

Growth and metabolic scaling in fish:

Unravelling how variation in growth affects metabolic scaling

Candidate

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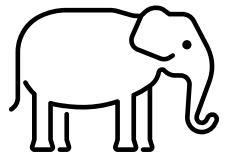
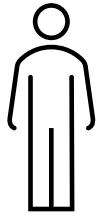
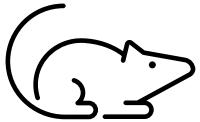
Prof. Ken Andersen

Why should you care?

- Some of the most important characteristics of an organism

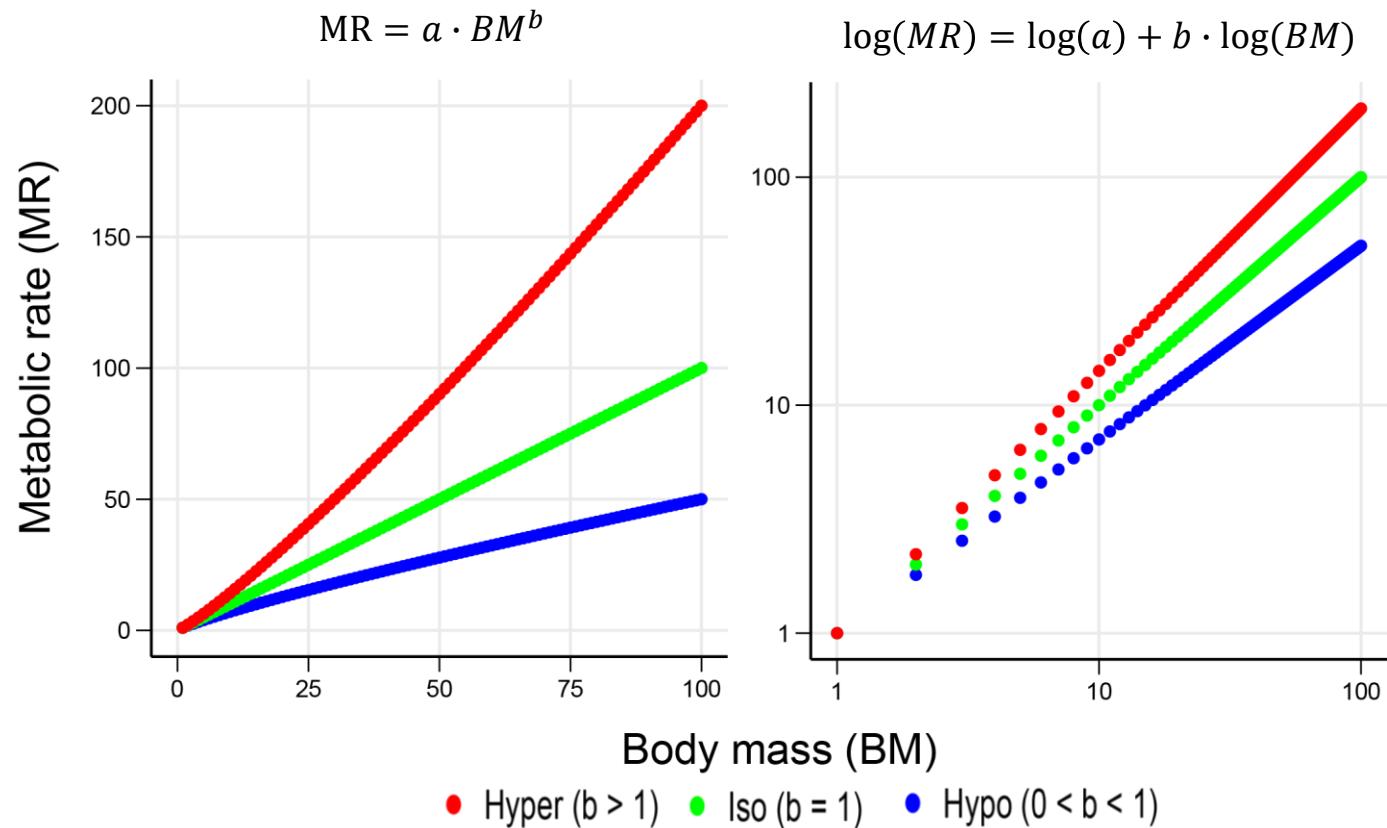
- Growth → 
- Metabolism → 

Variation



What it means to scale

- Allometric relationship
 - $MR = a \cdot BM^b$
 - a = scaling coefficient
 - b = scaling exponent



1. Metabolism

- What is it, how do we measure it and does its scaling vary?
- Why would it be related to growth?
- Why look at it ontogenetically, and what are the goals of my PhD

2. Manipulation growth in the lab (Paper II)

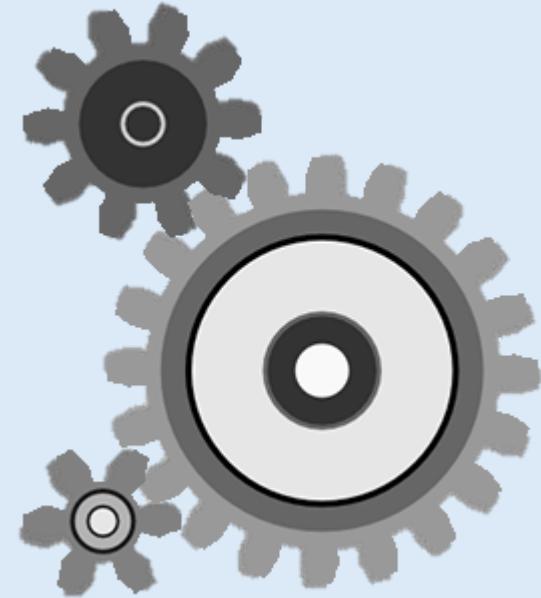
3. Looking at the patterns across species (Paper IV)

4. Ontogenetic scaling in the wild (Paper V)

5. Can what we see ontogenetically explain what we see statically (Paper I)

What is metabolism?

- The machinery that drives us
 - Anabolism - Building larger molecules
 - Catabolism - Breakdown of larger molecules



“The Fire of life”

- Max Kleiber

What is metabolism?

- Metabolic rate
 - Energy turnover
- But of what and where?

Resting?

- Standard metabolic rate (SMR)
- Basal metabolic Rate (BMR)



Routine?

- Routine metabolic rate (RMR)
- Field metabolic rate (FMR)



Maximum?

- Maximum metabolic rate (MMR)



What does it tell us?

- Food requirement

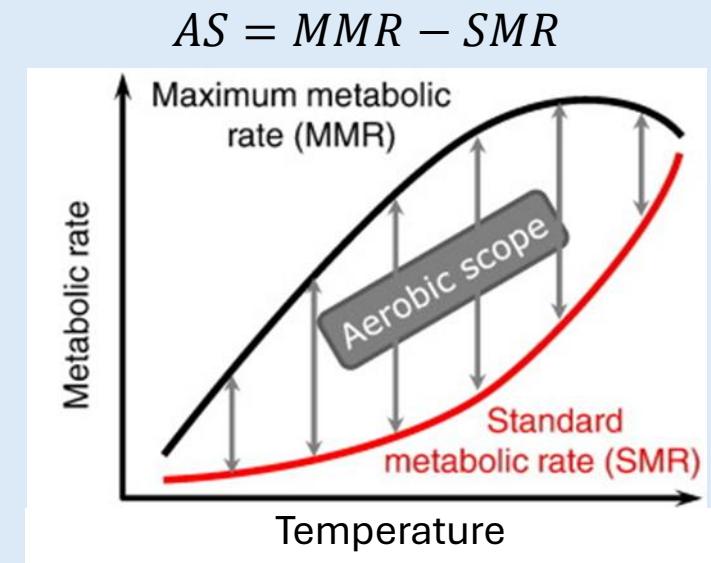


- Energy budget

- Aerobic scope (AS)

- Factorial aerobic scope (FAS)

$$FAS = \frac{MMR}{SMR}$$

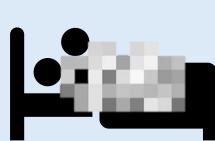


Verbeck et al. 2015

Escape danger



Reproduction



Foraging



Migration

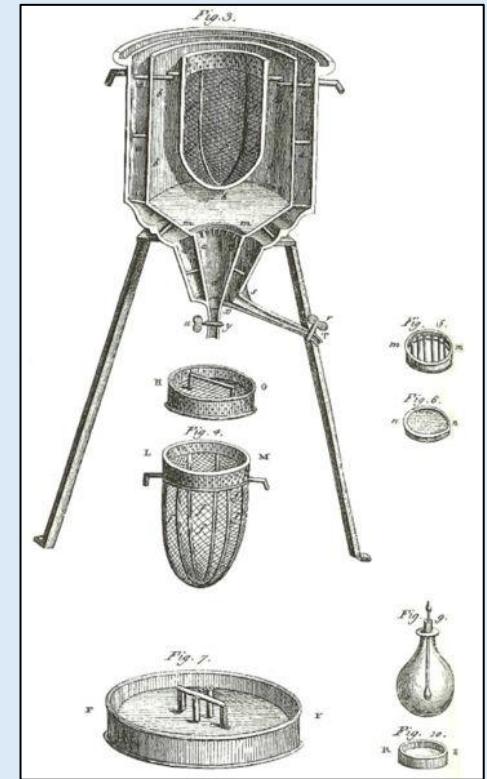
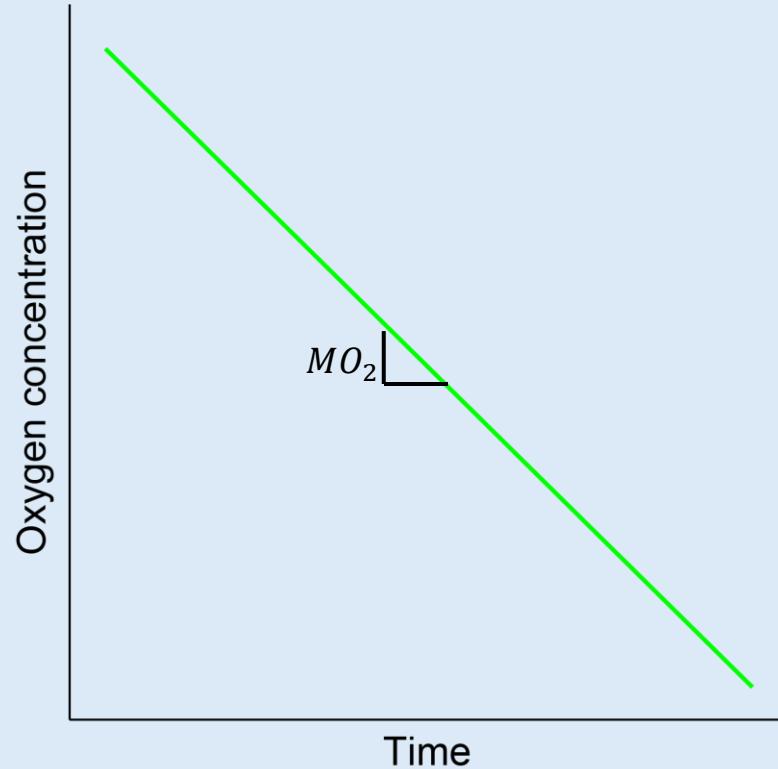
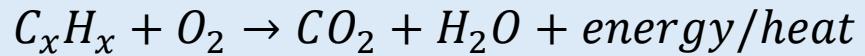


