# Why Lab-derived estimates of Thermal Tolerance Failed to Predict Survival of Winter Run Eggs in the Sacramento River

## (And What We Can Do About It)

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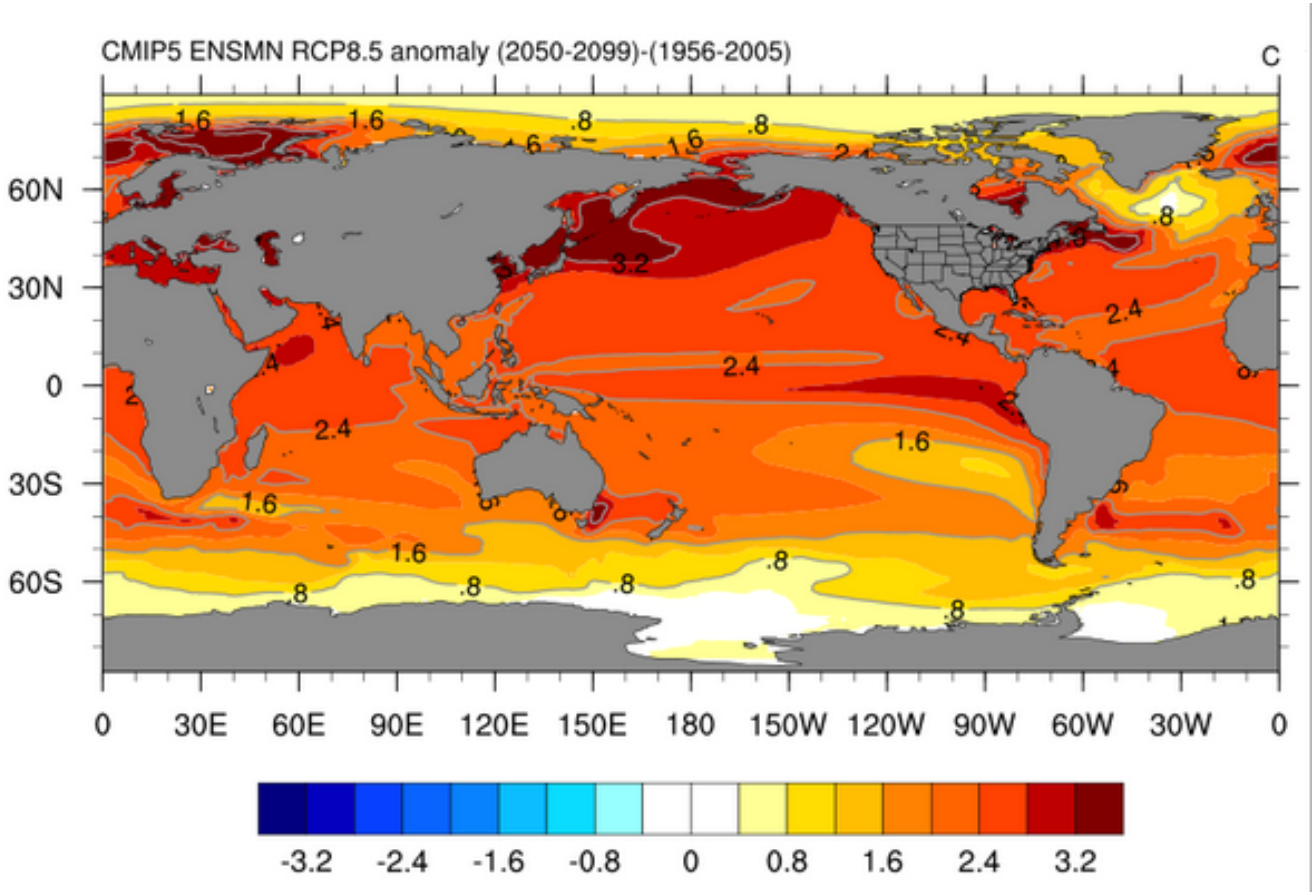
NOAA FISHERIES

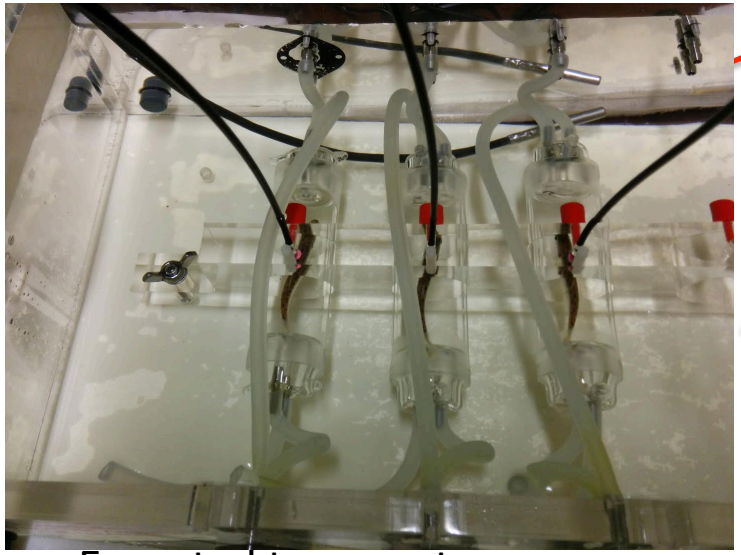
# It's getting warmer…



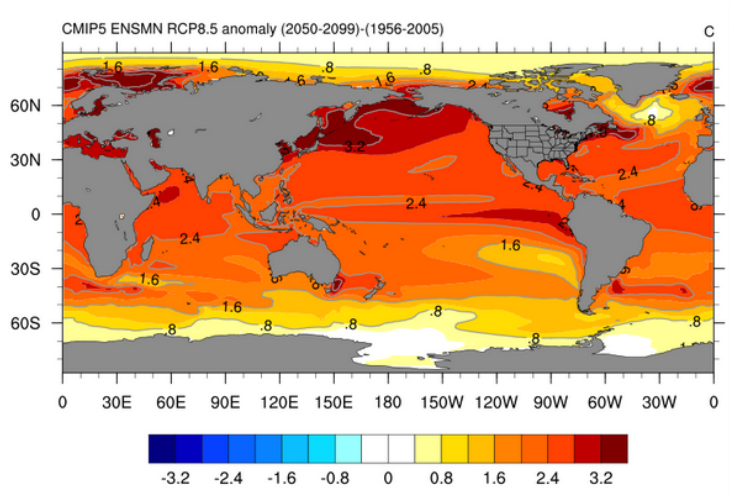

How will species respond?

# Thermal response curves

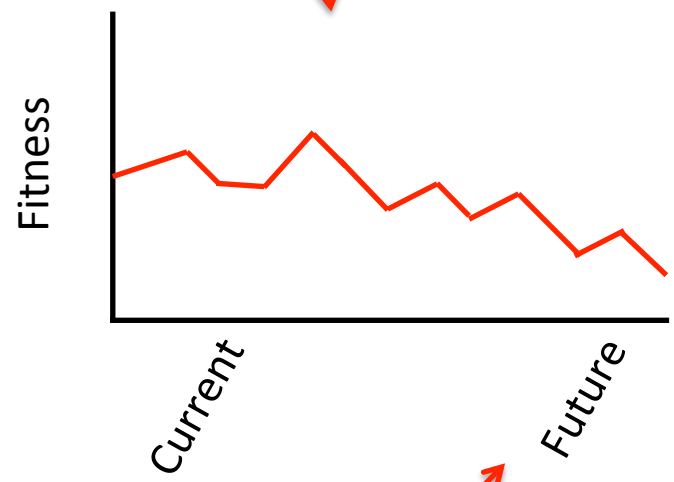
Lab experiment



Expected temperature exposure




Assumes relationship between temperature and performance in lab holds in nature




By the time we find out if that is true it's too late

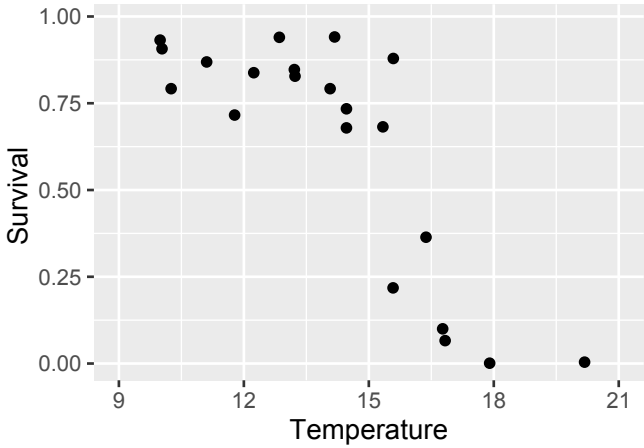
Are statistical/descriptive lab derived models of thermal tolerance predictive in nature?

