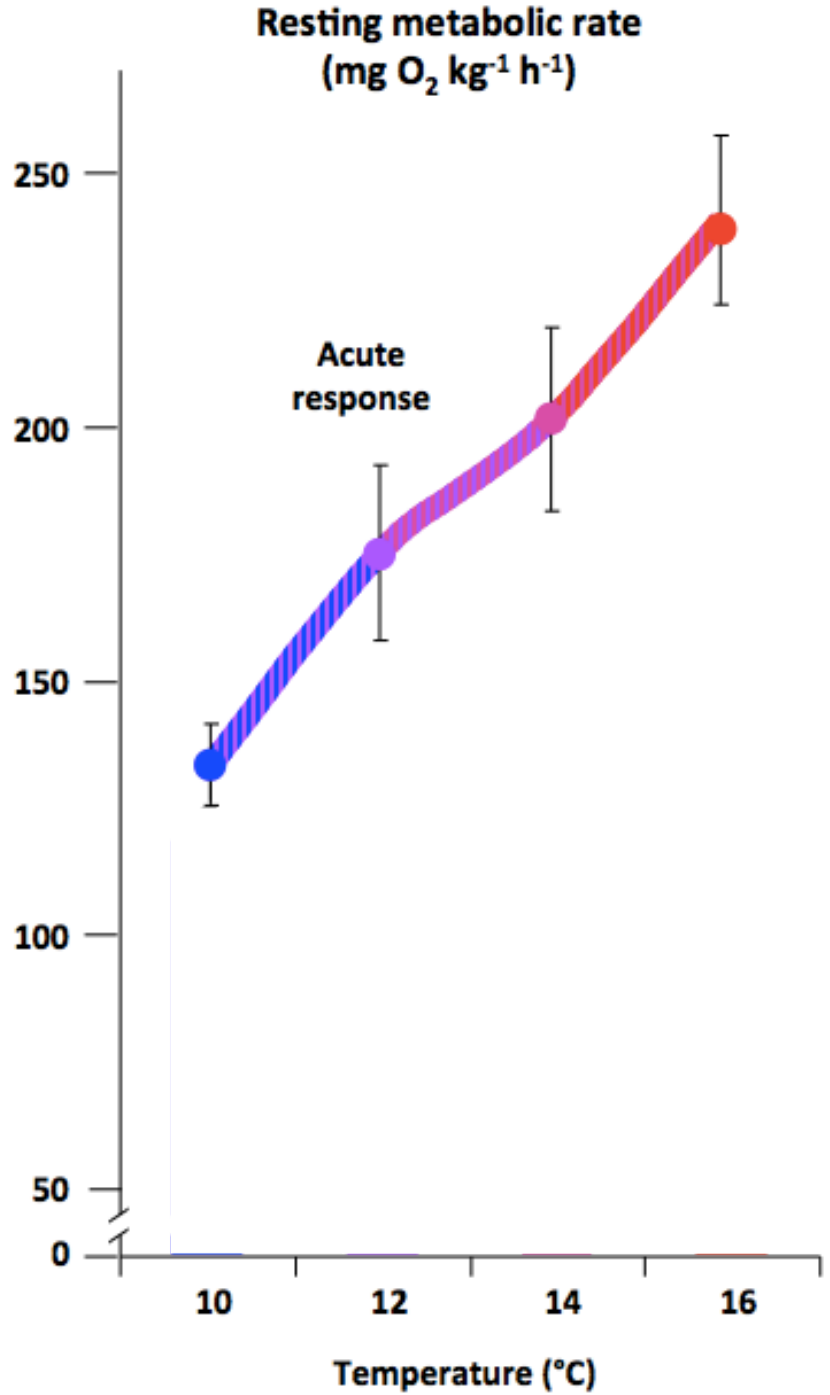


(Modified from Fry 1947 and Pörtner and Farrell 2008 Science, IPCC 2014 WGII Ch 6)