Growing



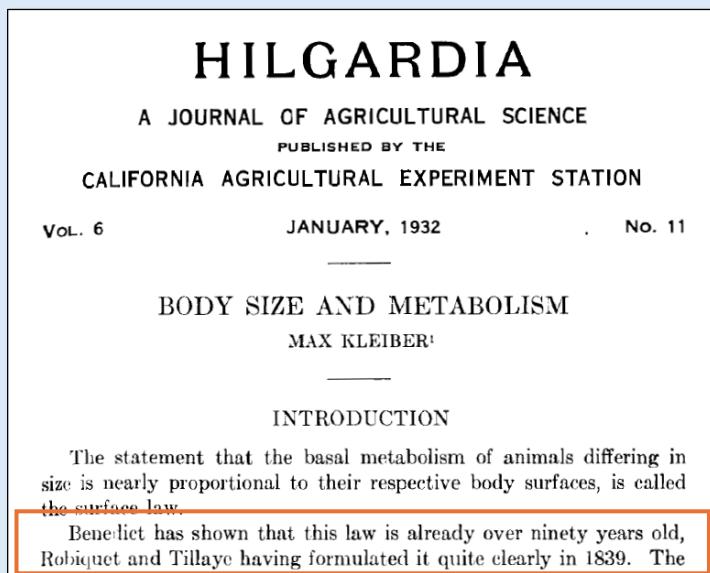
How do we measure metabolism

- Directly
 - Heat production
- Proxy
 - CO₂ production
 - O₂ use

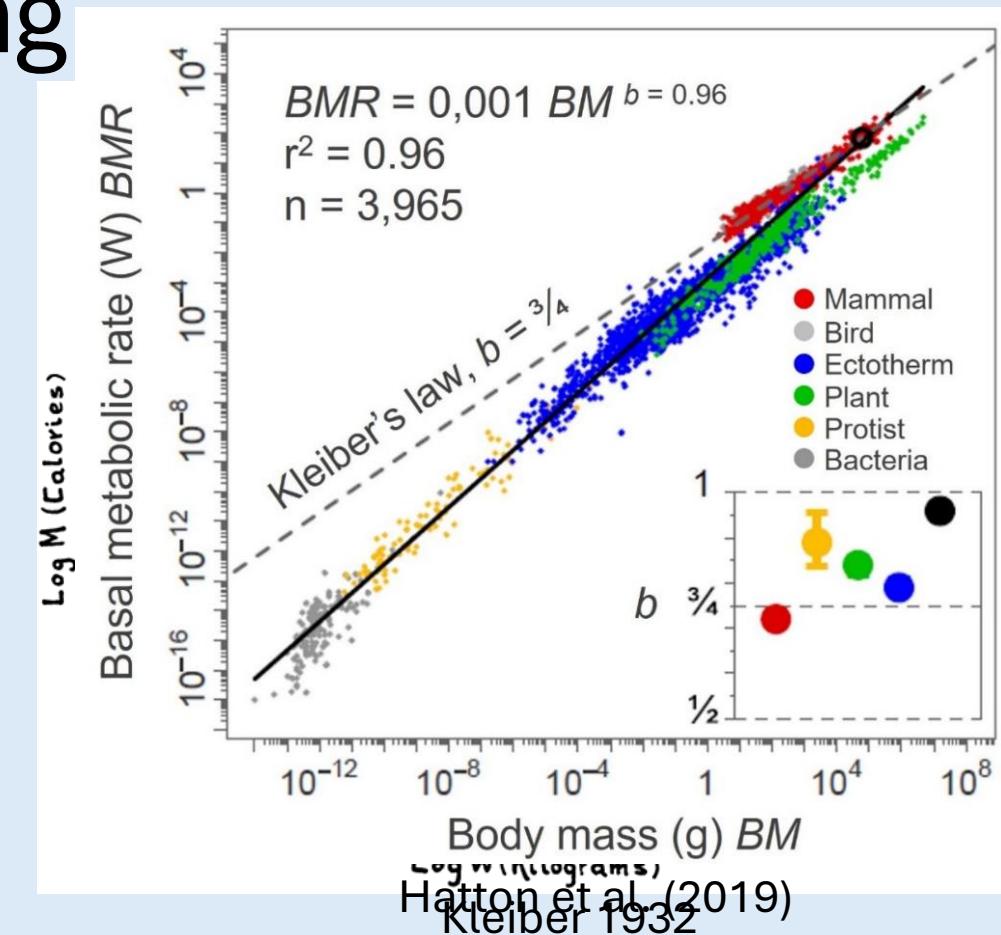


The road of metabolic scaling

- Old concept
 - But still relevant and debated

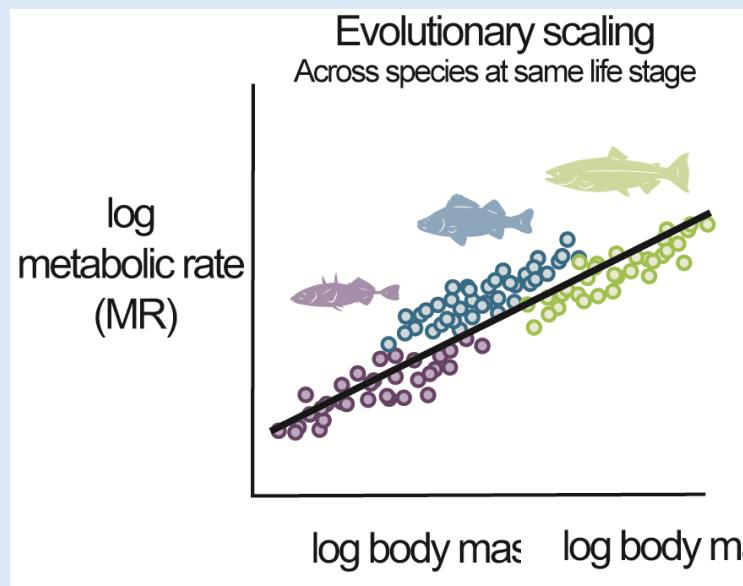


Benedict has shown that this law is already over ninety years old, Robiquet and Tillaye having formulated it quite clearly in 1839. The



The level to compare

- Three fundamental levels



Andreassen, Rosén & Norin 2025

Variation in scaling

- Not set or constant

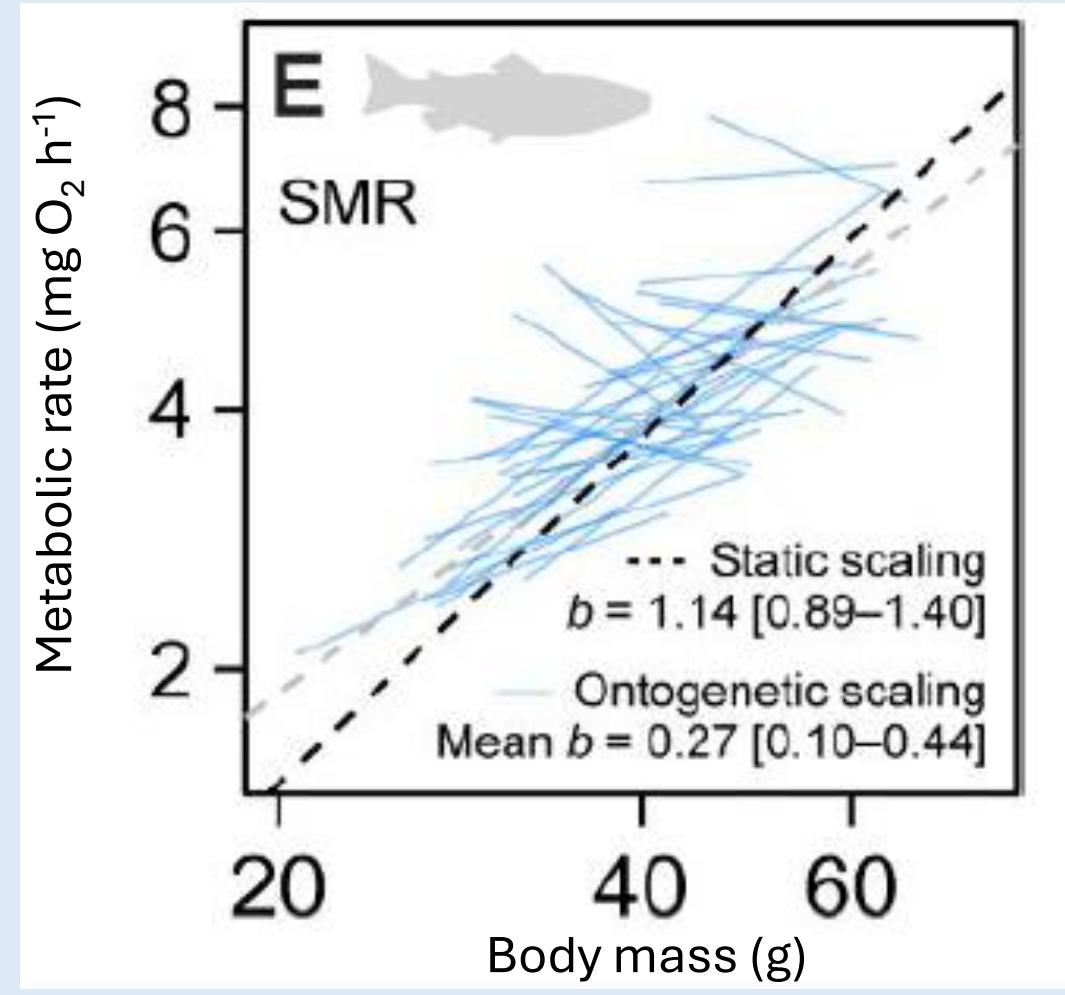
BIOLOGICAL REVIEWS Cambridge Philosophical Society

Full Access

Beyond the '3/4-power law': variation in the intra-and interspecific scaling of metabolic rate in animals

Douglas S. Glazier

First published: 15 March 2007 | <https://doi.org/10.1017/S1464793105006834> | Citations: 828



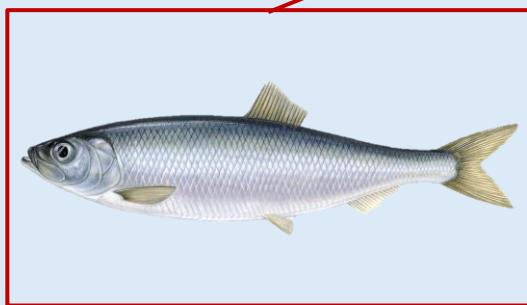
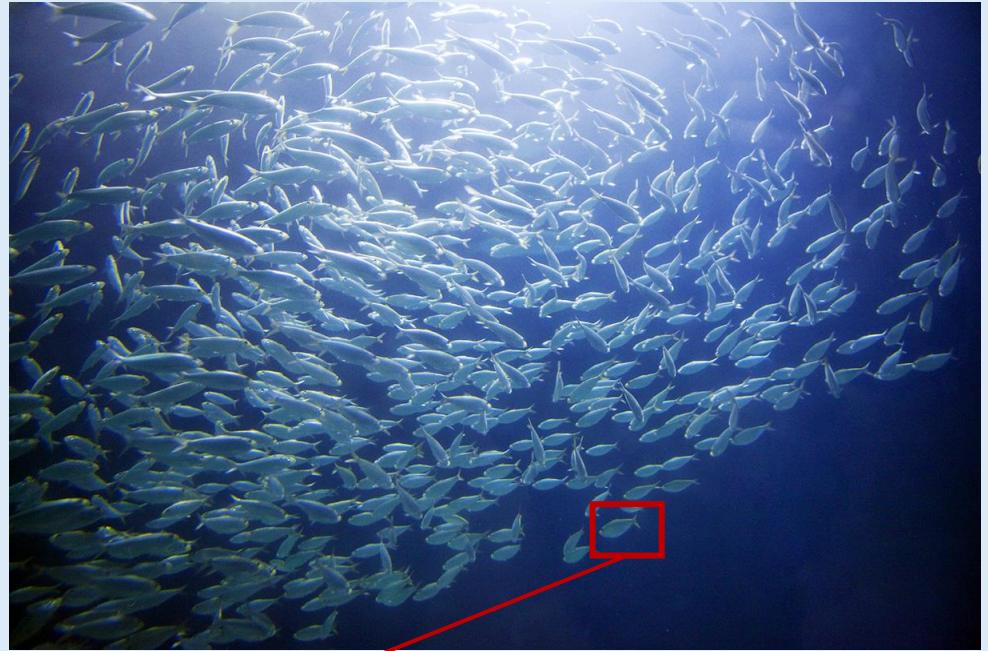
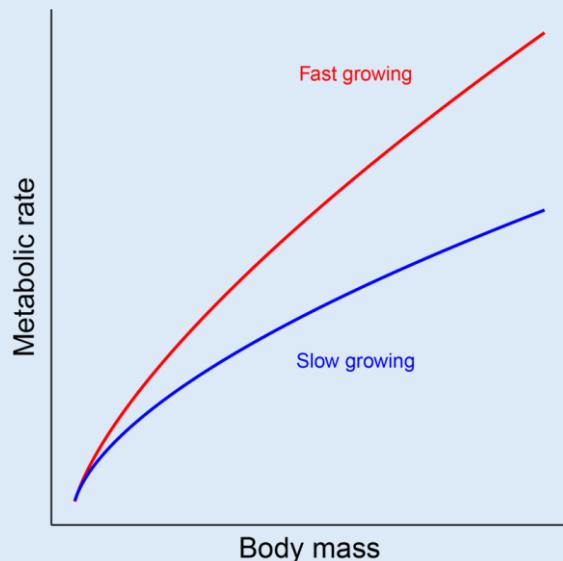
Norin 2022

Why would it be related to growth?

- Mass is gained through growth
- Growth is costly
 - Directly and indirectly

Why ontogenetic?

- It is all about the individual
- Many models, few tests



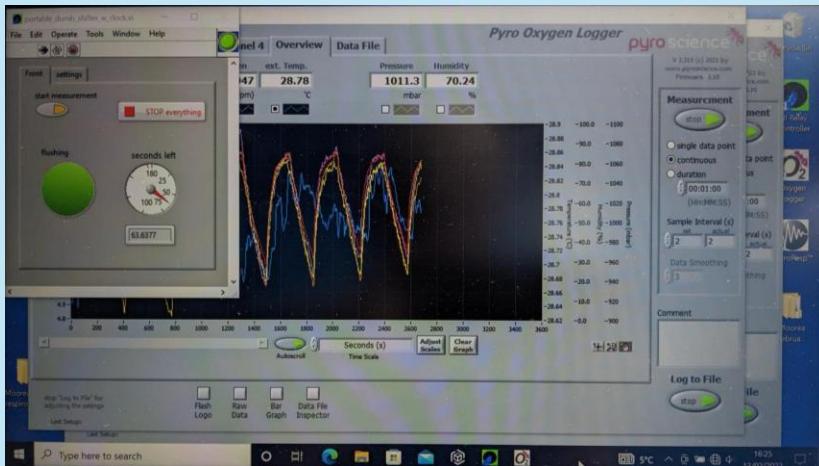
Goal of my PhD

Examine the link between scaling and growth at the individual level

- Examine the effect of food availability on the correlation between growth and metabolism (paper II)
- Look for evidence of trade-offs between scaling of growth and metabolism across species (paper IV)
- Explore scaling in a natural environment under anthropogenic change (paper V)
- Linking scaling levels (paper I)

Effect of food availability on the ontogenetic (co)scaling of metabolic rate and growth rate in fish

- Rosén, A., Storm, Z., Mills, S. C. & Norin T.