# A case study with Sacramento Winter-run

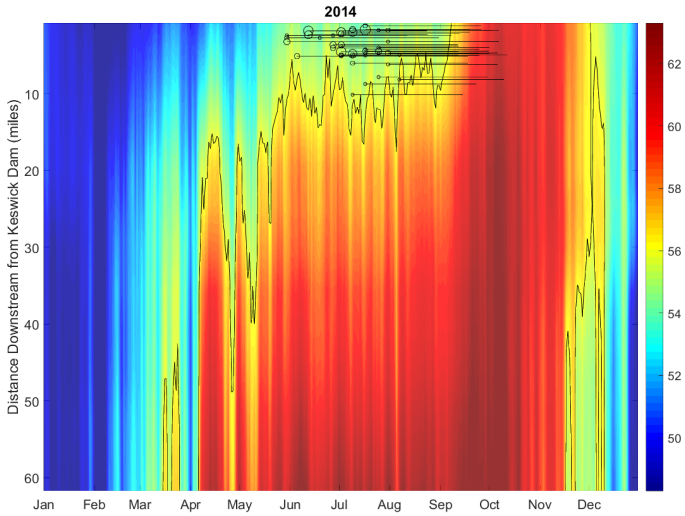
- ESA listed population
- Blocked from historic spawning grounds
- Embryos, most sensitive life stage to temperature
- Water release managed to avoid high embryo mortality
  - Temperature targets based on laboratory data

