Steep body mass scaling of biological rates in macrozooplankton supports a Surface Area dependent model

Martin Lilley, Andrew Hirst, Doug Glazier, David Atkinson

Marine Ecosystems Research Programme
Queen Mary University of London
Ocean Life Centre for Ocean Life VKR Centre of Excellence
JUNIATA COLLEGE
UNIVERSITY OF LIVERPOOL

Metabolism

$$\text{Respiration} = a\ \text{Mass}^b$$

- Respiration rate commonly related to organism size using a power function
- What determines the *b* power term has been a central question in ecology for over 100 years
- As organisms enlarge they commonly utilise less oxygen per unit mass ($b < 1$)
- Here we will focus on intra-specific scaling

Theories of Metabolic Scaling

Two groups of theories attempt to mechanistically describe metabolic scaling through resource supply:

Internal Transport Networks

1. Metabolic Theory of Ecology (West *et al.* 1999 Science)

2. Explosive Network Model (Banavar *et al*. 2010 PNAS)

$R = a\,M^{3/4}$

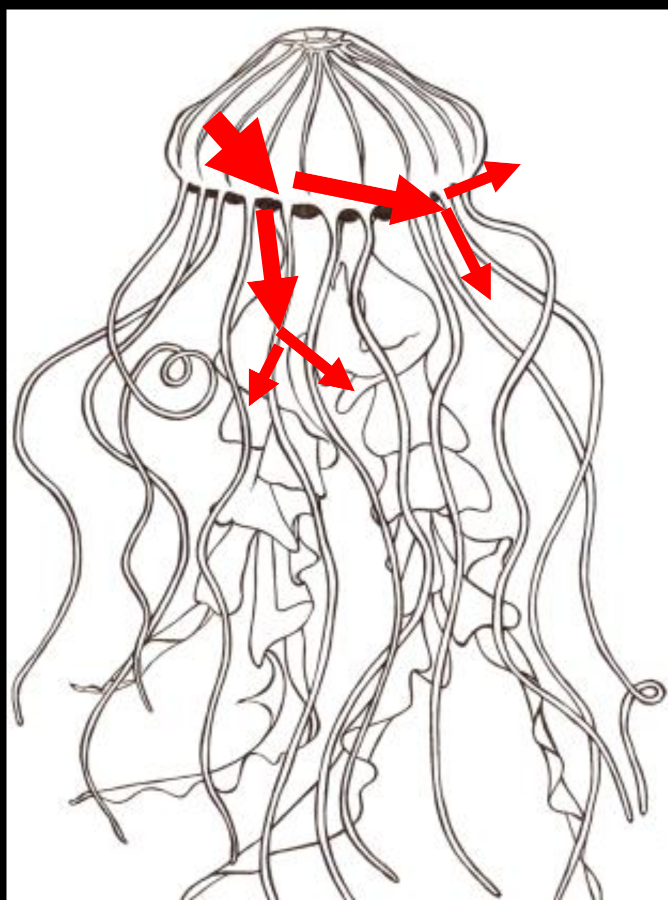
Surface Area Dependent Theory (originally used to describe heat loss in endotherms -Rubner 1883)

e.g. Dynamic Energy Budget (Kooijman 1986)

$R = a\,M^{2/3}$

Internal Transport Networks

$R = a\, M^{3/4}$



Internal Transport Networks

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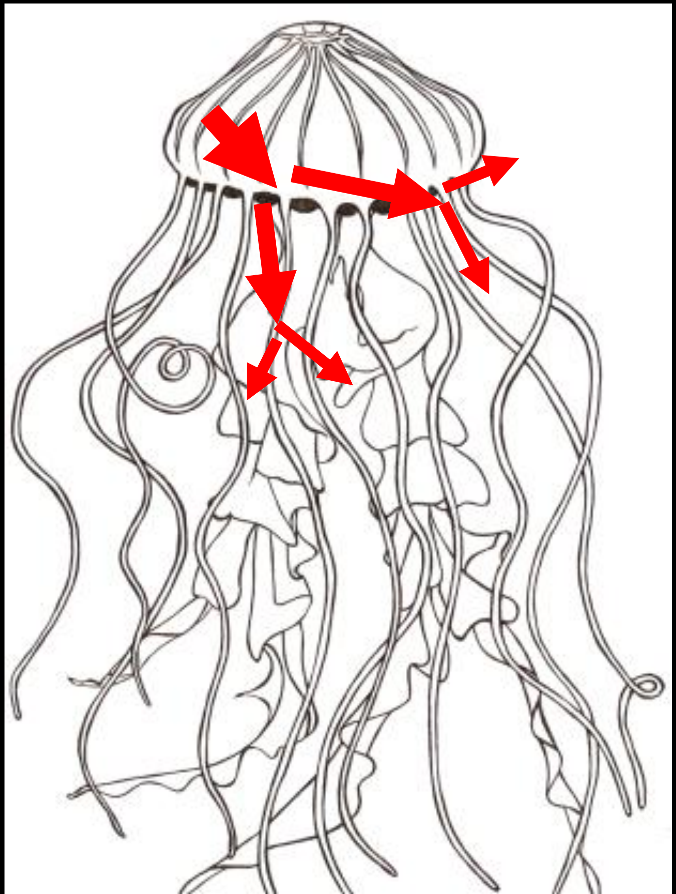


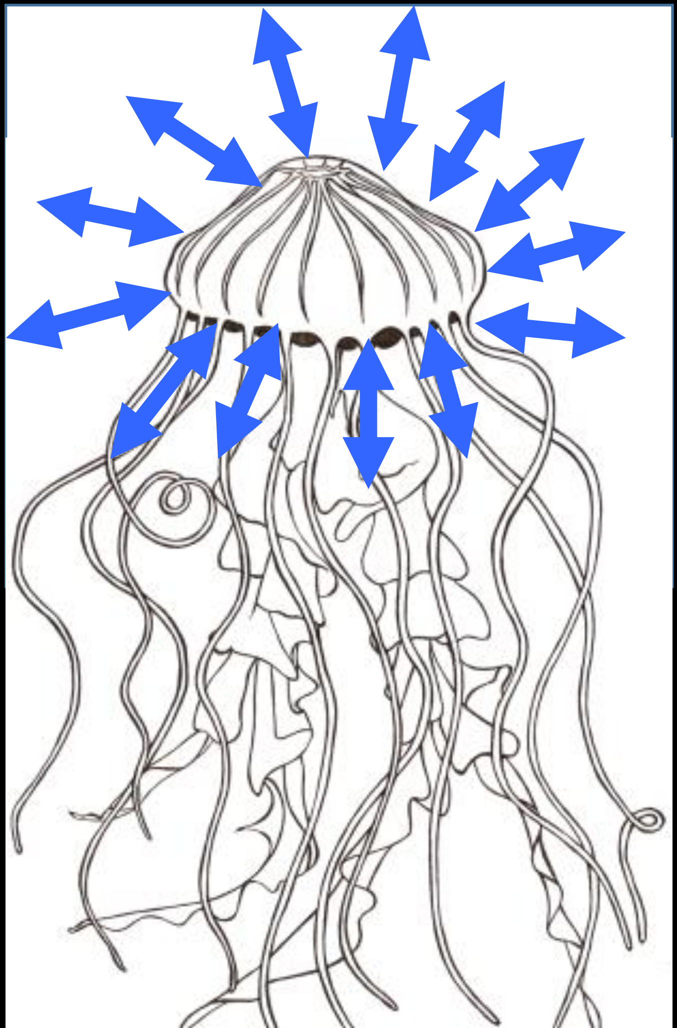
- Based on resources passing though branching networks, observed in some animals and plants

- Deliver of nutrients and energy to body tissues takes longer for large organisms thus they have a slower metabolic rate

- Banavar *et al*. (2010) have developed a more general transport model with fewer assumptions

Surface Area Model

$R = a\,M^{2/3}$



Surface area constrains rate of influx or efflux

Surface Area Model

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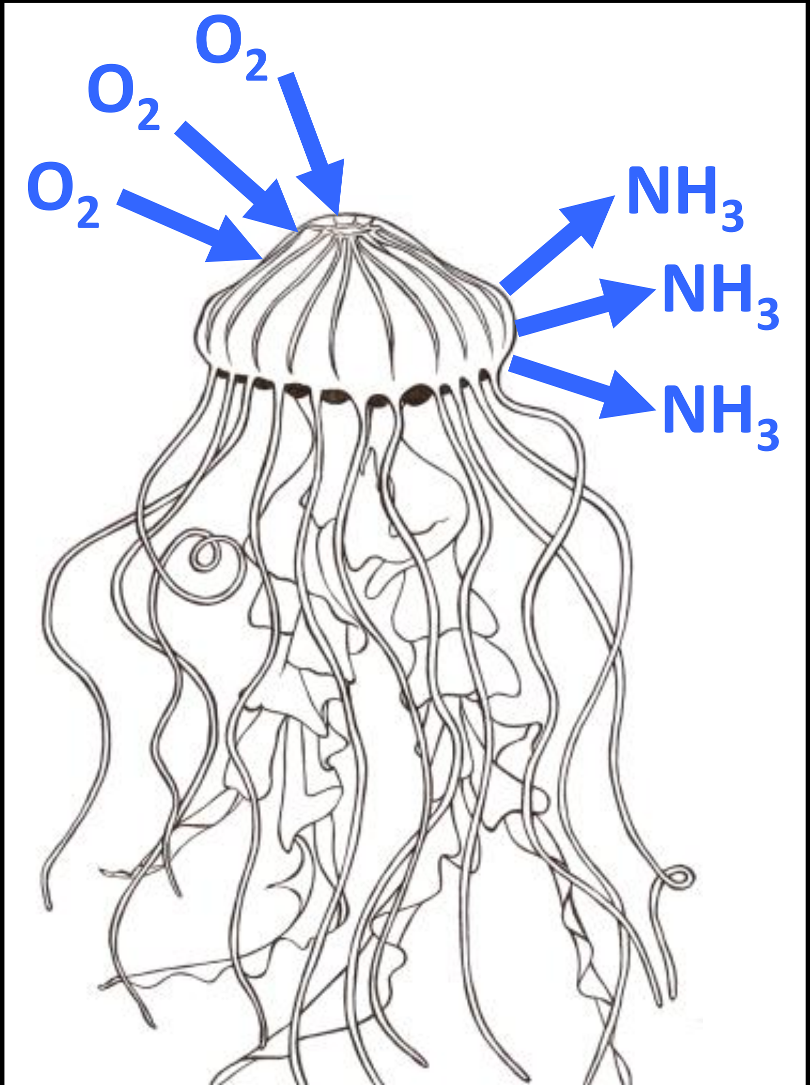