Acclimation



Atlantic halibut
Hippoglossus hippoglossus



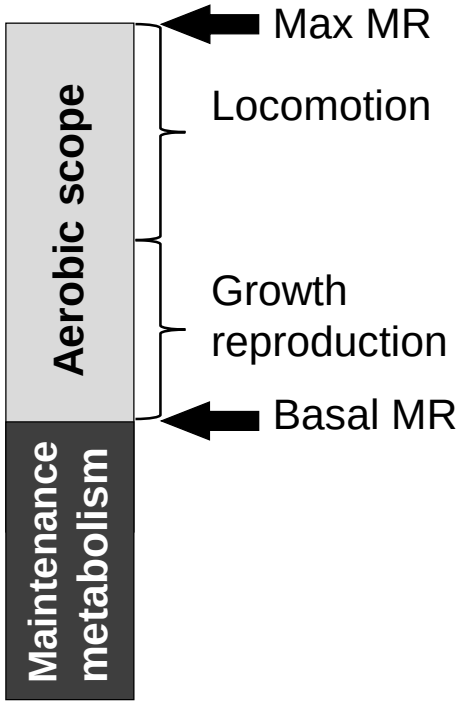
Gräns, Jutfelt et al. 2014 J Exp Biol

Aerobic scope

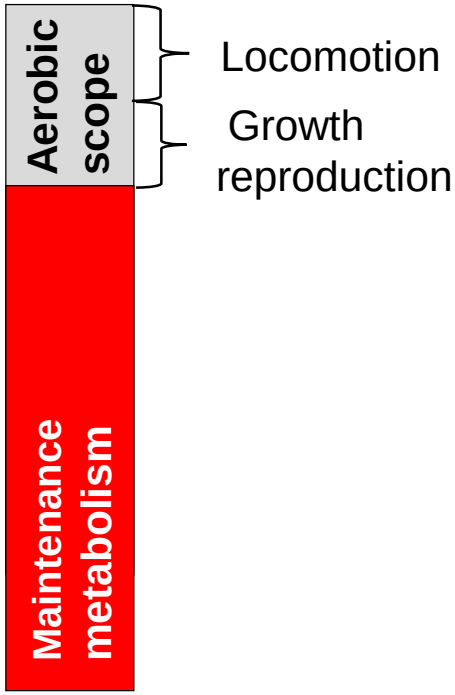
Acclimation



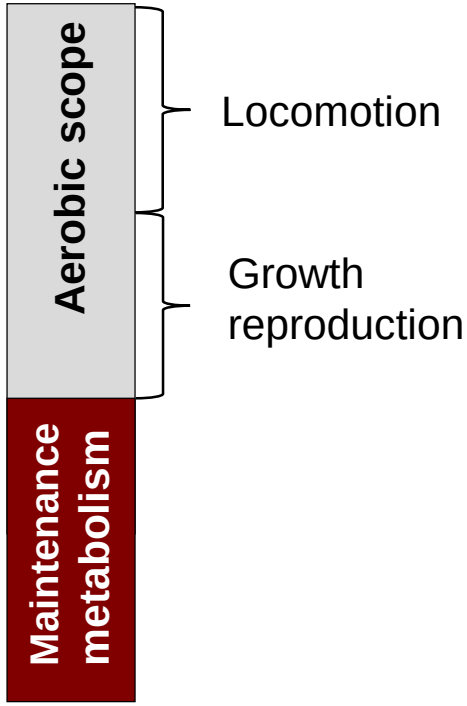
Optimal temperature



Acute warm



Acclimated warm



Adaptation?

Are fish sensitive to ocean acidification?



In theory: NO

<u>Three reasons</u>

1. Active muscles produce lots of CO_2

Are fish sensitive to ocean acidification?