# A case study with Sacramento Winter-run

Lab data



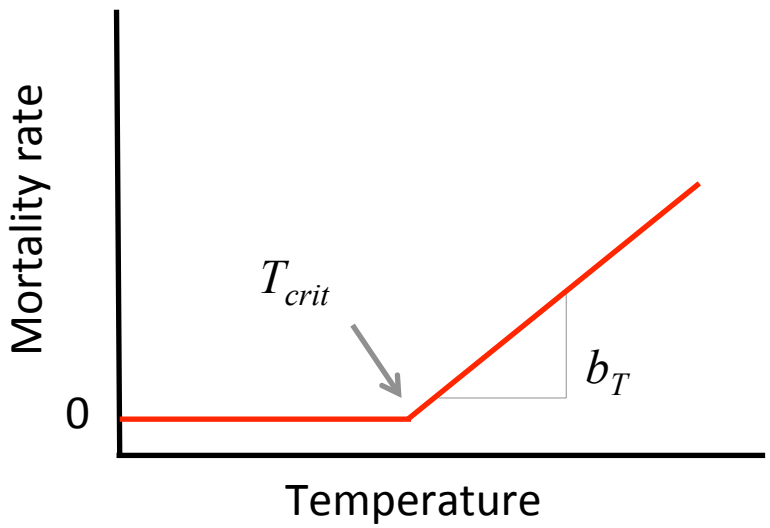

Exposure data

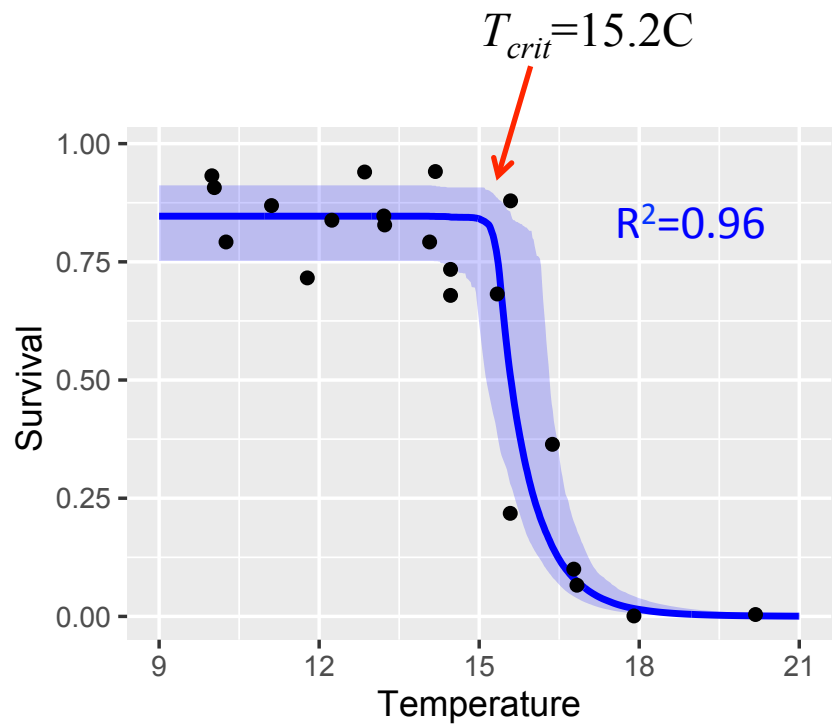



Red-bluff diversion dam survival data

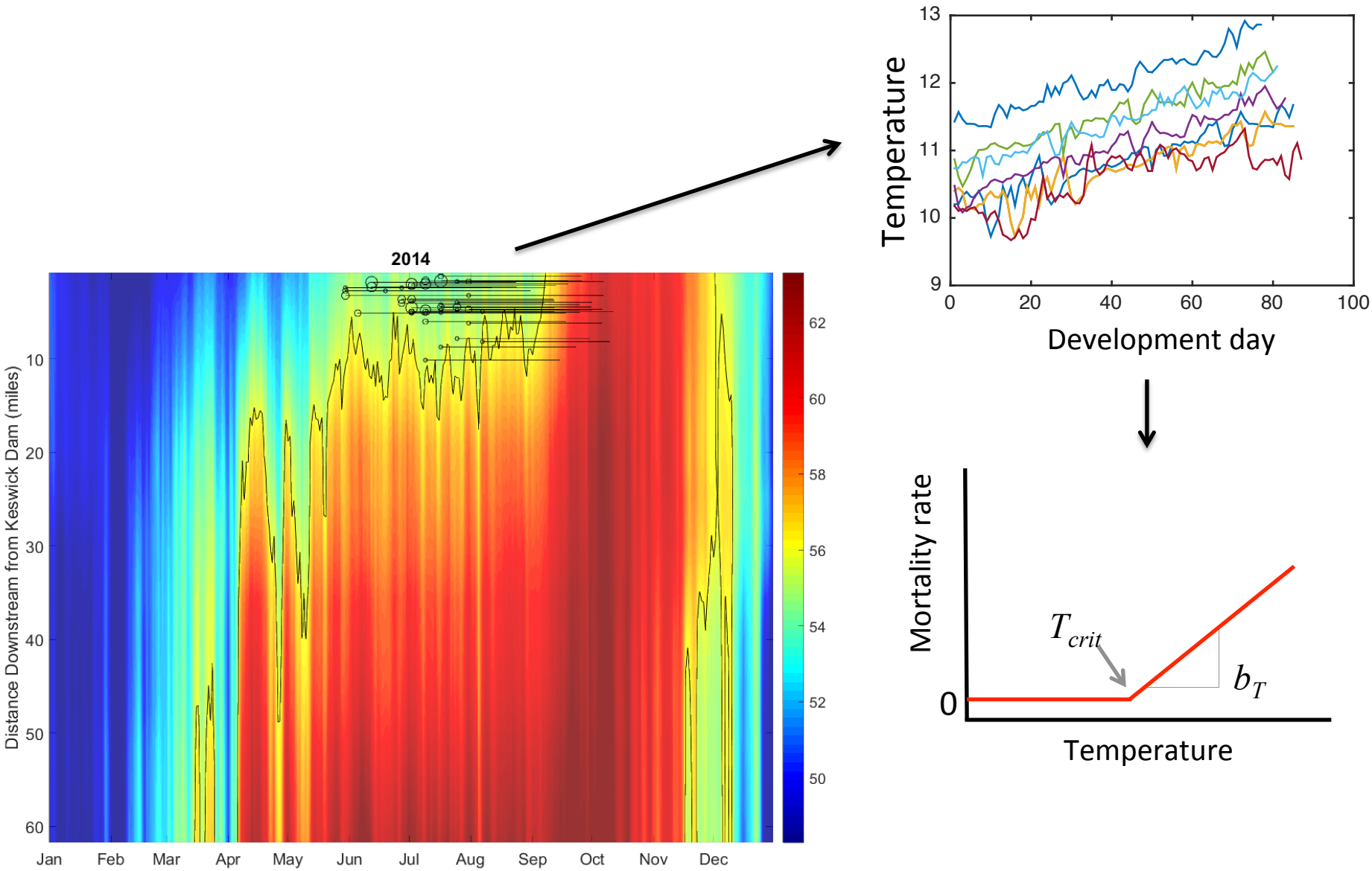
USFWS

# Thermal tolerance model




Data from: Combs and Burrows 1957, Jenson and Groot 1991, USFWS 1999

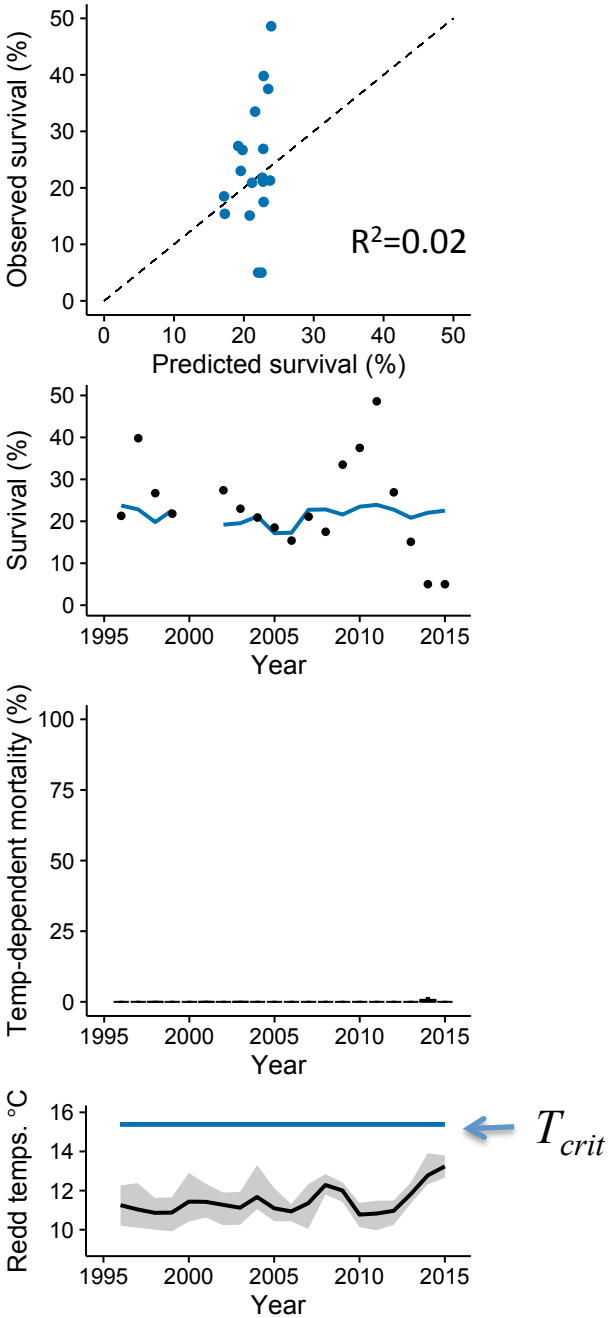

2014
Distance Downstream from Keswick Dam (miles)
10
20
30
40
50
60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
62
60
58
56
54
52
50
Temperature
13
12
11
10
9
0
20
40
60
80
100
Development day
Mortality rate
$T_{crit}$
$b_T$
0
Temperature

# Testing the lab model

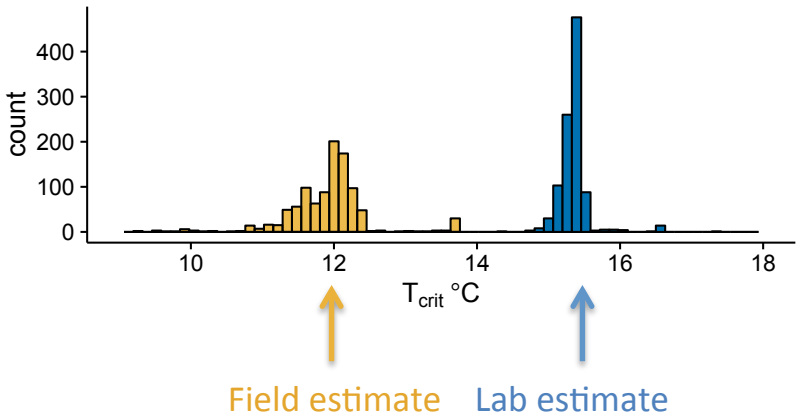
## Why so bad?

- H1: Factors other then temperature drive annual variation in survival
- H2: Thermal tolerance in the field differs from the lab

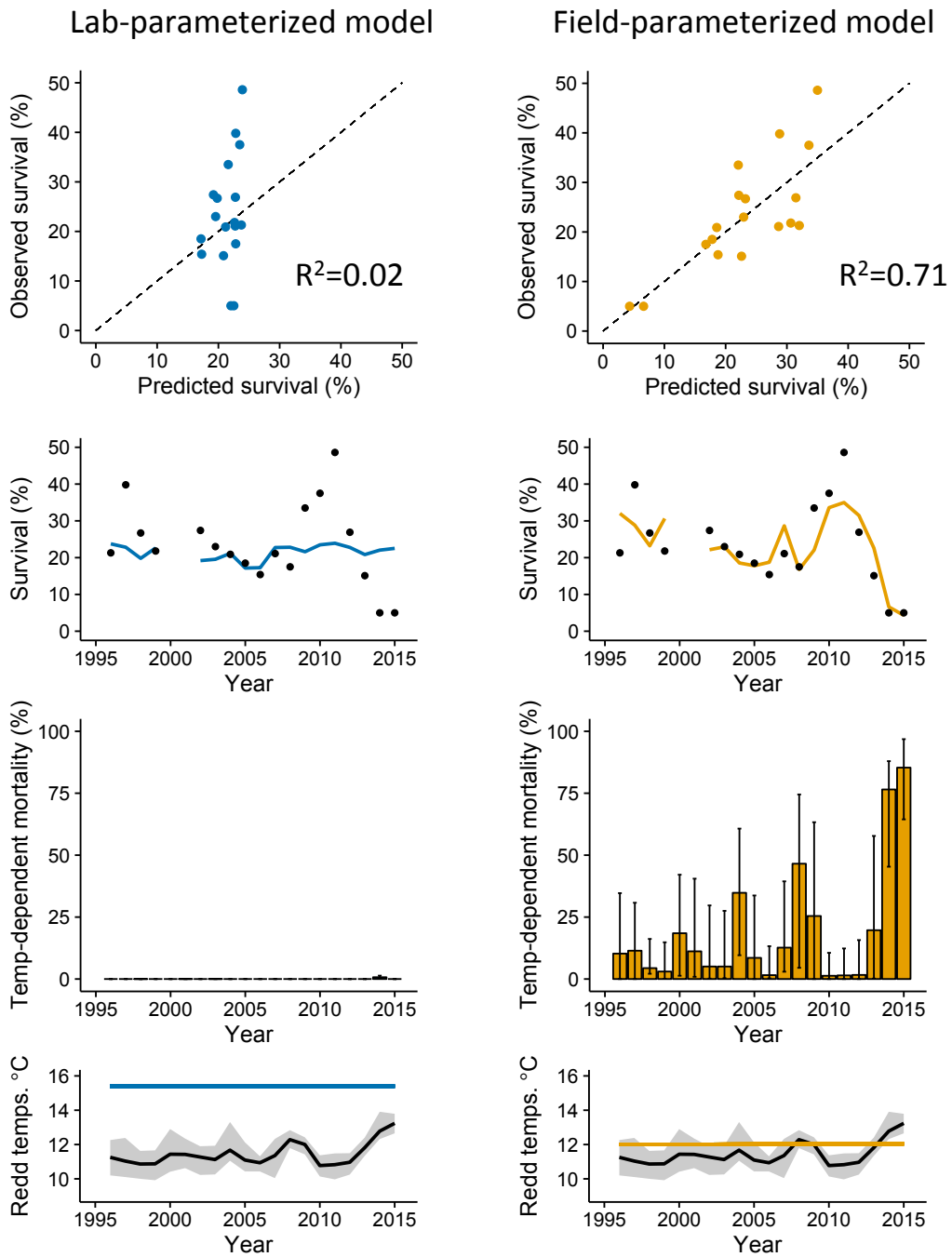
Test: rerun analysis, but estimate thermal tolerance parameters using field data