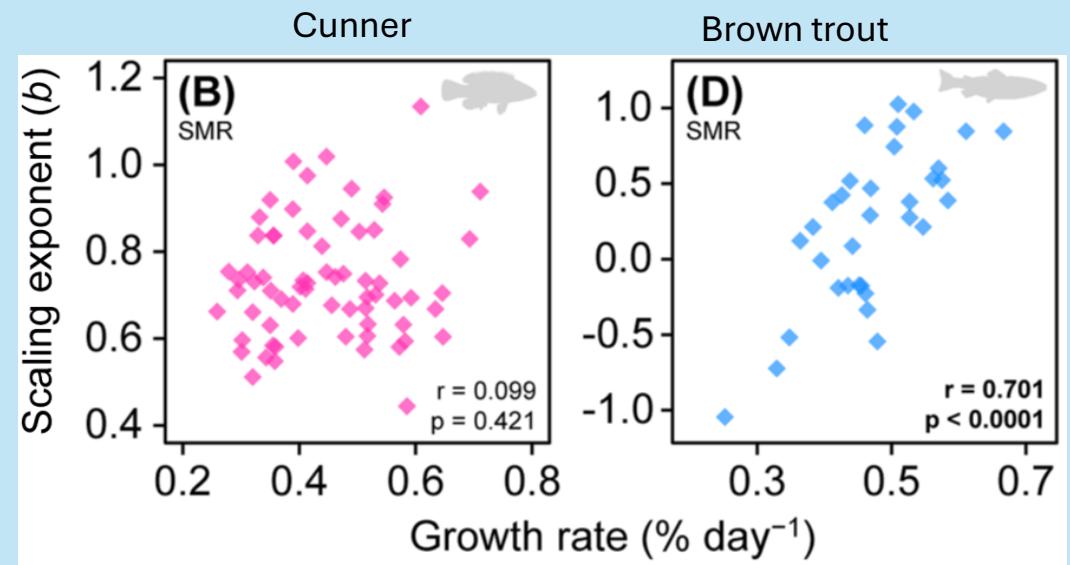
Manuscript written

Motivation/Goal

- Food restriction?
 - Natural condition
- Direct way to manipulate growth

$$MR = a \cdot BM^b$$

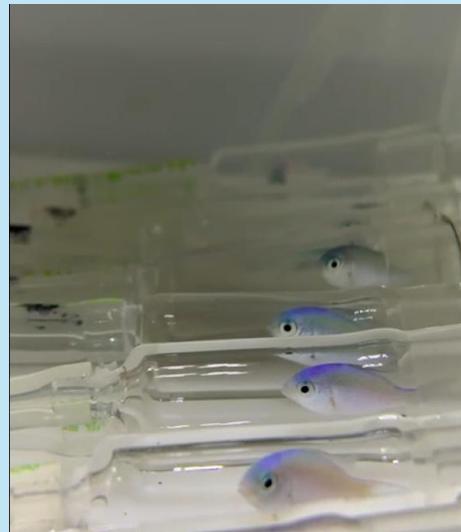
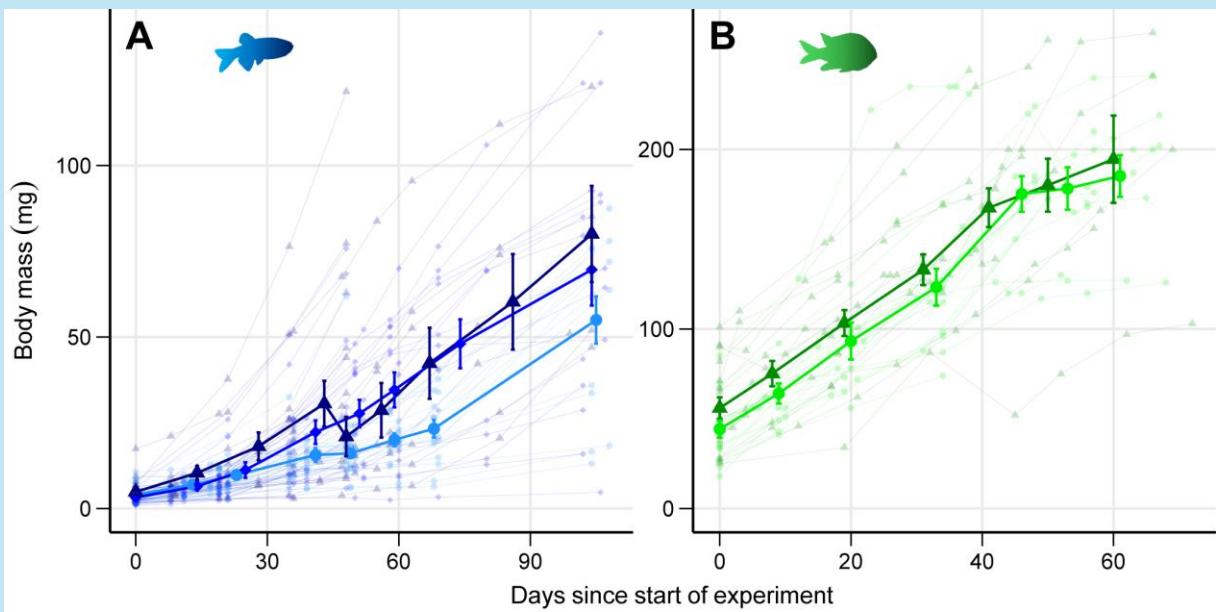
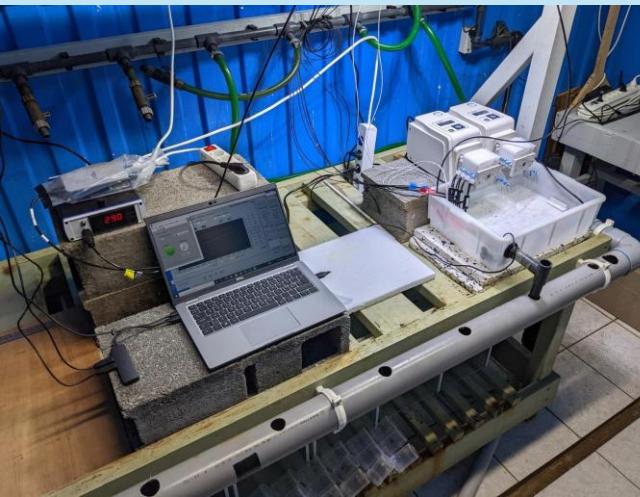
SMR = Standard metabolic rate



Norin 2022

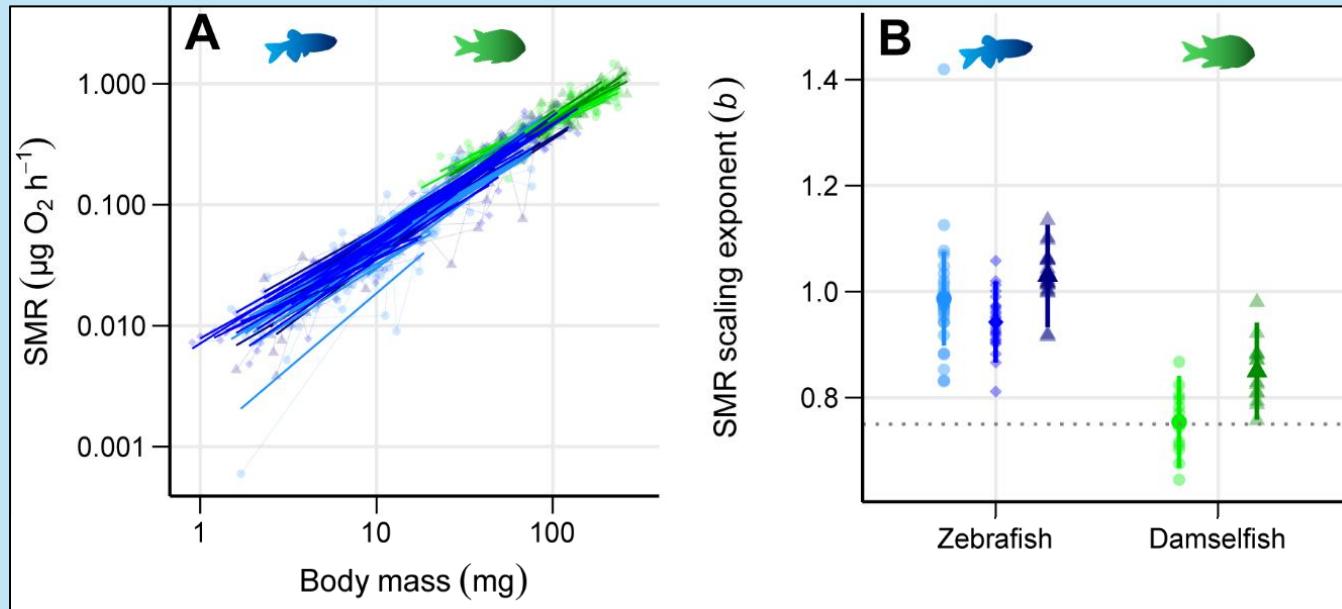
Setup

- Zebrafish
- Blue-green damselfish



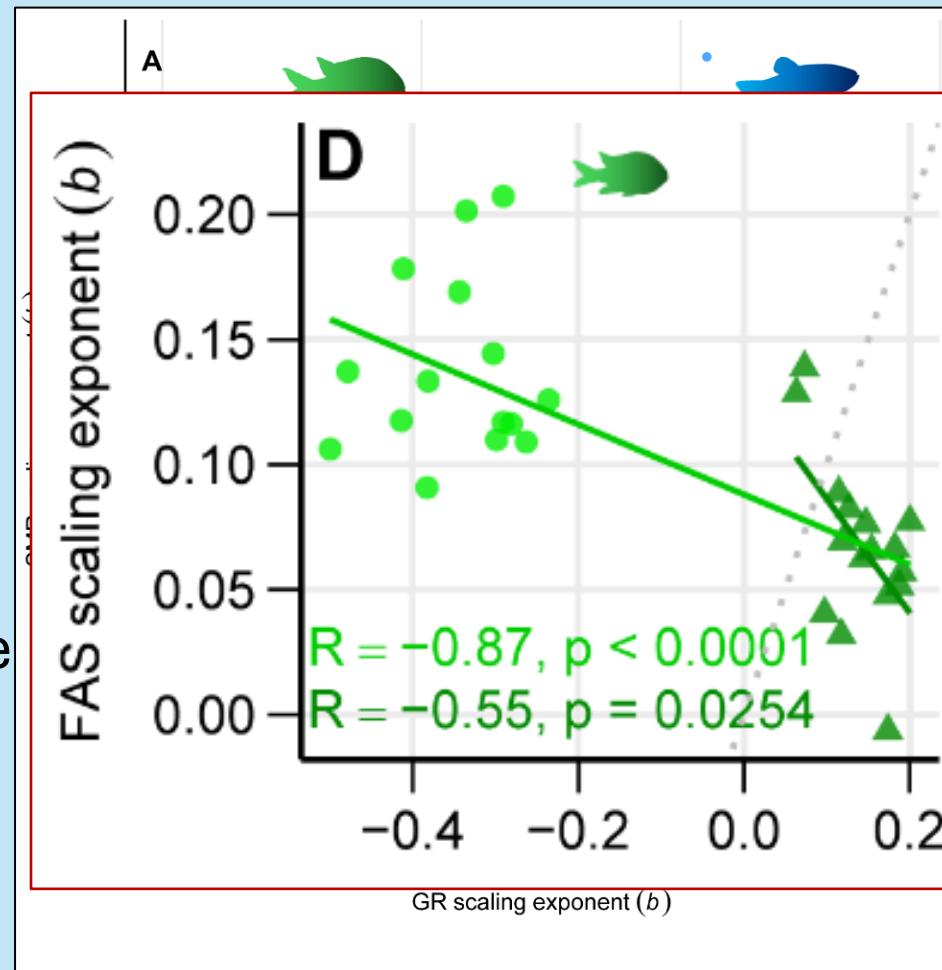
Results

- SMR = Standard metabolic rate
- MR = $a \cdot BM^b$
- b = scaling exponent
- Damselfish
- Zebrafish



Results

- SMR = Standard metabolic rate
- MR = $a \cdot BM^b$
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- Damselfish
- Zebrafish
- MMR = Maximum metabolic rate
- AS = Aerobic scope
- FAS = Factorial aerobic scope

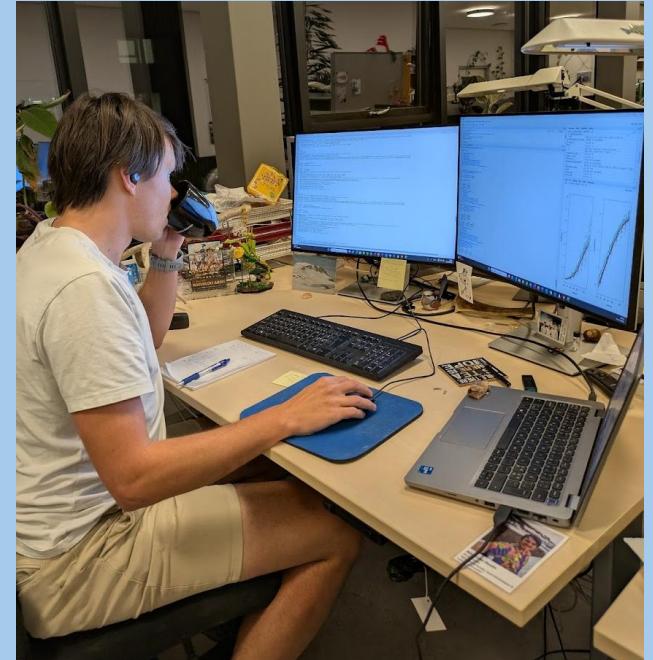


Take home message

- Species-specific effect  ≠ 
- Potential trade-off?

Co-variation and trade-offs in ontogenetic scaling of growth and metabolic rates

- Rosén, A., Andreassen, A. H., Storm, Z., Exsteen, J. W., Moesby, A. F., Raqbi, S., Beldade, R., Mills, S. C., & Norin, T.

