Characteristic sizes of life in the oceans

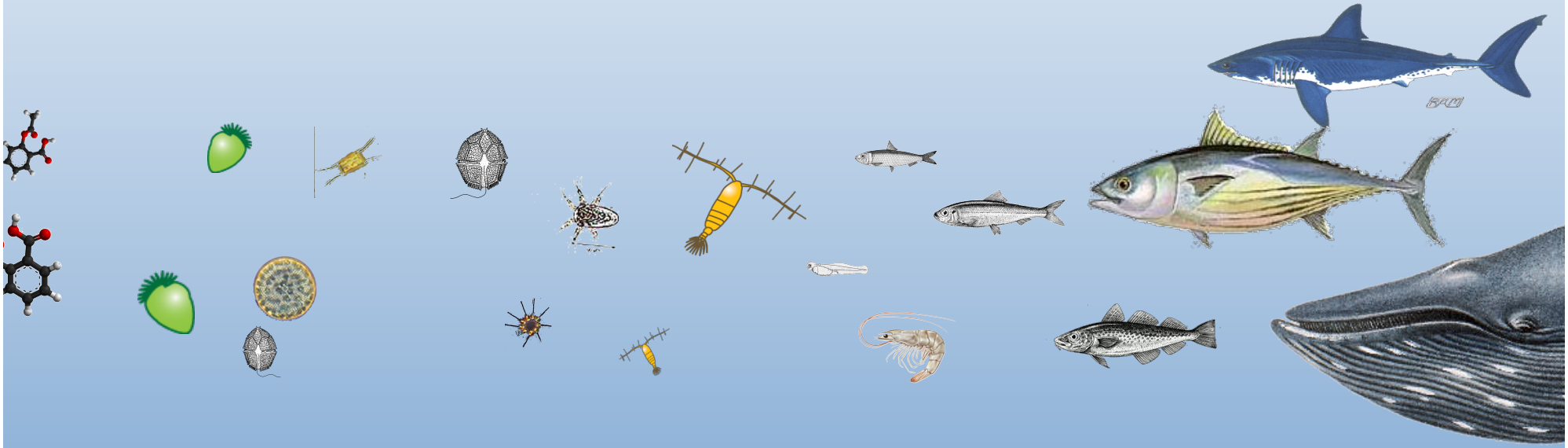
from bacteria to whales

Ken H. Andersen, Terje Berge, Rodrigo Goncalves, Martin Hartvig, Jan Heuschele, Samuel Hylander, Nis S. Jacobsen, Christian Lindemann, Erik A. Martens, Anna Neuheimer, Karin Olsson, Artur Palacz, Mark Payne, Fi Prowe, Julie Sainmont, Sachia J. Traving, Andy Visser, Navish Wadhwa and Thomas Kiørboe