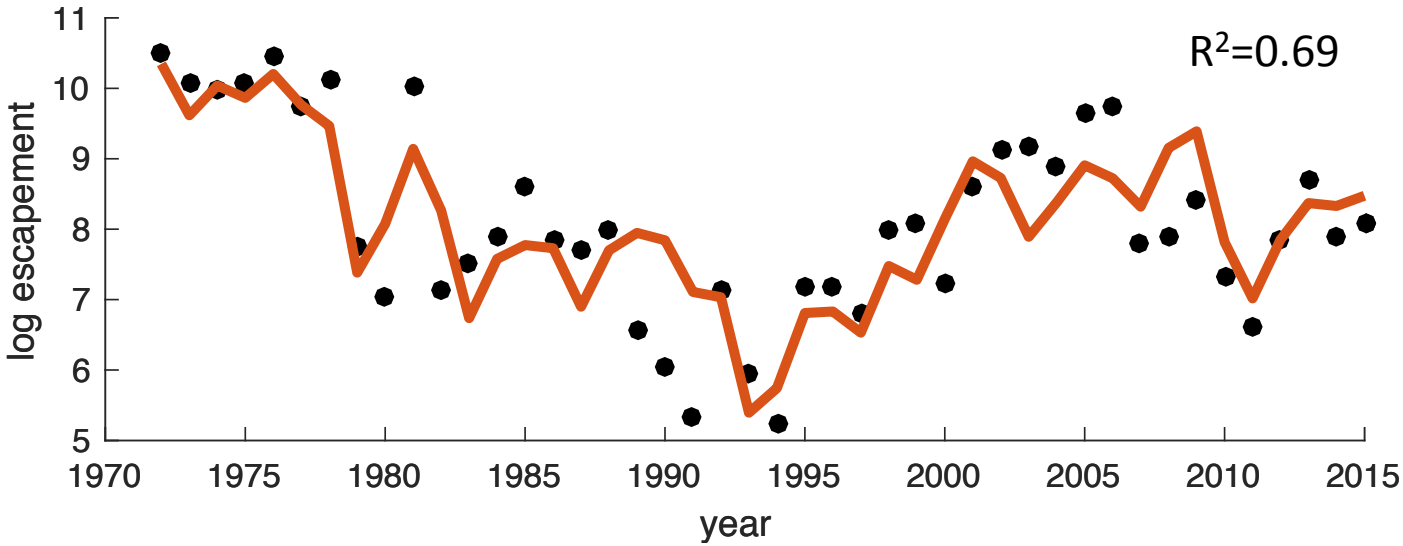
# Lab vs. field




Thermal tolerance in the field
3C lower than in the lab!



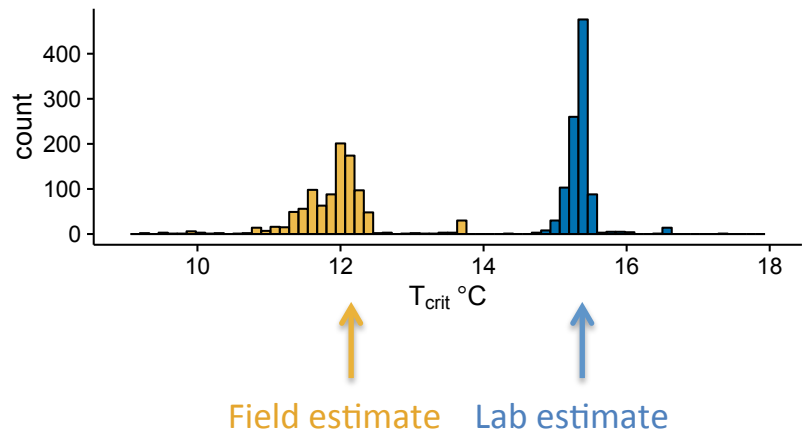
# Can other data be used to test the extent of temperature-dependent mortality in embryos?




Temperature and density dependent embryonic survival alone explain ~70% of variation in winter run population dynamics from 1970-2015

The $T_{crit}$ estimated from escapement data (11.5°C) not statistically different from estimate from egg-to-fry survival data (12.0°C)

# Fortunately, field data available for winter-run to reality check lab-derived model




But for many species, such data does not exist

What mechanism can account for differences in thermal tolerance?

# Oxygen limitation?

**Climate Change Affects Marine Fishes Through the Oxygen Limitation of Thermal Tolerance**

Hans O. Pörtner* and Rainer Knust

Science 2007

**Differences in Thermal Tolerance Among Sockeye Salmon Populations**

Erika J. Eliason,[1]* Timothy D. Clark,[1,2,3] Merran J. Hague,[4] Linda M. Hanson,[2] Zoë S. Gallagher,[1] Ken M. Jeffries,[3] Marika K. Gale,[3] David A. Patterson,[4] Scott G. Hinch,[3] Anthony P. Farrell[1,2]

Science 2011

**Climate change tightens a metabolic constraint on marine habitats**

Curtis Deutsch,[1]* Aaron Ferrel,[2]† Brad Seibel,[3] Hans-Otto Pörtner,[4] Raymond B. Huey[5]

Science 2015

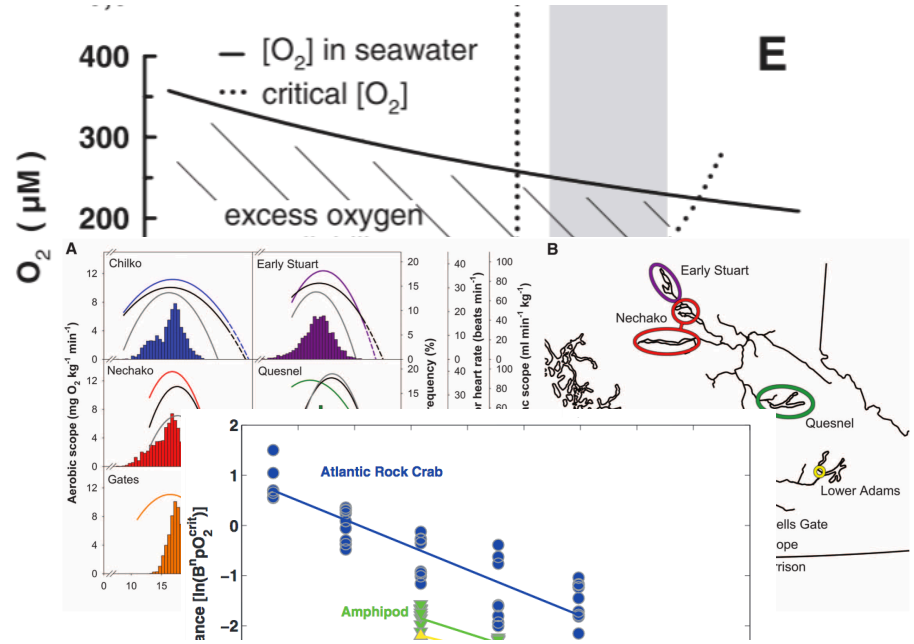
**Warming-induced reductions in body size are greater in aquatic than terrestrial species**

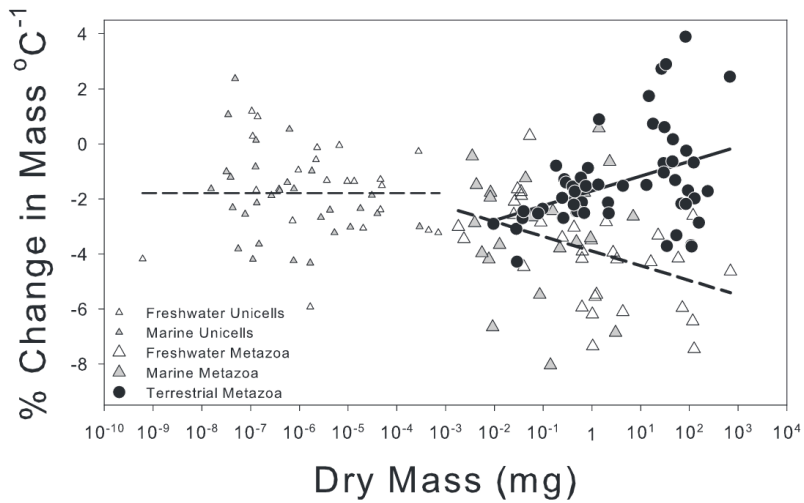
Jack Forster[a], Andrew G. Hirst[a,1], and David Atkinson[b]