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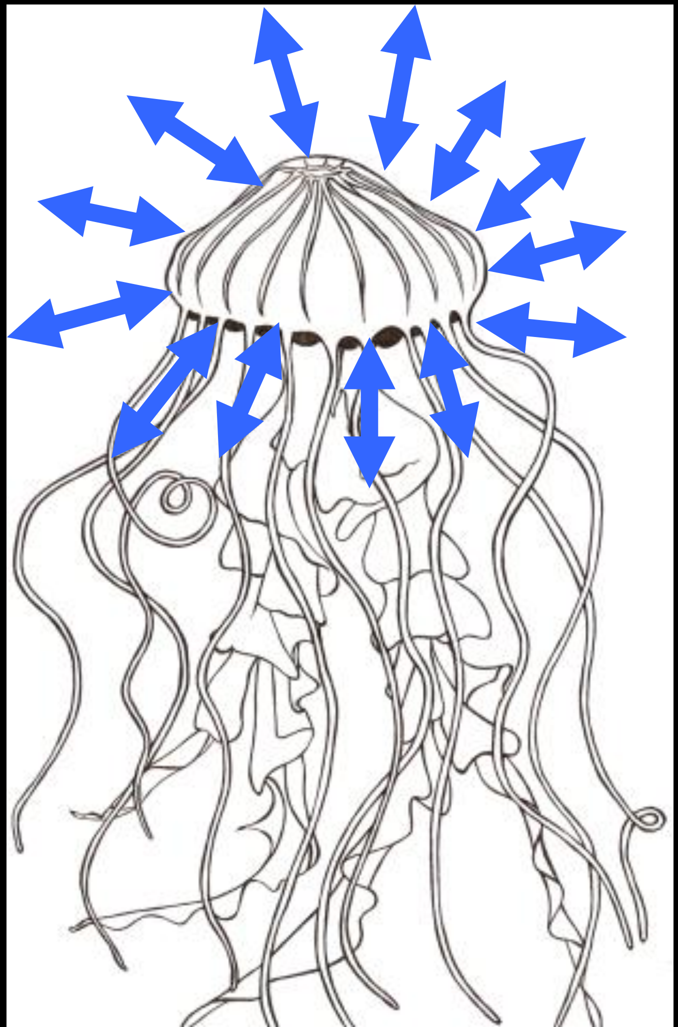
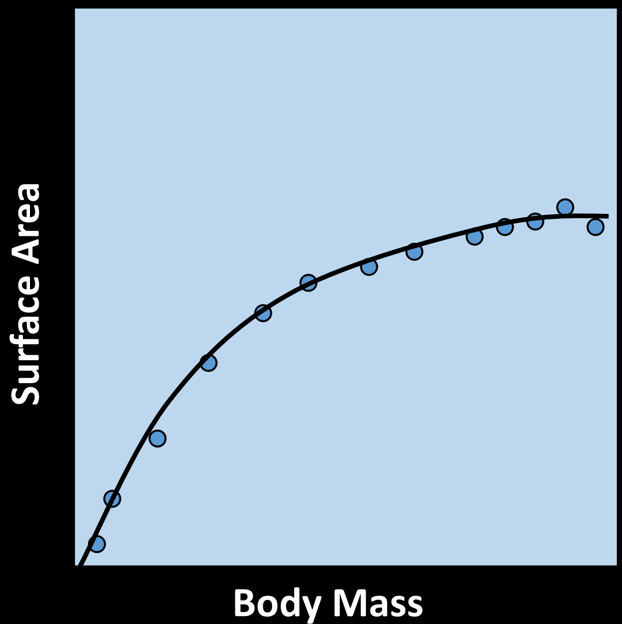


Why a power of 2/3rds?

Isomorphic Increase

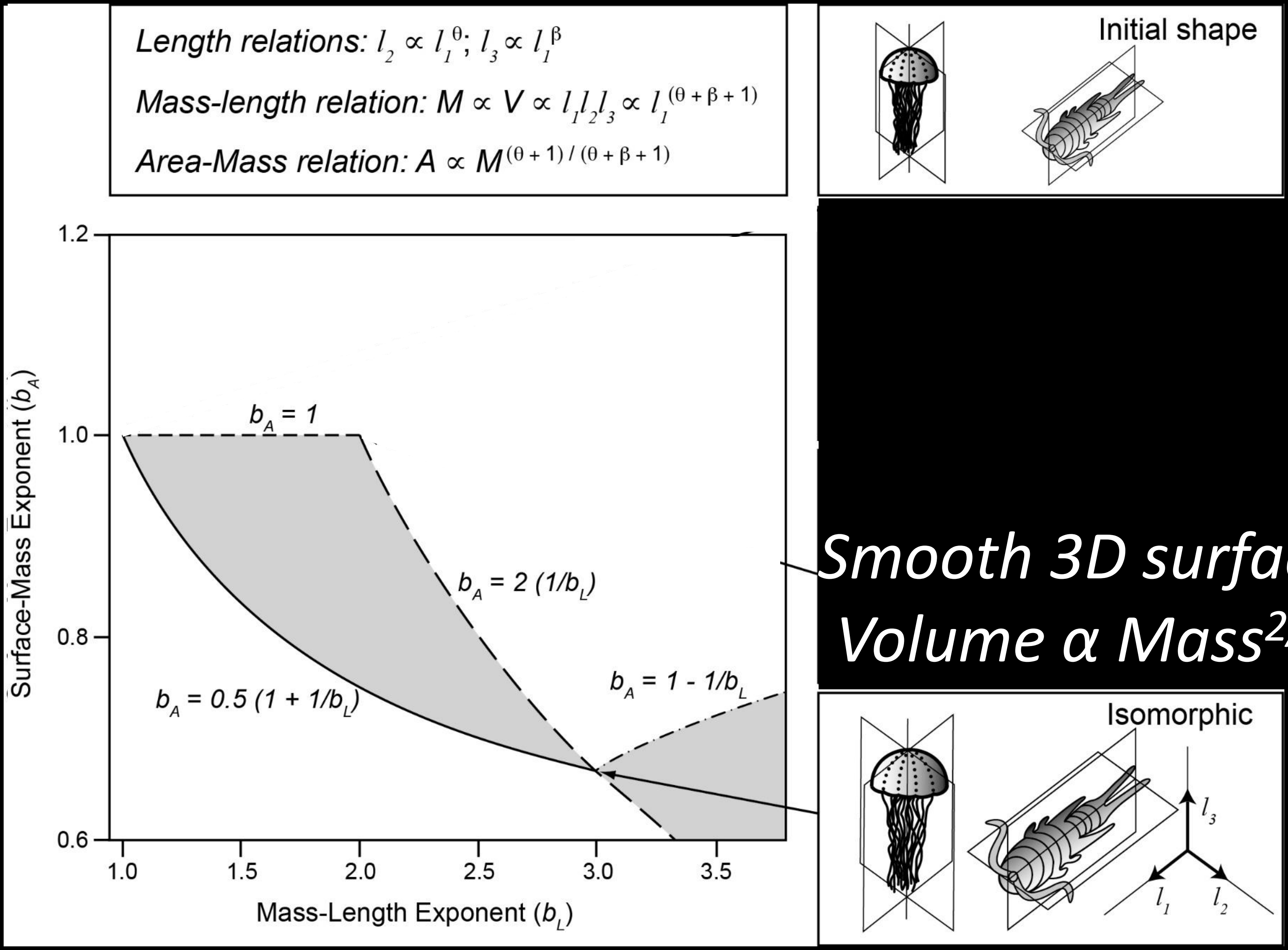


Surface Area = *a* Mass$^{2/3}$

so, SA Model predicts:

Respiration = *a* Mass$^{2/3}$

Predicting Surface Area



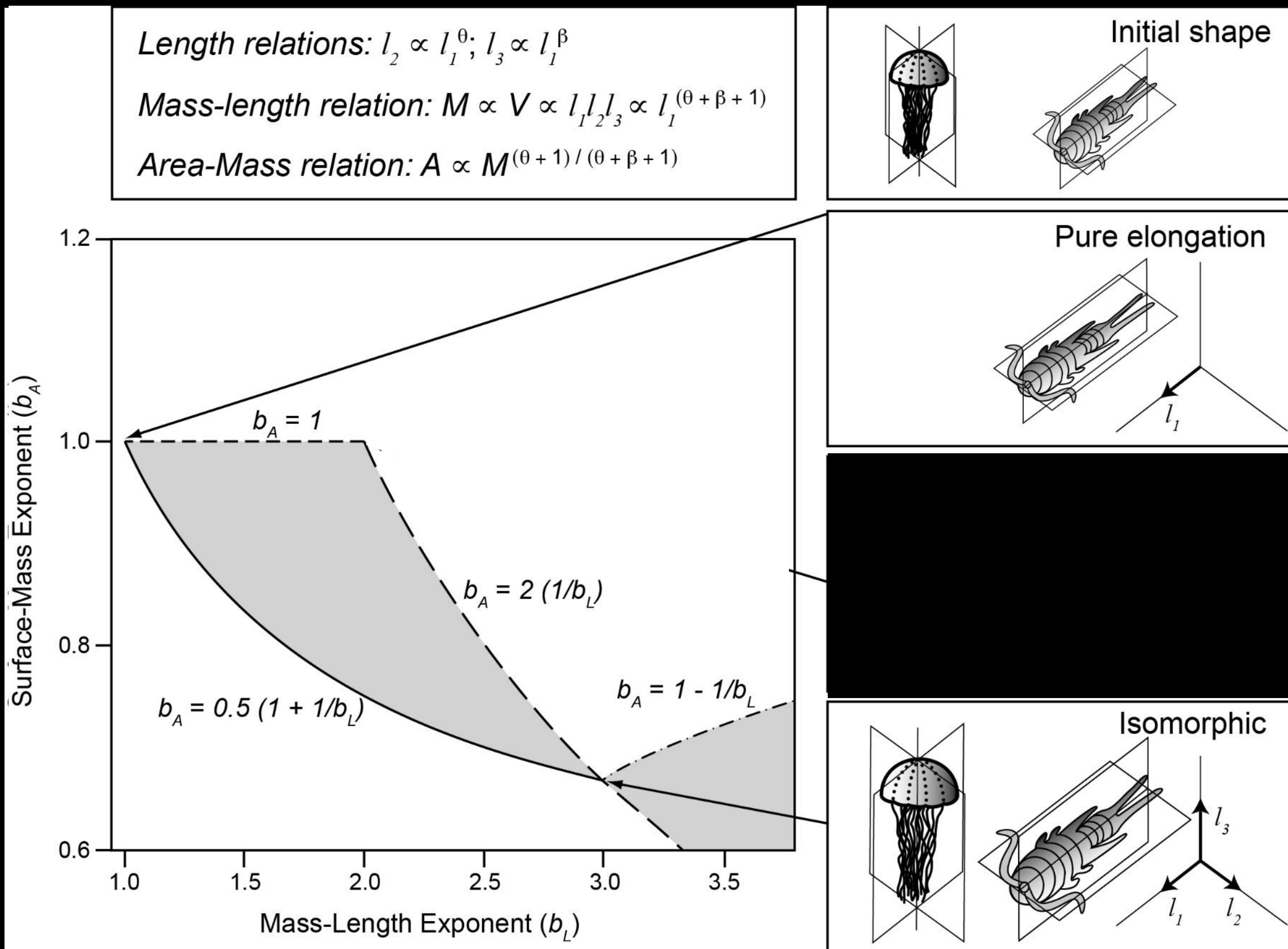
Smooth 3D surface

Volume α Mass$^{2/3}$

b_L=3

Hirst et al. (2014) Ecol Lett

Predicting Surface Area

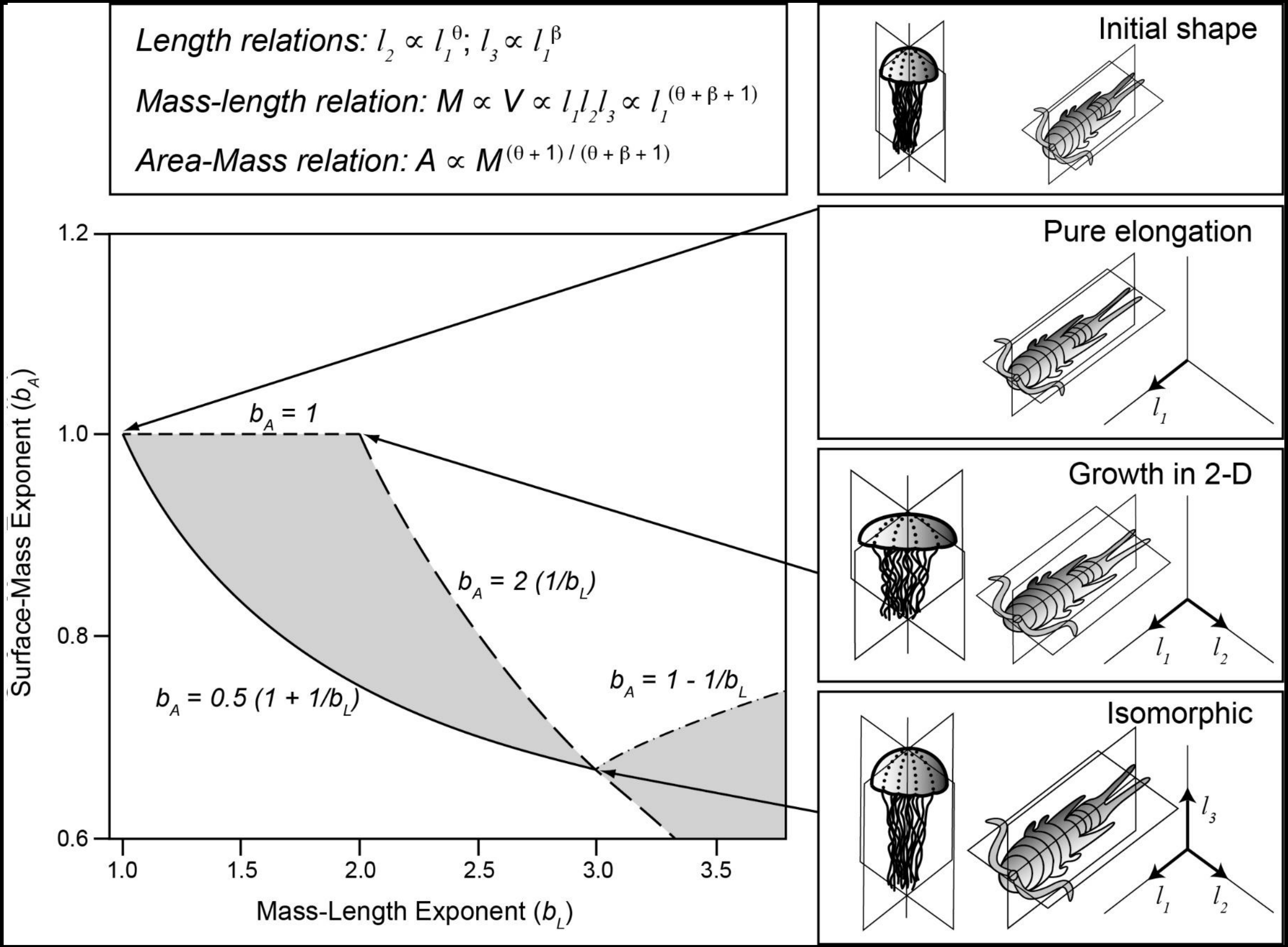


$b_L = 1$

$b_L = 3$

Hirst et al. (2014) Ecol Lett

Predicting Surface Area



$b_L = 1$

$b_L = 2$

$b_L = 3$

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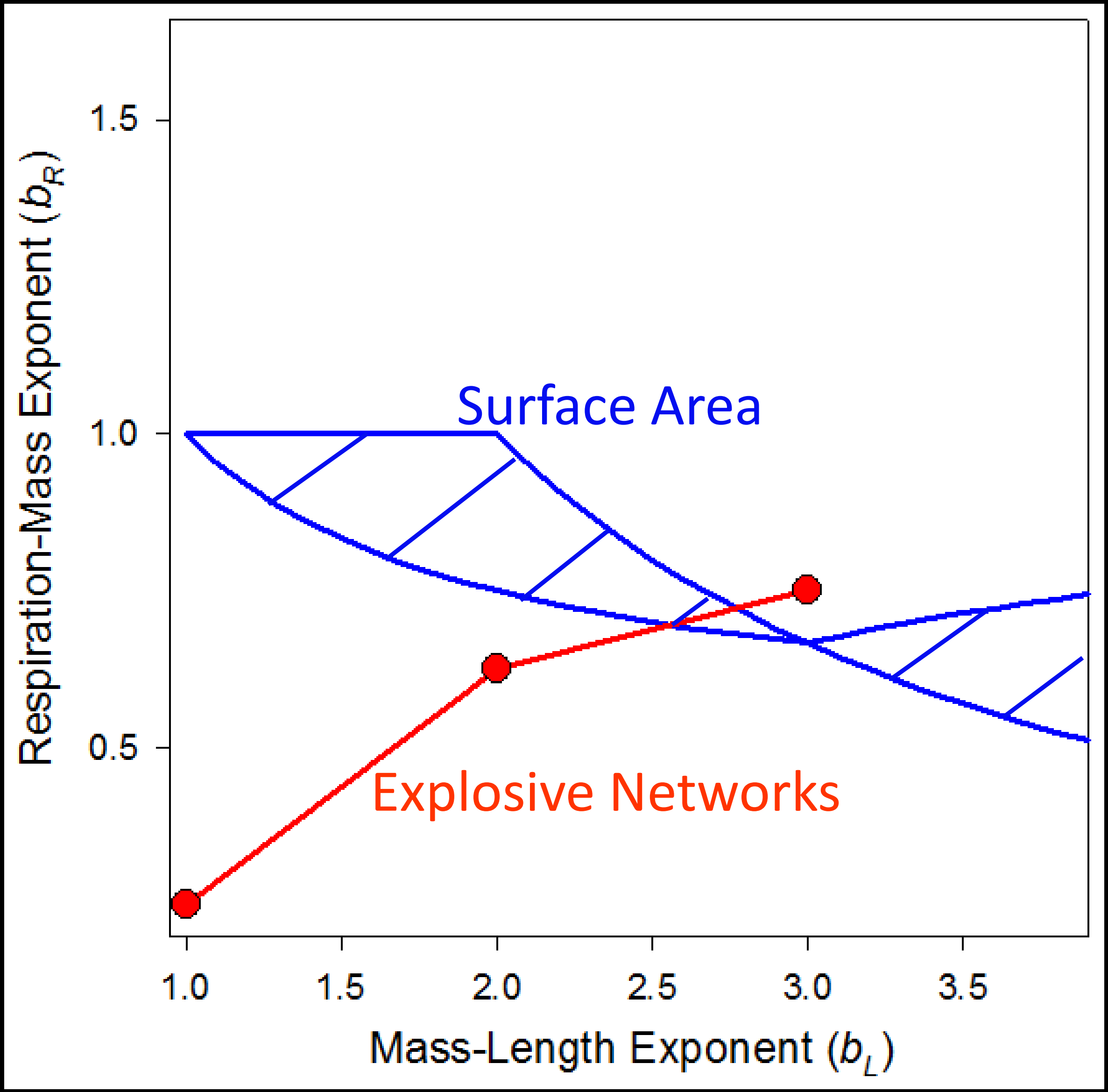
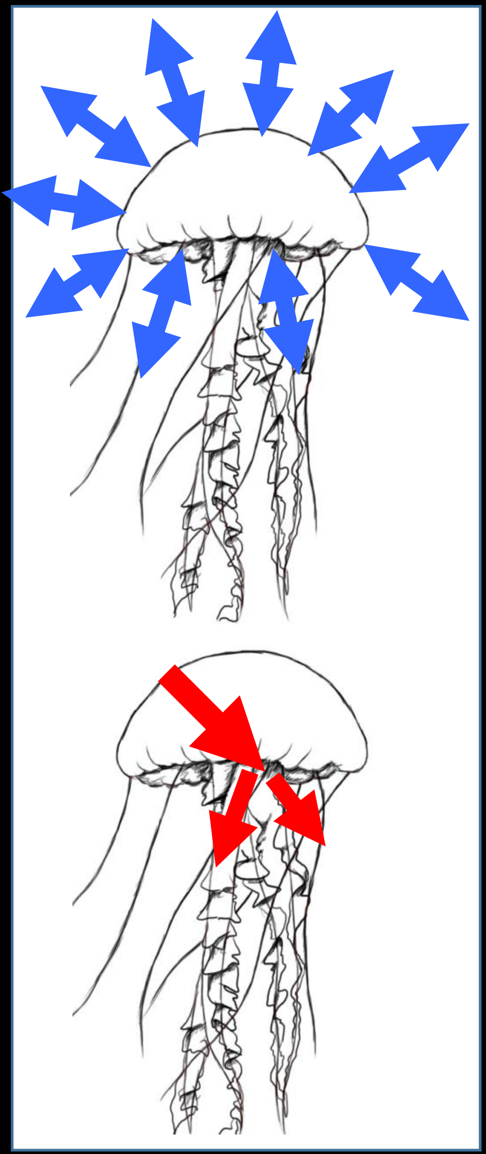
Divergent Predictions





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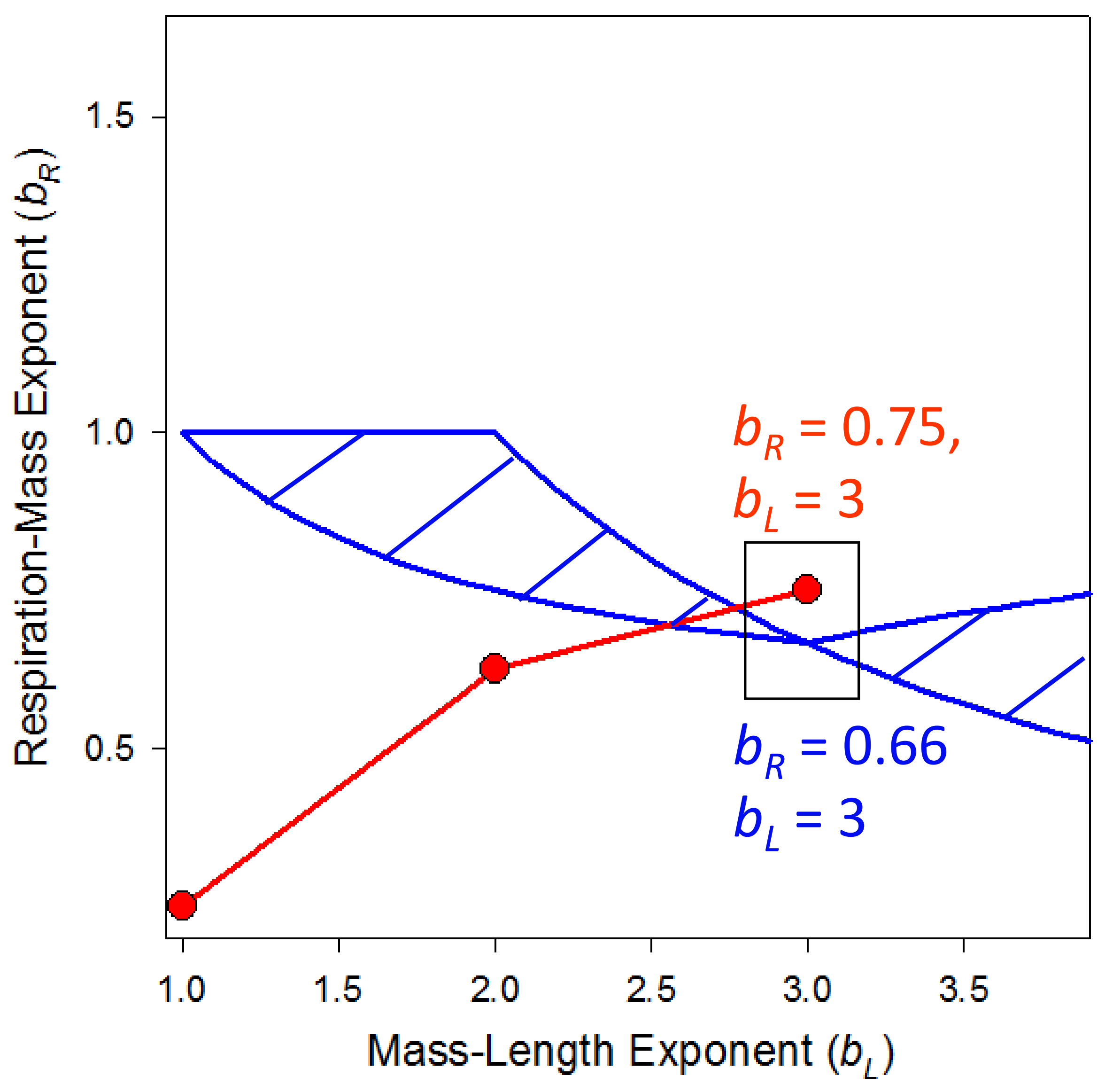