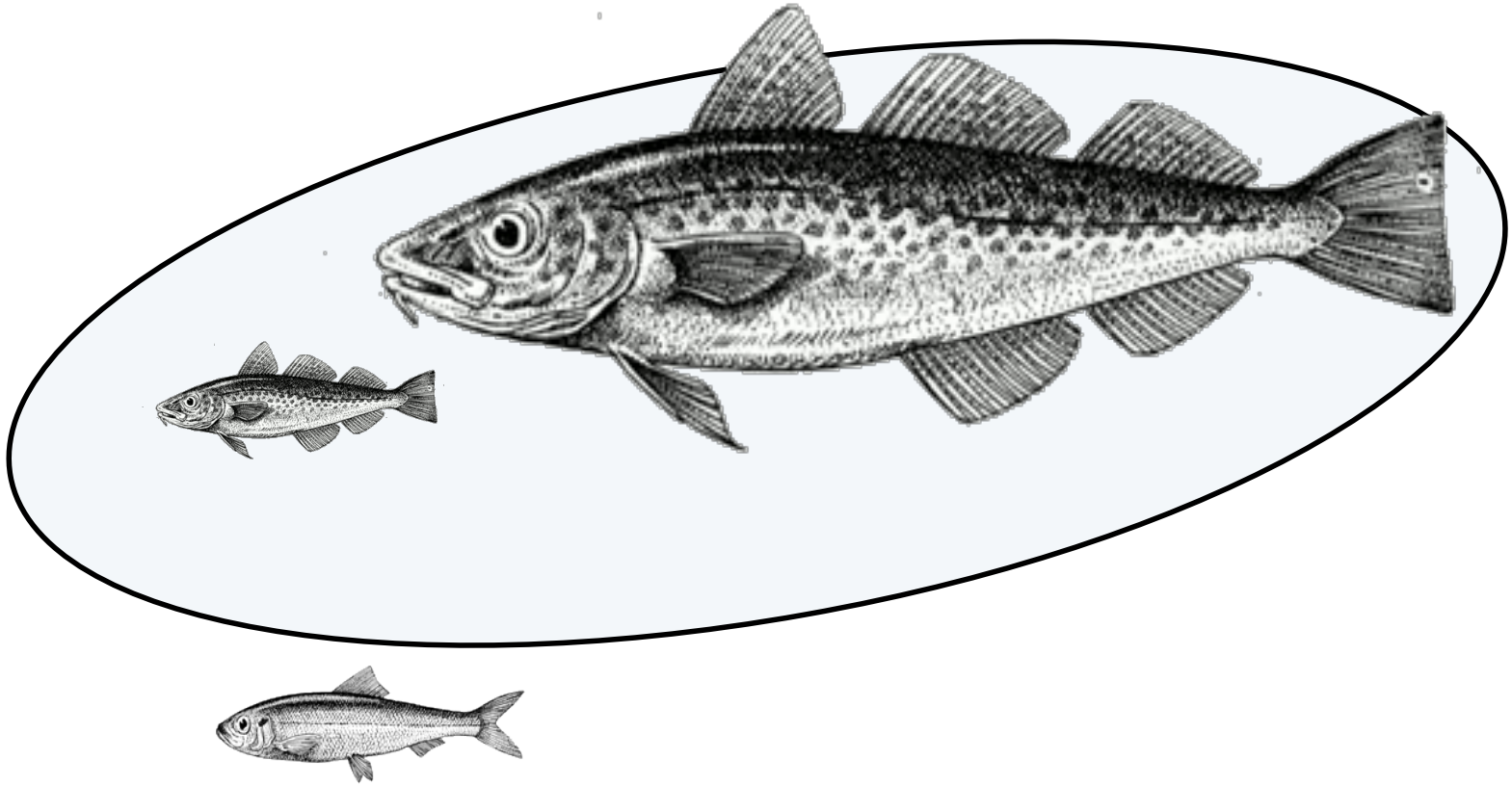
"The most obvious differences between different animals are differences of size, but for some reason the zoologists have paid singularly little attention to them. In a large textbook of zoology before me I find no indication that the eagle is larger than the sparrow, or the hippopotamus bigger than the hare, though some grudging admissions are made in the case of the mouse and the whale. But yet it is easy to show that a hare could not be as large as a hippopotamus, or a whale as small as a herring. ***For every type of animal there is a most convenient size, and a large change in size inevitably carries with it a change of form****."*