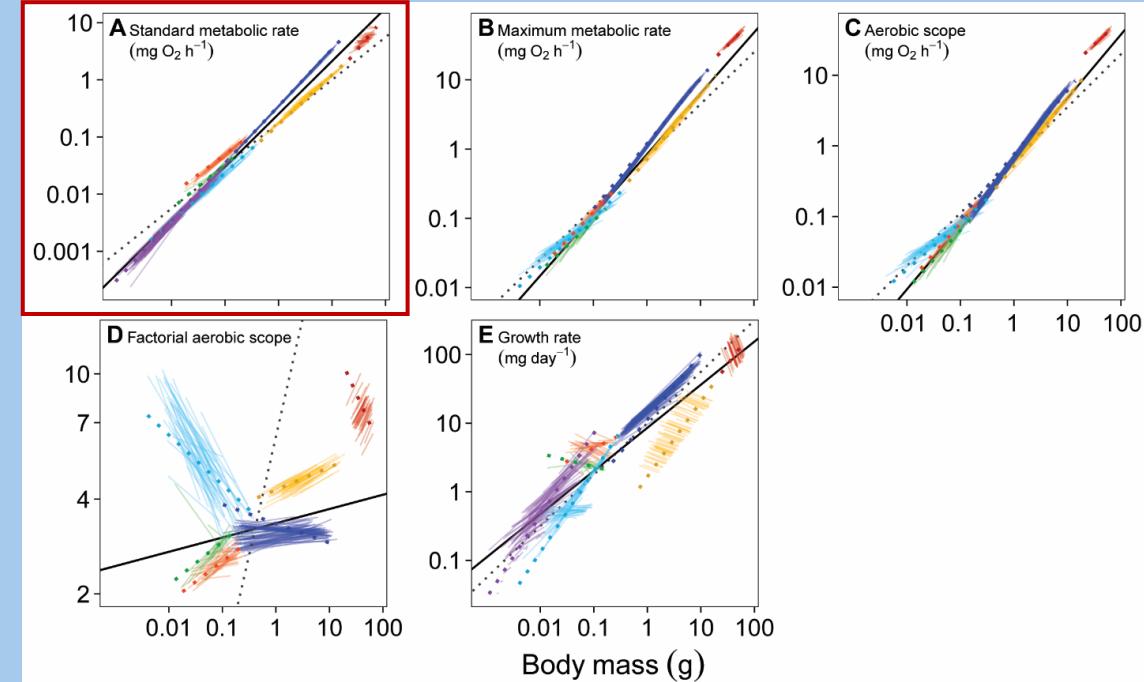
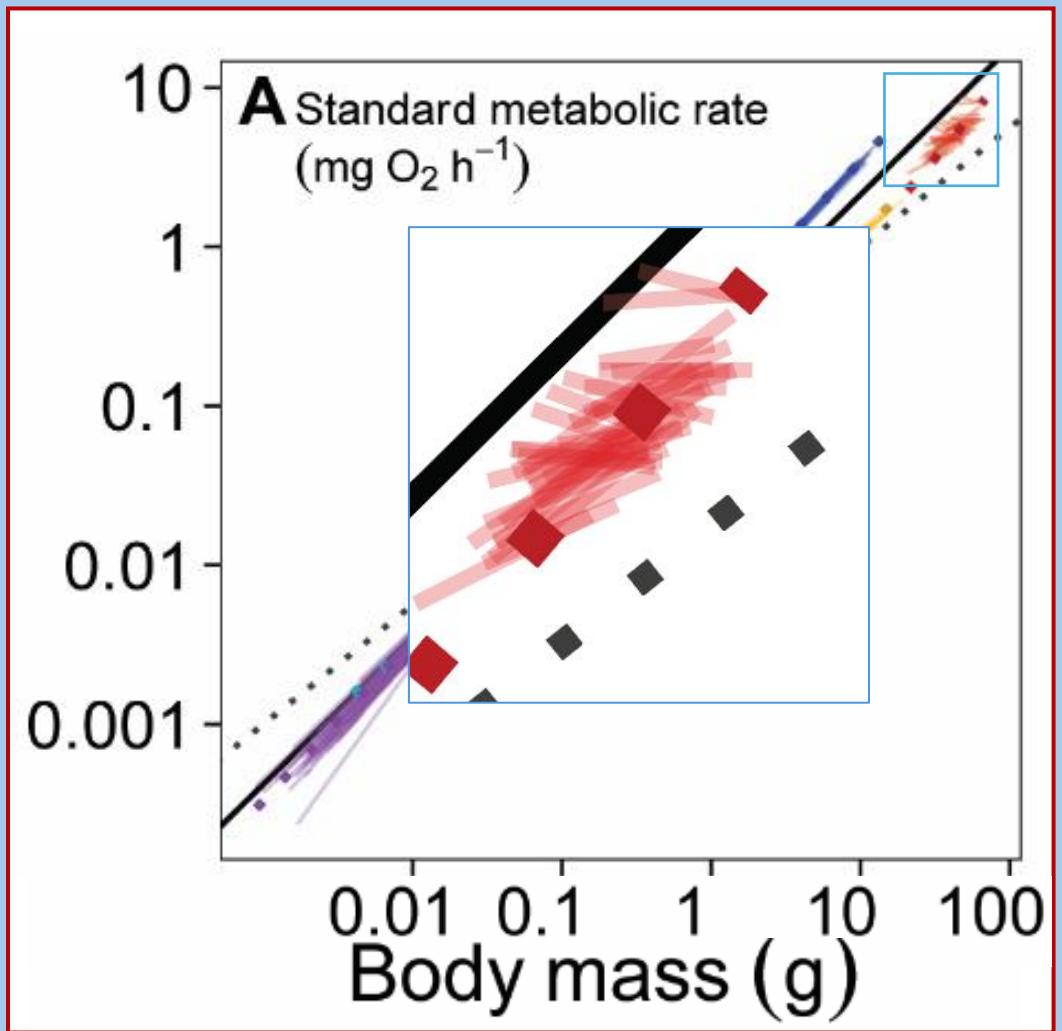


Overview

7 species, 389 individuals, 2500 measurements

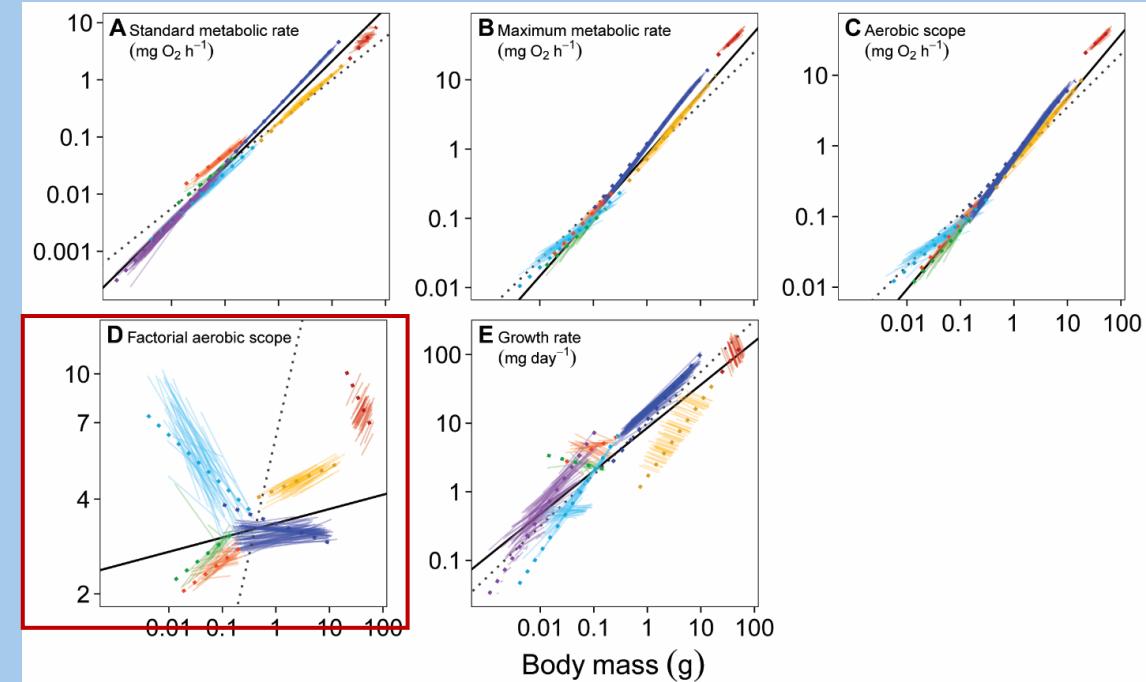
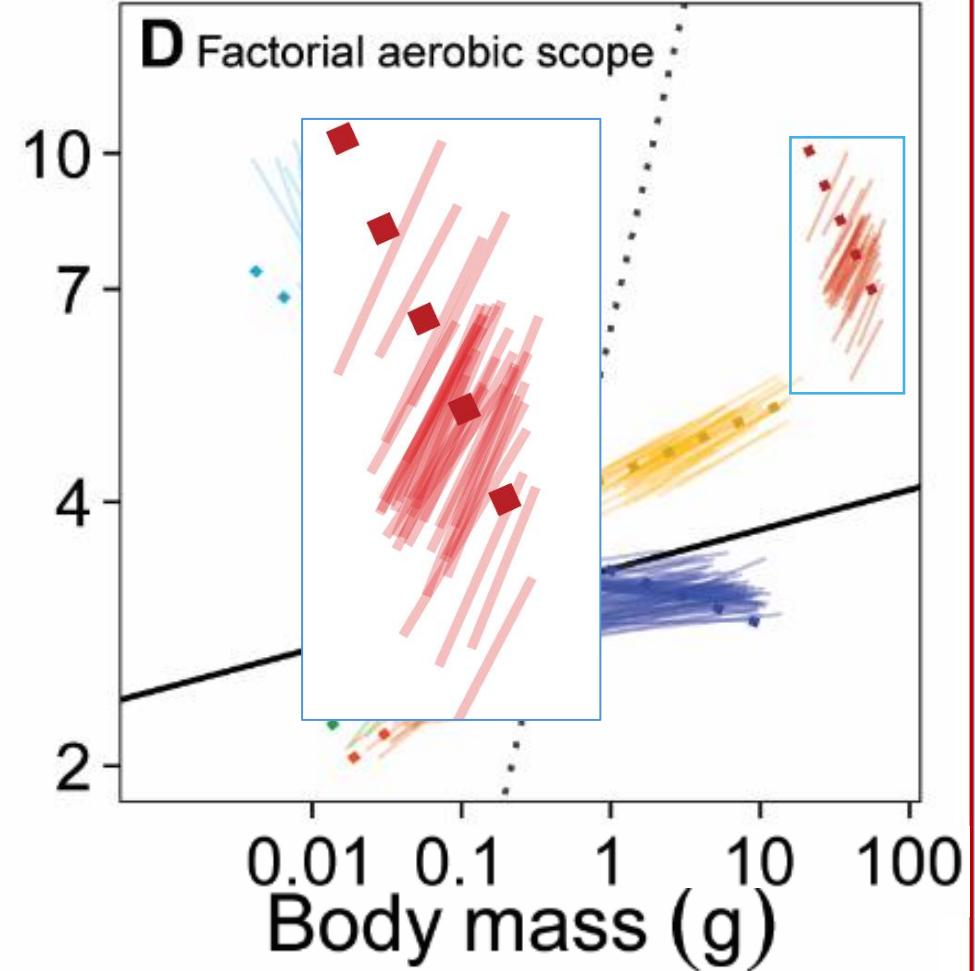


Results

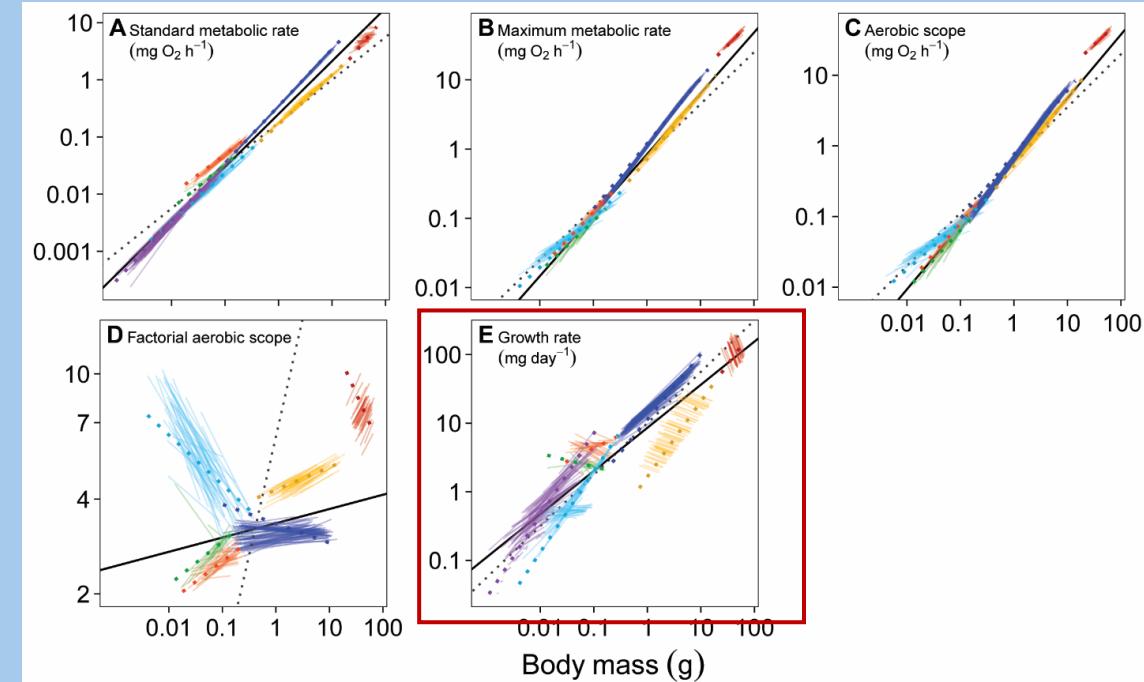
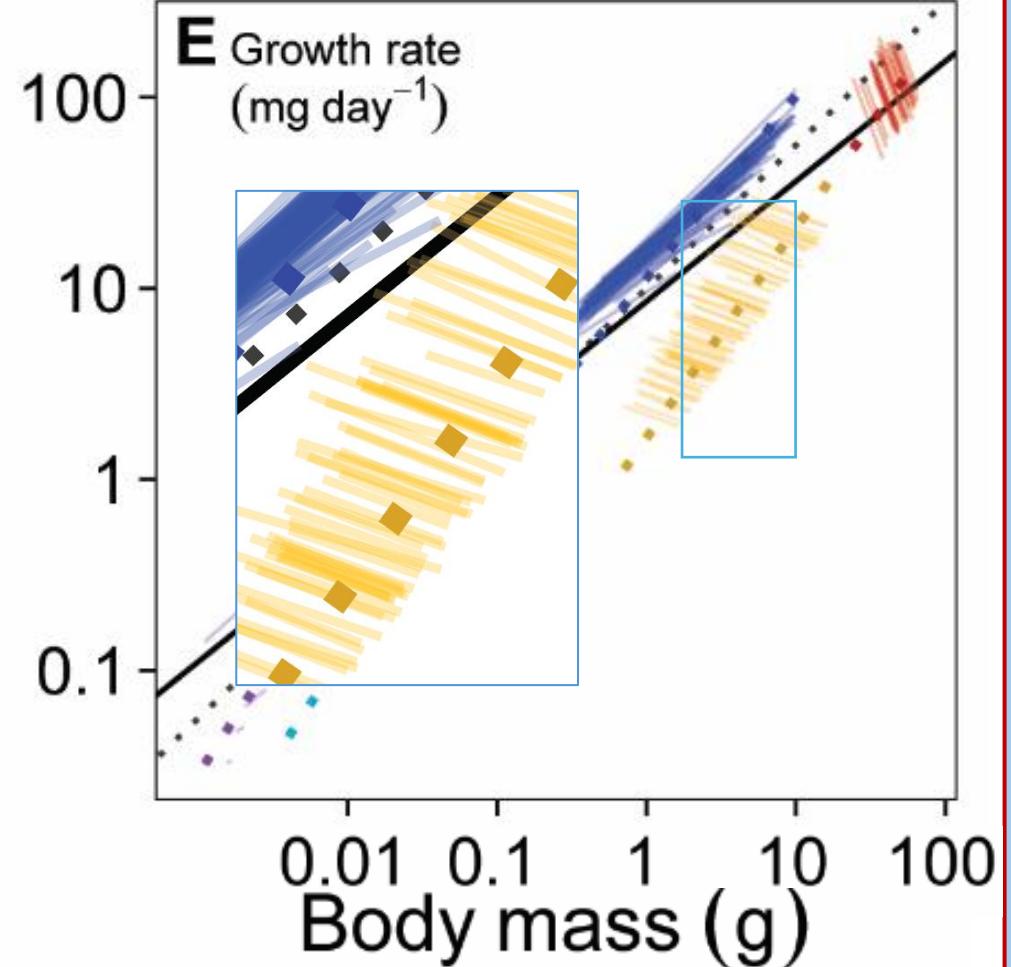