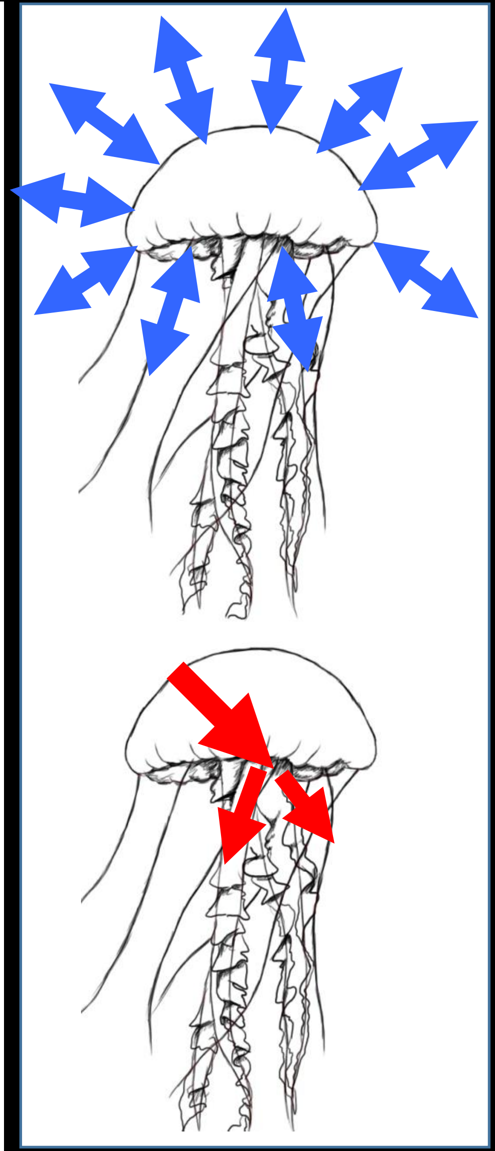

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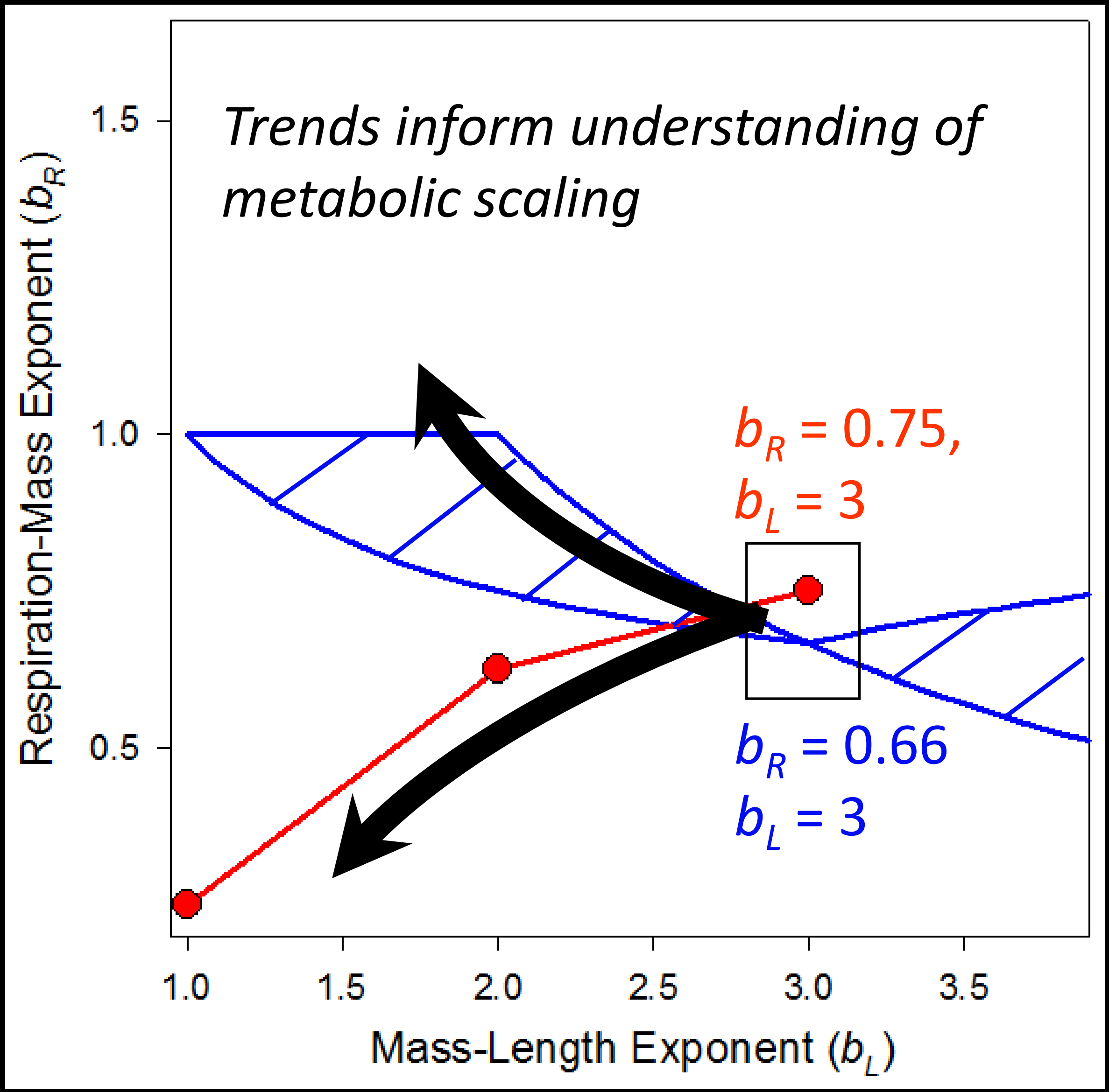
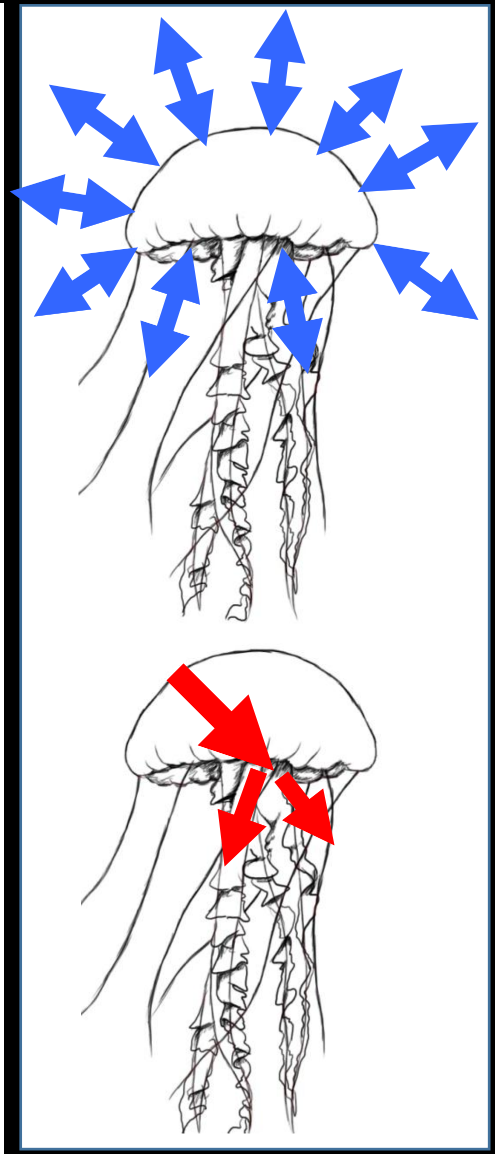
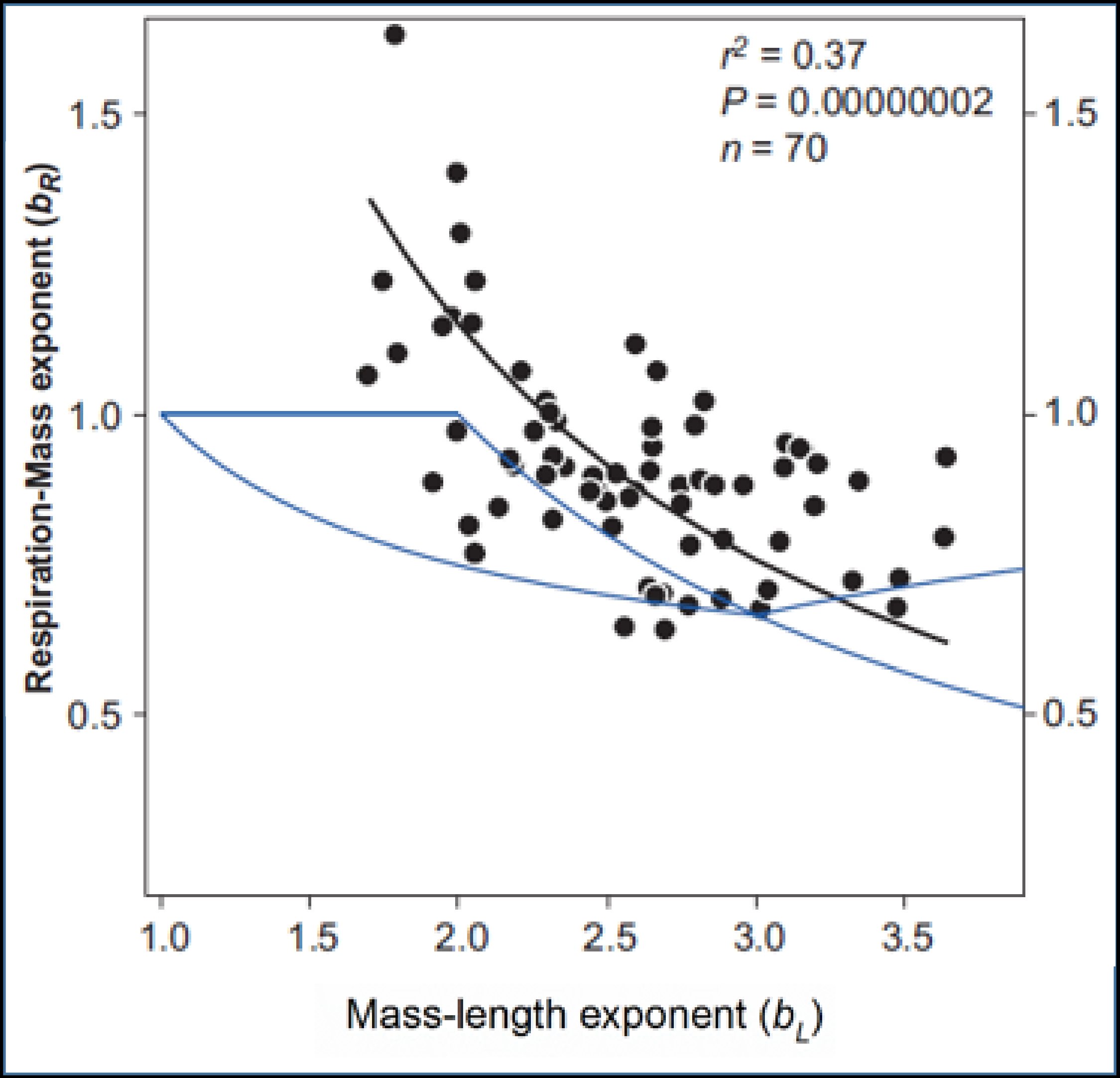