[a]School of Biological and Chemical Sciences, Queen Mary University of London, London E1 4NS, United Kingdom; and [b]Institute of Integrative Biology, University of Liverpool, Liverpool L69 7ZB, United Kingdom

Edited by James H. Brown, University of New Mexico, Albuquerque, NM, and approved October 2, 2012 (received for review June 22, 2012)

PNAS 2012

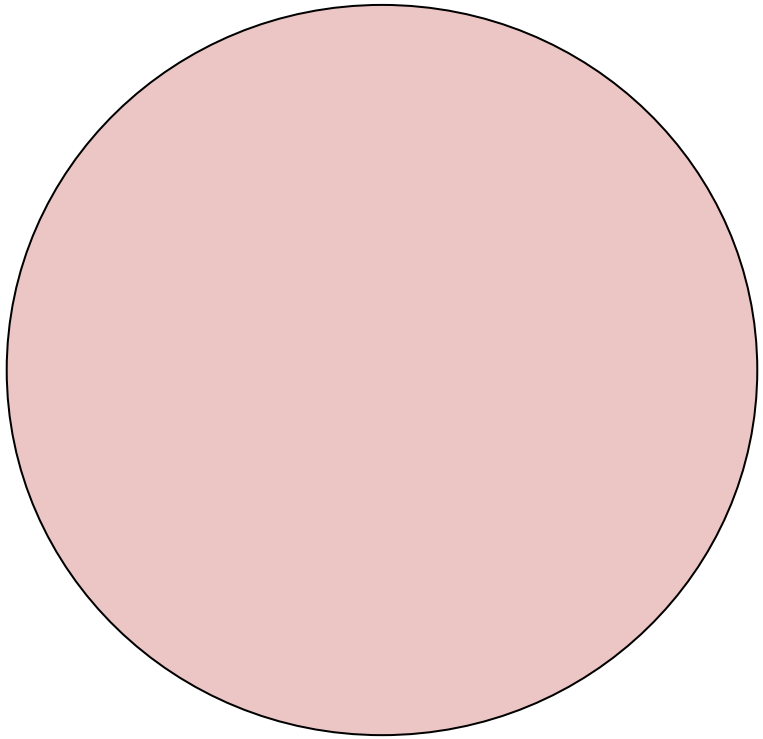


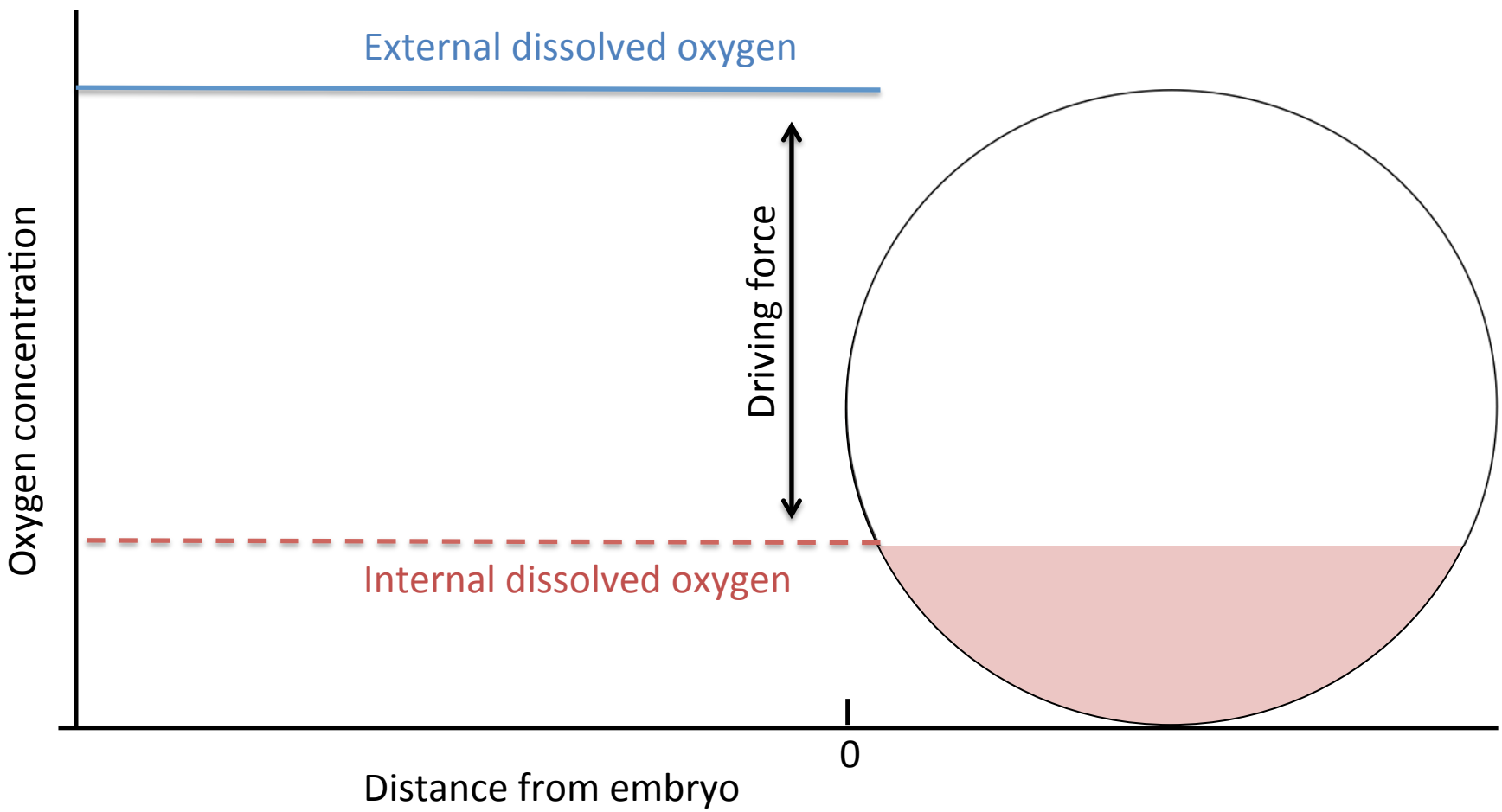
# Oxygen limitation?

In embryos?