From "On being the right size", J.B.S. Haldane, 1926

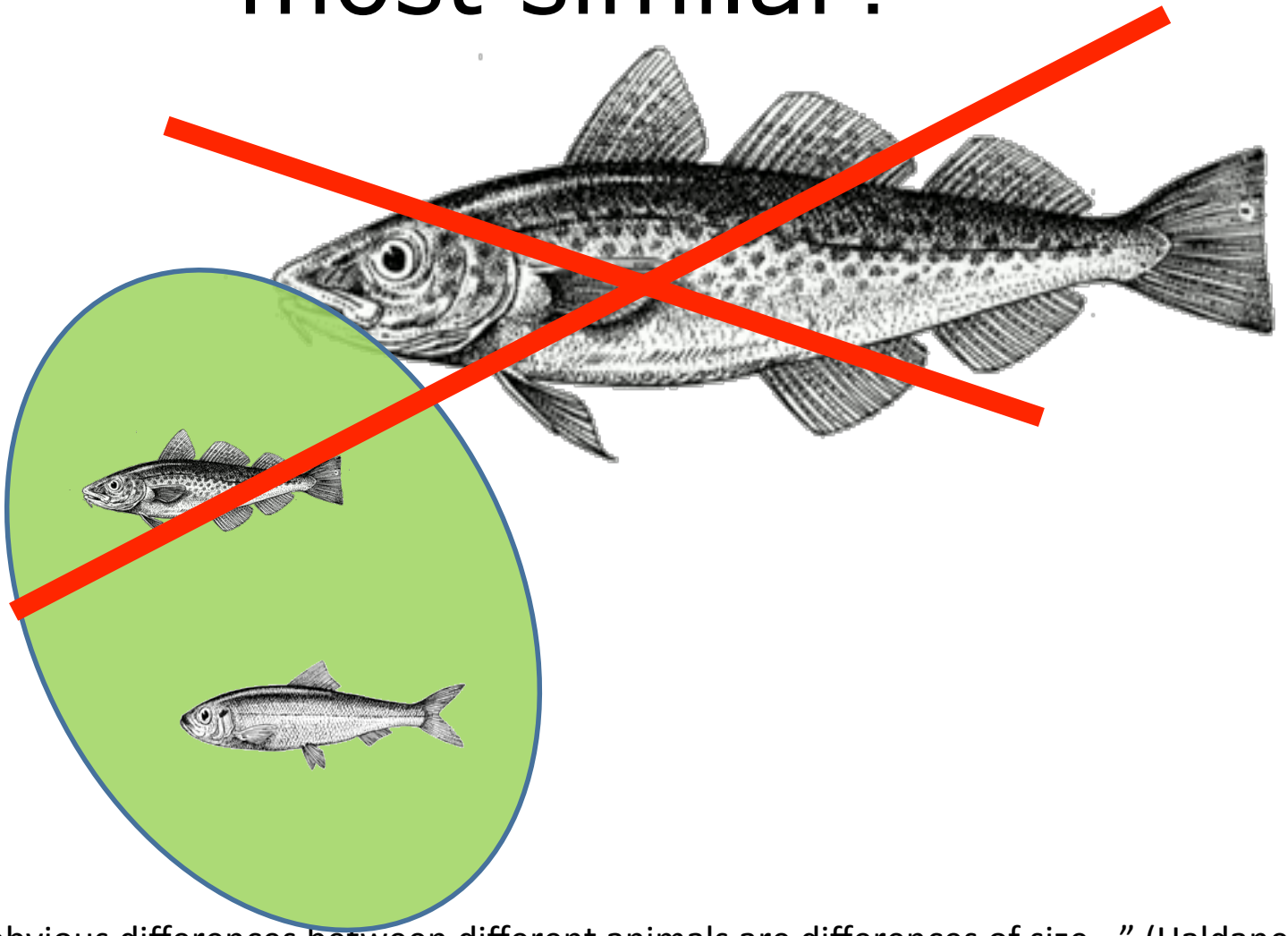
Life in the ocean



Which two fish are most similar?