Macroplankton Diversity

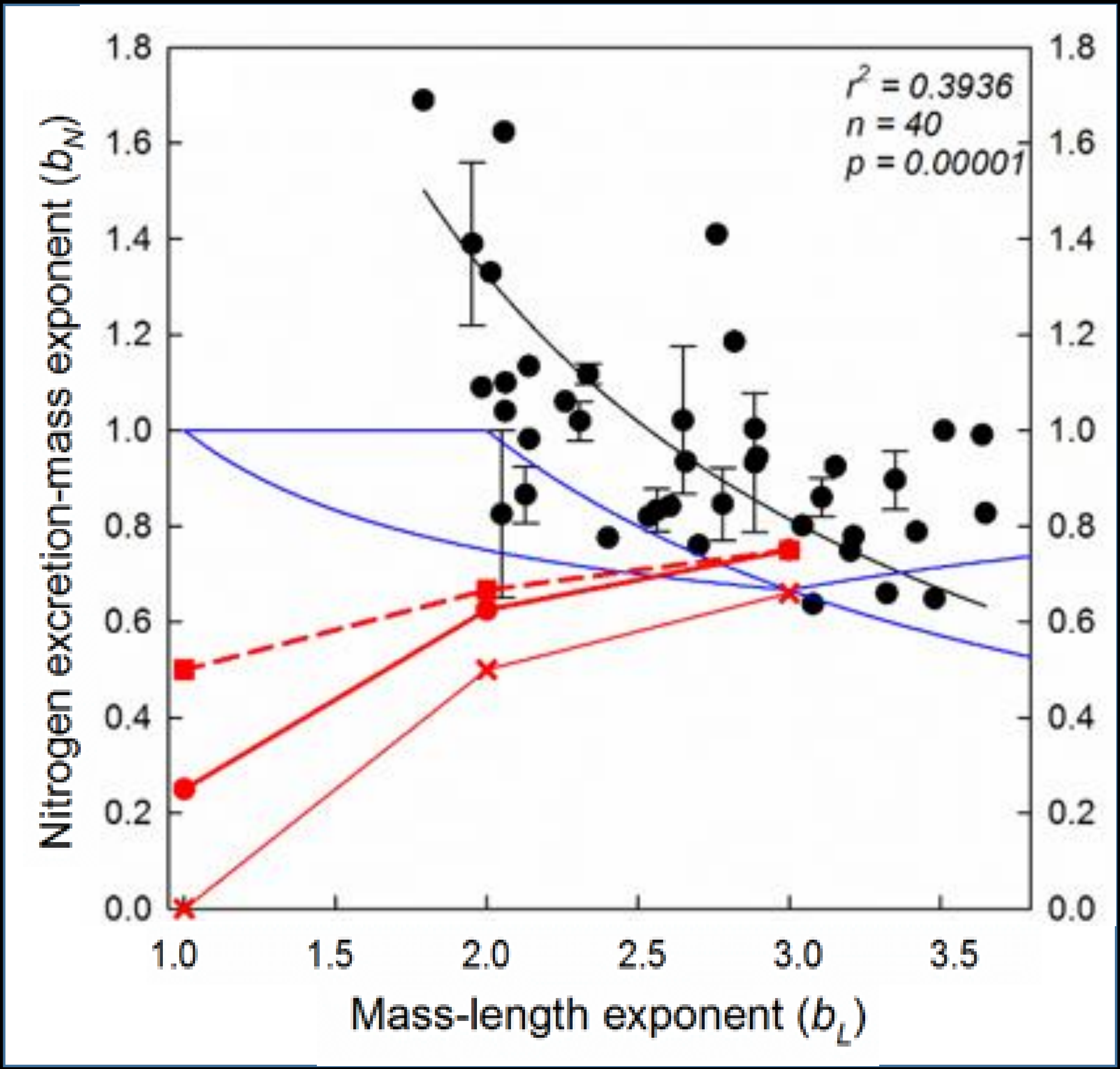
Pelagic Invertebrate Respiration



- Across 70 species there is wide variation in Respiration-scaling.
- Body forms are diverse
- Scaling follows the Surface-Area theory
- Steeper scaling is observed in species growing in 1D, compared to 2D or 3D growth.

Hirst et al. (2014) Ecol Lett

Pelagic Nitrogen Excretion



- N-excretion scaling parallels Respiration scaling
- Higher variation, due to different N-products and fewer data.

Hirst et al. (*in review*)

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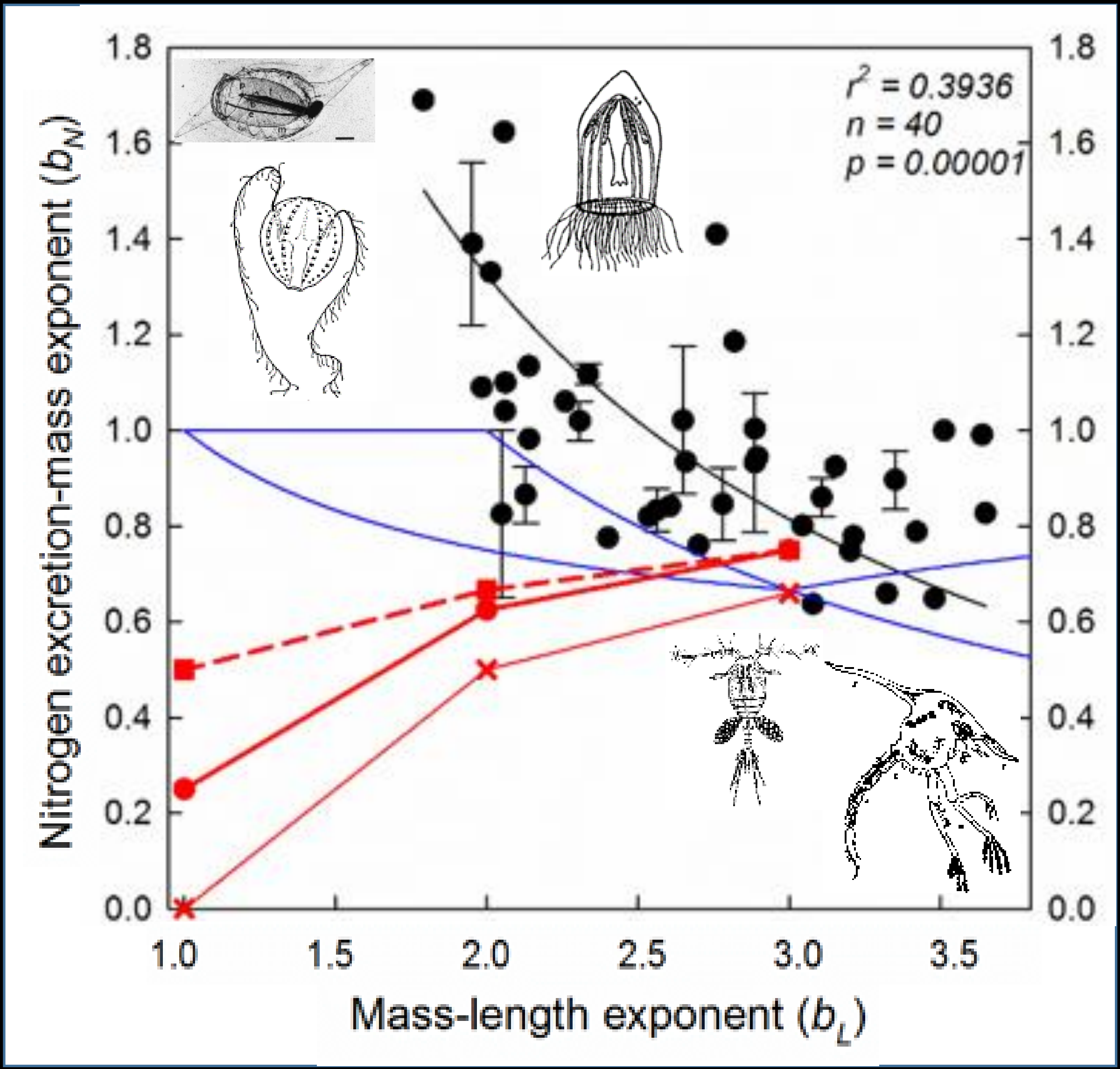

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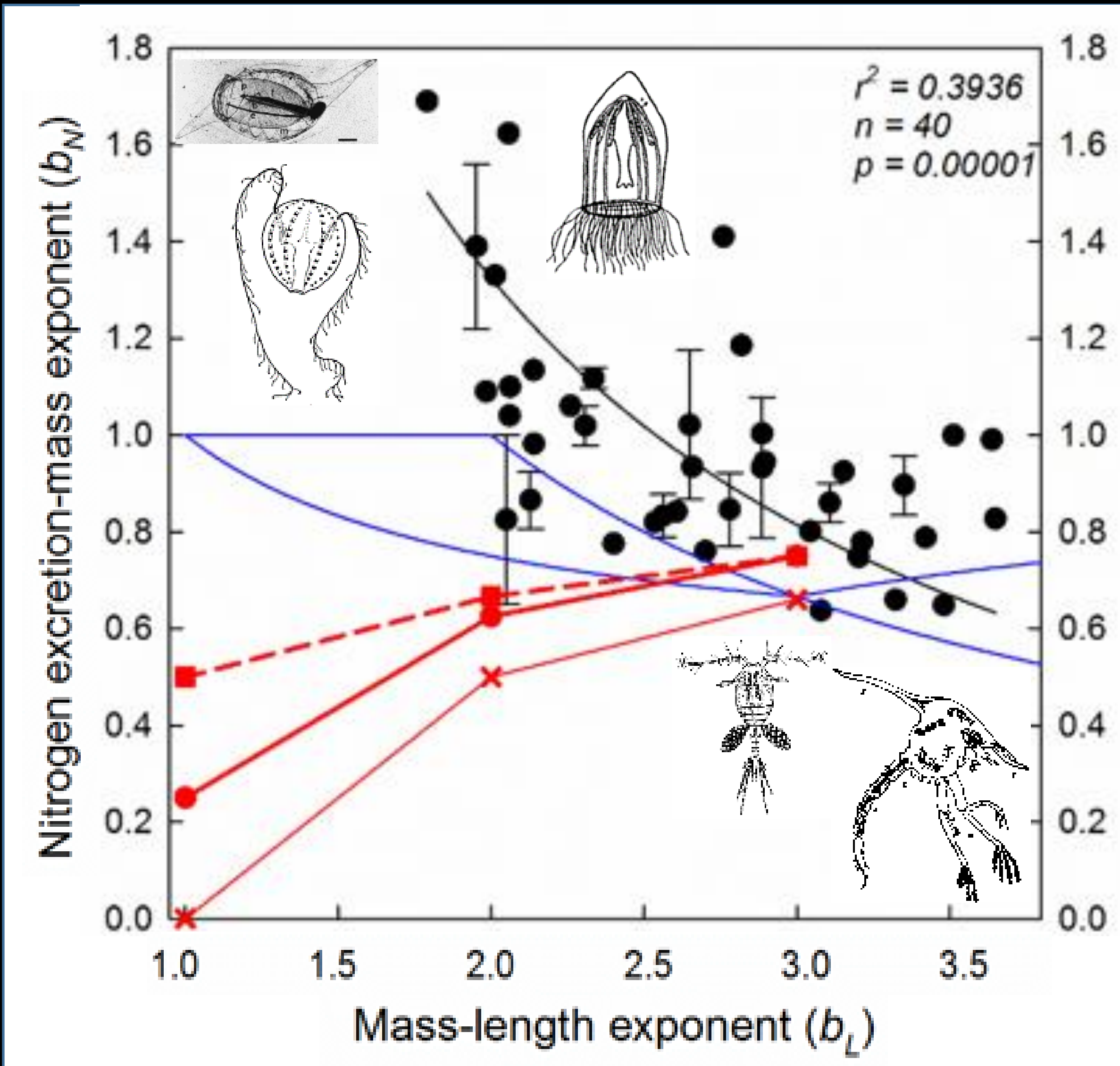
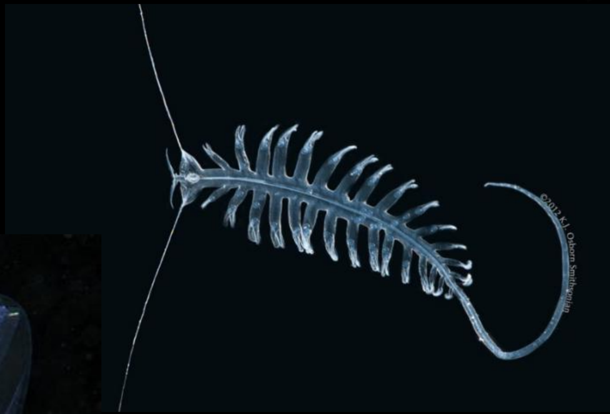


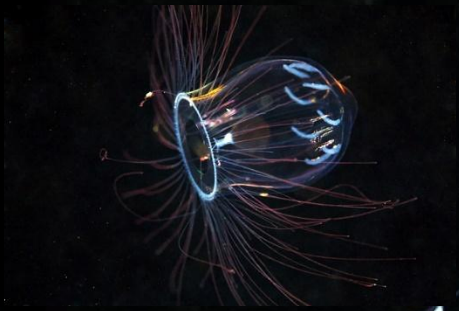
- N-excretion scaling parallels Respiration scaling
- Higher variation, due to different N-products and fewer data.
- Macrozooplankton still conform to the SA model – with variability and body structure differences
- Steeper scaling at 2D v 3D growth.