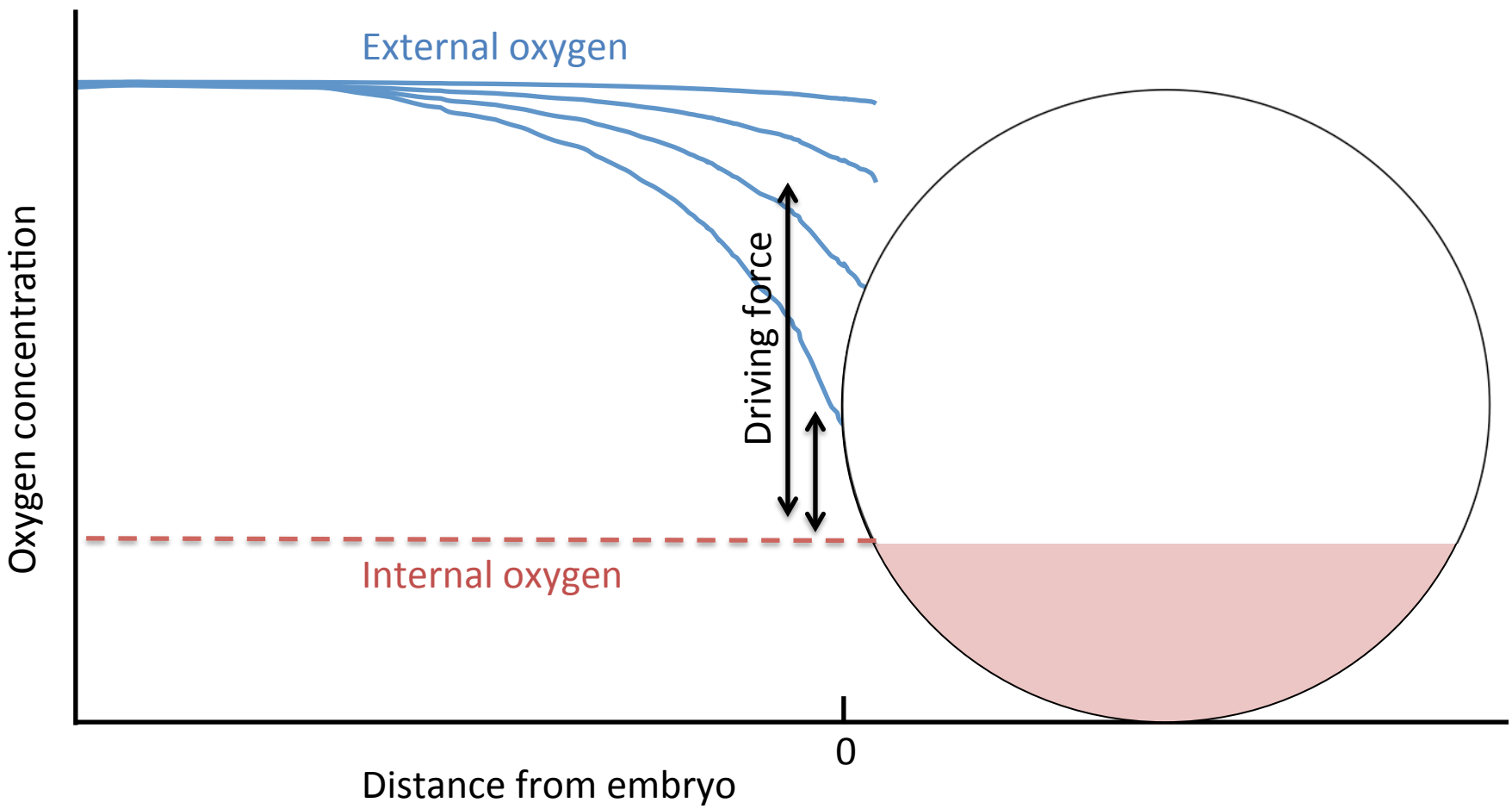
- No circulatory system
- High mass-specific oxygen demand
- Supply dependent on environment
  - DO
  - Flow



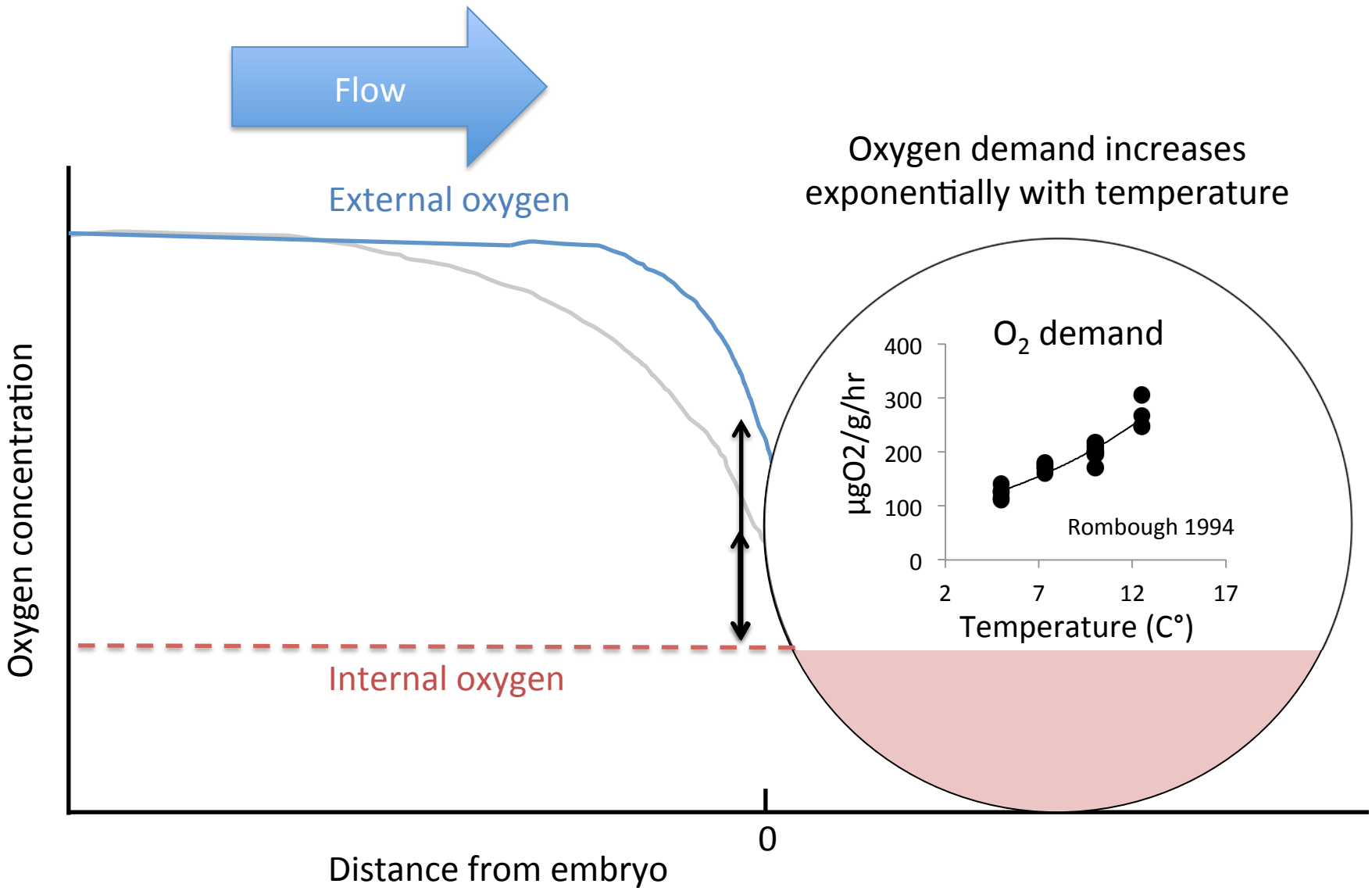
# Oxygen limitation?



