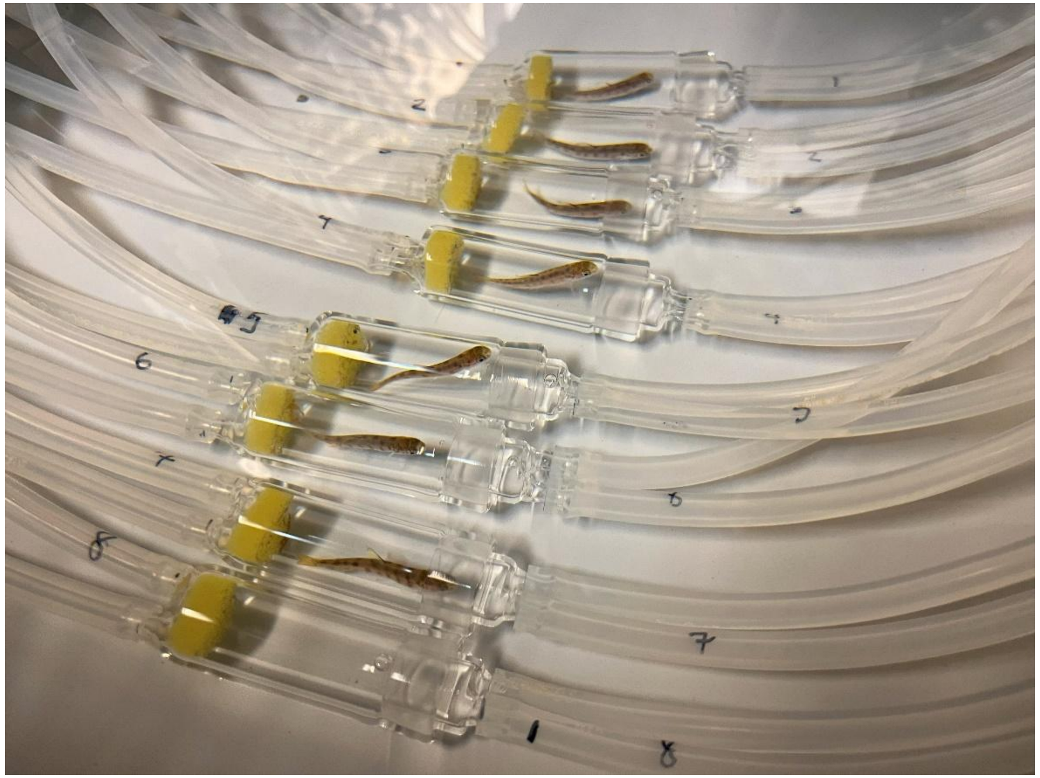


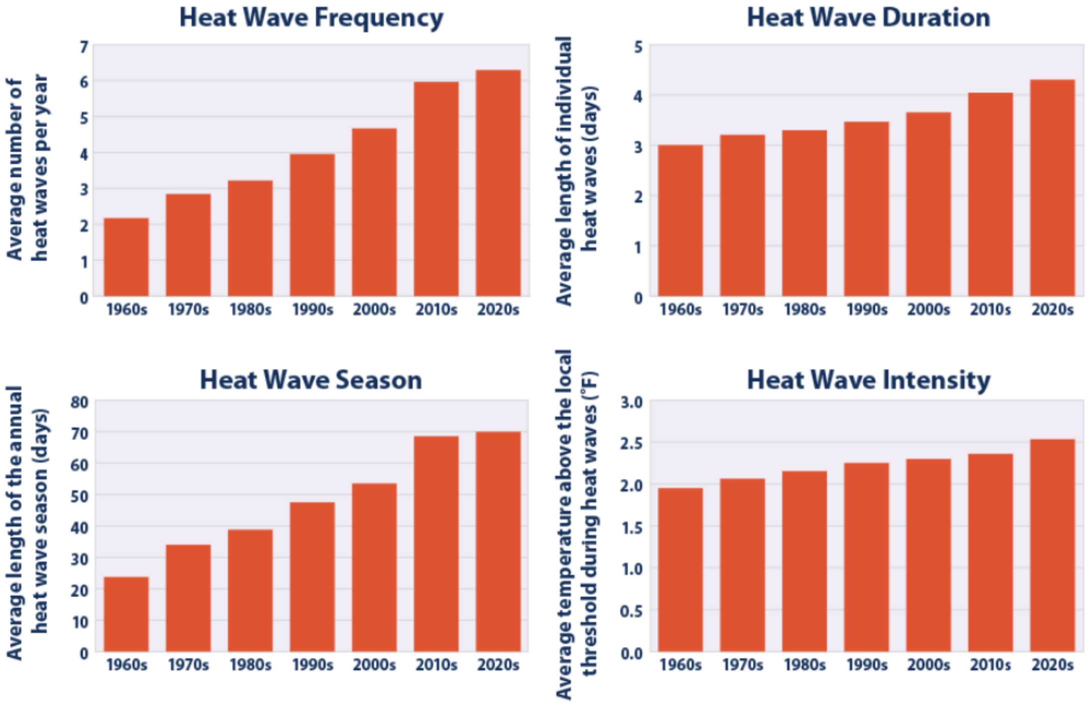
Alexander Rosén

Early-life heatwave has life-stage-specific effects on later-life ontogenetic scaling of fish metabolic and growth rates

Danmarks
Tekniske
Universitet

A changing world

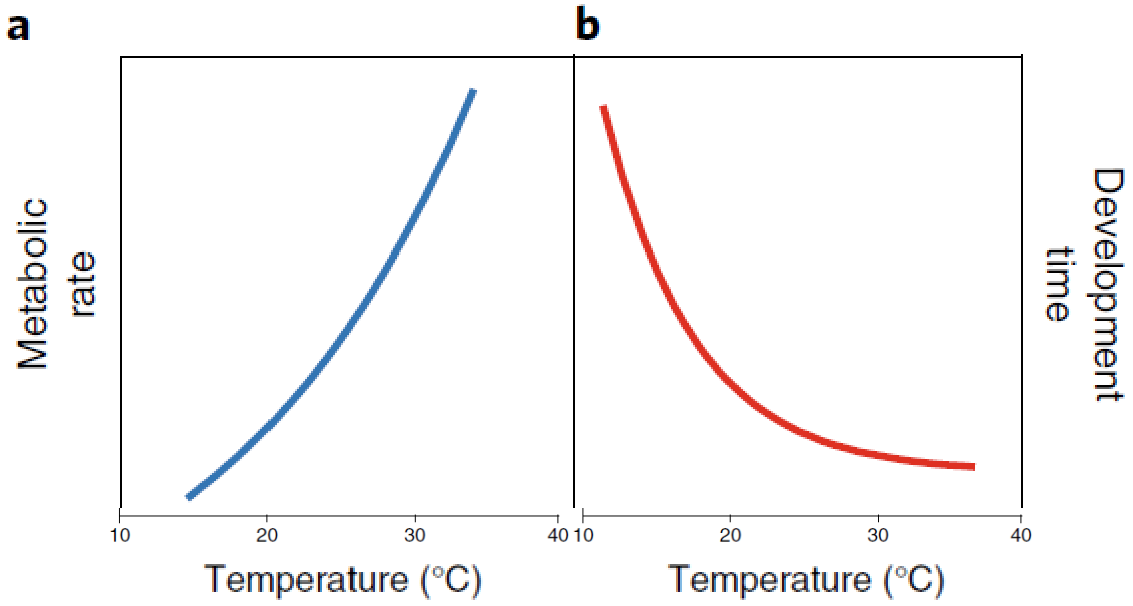
- The world is becoming warmer
- Heatwaves are becoming more common, hotter and last longer
- Particularly rapid in freshwater