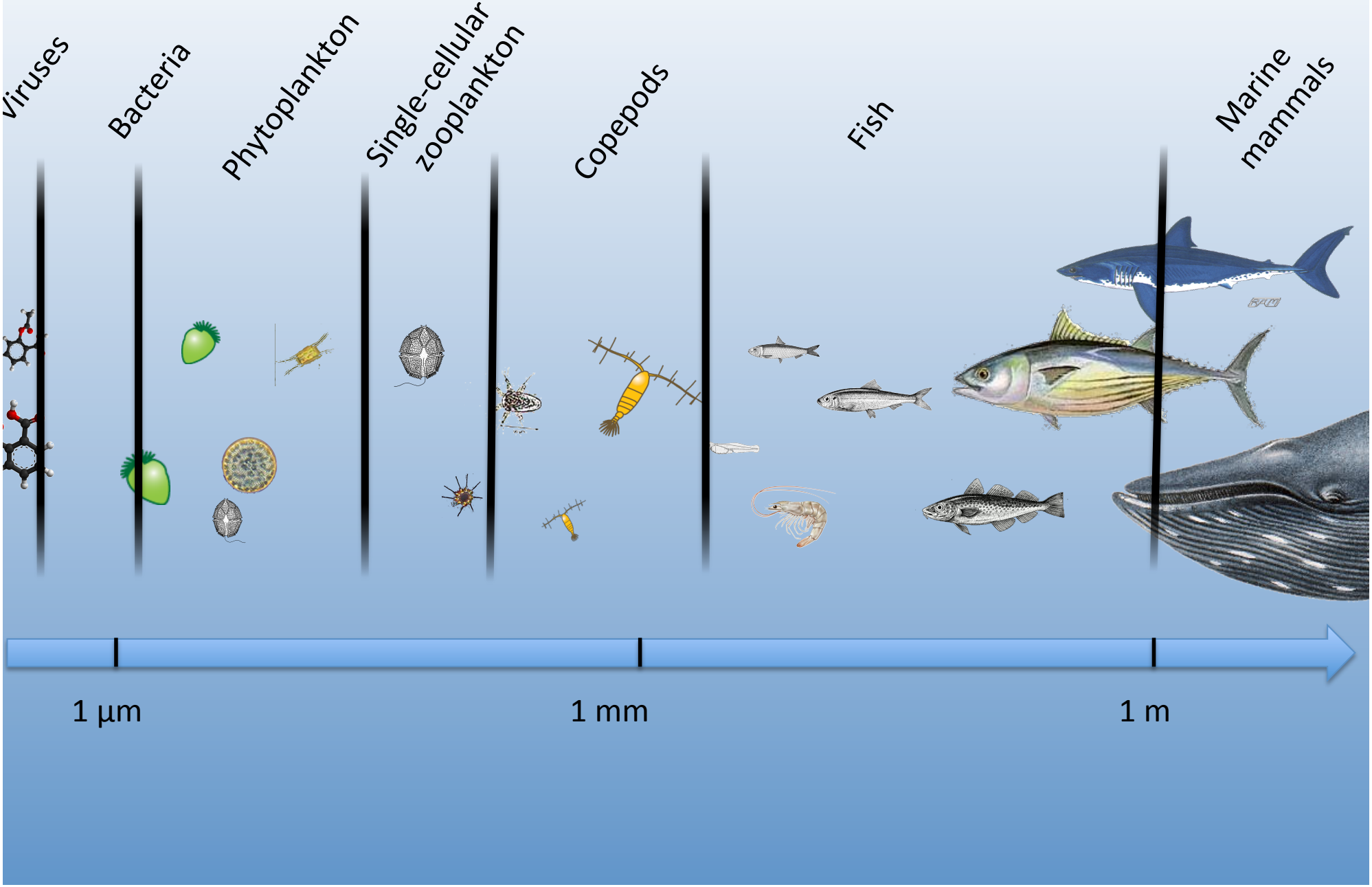


Which two fish are ecologically most similar?