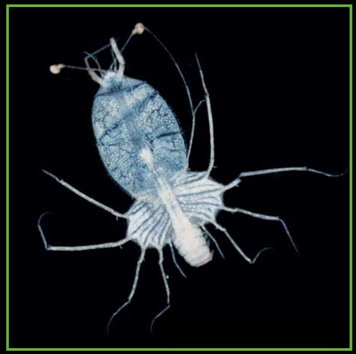
Hirst et al. (*in review*)

Macroplankton Diversity
Shape-shifting







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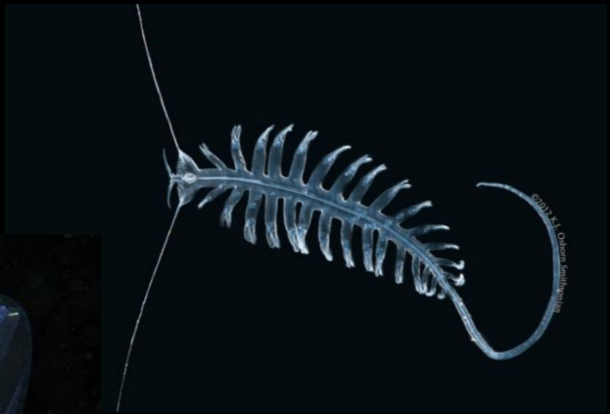
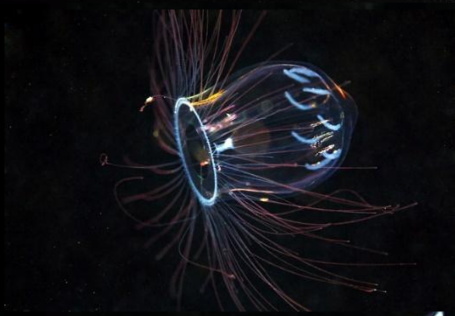
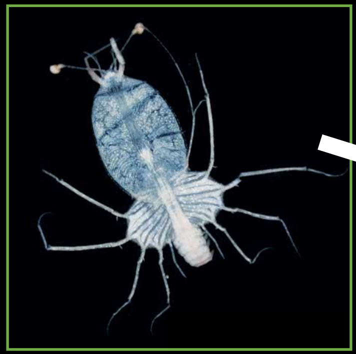
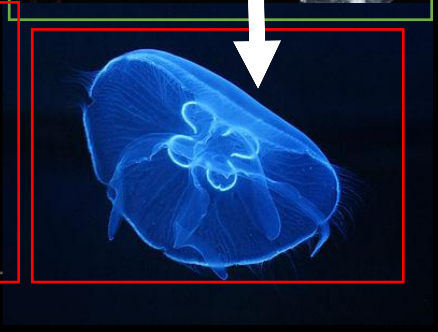


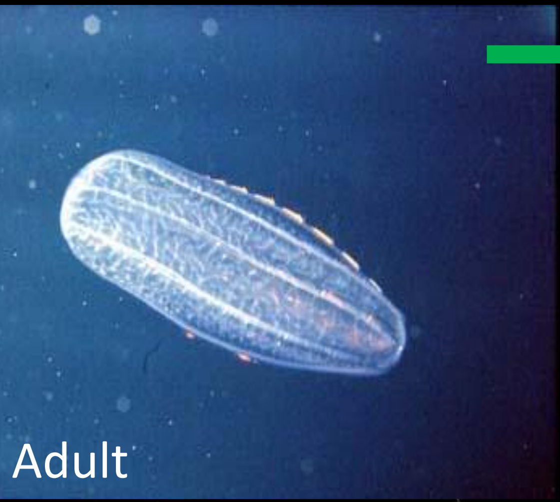


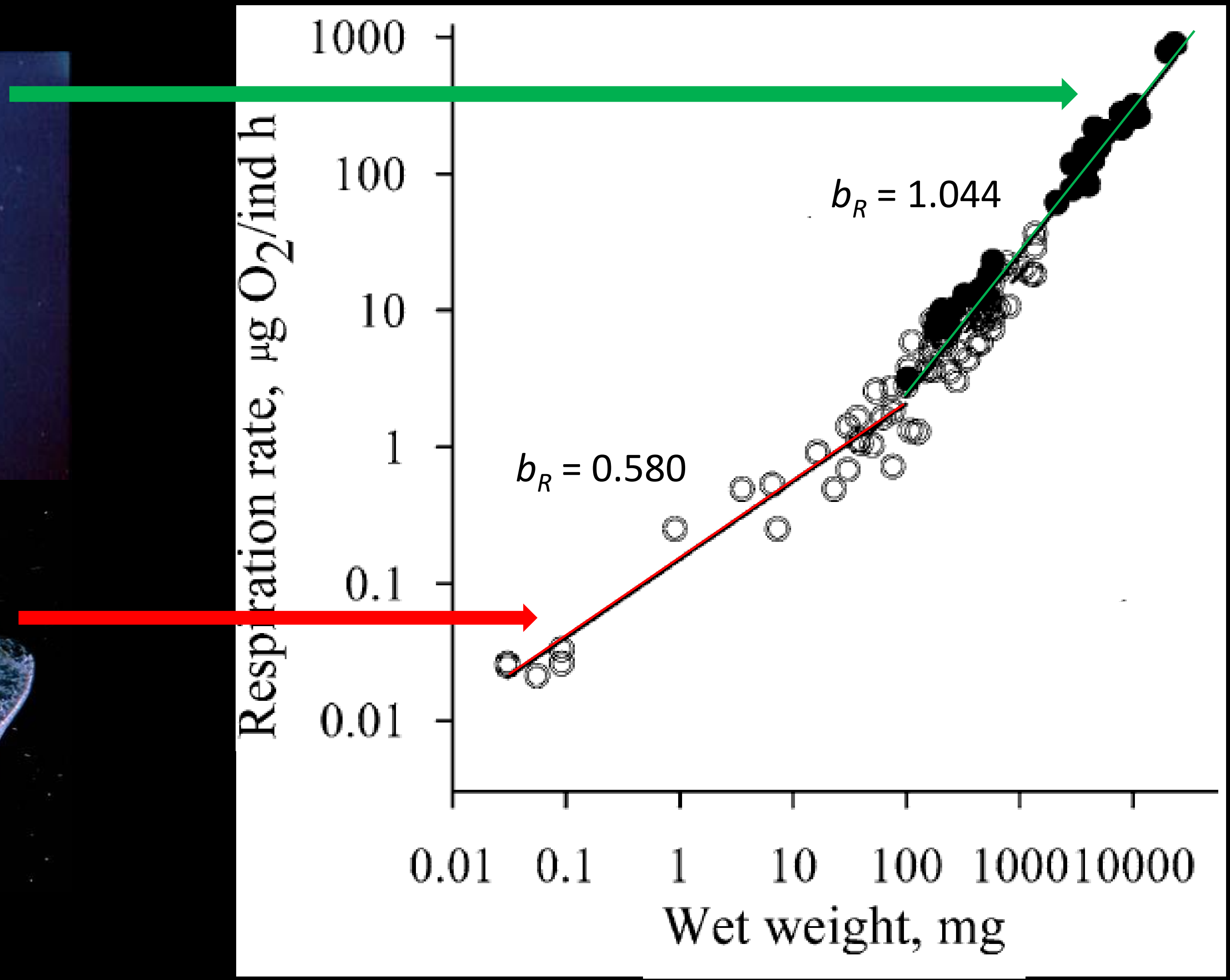




Organisms With Biphasic Growth



Beroe ovata



From Svetlichny *et al.* (2004)

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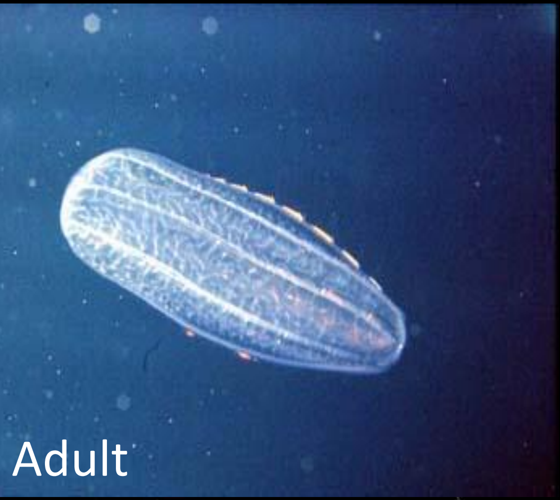

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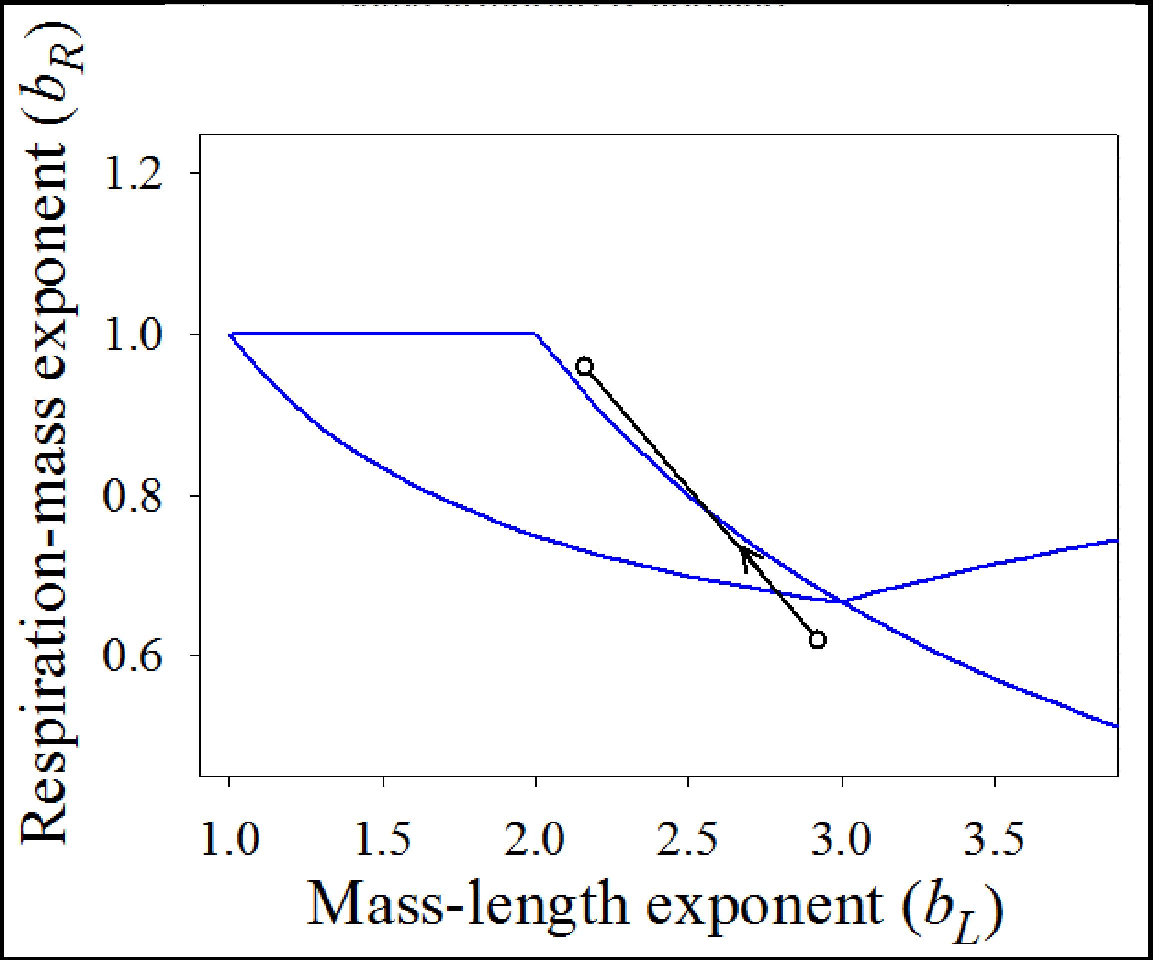
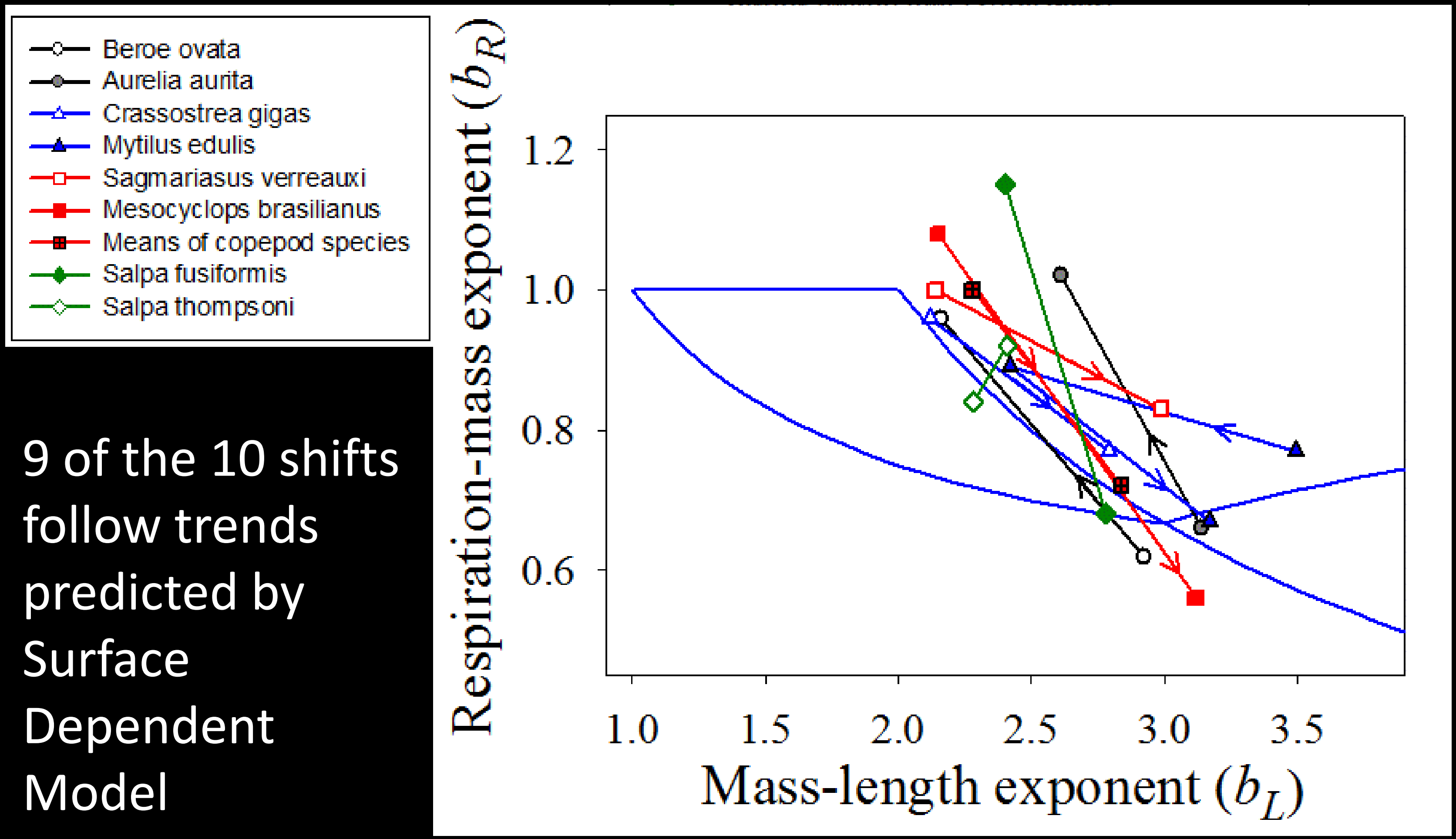