# Oxygen limitation?

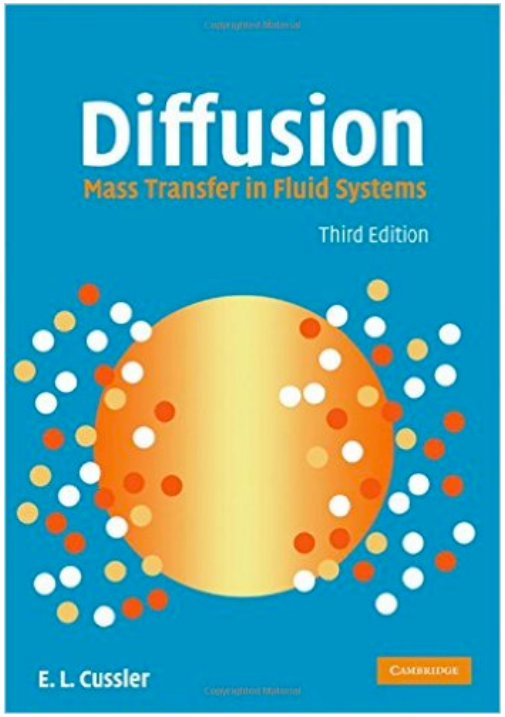


# Oxygen limitation?

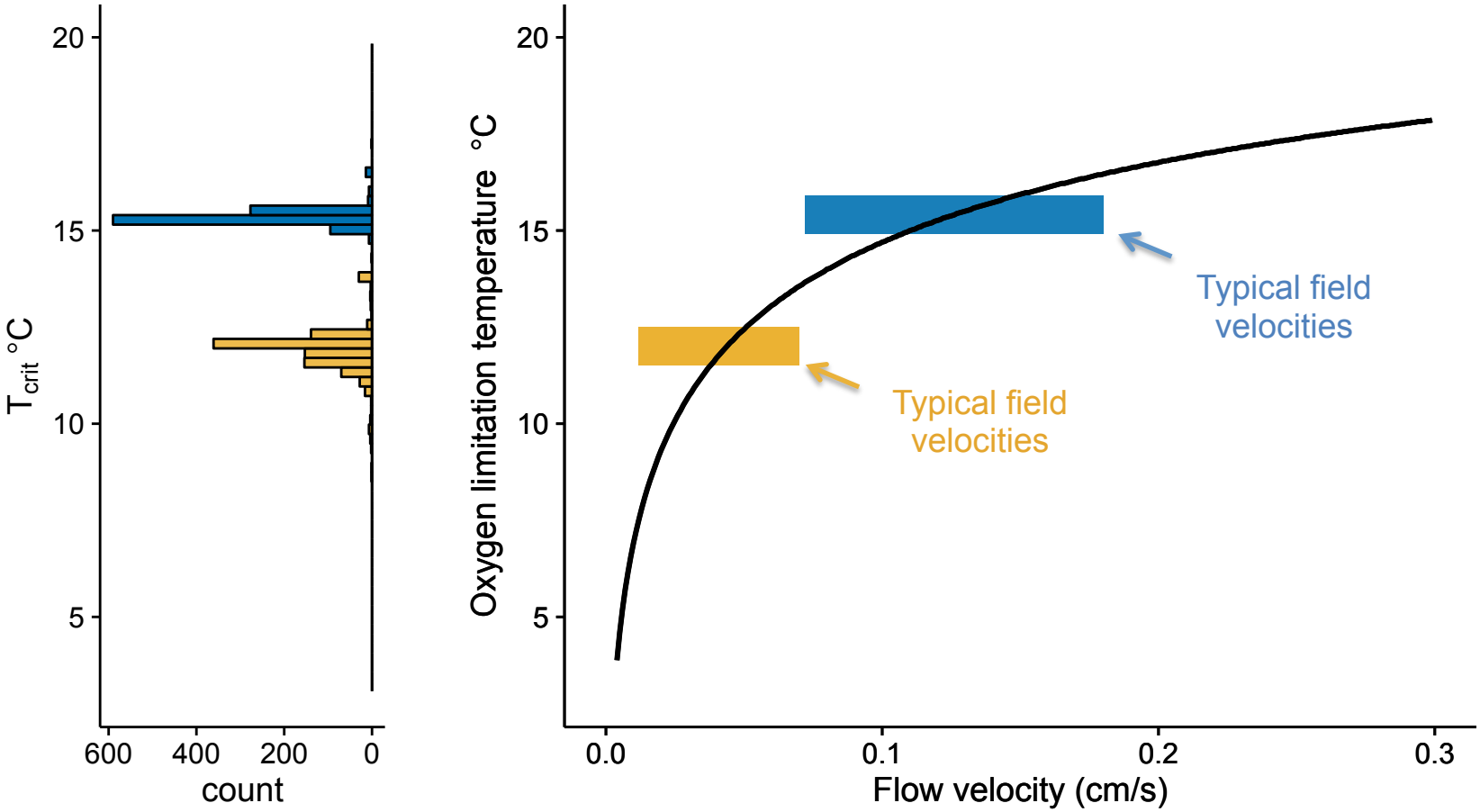


# Mass-transfer theory

- Physics worked out long ago, but rarely applied
- Can calculate thermal tolerance function of flow, DO
- Few parameters needed
  - Biological (4)
    - Temp-dependent metabolic rate (2)
    - Critical oxygen tension and egg conductance (2)
  - Physical (2)
    - Look up in a textbook