In theory: NO

<u>Three reasons</u>

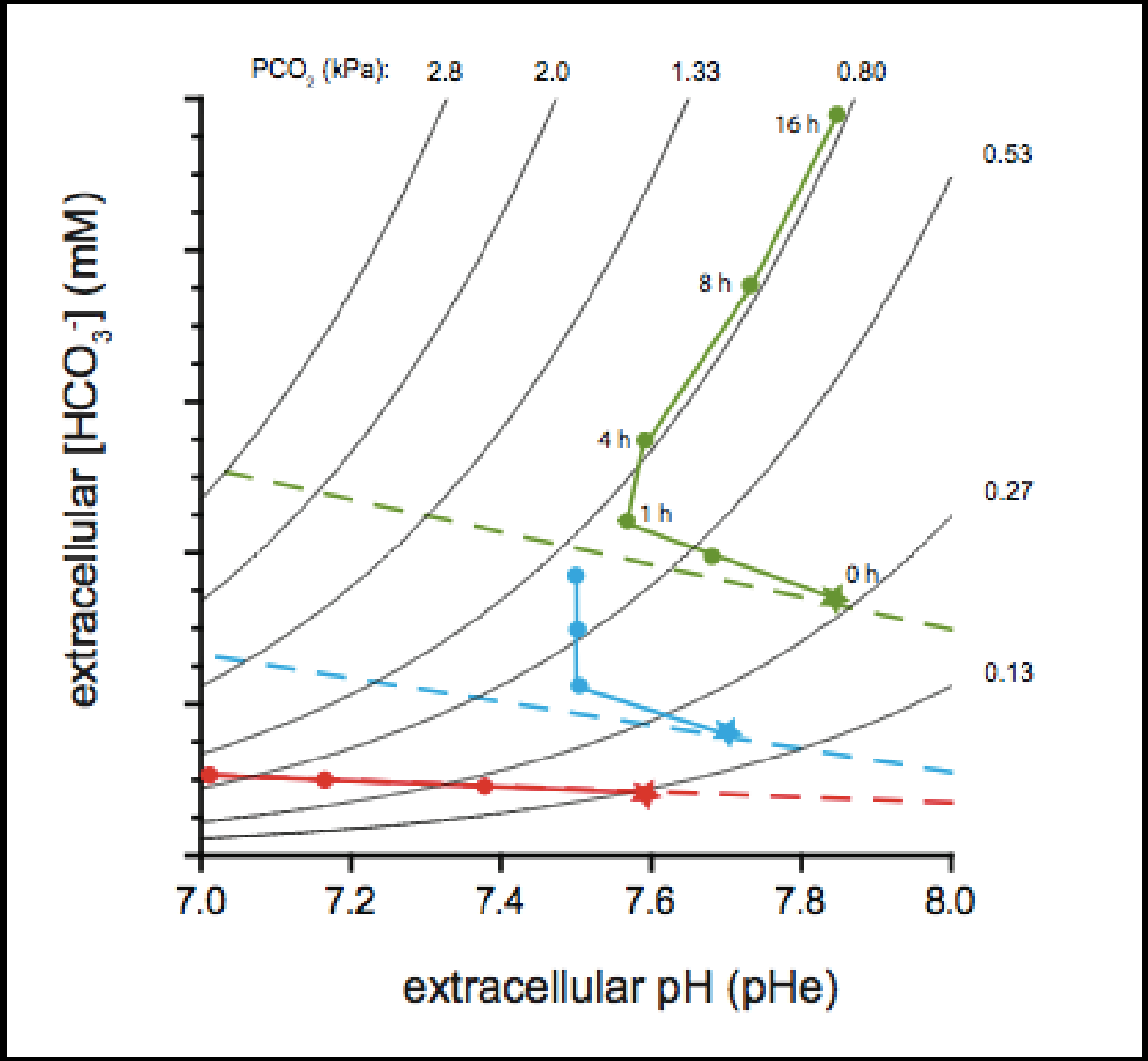
1. Active muscles produce lots of CO_2
2. Low increase of internal pCO_2

Are fish sensitive to ocean acidification?

In theory: NO

<u>Three reasons</u>

1. Active muscles produce lots of CO_2
2. Low increase of internal pCO_2
1. Internal buffering of HCO_3^- and other buffers



Behavioural effects of CO_2 in fish?

- Olfaction
- Hearing
- Learning
- Activity
- Predator escape
- Lateralization



Behavioural change in Nordic species?



Goby larvae — Yes?