- Brown trout
 - Damselfish
 - Clownfish
 - Cunner
 - Guppy
 - Rainbow trout
 - Zebrafish
 - ... 0.75 reference line
 - Regression

Results

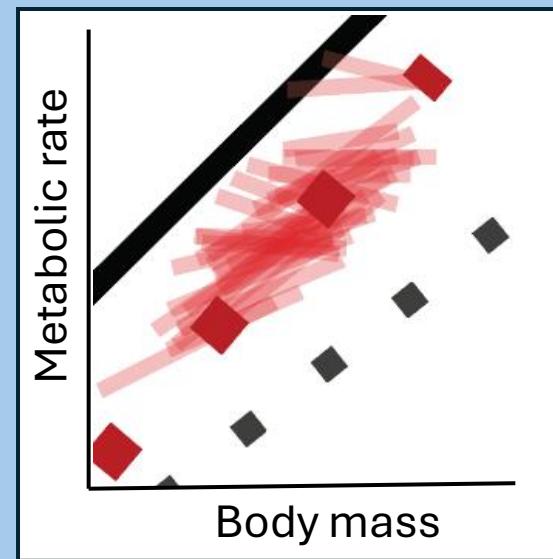
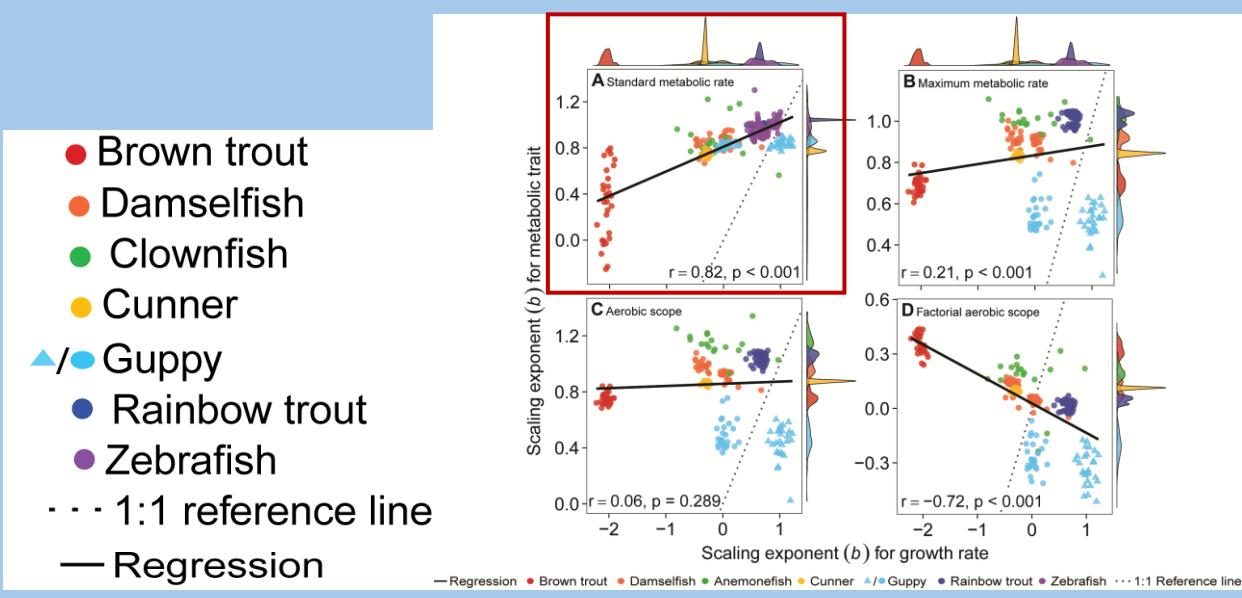
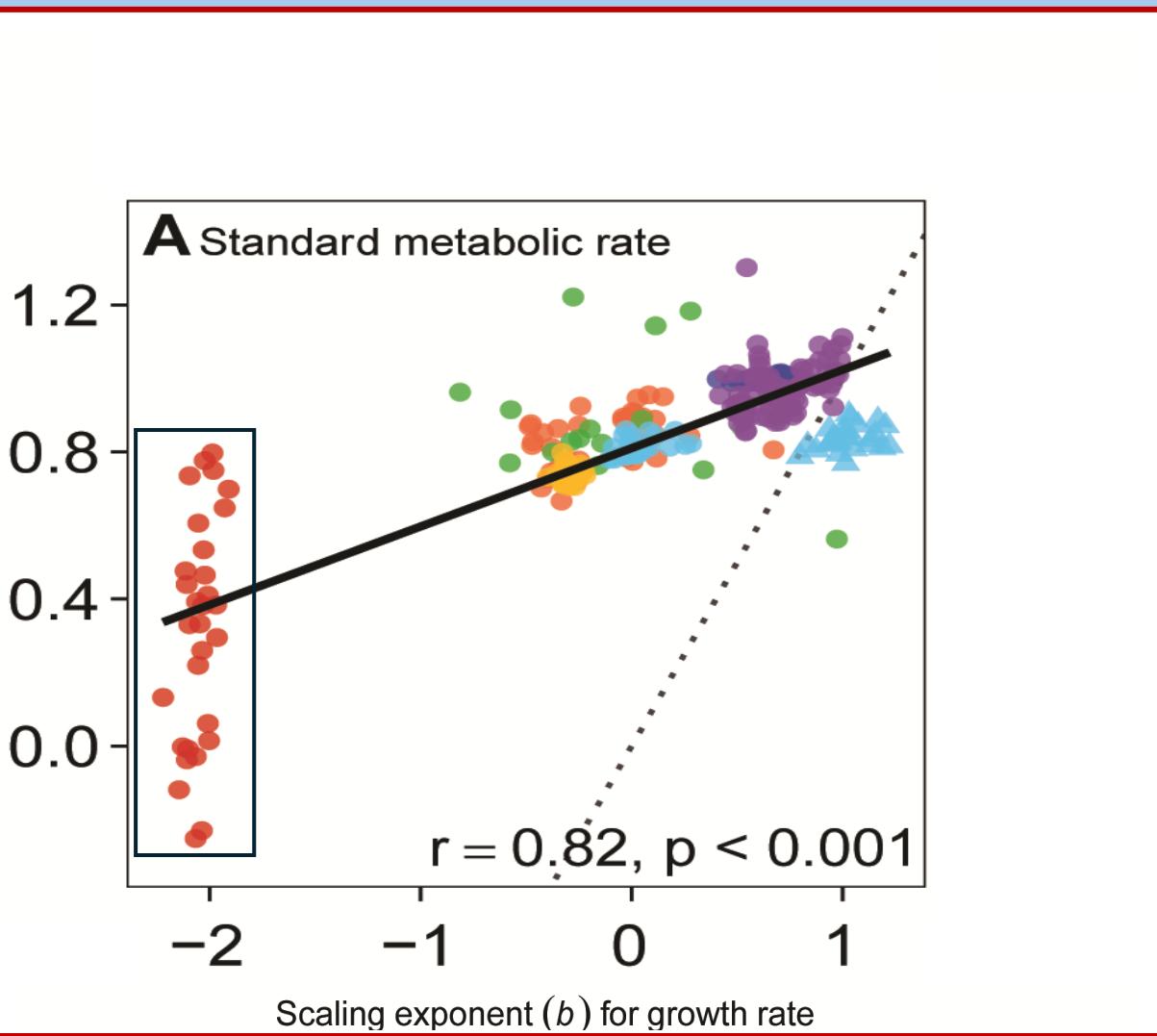


Results

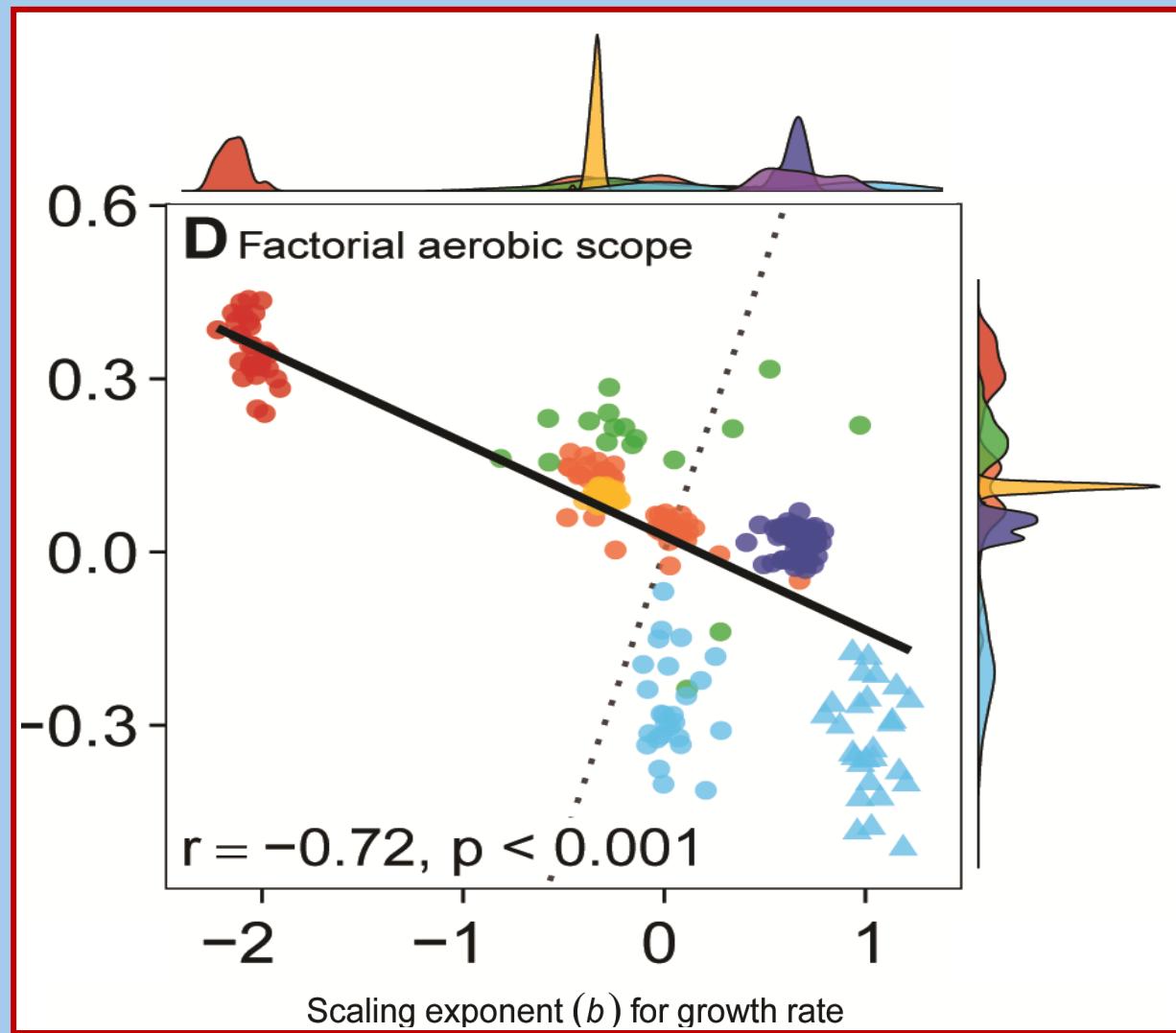


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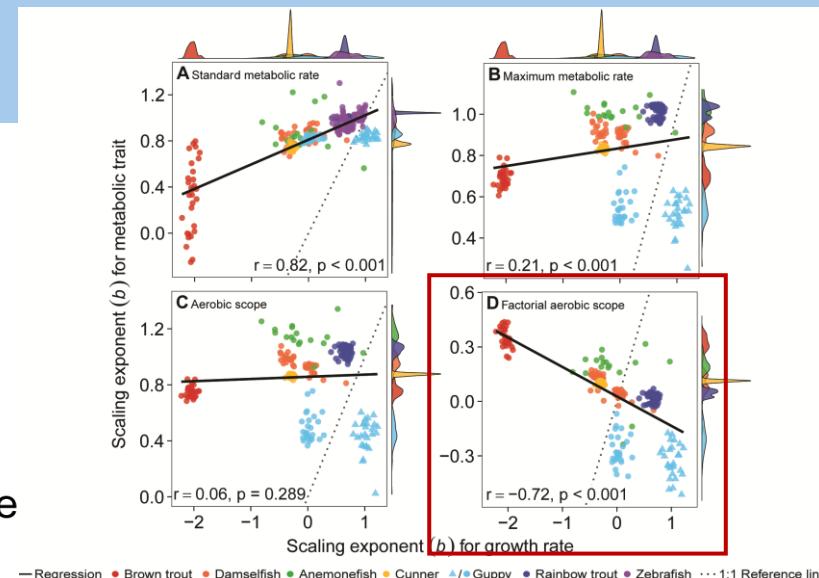
Results



Results



- Brown trout
- Damselfish
- Clownfish
- Cunner
- △/○ Guppy
- Rainbow trout
- Zebrafish
- - - 1:1 reference line
- Regression

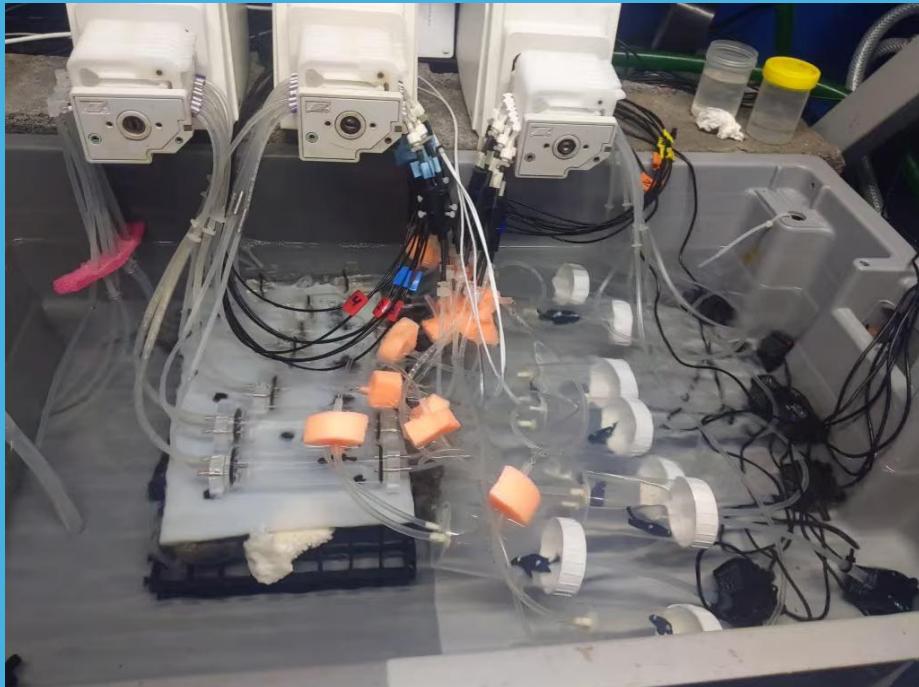


Take home message

- Differences between species
- Potential difference between static and ontogenetic
- Potential trade-off between growth and aerobic capacity
- Narrower range in scaling exponents for metabolism compared to growth