Glazier et al (2015)

Organisms With Distinct Life Phases



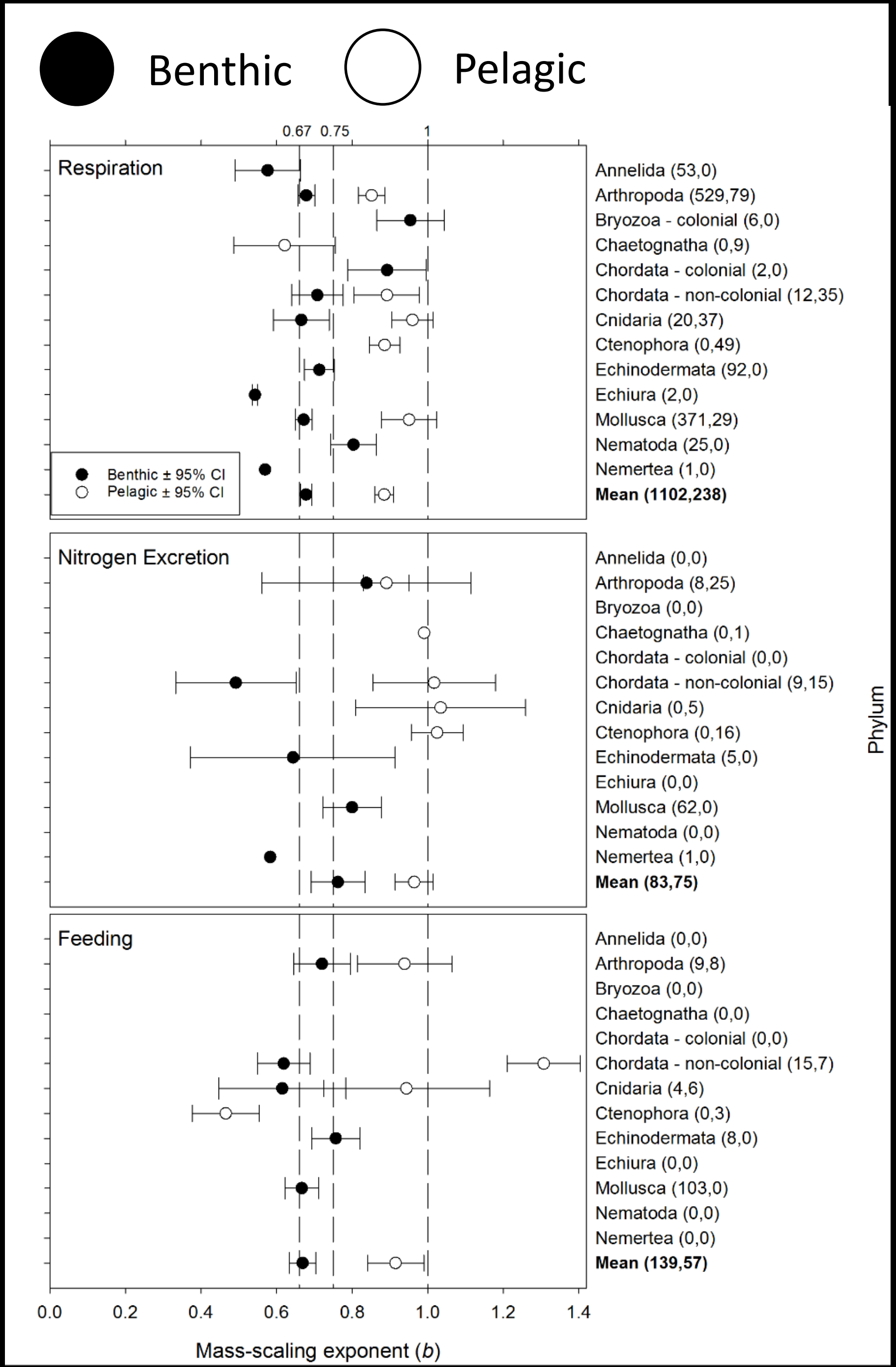
9 of the 10 shifts follow trends predicted by Surface Dependent Model

Glazier et al (2015)

Benthic/Pelagic scaling

Do marine benthic invertebrates show the same patterns as pelagic species?

*Metabolism (Rate/ind/time) = a * Mass of the individual* ^{b}



Lilley et al. *in prep*

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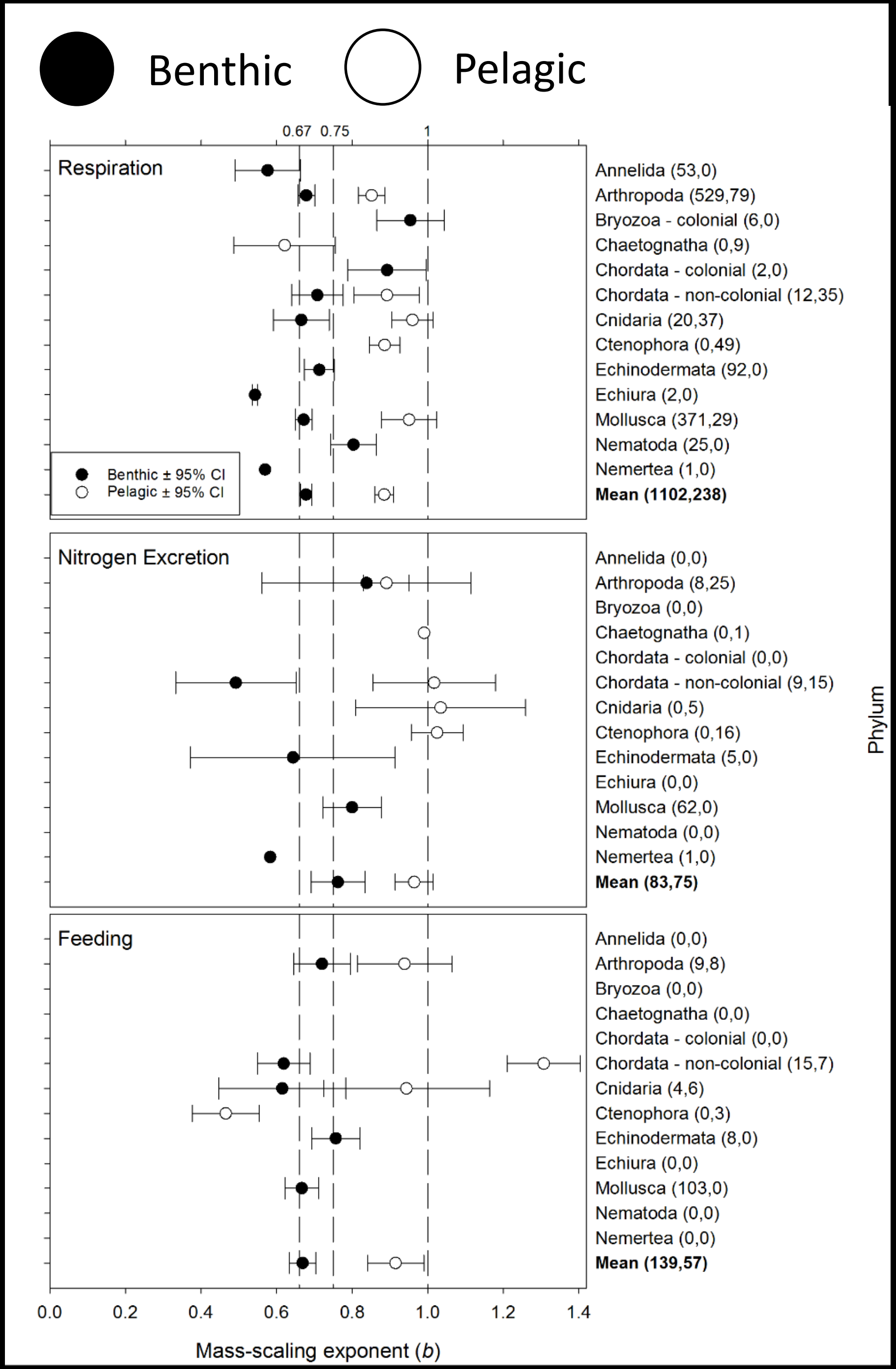
- Metabolism-mass scaling Benthic species < pelagic species.
- Increased scaling:
  - increased activity?
  - feeding method?
  - trophic position?



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Scaling of metabolic rates with body mass of an individual.