Goby adults — No



Stickleback larvae — No

Stickleback adults — Yes?, No



Atlantic cod larvae — No

Atlantic cod juveniles — No



Wrasse juvenile — No

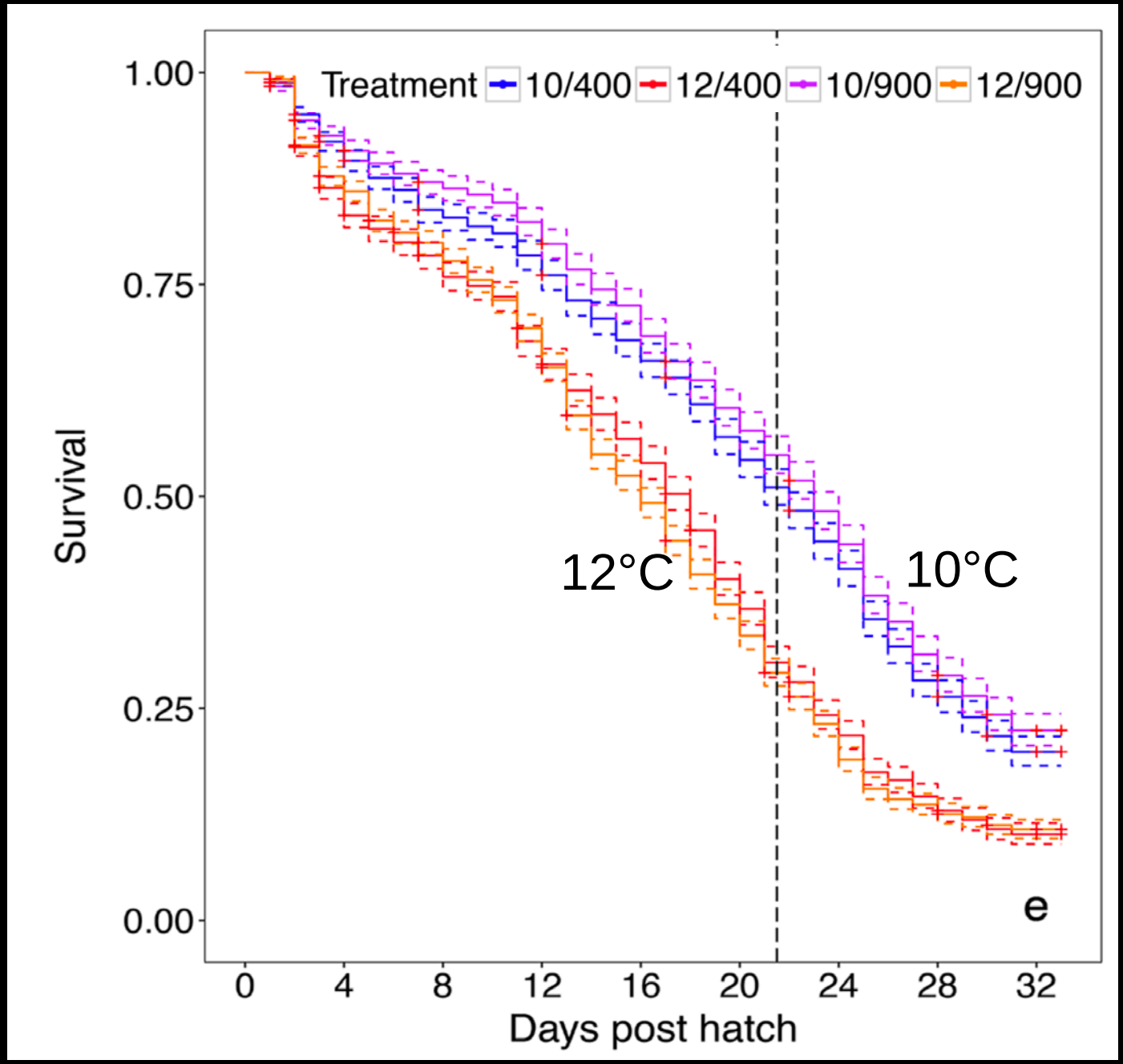


Small-spotted catshark — Yes?, No

Neurophysiological problem?