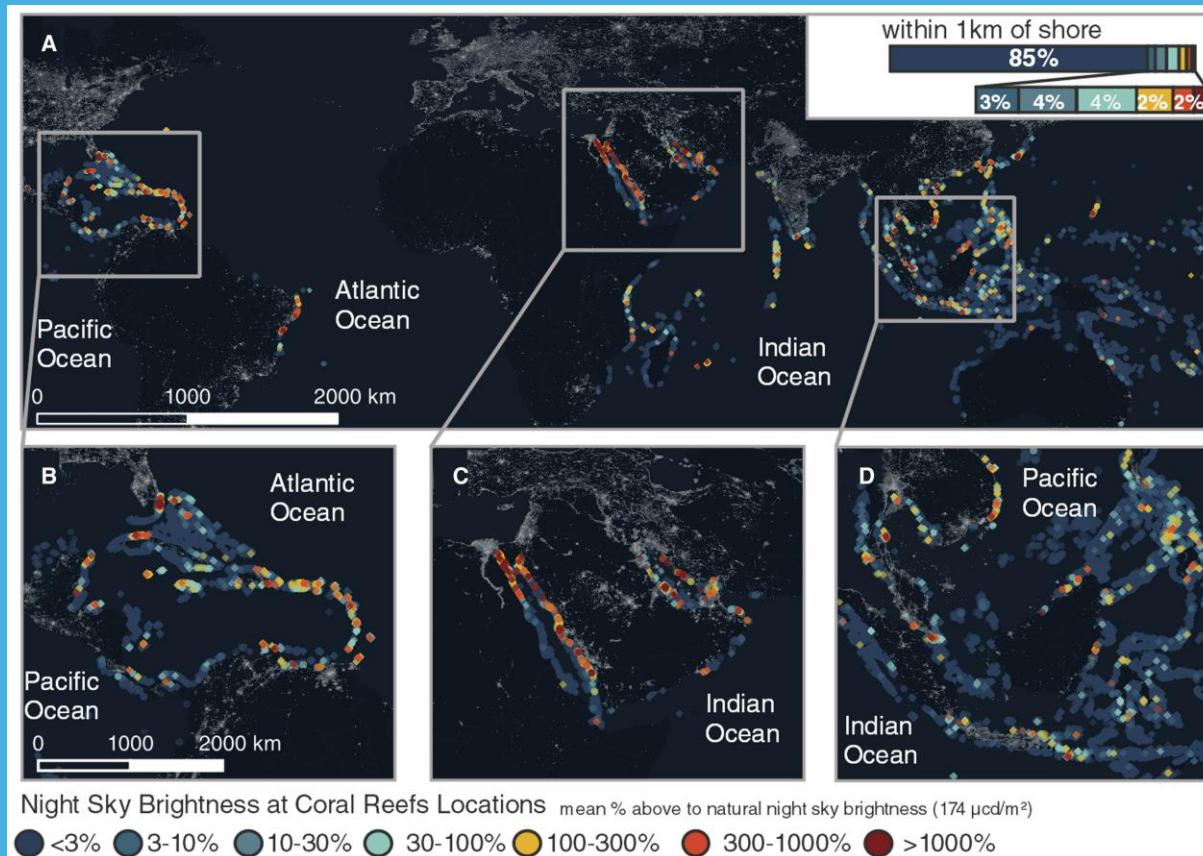
Shining a light on it: Repeated measurements of metabolism and growth on fish in the wild under the influence of light pollution

- Rosén, A., Mills, S. C. & Norin, T.



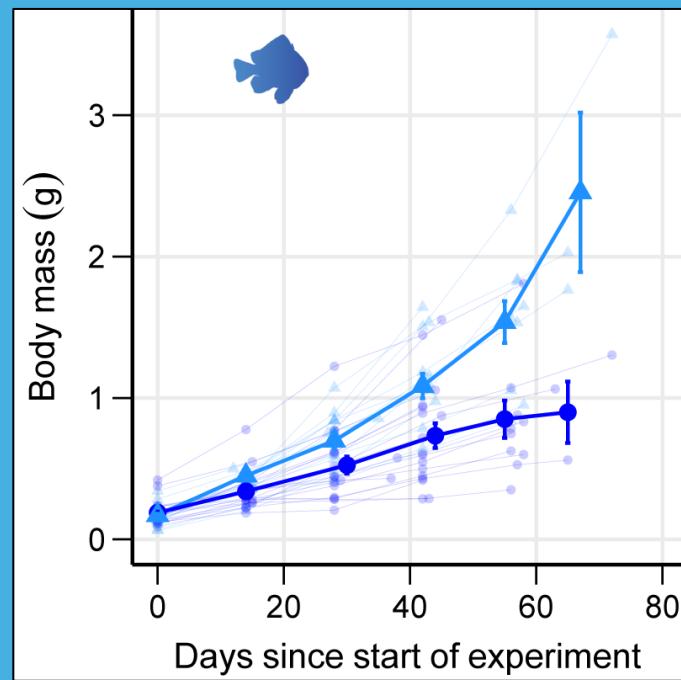
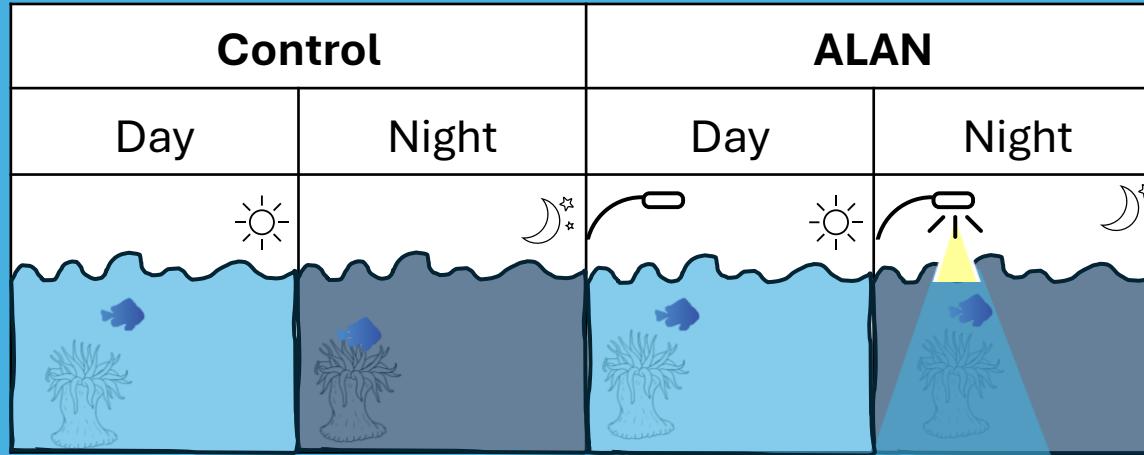
Motivation/Goal

- Genuine natural conditions
- Effect of anthropogenic pressures
- Artificial light at night (ALAN)



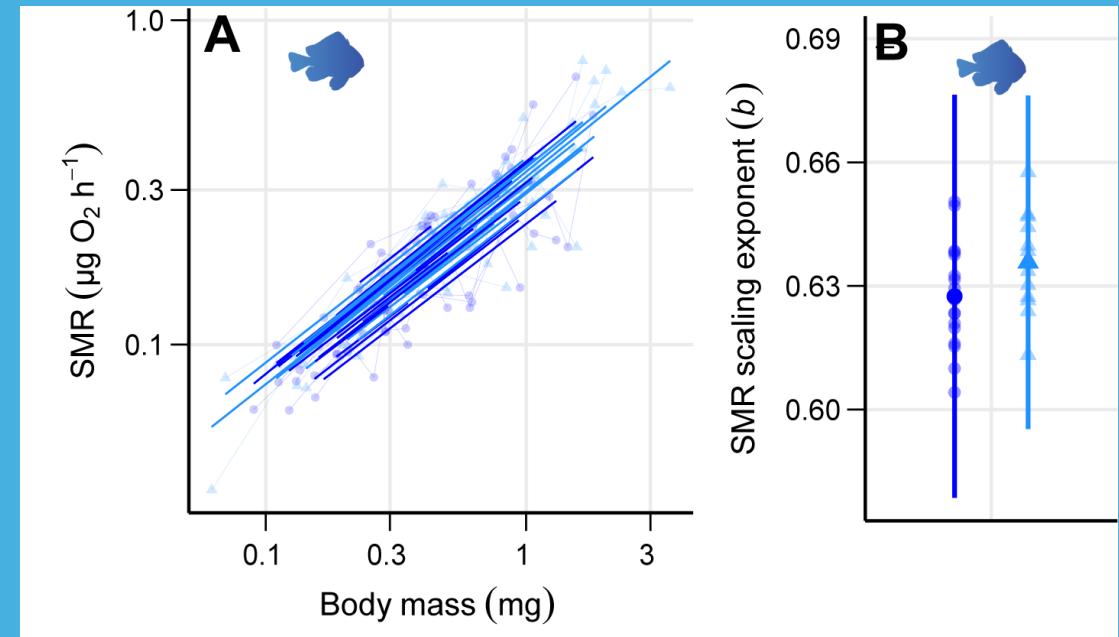
Ayalon et al. 2021

Setup



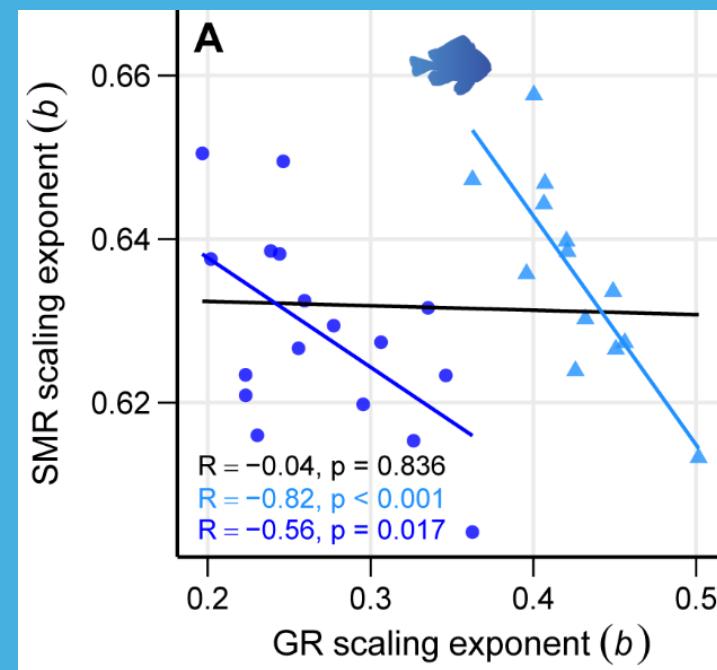
Results

- $MR = a \cdot BM^b$
- b = scaling exponent
- SMR = Standard metabolic rate
- Control
- ALAN (artificial light at night)



Results

- $\text{MR} = a \cdot BM^b$
- b = scaling exponent
- SMR = Standard metabolic rate
- Control
- ALAN (artificial light at night)



Take home message

- Opposite pattern than what is observed in the lab
- Correlation depends on the way growth is expressed