NOAA 2024

Growth, metabolism and temperature

- Growth and metabolism
  - Directly linked though temperature

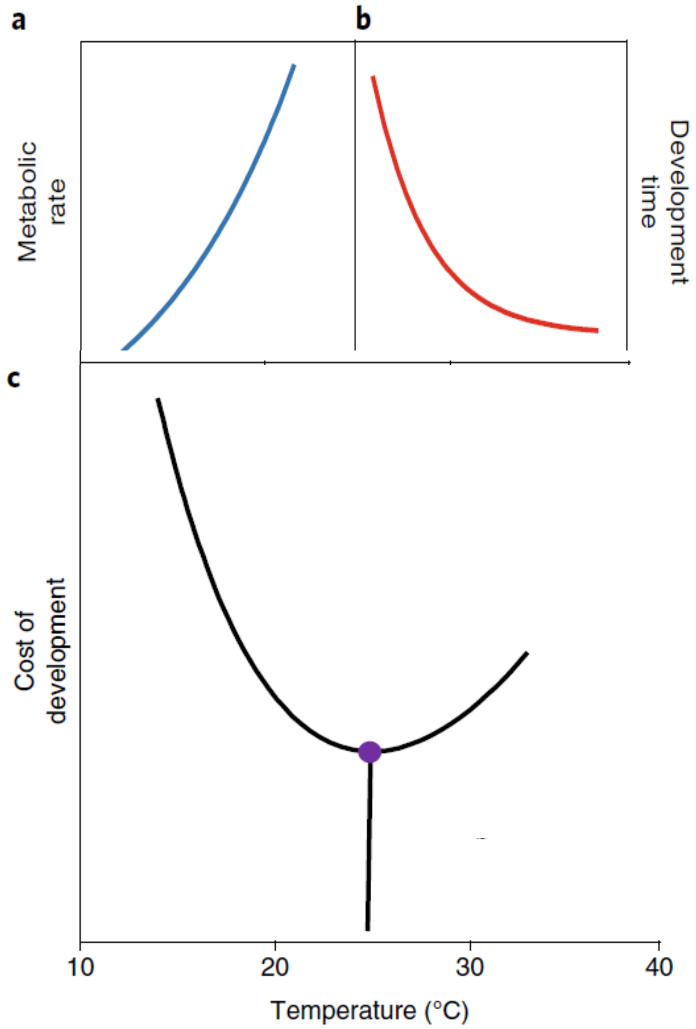


Marshall *et al*. (2020)

Growth, metabolism and temperature

- Growth and metabolism
  - Indirectly linked though temperature
  - Linked to an optimal temperature?

- Stage specific?
  - Lasting effects?



Marshall *et al*. (2020)

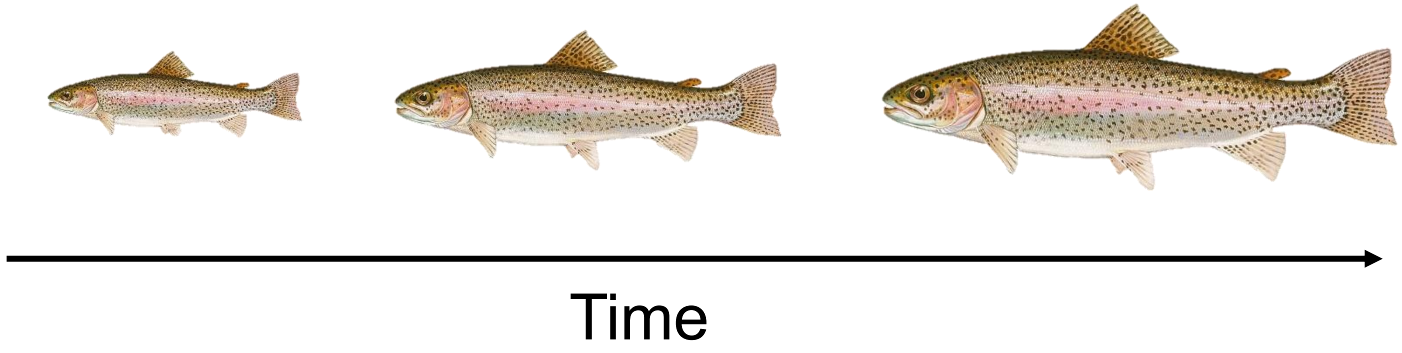
Design

- Heat wave simulation
- Rainbow trout (*Oncorhynchus mykiss*)
  - 3 Treatments across 2 life stages
    - Egg and yolk

Egg stage	Yolk stage	Experiment	
10°C	10°C	10°C	10°C Egg
14°C	10°C	10°C	14°C Egg
10°C	14°C	10°C	14°C yolk

Long-term carryover effect

- Development of metabolism and growth with body mass
  - A.k.a. their scaling



Metabolic scaling

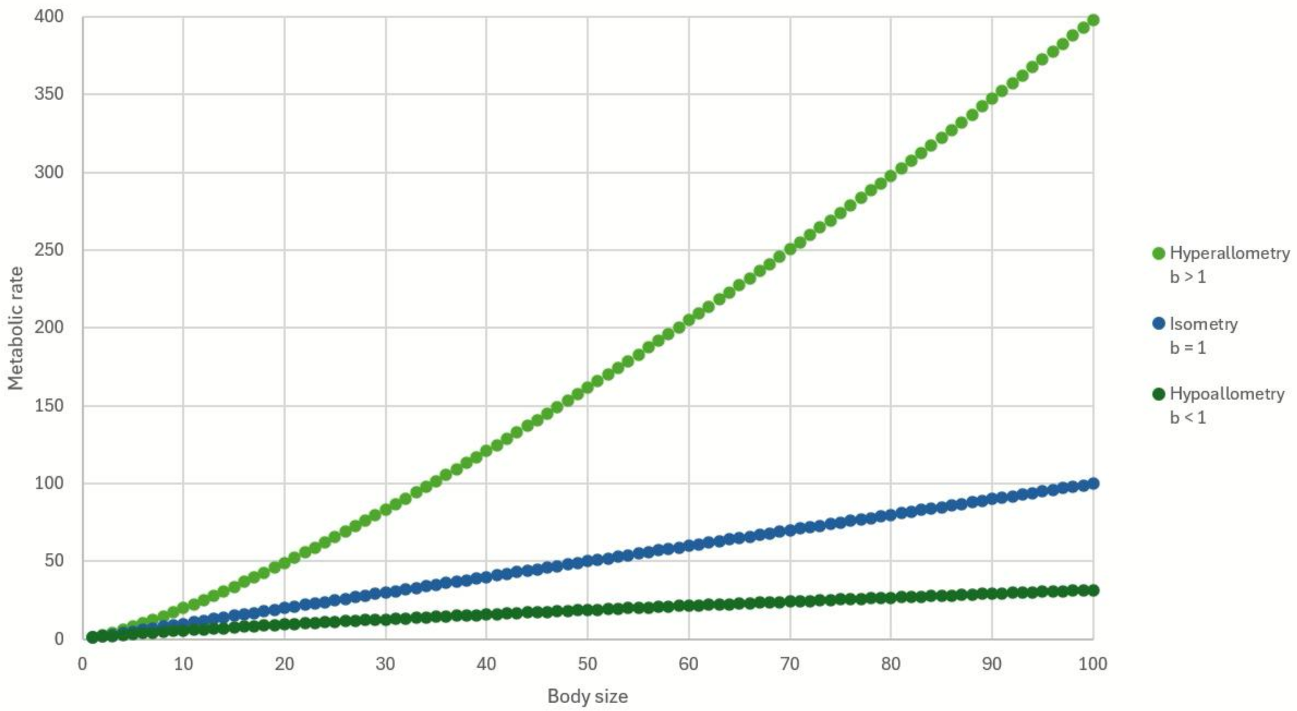
- Relationship between metabolic rate and body mass
  - Power function

    a = scaling coefficient

    b = scaling exponent

  - Isometric or allometric

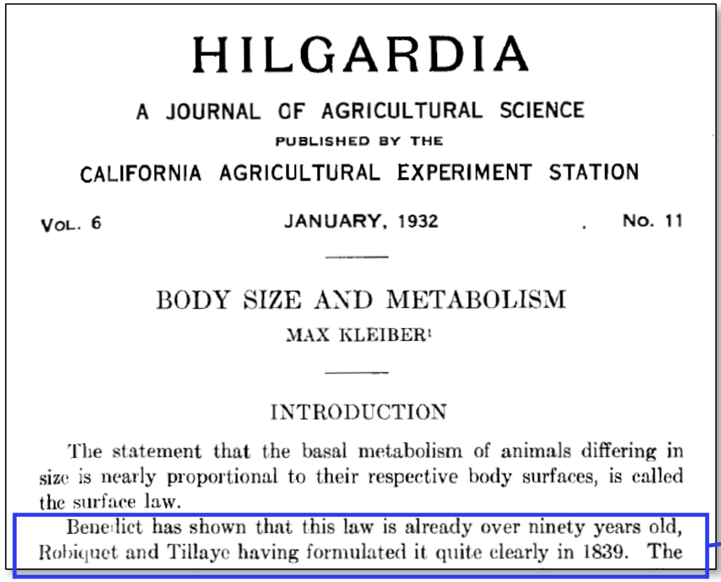
$$\mathrm{MR} = a * BM^b \leftrightarrow \log(MR) = \log(a) + b * \log(BM)$$