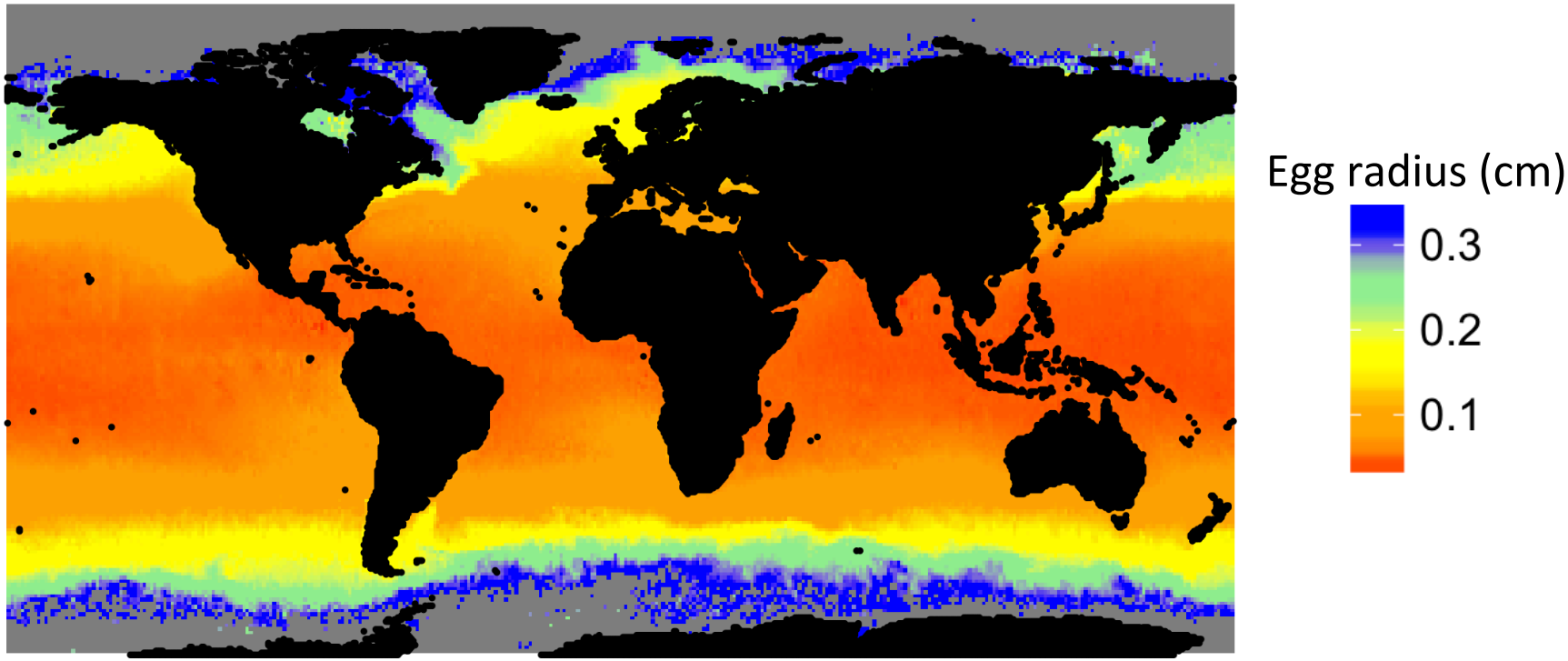


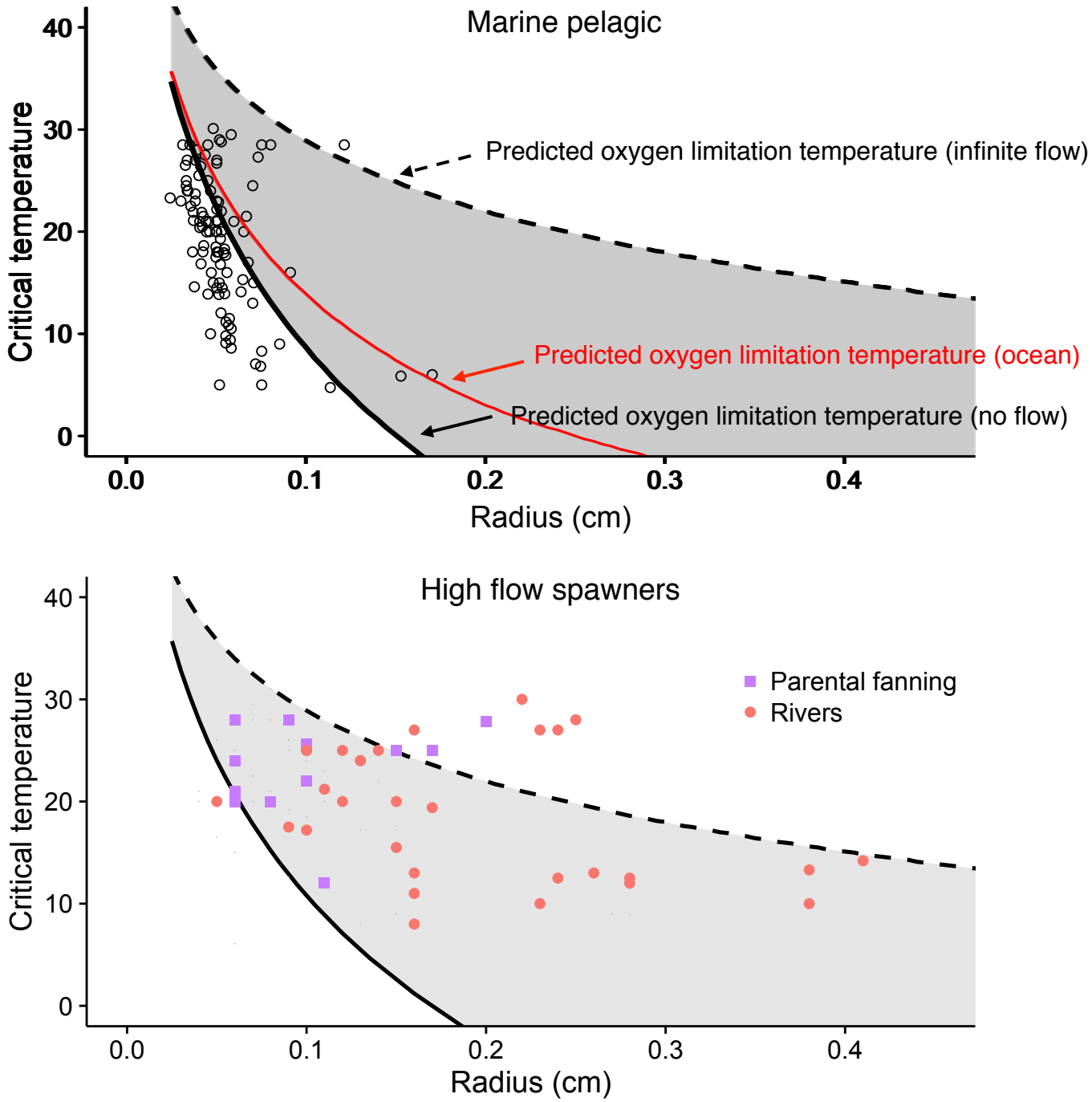

$$U_{crit} = \frac{\mu\left(\frac{5N\delta R k_e}{2D\left(4\pi R^2 k_e\left(P_e - P_i^*\right) - N\delta\right)} + \frac{5}{2}\right)^2}{2R\left(\frac{\mu}{D}\right)^{2/3}}$$

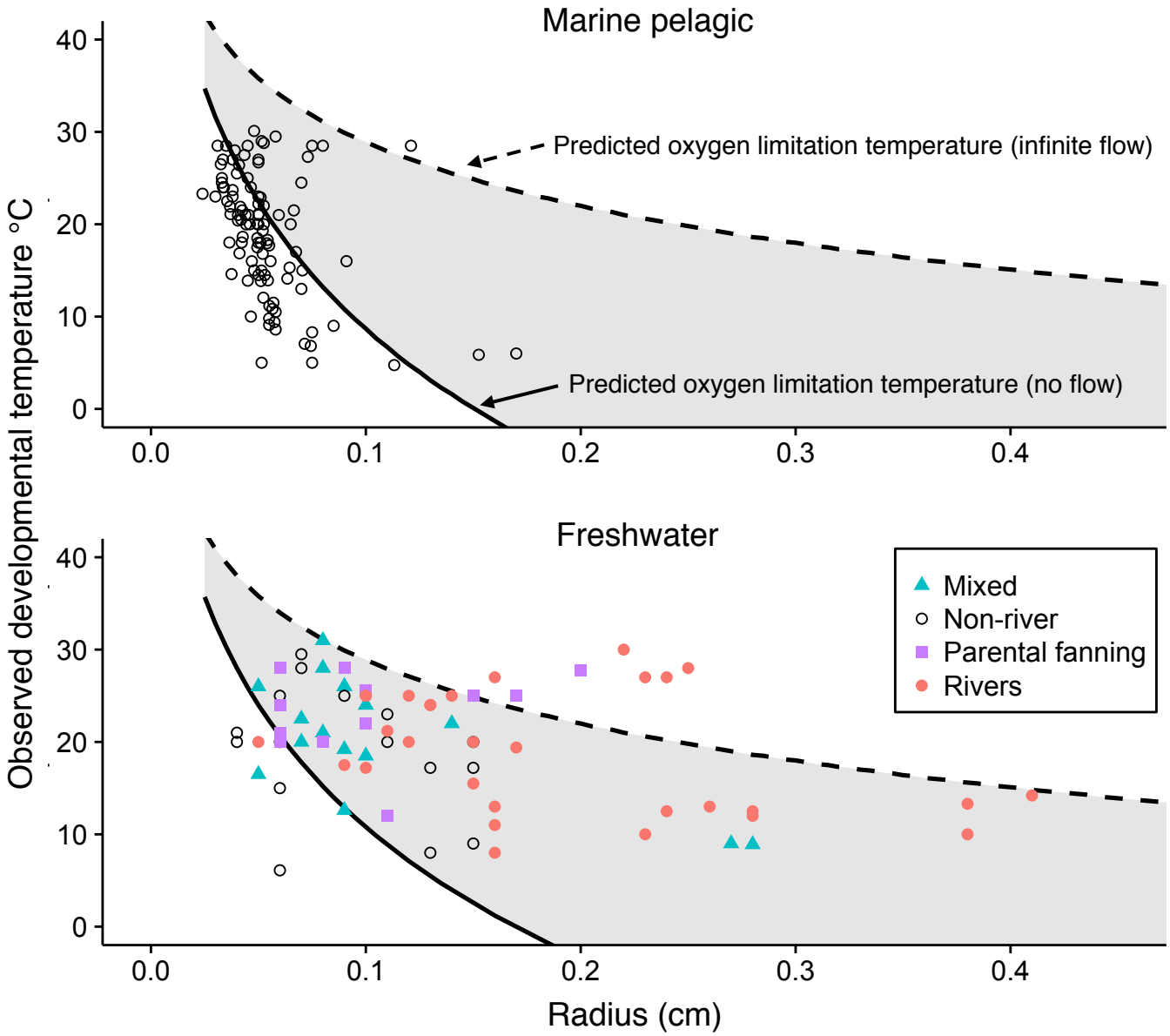

20
15
10
5
$T_{crit}$ °C
600
400
200
0
count
Oxygen limitation temperature °C
0.0
0.1
0.2
0.3
Flow velocity (cm/s)
Typical field velocities
Typical field velocities

# How general is $O_2$ limitation in fish embryos?

- Testable predictions
  - Maximum egg size decreases with temperature

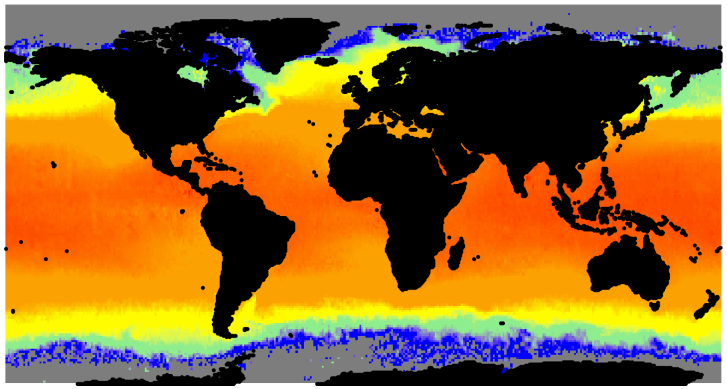



Marine pelagic
Predicted oxygen limitation temperature (infinite flow)
Predicted oxygen limitation temperature (ocean)
Predicted oxygen limitation temperature (no flow)
Critical temperature
Radius (cm)
High flow spawners
Parental fanning
Rivers
Critical temperature
Radius (cm)


Marine pelagic
Predicted oxygen limitation temperature (infinite flow)
Predicted oxygen limitation temperature (no flow)
Freshwater
Mixed
Non-river
Parental fanning
Rivers
Observed developmental temperature °C
Radius (cm)
0
10
20
30
40
0.0
0.1
0.2
0.3
0.4

# Summary

- Thermal tolerance is not a fixed value
- Lab studies still needed to quantify thermal tolerance, but…
- Their ability to forecast species responses to climate change are greatly enhanced when linked with mechanism-based models



*Ecology Letters*, (2016) doi: 10.1111/ele.12705

LETTER

**Phenomenological vs. biophysical models of thermal stress in aquatic eggs**