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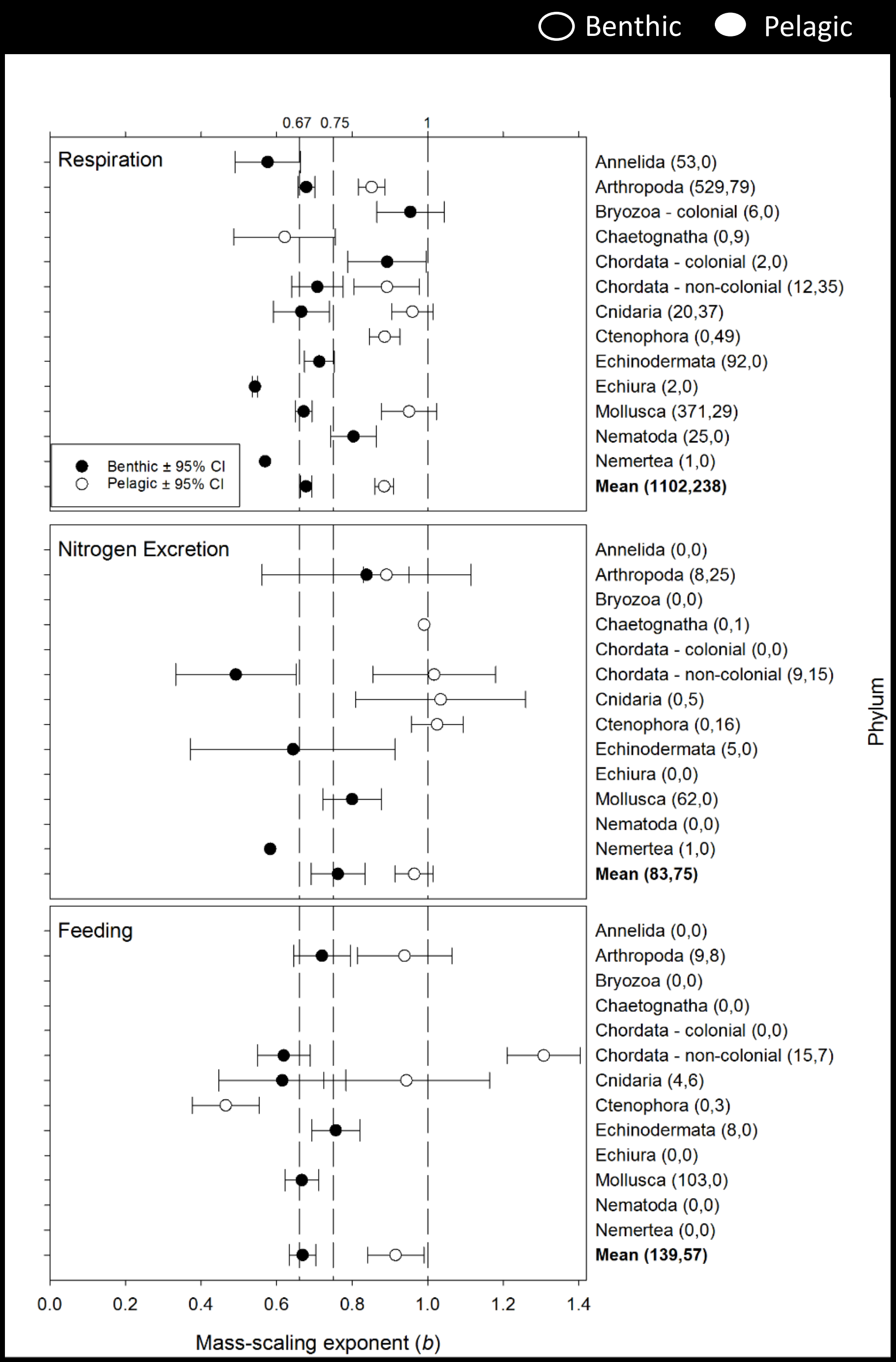

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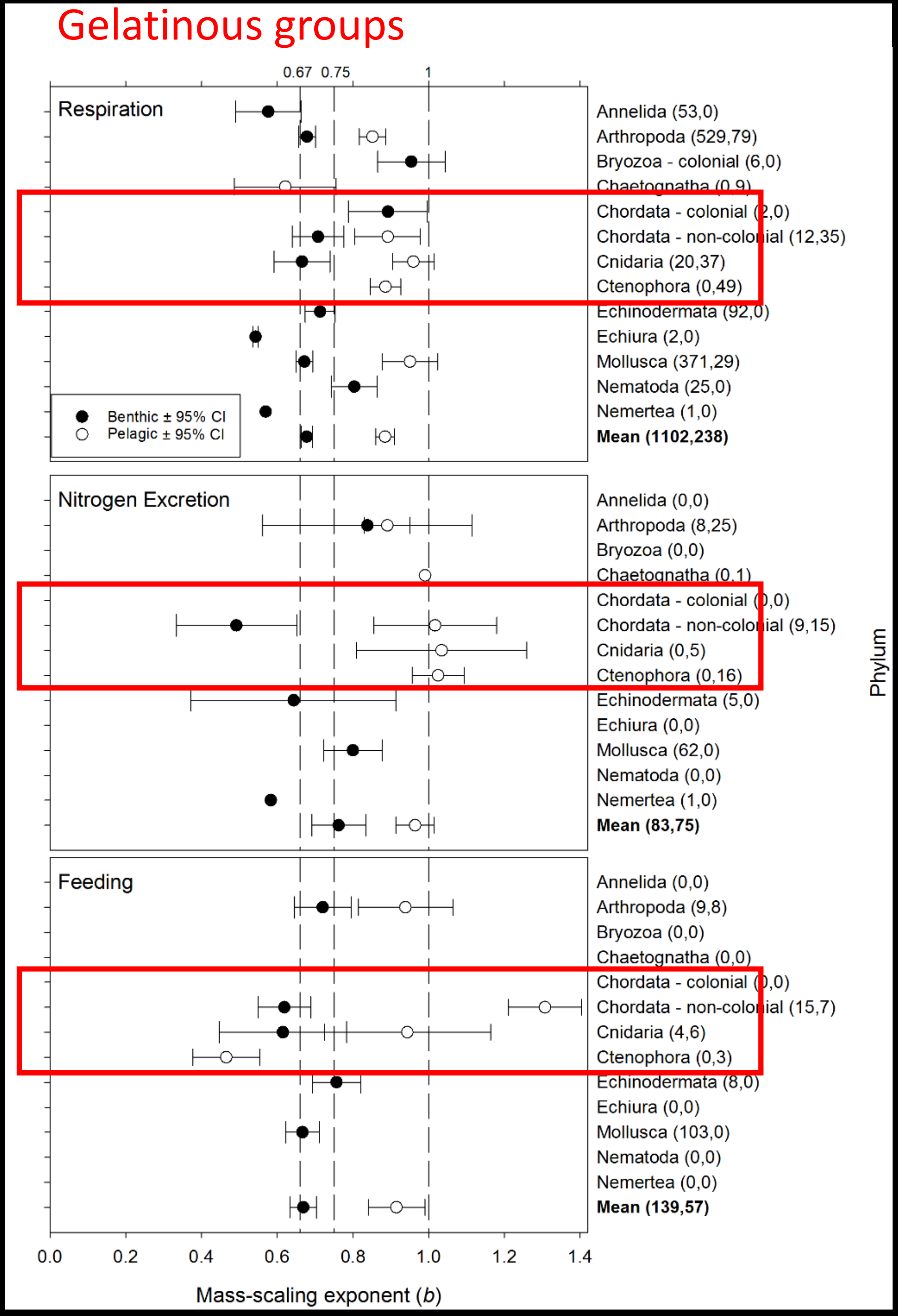
- Consistently steeper scaling:
  Respiration - Pelagic > Benthic
  N-excretion - Pelagic > Benthic
  Feeding rates – similar trends
- Mechanism:
  Activity levels typically cause slower metabolic rates in benthic species.

Benthic Pelagic



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- Mechanism:
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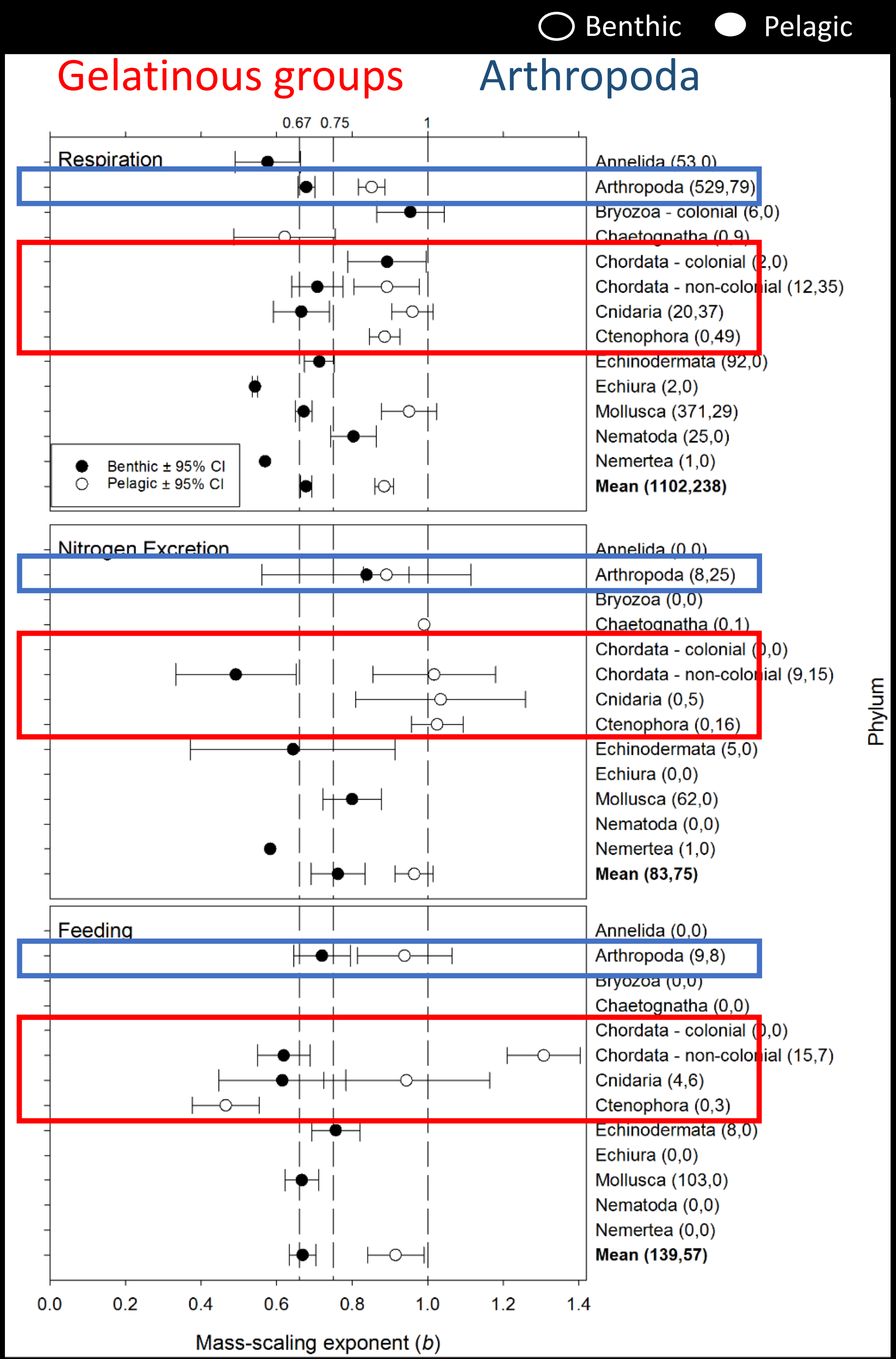
- Arthropoda integuments change the surface area available, but there are still scaling differences between larvae and adult.



Lilley et al. *in prep*

Conclusions

Body size is known to influence metabolic rates, but the scaling factors have been debated for years.

Recent analyses provide support for the Surface Area model in planktonic invertebrates by linking mass-length to metabolism.

Taxonomic differences may be due to habitat and activity levels.

Some species change their metabolic scaling through their development

Benthic invertebrates lower activity levels reduce metabolic scaling compared to pelagic species.

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Department for Environment Food & Rural Affairs

Contact

m.lilley@qmul.ac.uk
a.g.hirst@qmul.ac.uk

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