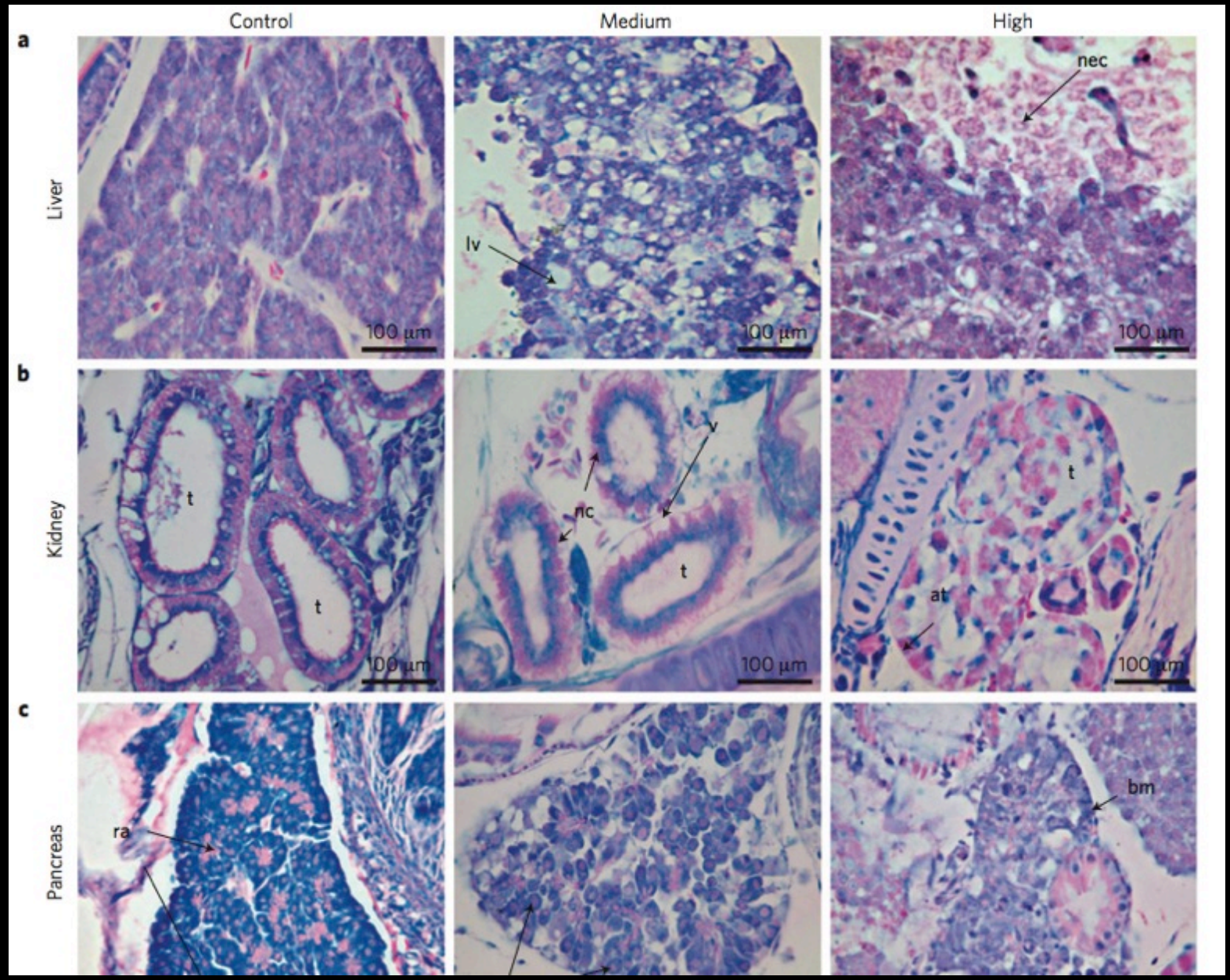
Forsgren et al. 2013; Sundin and Jutfelt 2015; Jutfelt et al. 2013; Näslund et al. Jutfelt 2014; Sundin and Jutfelt In prep; Maneja et al. 2013; Jutfelt et al. 2013; Jutfelt et al. 2015; Sundin and Jutfelt 2015; Green and Jutfelt 2014