Metabolic scaling

- Relationship between metabolic rate and body size
  - Power function $\mathrm{MR} = a * BM^b$
  - Isometric or allometric

- Old concept
  - But still relevant and debated



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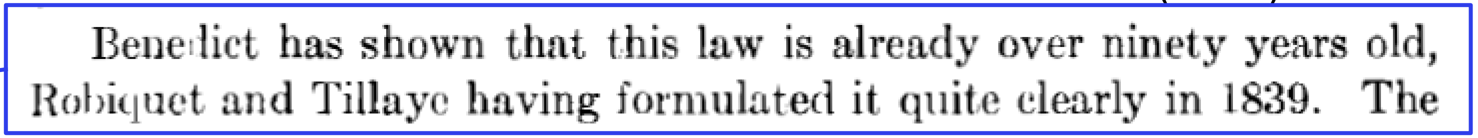
BODY SIZE AND METABOLISM

MAX KLEIBER[1]

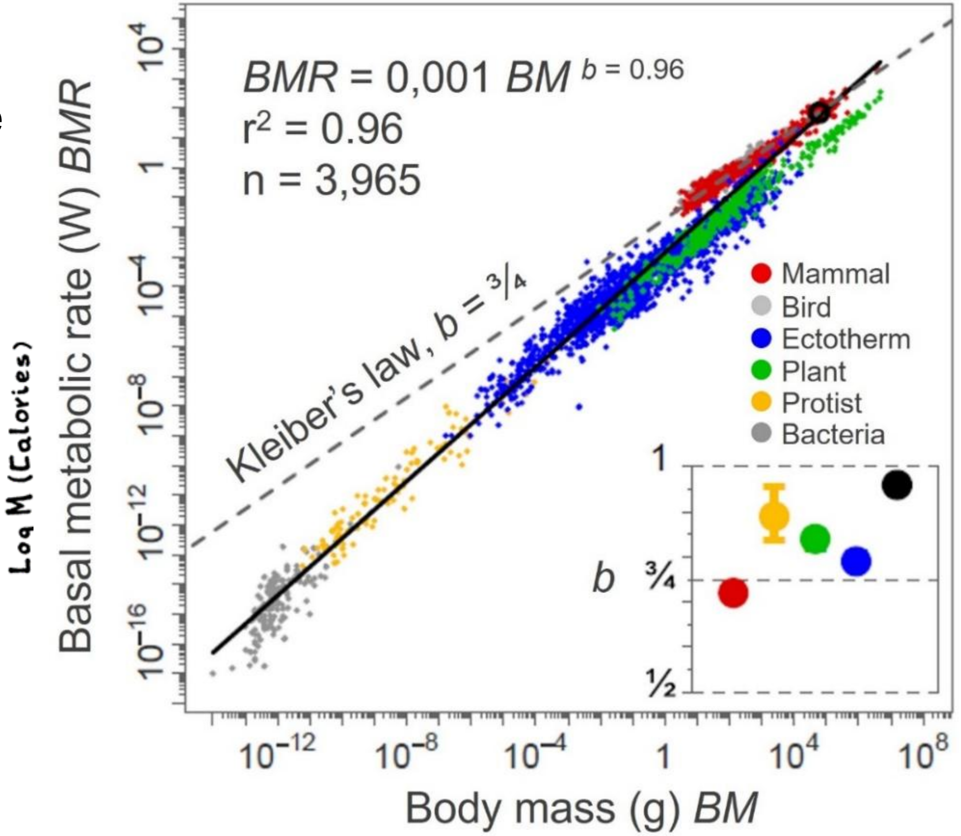
INTRODUCTION

The statement that the basal metabolism of animals differing in size is nearly proportional to their respective body surfaces, is called the surface law.

Benedict has shown that this law is already over ninety years old, Robiquet and Tillaye having formulated it quite clearly in 1839. The



Benedict has shown that this law is already over ninety years old, Robiquet and Tillaye having formulated it quite clearly in 1839. The



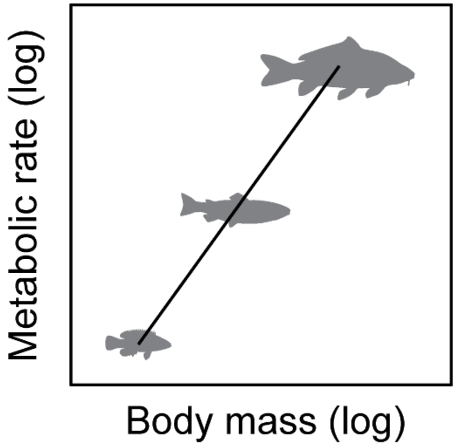
Kleiber 1932
Hatton et al. (2019)

The levels of metabolic scaling

- Metabolic scaling is not just metabolic scaling

Evolutionary:

Across species
different species of different sizes



Static:

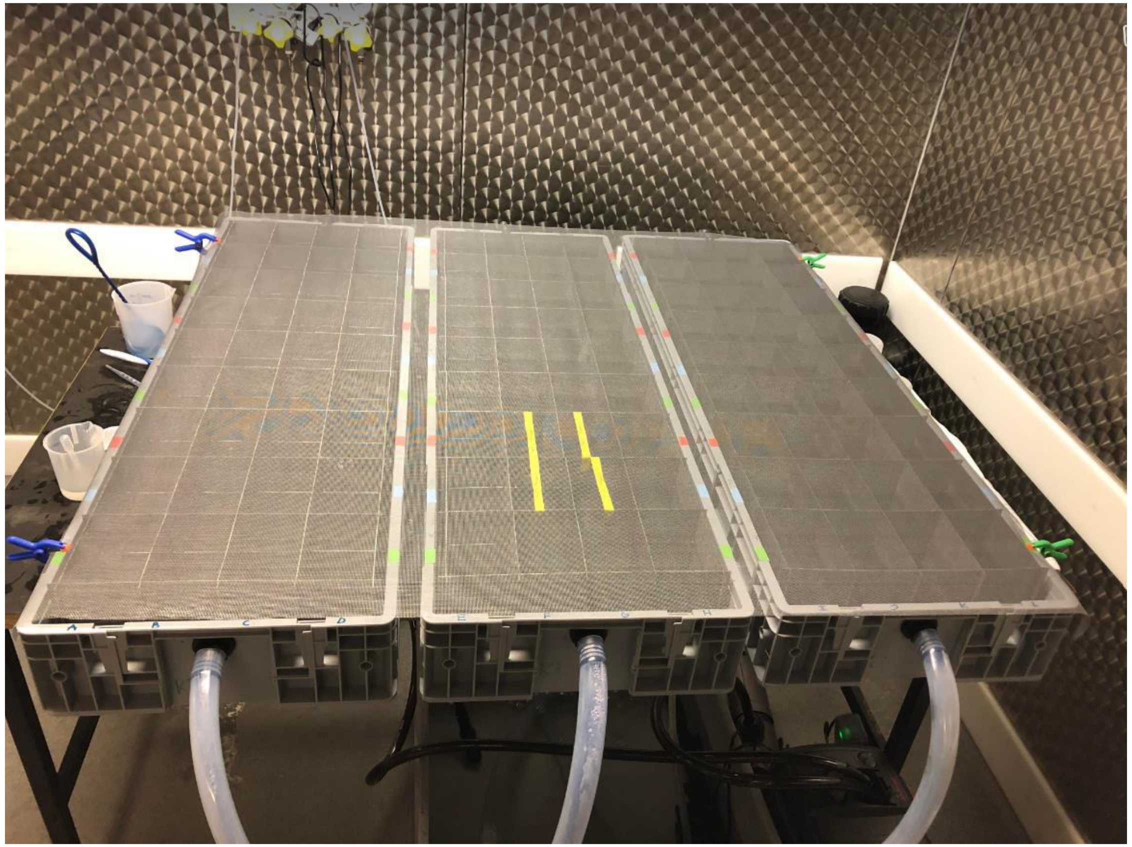
Ontogenetic:

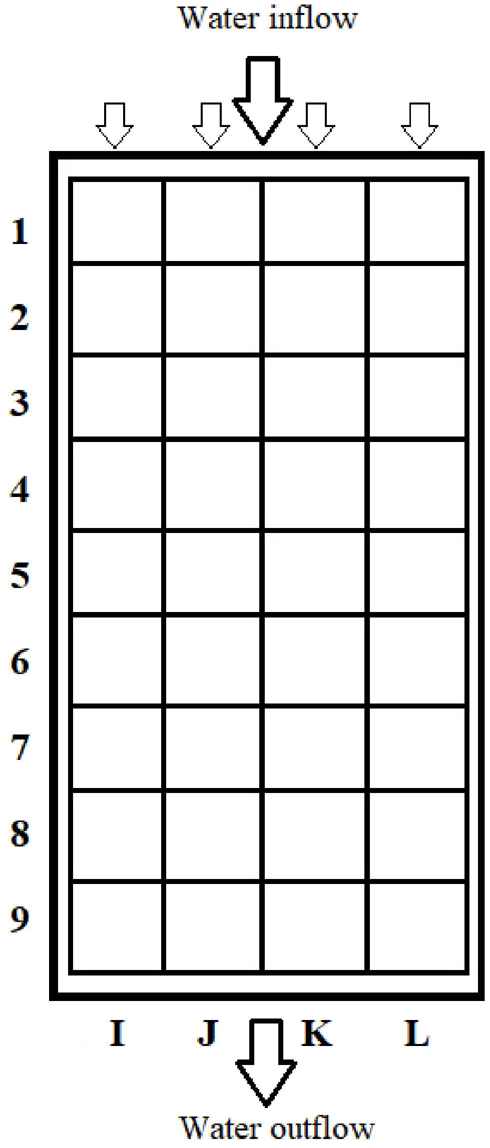
Aim

- Test long-term effect of developmental-stage-specific heatwave
  - Effect on growth, metabolism, the scaling of these and their relationships

Setup

- Fish kept in individual compartments separated by a steel mesh





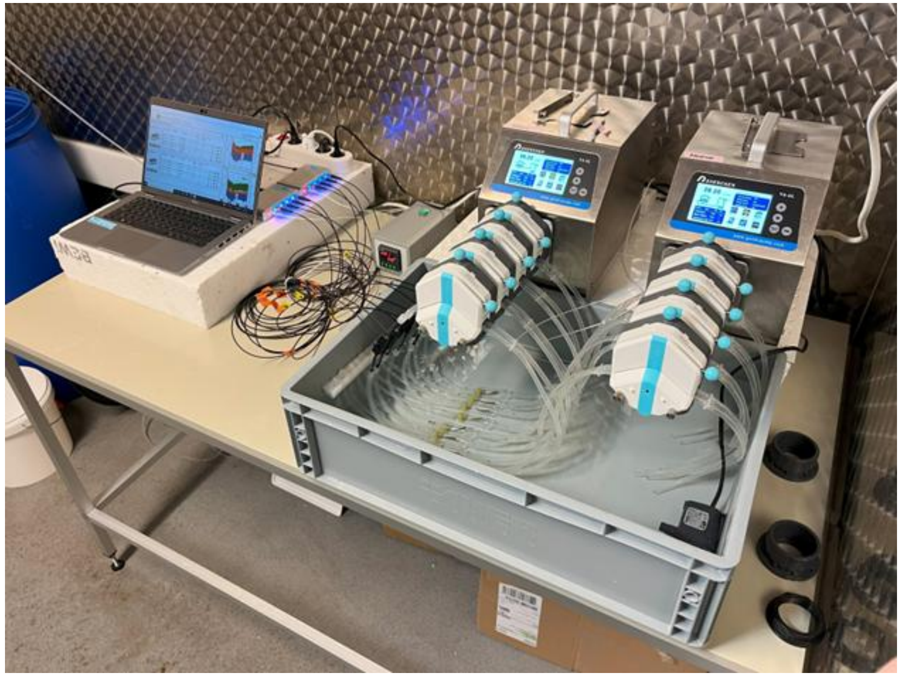
Measurements

+

- Maximum metabolic rate (MMR):
  – Chased fish for 1 min

- Standard metabolic rate (SMR):
  – Measured overnight using intermittent flow respirometry

- Repeat every 14 days for each individual

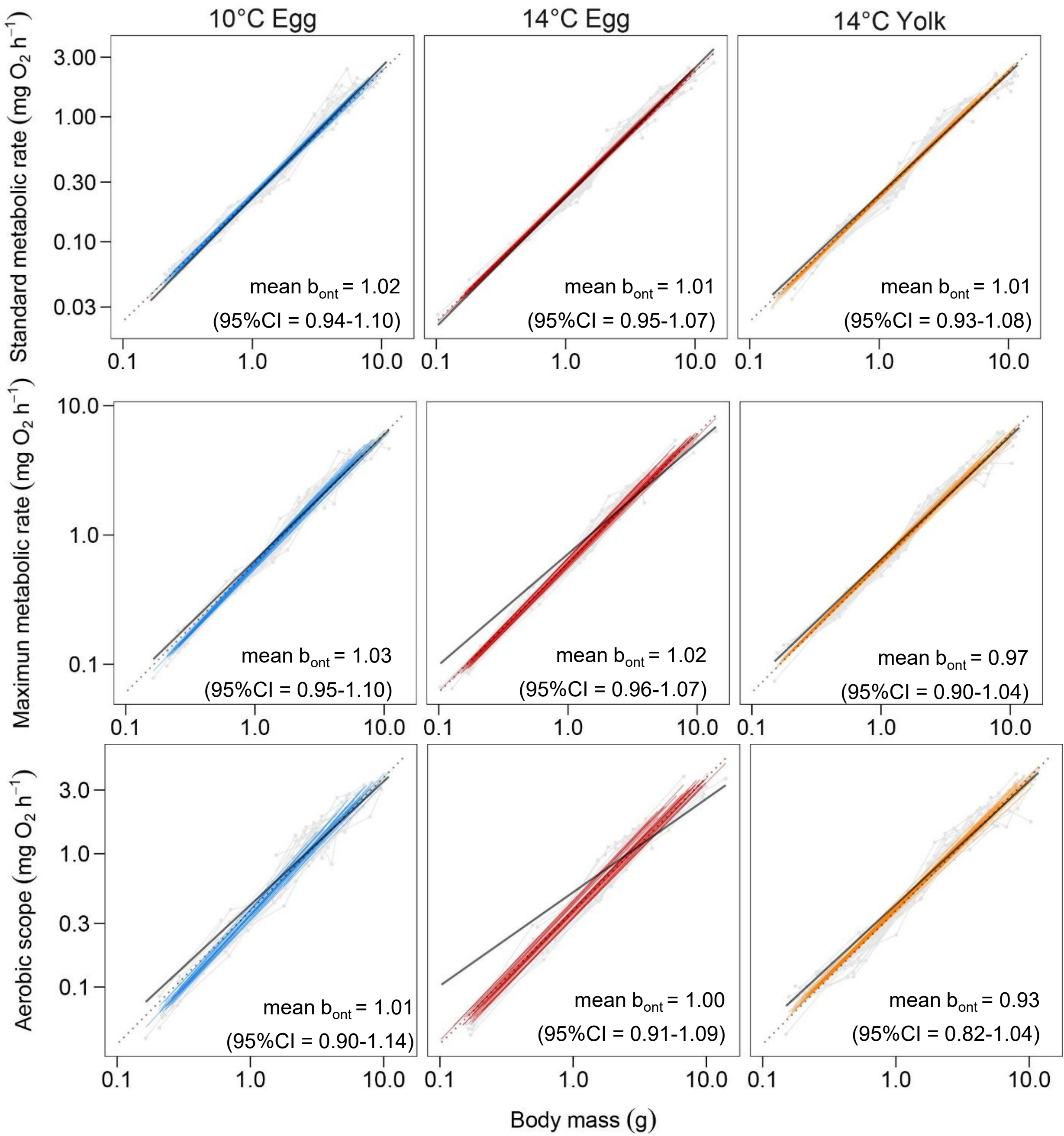


Metabolic rate

- SMR:
  - No difference in SMR scaling
- MMR:
  - 14°C Yolk scales lower than 10°C Egg and 14°C Egg
- Aerobic scope (AS):
  - 14°C Yolk scales lower than 10°C Egg and 14°C Egg