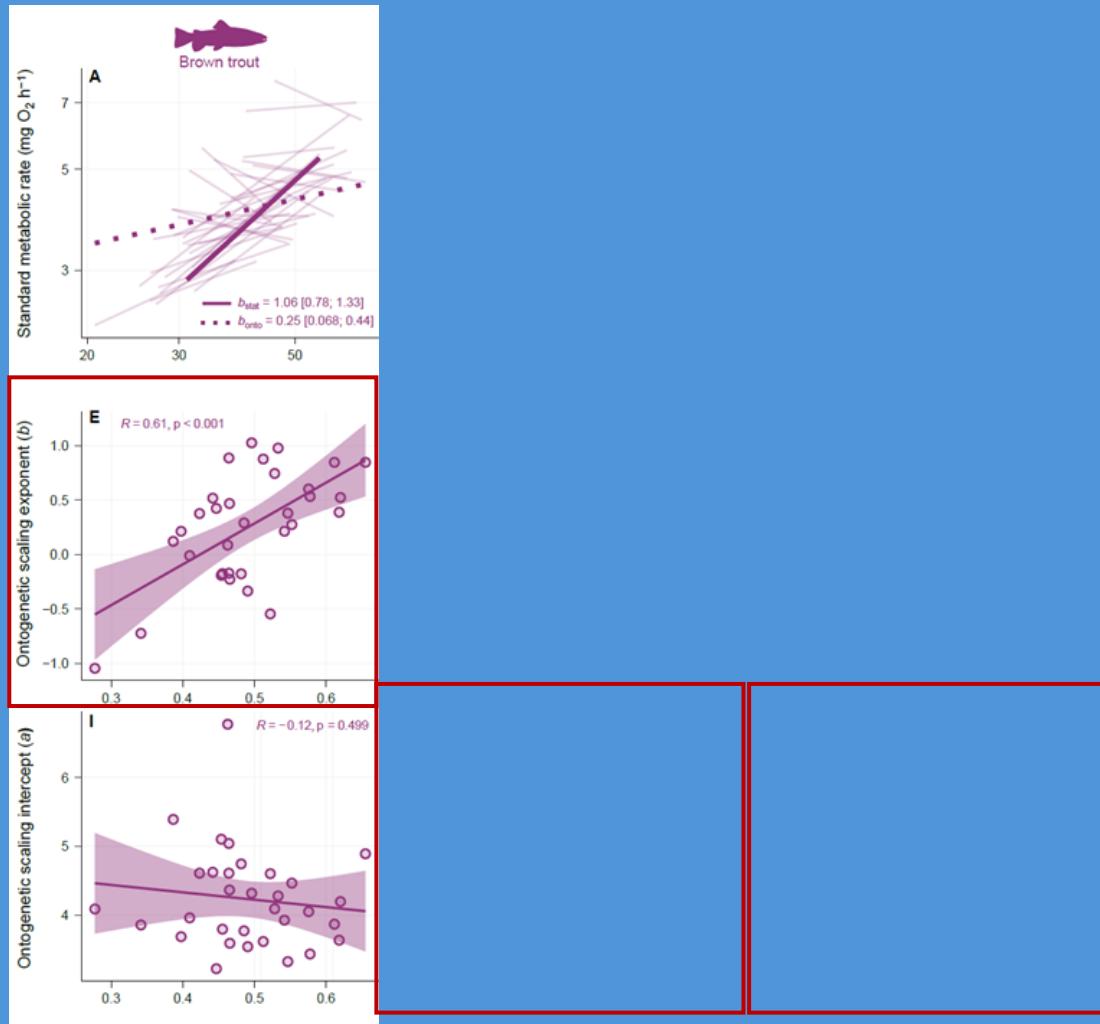
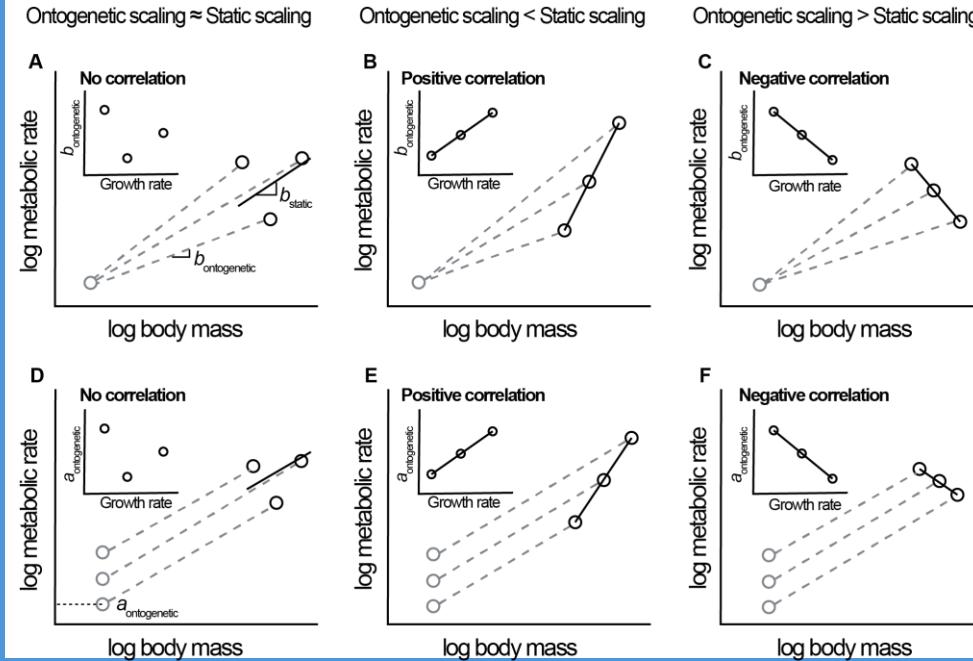
Ontogenetic growth and size-at-age shape metabolic scaling

- Andreassen, A. H., Rosén, A., & Norin, T.

Do patterns at the ontogenetic level shape higher levels?

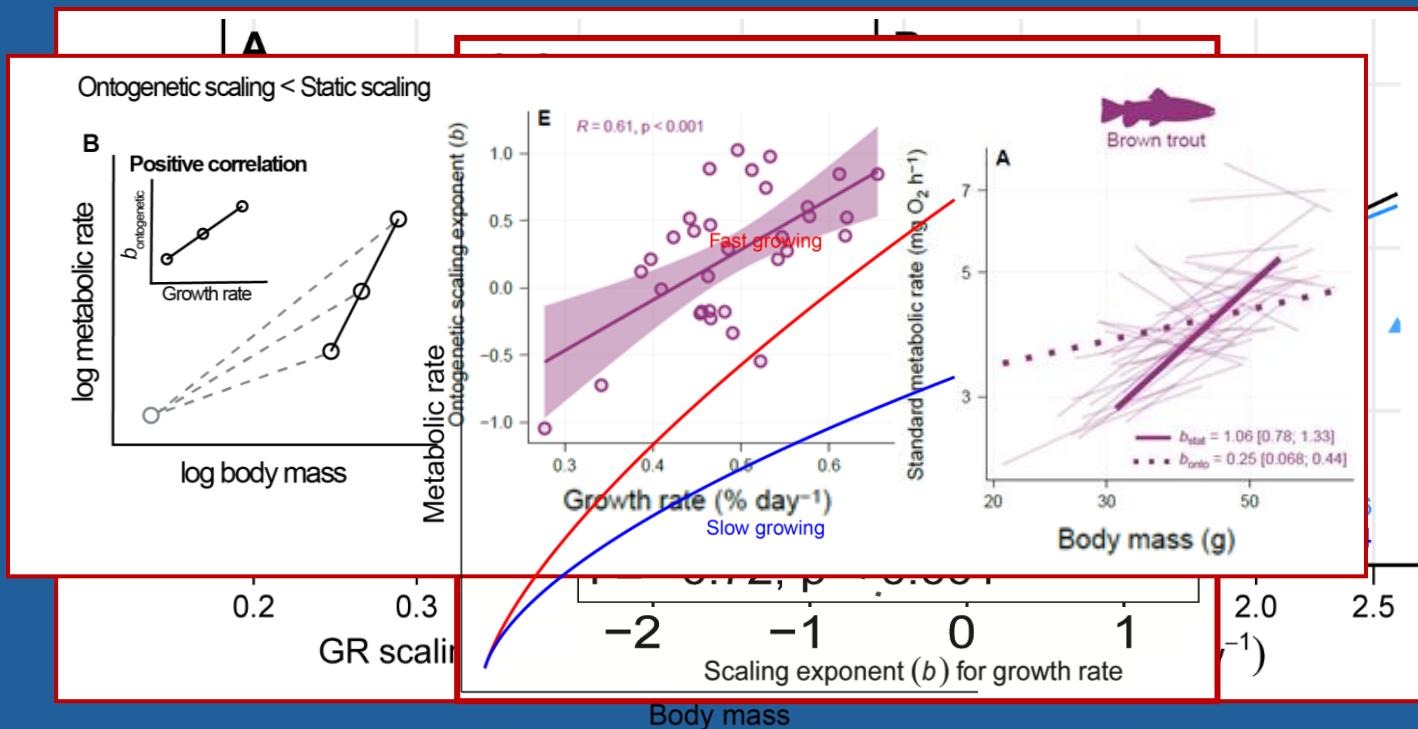
- Theory matches results?

$$MR = a \cdot BM^b$$

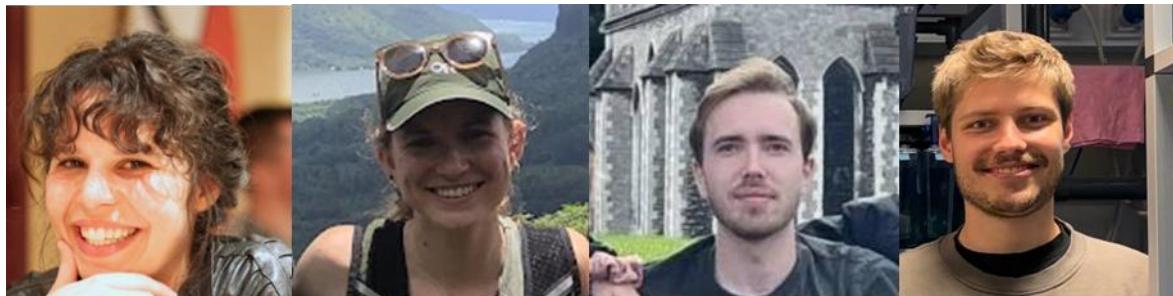


Overall take home message

- The scaling of metabolic rate and growth is linked
- Potential trade-off in scaling of metabolism and growth
- Scaling patterns at the ontogenetic level can shape patterns at higher levels
- Care should be taken when scaling exponent



Thank you making my PhD possible!

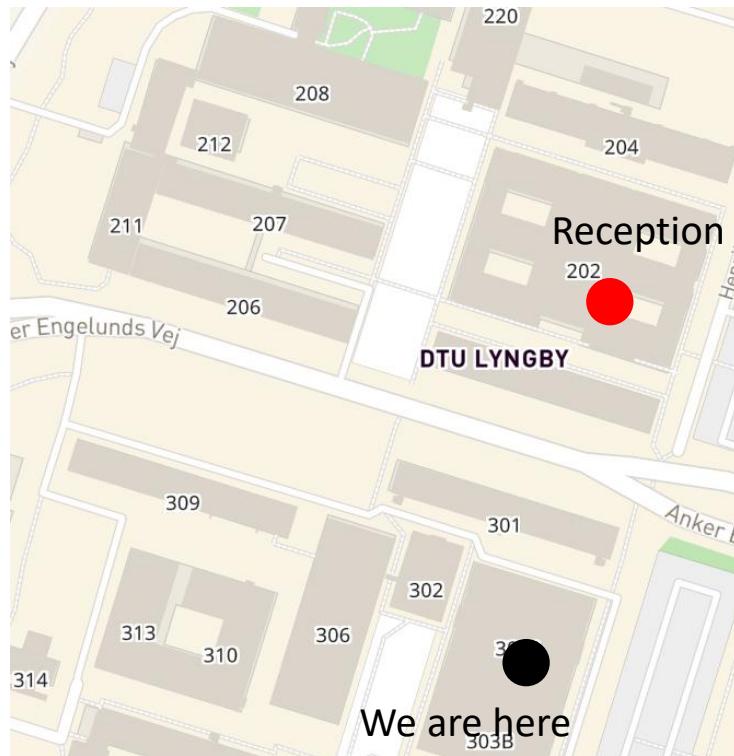


Thank you for making my PhD amazing 😊



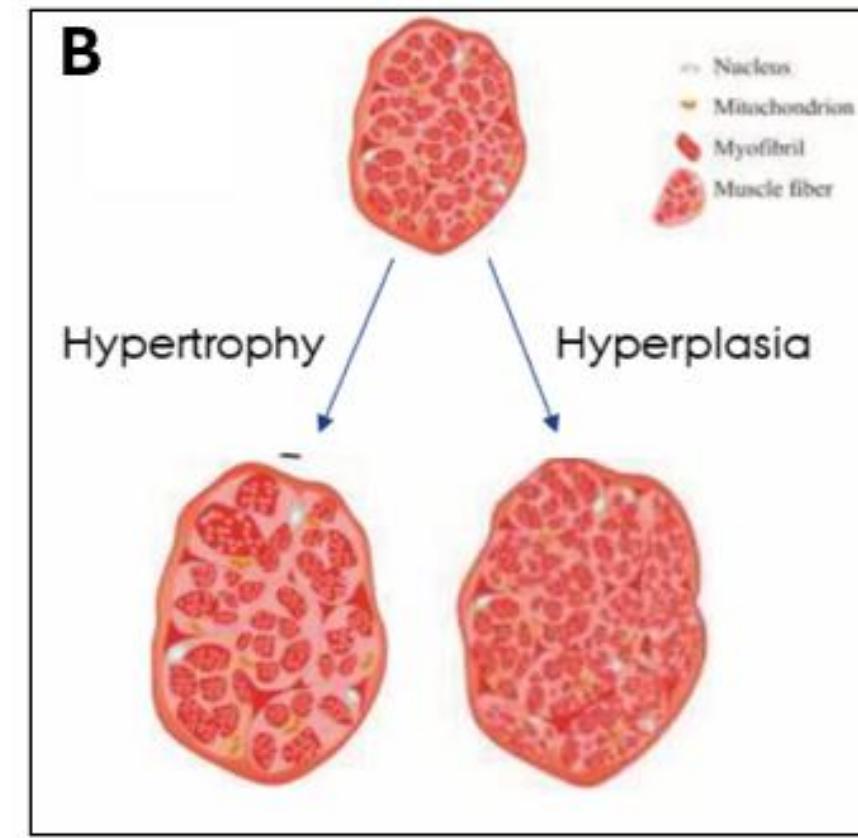
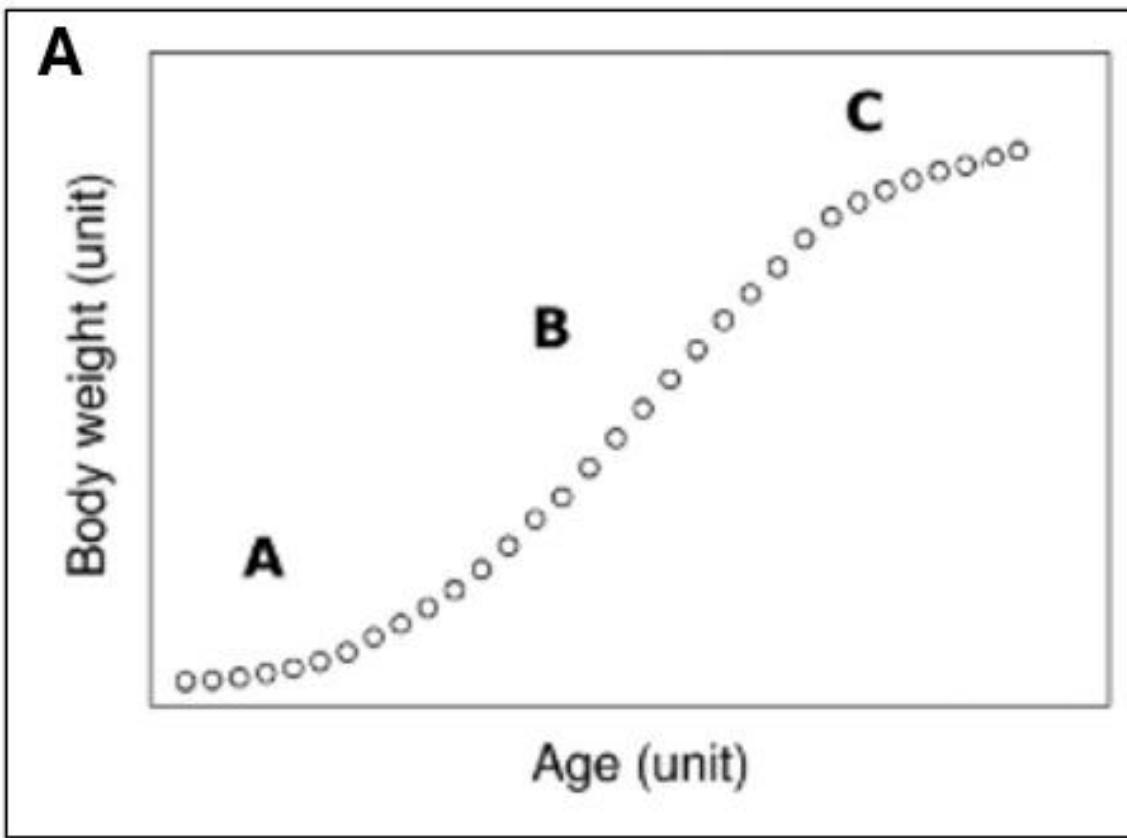
See you all at the reception after ☺