Herring larvae survival Temperature and CO_2



Tissue damage in Atlantic cod larvae

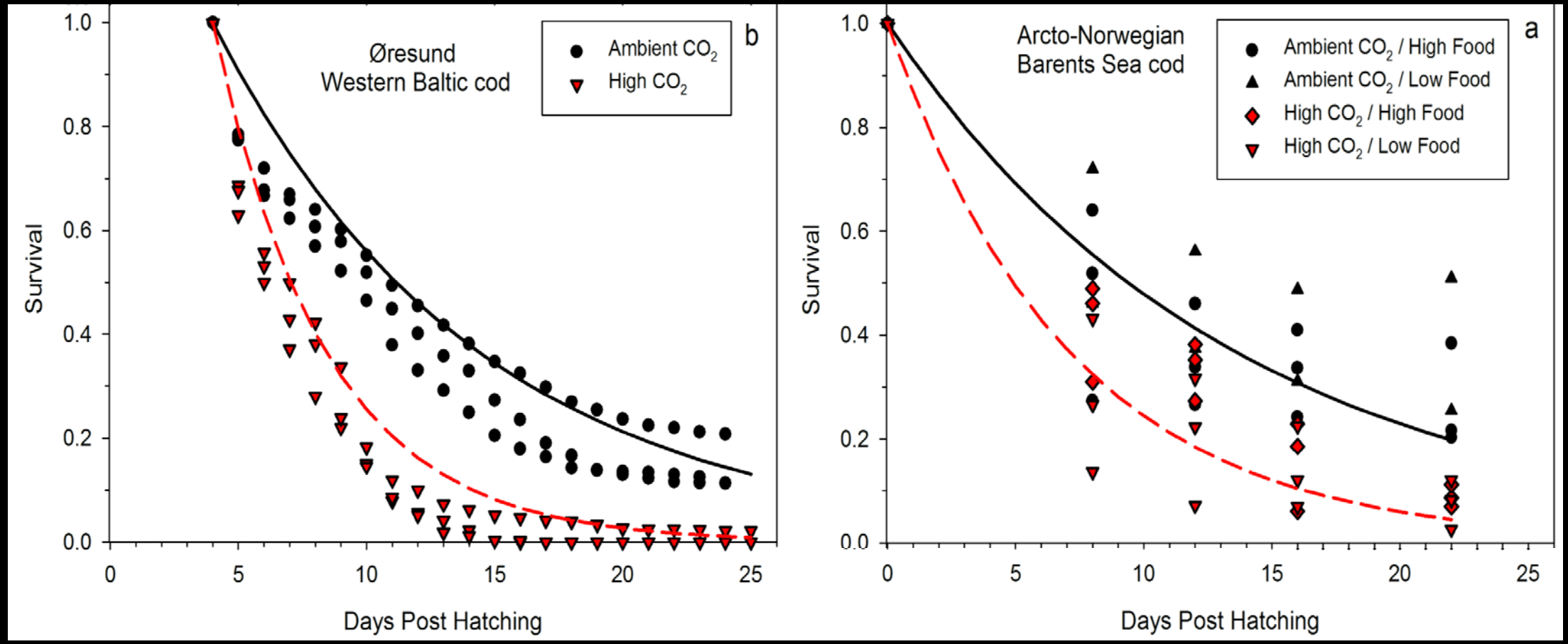
Control CO_2 | High CO_2 | Very high CO_2



Frommel et al 2012 Nature Climate Change



Cod larvae recruitment collapse?



Stiasny et al. 2016 Ocean Acidification Effects on Atlantic Cod Larval Survival and Recruitment to the Fished Population

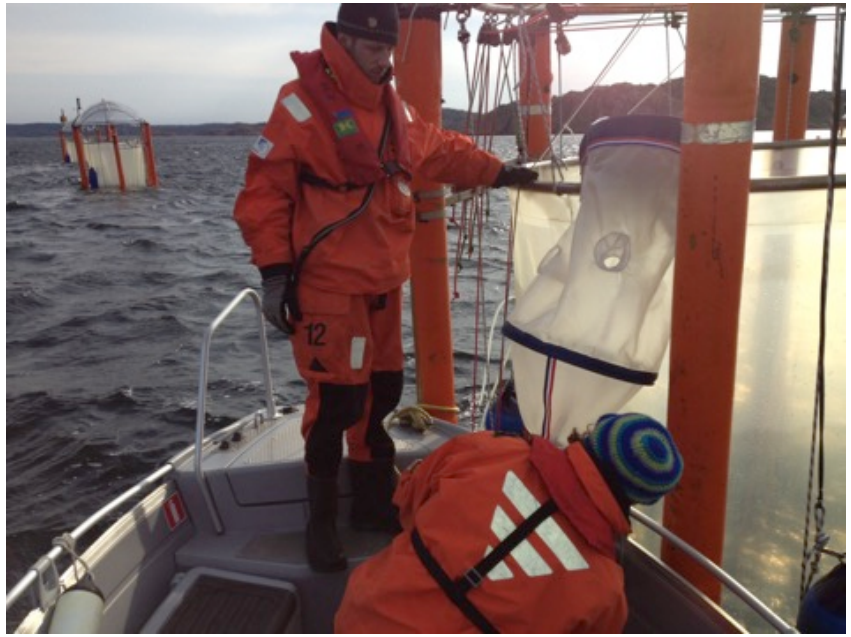
Mesocosms





Ecosystem effects

Geomar KOSMOS Kristineberg mesocosms 2013
Michael Sswat and Catriona Clemmesen





- Ten large mesocosms (19 m, 50m^3), five months, 70 people
- Enclosed natural ecosystems
- Five with control water and five with 760 ppm
- Added 1000 herring eggs to each
- Simultaneous lab experiments