- SMR “outscales” MMR
  - Less aerobic capacity for 14°C Yolk

Egg stage	Yolk stage	Experiment	
10°C	10°C	10°C	10°C Egg
14°C	10°C	10°C	14°C Egg
10°C	14°C	10°C	14°C yolk

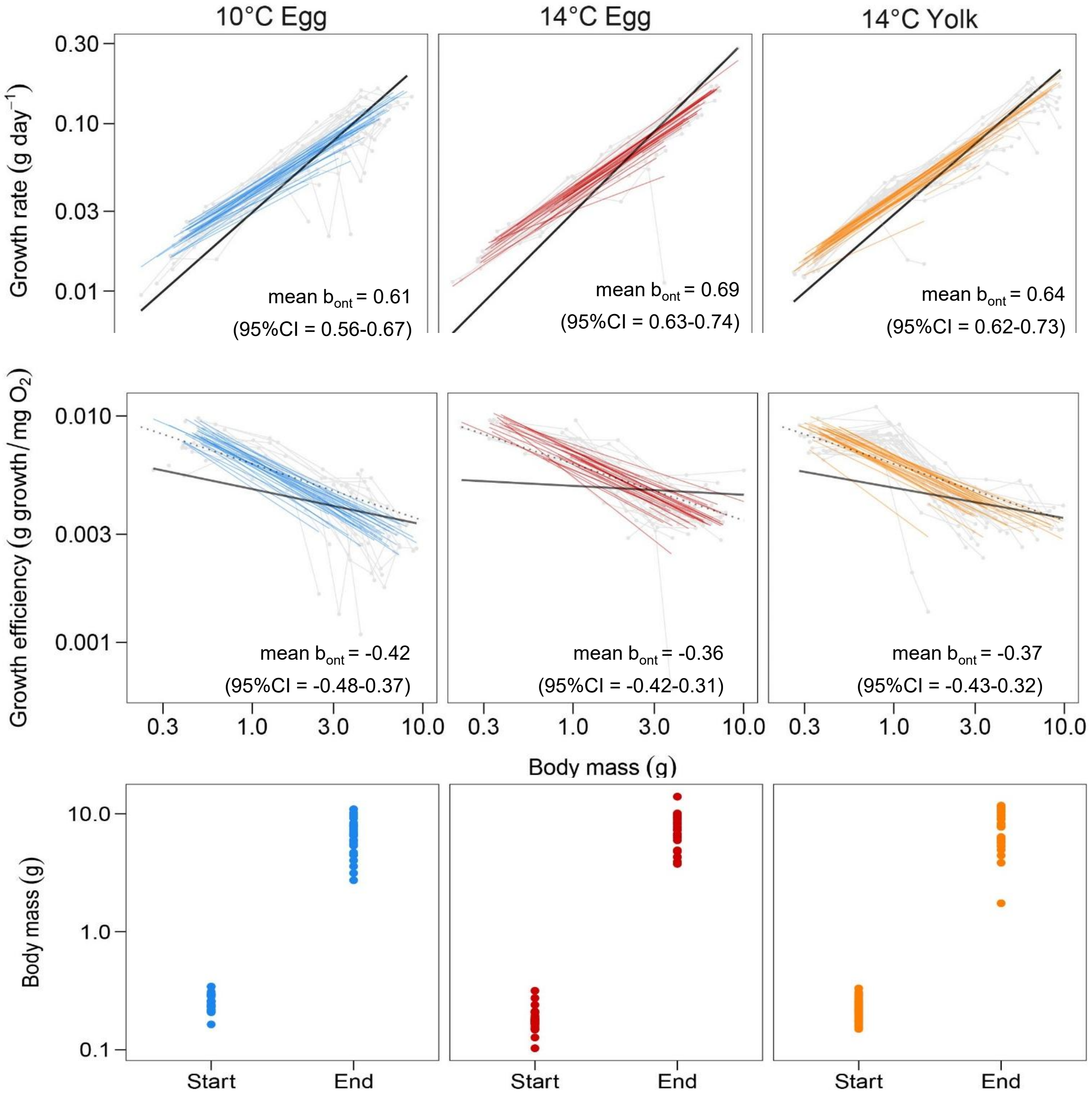


Growth

- Growth rate
  - 10°C Egg scales lower than 14°C Egg
- Growth efficiency
  - 10°C Egg scales lower than 14°C Egg

- Difference in mass at start
  - 10°C Egg > 14°C Yolk > 14°C Egg
- No difference in mass at end
  - Catch-up growth

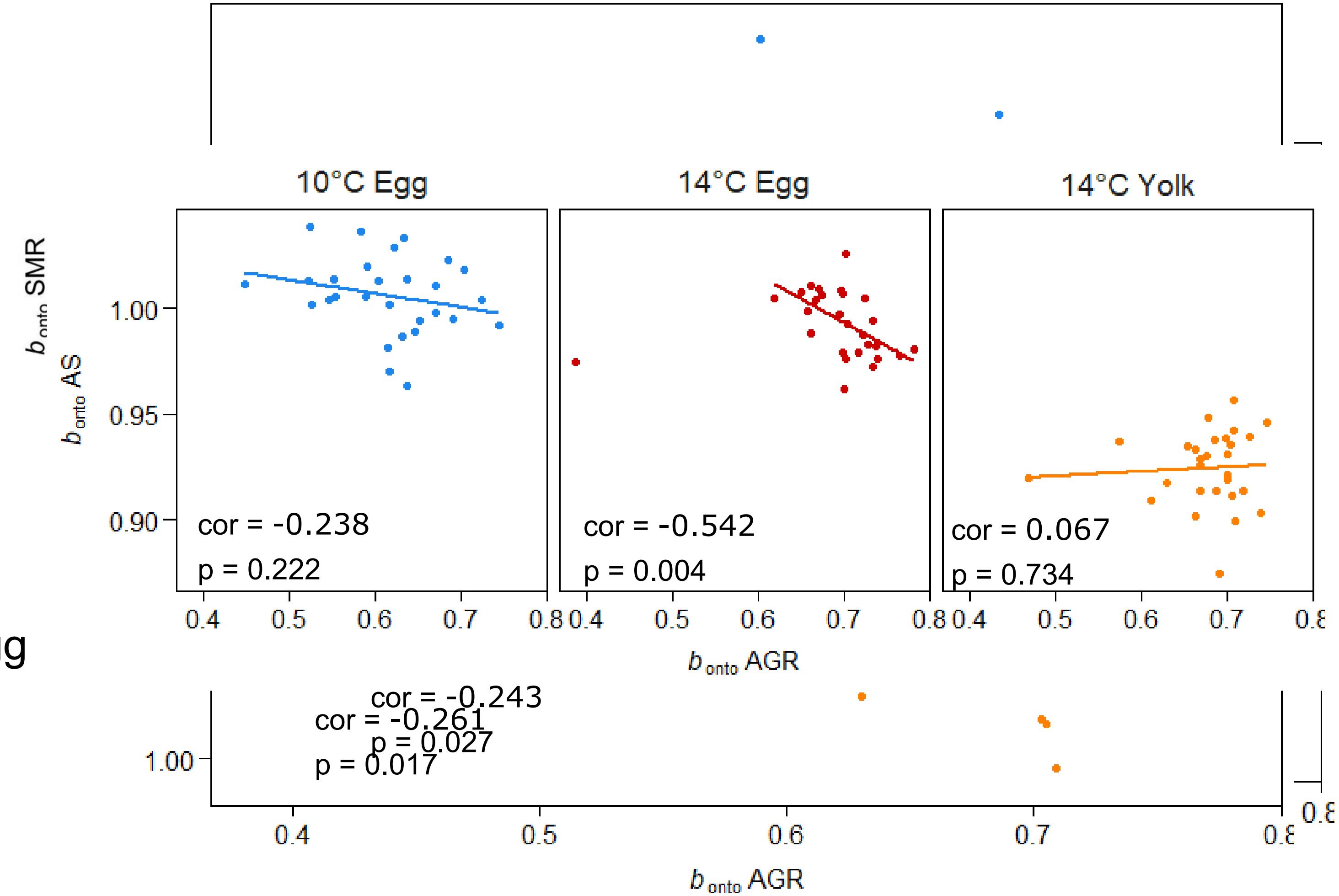
Egg stage	Yolk stage	Experiment	
10°C	10°C	10°C	10°C Egg
14°C	10°C	10°C	14°C Egg
10°C	14°C	10°C	14°C yolk