- Alcove on the 1. floor
Building 202 (Biosfæren)



“Champagne:
In victory I deserve it;
In defeat I need it.”
- Churchill

Growth in fish



Future research

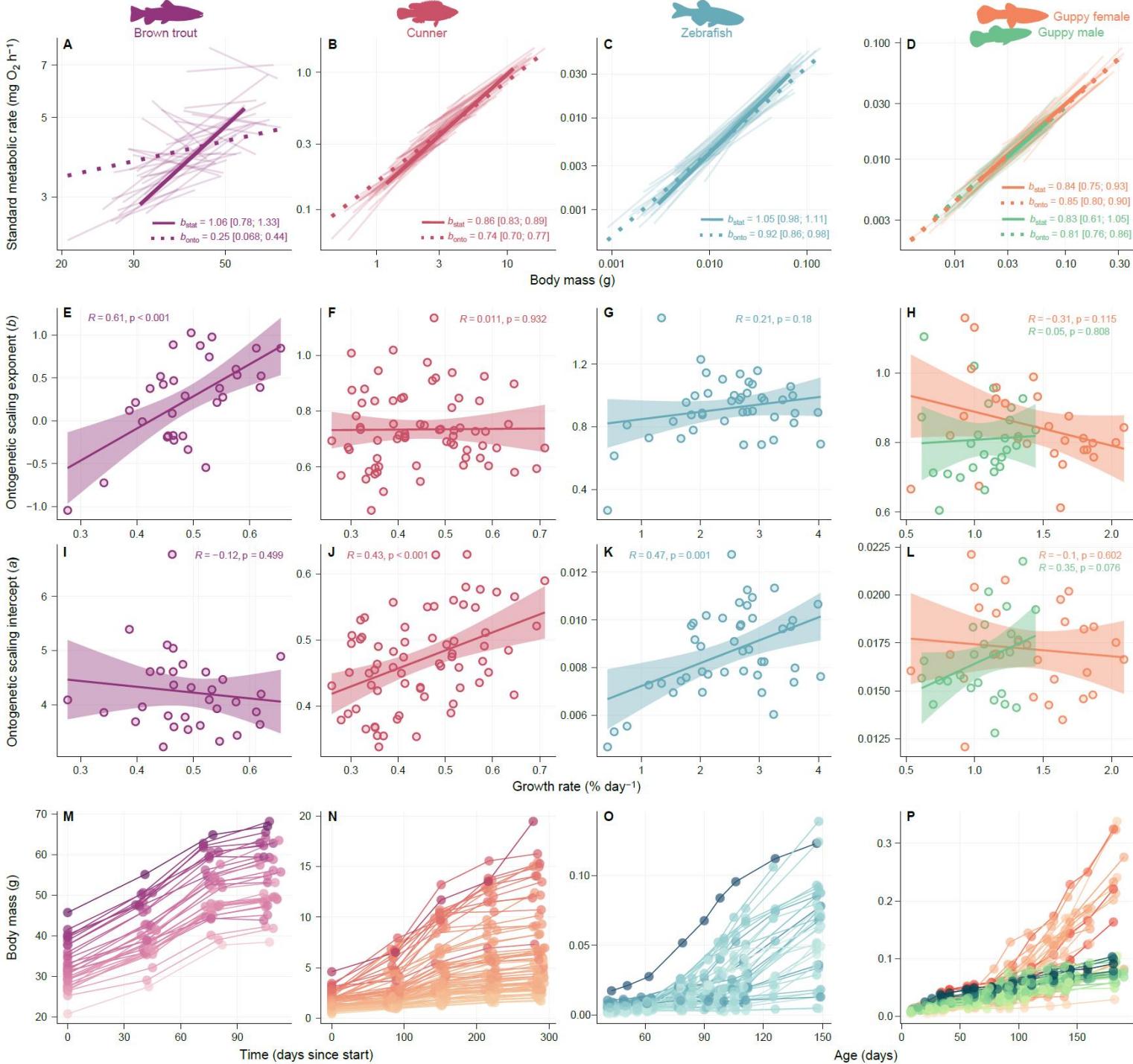
- Why they correlate – a better mechanistic understanding
 1. Inhibit protein synthesis
 2. Manipulate mitochondrial function
 3. Repeated measurements of tissue
- The permanent cost high growth rate
- How it works in the wild
 1. Is the effect of an environmental factor permanent
 2. Couple with real-world fitness

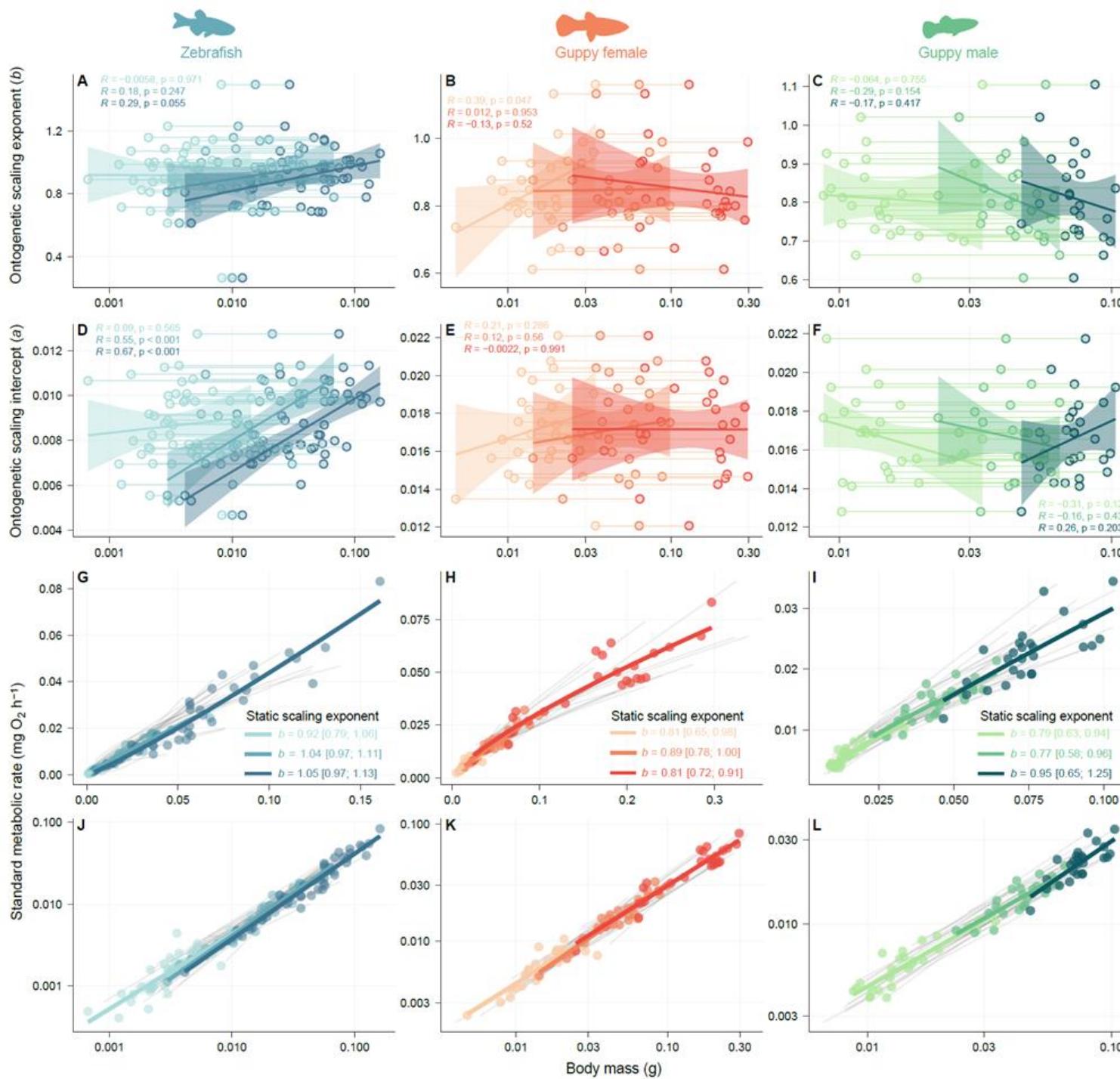
How to measure metabolic rate

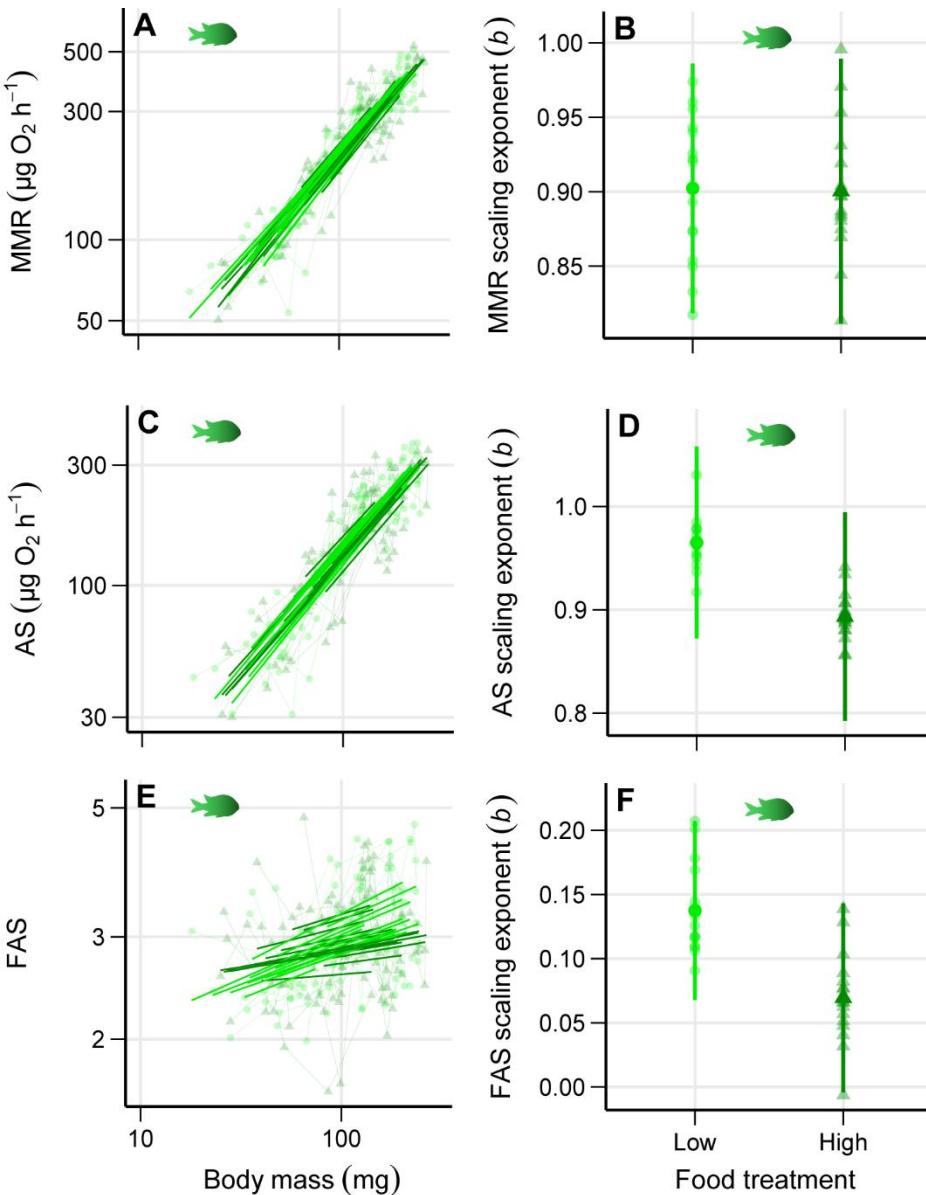
- Flow through, closed, intermittent

Things that I would do differently

- Measure MMR in zebrafish
- Note down other factors for wild fish such as behaviour







Species	Trait	L	M	H
Zebrafish	SMR	0.99 [0.9, 1.08]	0.94 [0.86, 1.02]	1.03 [0.93, 1.13]
Zebrafish	GR	0.54 [0.35, 0.73] ^a	0.68 [0.54, 0.82] ^{a,b}	0.90 [0.69, 1.11] ^b
Damselfish	SMR	0.75 [0.66, 0.84]	—	0.85 [0.76, 0.94]
Damselfish	MMR	0.90 [0.82, 0.98]	—	0.90 [0.81, 0.99]
Damselfish	AS	0.97 [0.88, 1.06]	—	0.89 [0.79, 0.99]
Damselfish	FAS	0.14 [0.07, 0.21]	—	0.07 [0, 0.14]
Damselfish	GR	-0.35 [-0.72, 0.02]	—	0.14 [-0.26, 0.54]

Species	Trait	L	M	H	Across
Zebrafish	SMR	R = 0.15, p = 0.475	R = -0.09, p = 0.656	R = 0.17, p = 0.482	R = 0.23, p = 0.052
Damselfish	SMR	R = -0.34, p = 0.217	—	R = -0.03, p = 0.926	R = 0.59, p > 0.001
Damselfish	MMR	R = -0.33, p = 0.229	—	R = 0, p = 0.992	R = -0.06, p = 0.751
Damselfish	AS	R = -0.15, p = 0.583	—	R = -0.11, p = 0.673	R = -0.83, p > 0.001
Damselfish	FAS	R = 0.07, p = 0.798	—	R = -0.56, p = 0.025	R = -0.72, p > 0.001
Both	SMR	—	—	—	R = 0.74, p > 0.001