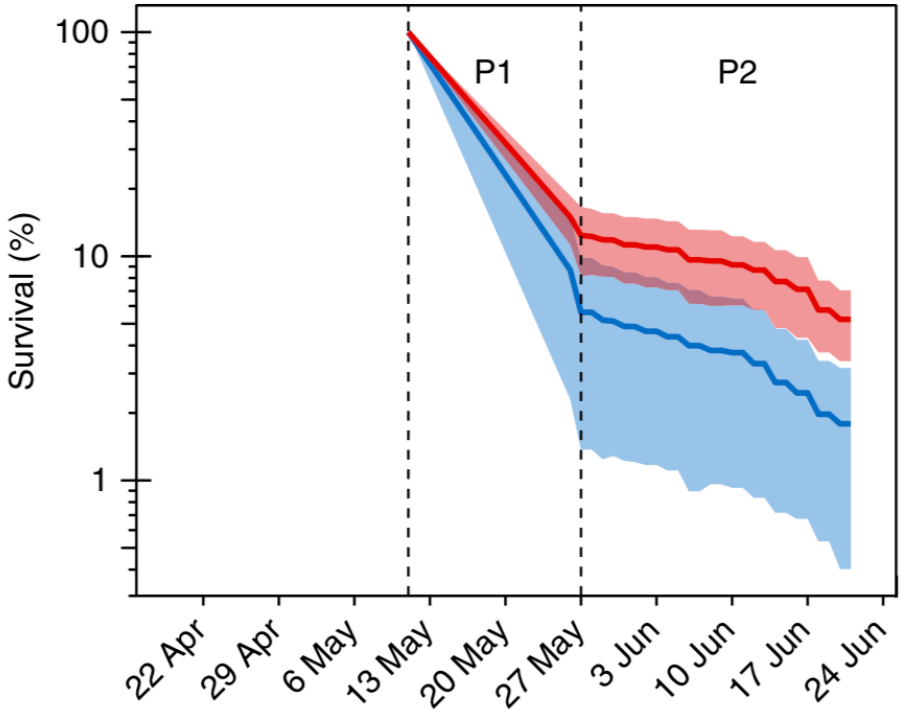


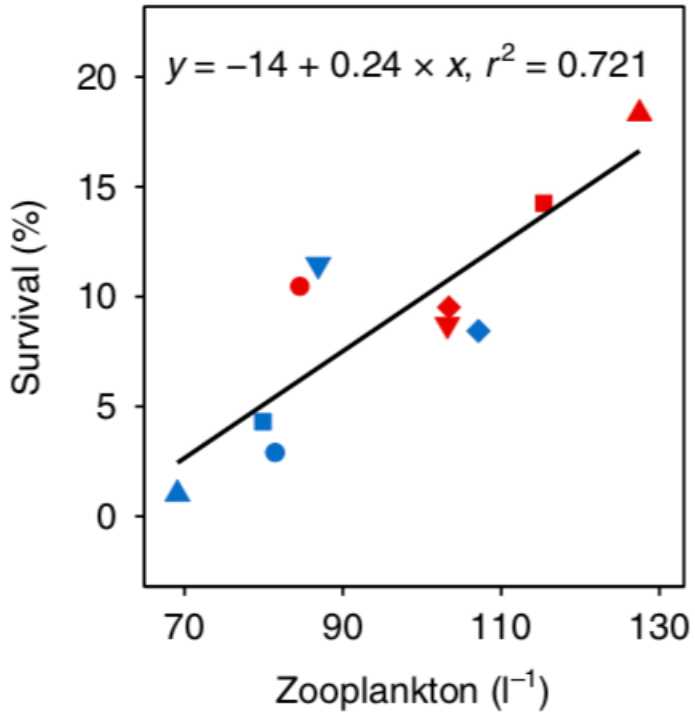


Ecosystem effects

Geomar KOSMOS Kristineberg mesocosms 2013







nature ecology & evolution

Food web changes under ocean acidification promote herring larvae survival

Michael Sswat[1], Martina H. Stiasny[1,2], Jan Taucher[1], Maria Algueró-Muñiz[3], Lennart T. Bach[1], Fredrik Jutfelt[4,5], Ulf Riebesell[1] and Catriona Clemmesen[1*]

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Göran Nilsson
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