Covariation

- SMR ~ Growth rate:
  – Overall negative corelation
  – No in-group correlation
- AS ~ Growth rate:
  – Overall negative correlation
  – Negative correlation in 14°C Egg

- Cost of catch-up growth



Egg stage	Yolk stage	Experiment	
10°C	10°C	10°C	10°C Egg
14°C	10°C	10°C	14°C Egg
10°C	14°C	10°C	14°C yolk

Implication and take-home message

- Long-term effect of early-life event

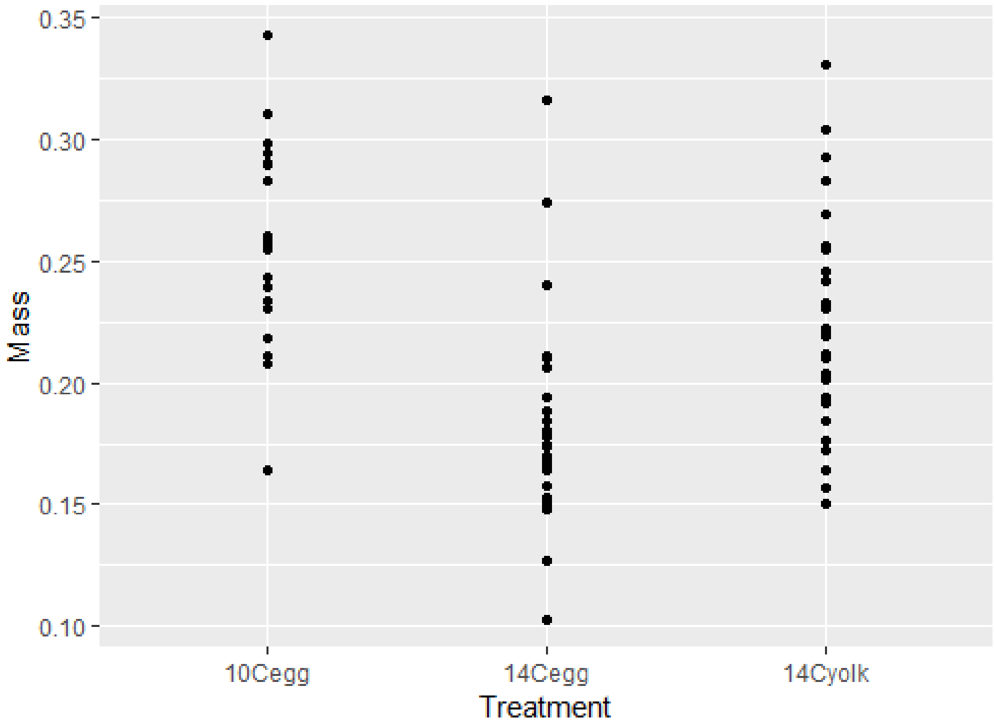
- Different scaling relationships can be affected independent of each other

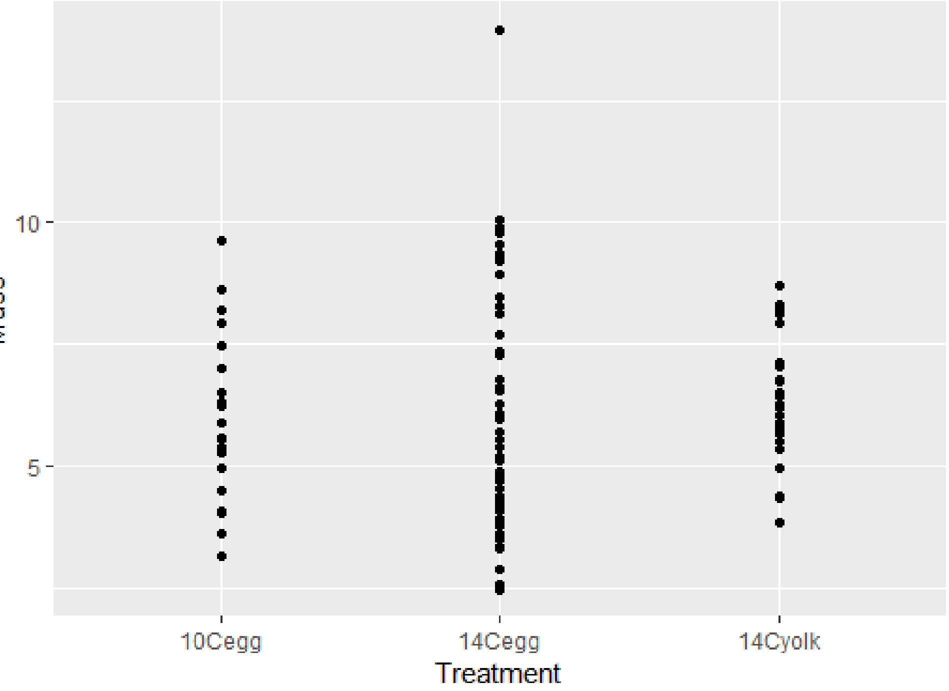
Acknowledgements

Aksel Moesby

Weights at first measurement

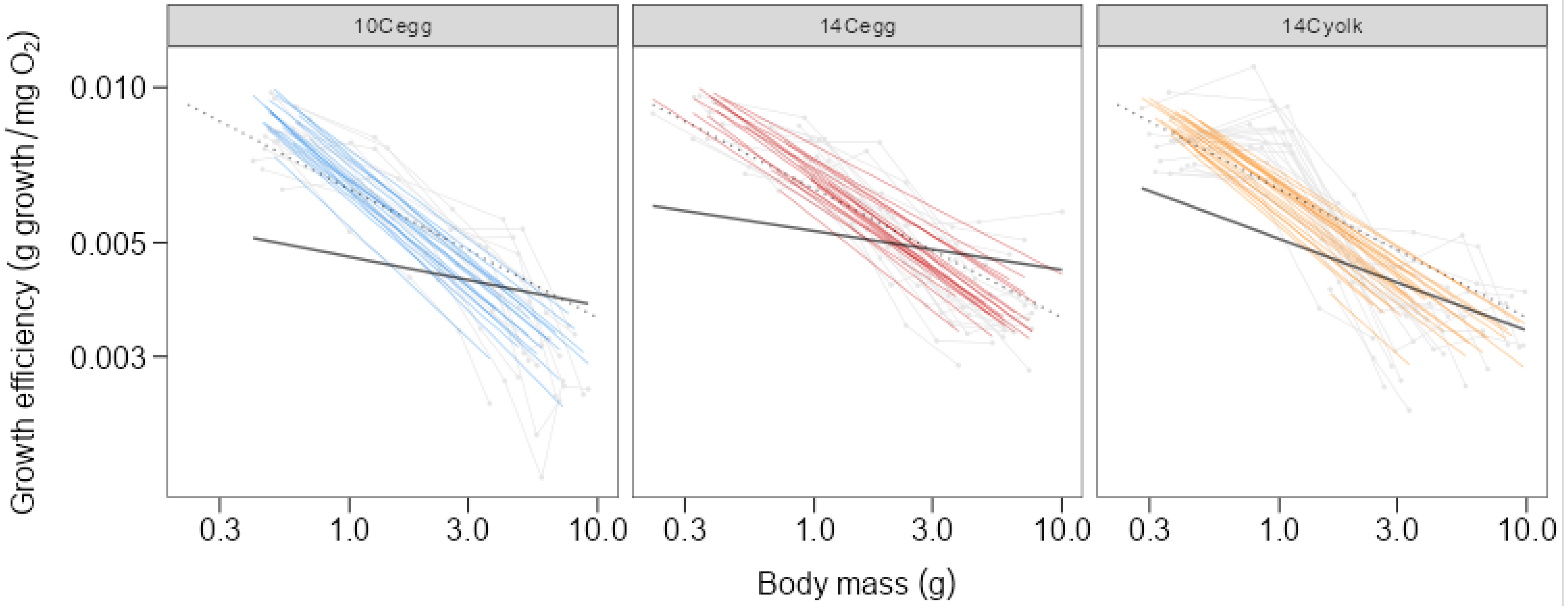
```
Coefficients:
                  Estimate Std. Error t value Pr(>|t|)    
(Intercept)       0.255920   0.008785  29.131  < 2e-16 ***
Treatment14Cegg  -0.072994   0.012192  -5.987 6.37e-08 ***
Treatment14Cyolk -0.032706   0.012087  -2.706  0.00838 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```






```
Coefficients:
                 Estimate Std. Error t value Pr(>|t|)    
(Intercept)      5.921200   0.409075  14.475   <2e-16 ***
Treatment14Cegg  0.009531   0.497790   0.019    0.985    
Treatment14Cyolk 0.448920   0.578519   0.776    0.440    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Static effect can be quite different then ontogenetic



Ontogenetic scaling exponents & 95% CIs (coloured lines):

$b_{ont,\,10Cegg}$ = -0.414 [ ] **p=0.010**
$b_{ont,\,14Cegg}$ = -0.323 [ ] p=0.296
$b_{ont,\,14Cyolk}$ = -0.371 [ ] *p=0.092*

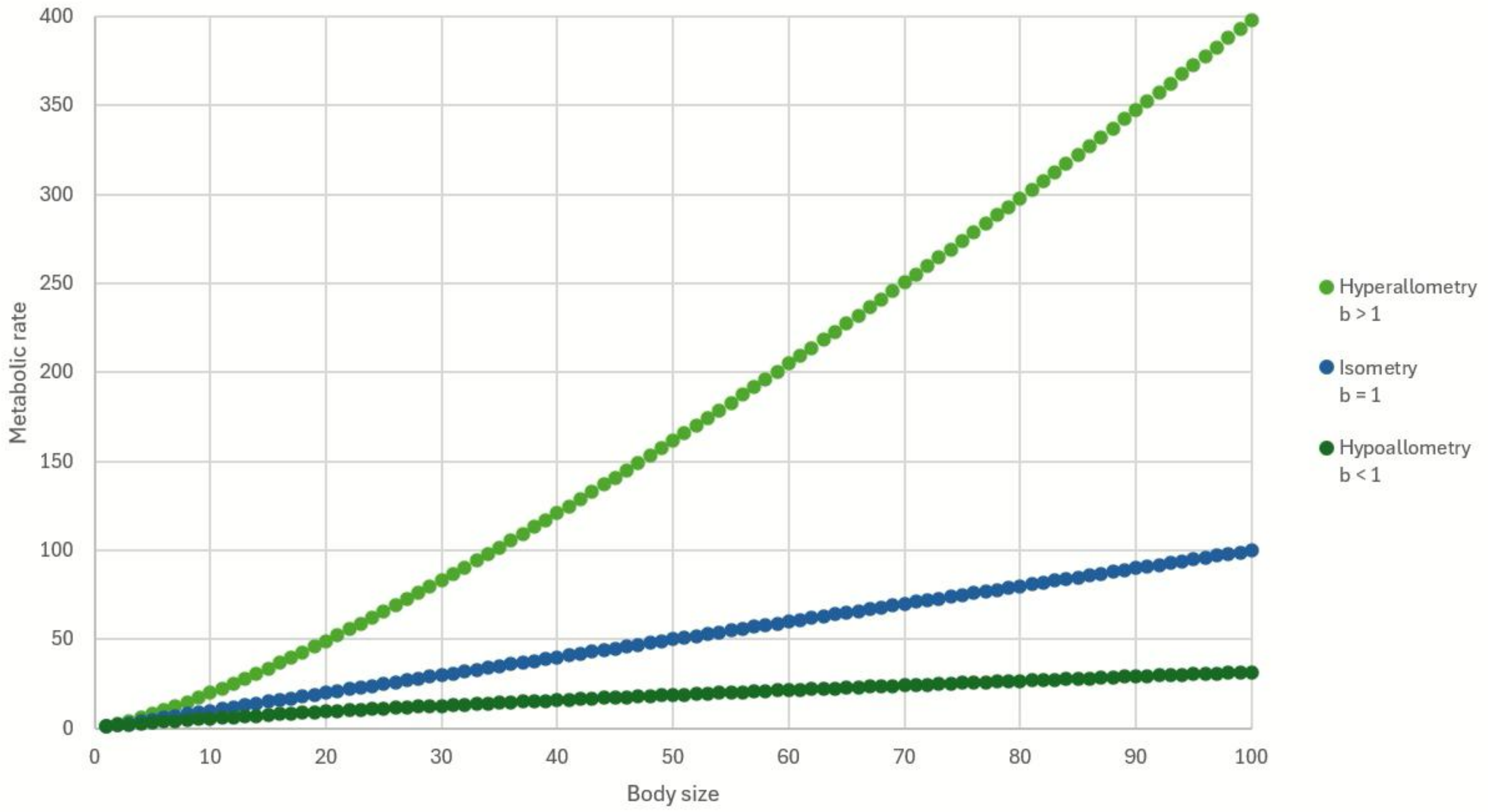
Static scaling exponents & 95% CIs (solid black lines):

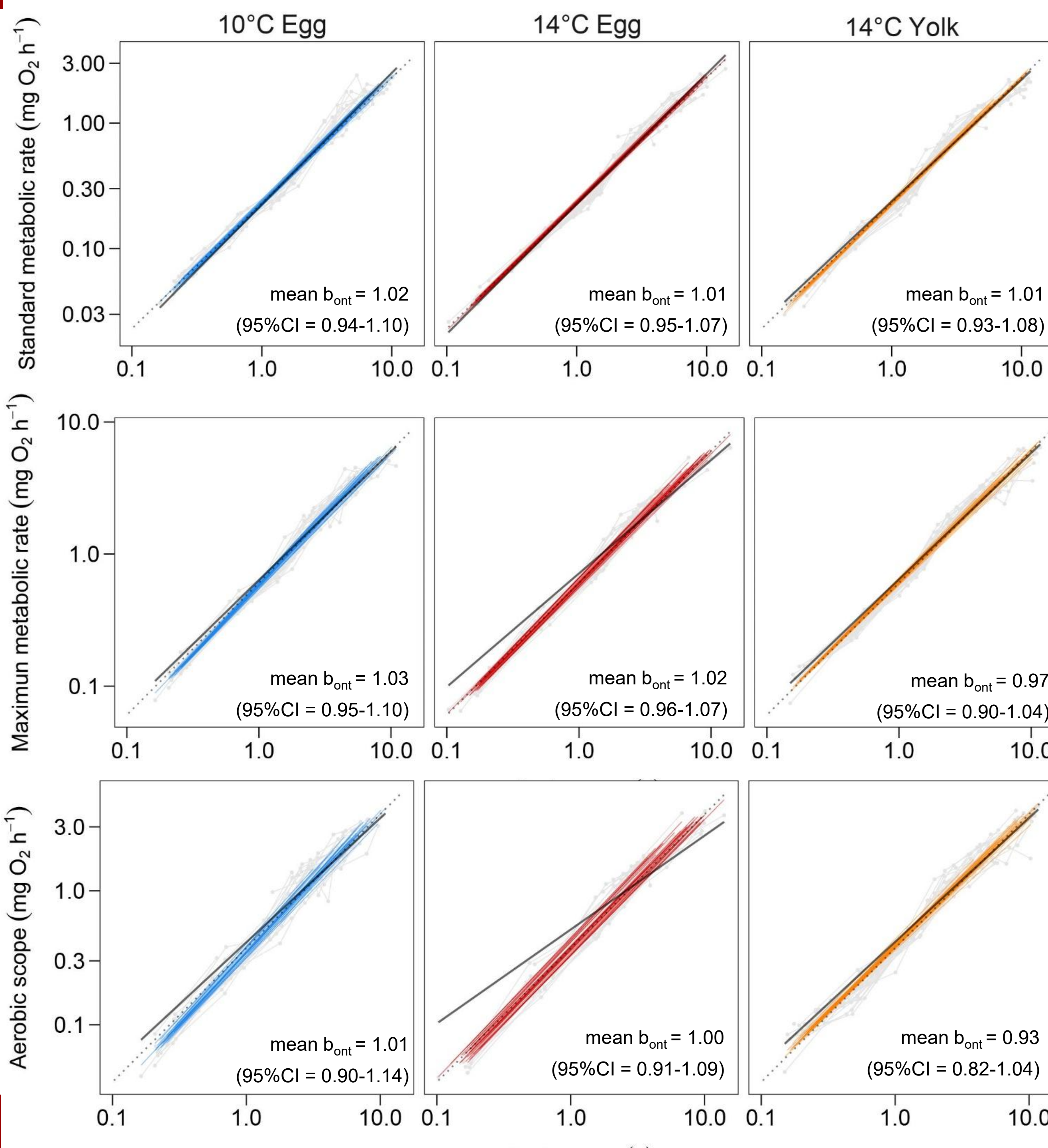
$b_{stat,\,10Cegg}$ = -0.151 [ ] p=0.611
$b_{stat,\,14Cegg}$ = -0.077 [ ] p=0.398
$b_{stat,\,14Cyolk}$ = -0.129 [ ] p=0.788

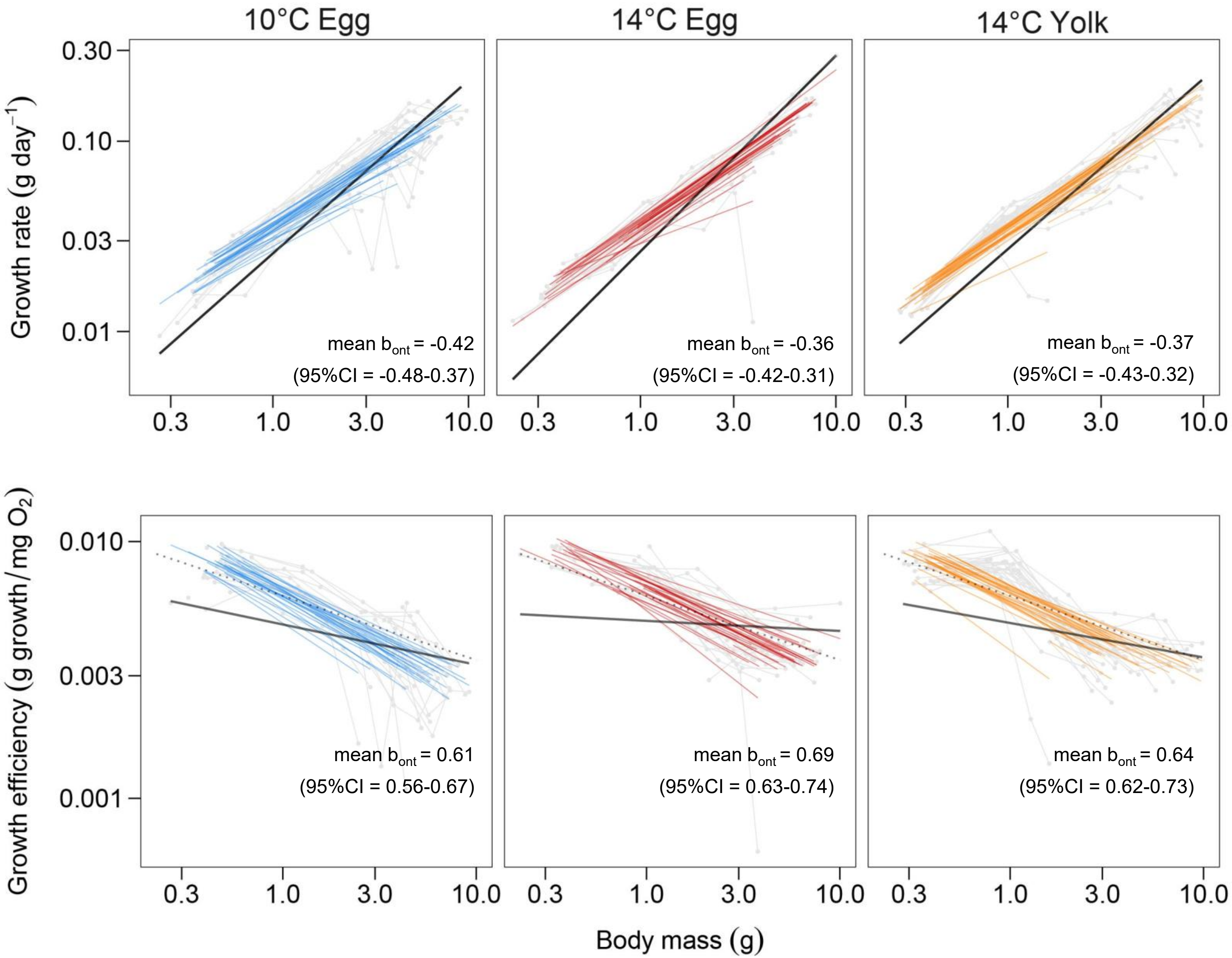
Statistical difference between ontogenetic and static *b*:

p_{10Cegg} = 0.019
p_{14Cegg} = 0.016
$p_{14Cyolk}$ = 0.062

Dotted visual aid reference line has *b* = -0.25


400
350
300
250
200
150
100
50
0
Metabolic rate
0
10
20
30
40
50
60
70
80
90
100
Body size
Hyperallometry
b > 1
Isometry
b = 1
Hypoallometry
b < 1


10°C Egg
14°C Egg
14°C Yolk
Standard metabolic rate (mg O_2 h^{-1})
Maximun metabolic rate (mg O_2 h^{-1})
Aerobic scope (mg O_2 h^{-1})
mean b_{ont} = 1.02
(95%CI = 0.94-1.10)
mean b_{ont} = 1.01
(95%CI = 0.95-1.07)
mean b_{ont} = 1.01
(95%CI = 0.93-1.08)
mean b_{ont} = 1.03
(95%CI = 0.95-1.10)
mean b_{ont} = 1.02
(95%CI = 0.96-1.07)
mean b_{ont} = 0.97
(95%CI = 0.90-1.04)
mean b_{ont} = 1.01
(95%CI = 0.90-1.14)
mean b_{ont} = 1.00
(95%CI = 0.91-1.09)
mean b_{ont} = 0.93
(95%CI = 0.82-1.04)



10°C Egg
14°C Egg
14°C Yolk
Growth rate (g day⁻¹)
0.30
0.10
0.03
0.01
mean b_{ont} = -0.42
(95%CI = -0.48-0.37)
mean b_{ont} = -0.36
(95%CI = -0.42-0.31)
mean b_{ont} = -0.37
(95%CI = -0.43-0.32)
Growth efficiency (g growth / mg O_2)
0.010
0.003
0.001
mean b_{ont} = 0.61
(95%CI = 0.56-0.67)
mean b_{ont} = 0.69
(95%CI = 0.63-0.74)
mean b_{ont} = 0.64
(95%CI = 0.62-0.73)
0.3
1.0
3.0
10.0
Body mass (g)

	Egg stage	Yolk stage	Experiment
10°C Egg	10°C	10°C	10°C
14°C Egg	14°C	10°C	10°C
14°C yolk	10°C	14°C	10°C