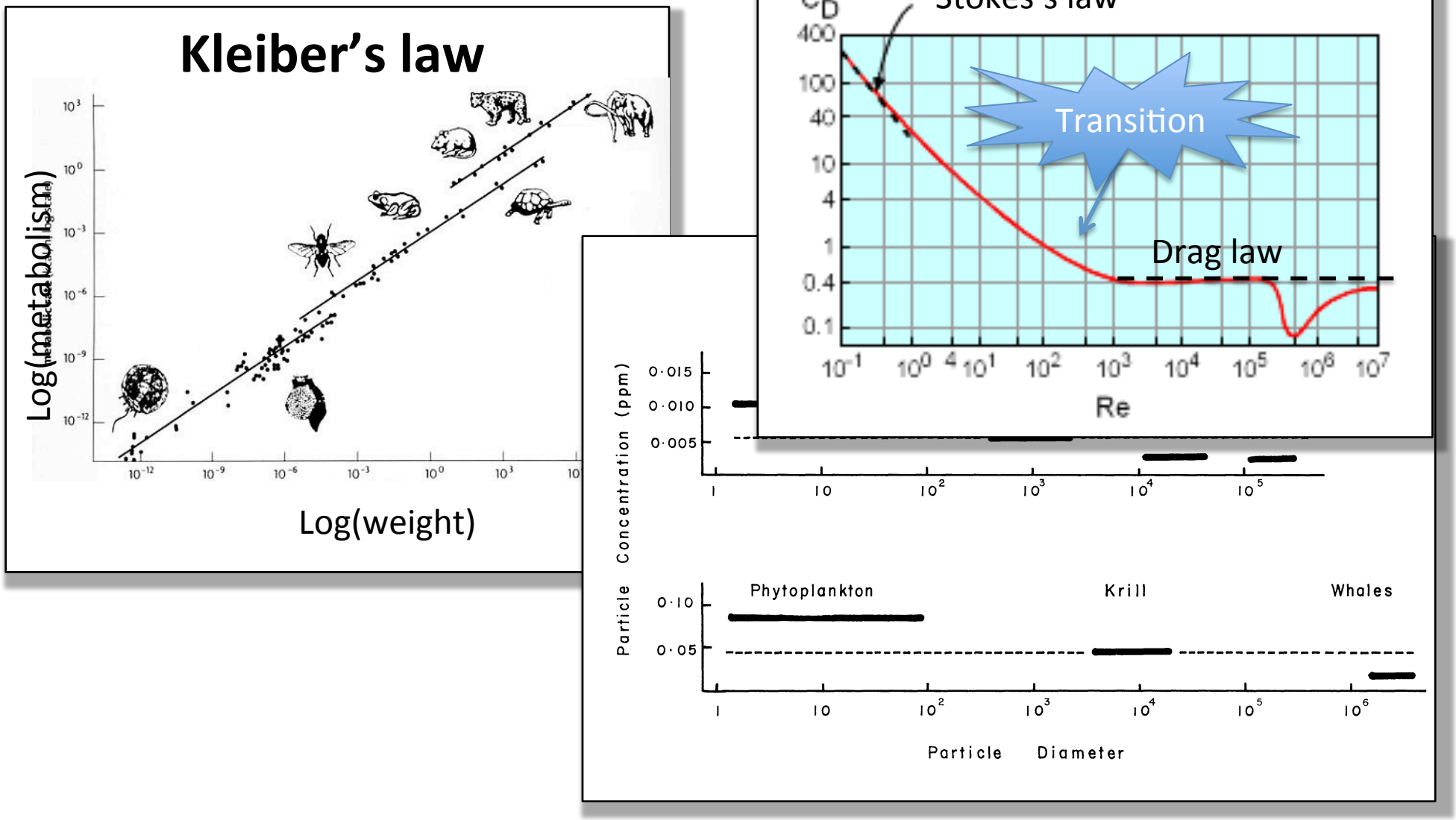


"The most obvious differences between different animals are differences of size..." (Haldane, 1928)

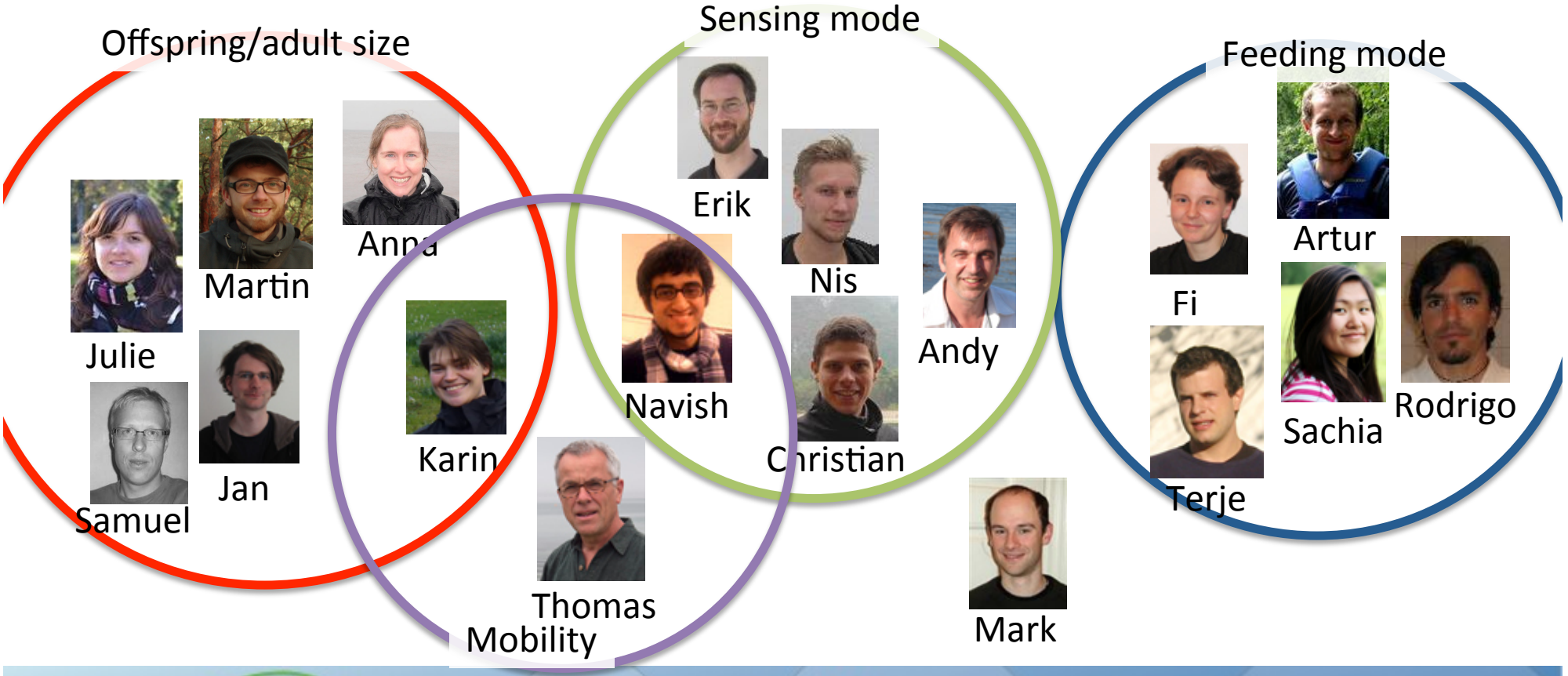
Life in the ocean



Power law scaling



What determines the sizes of transitions between life forms?

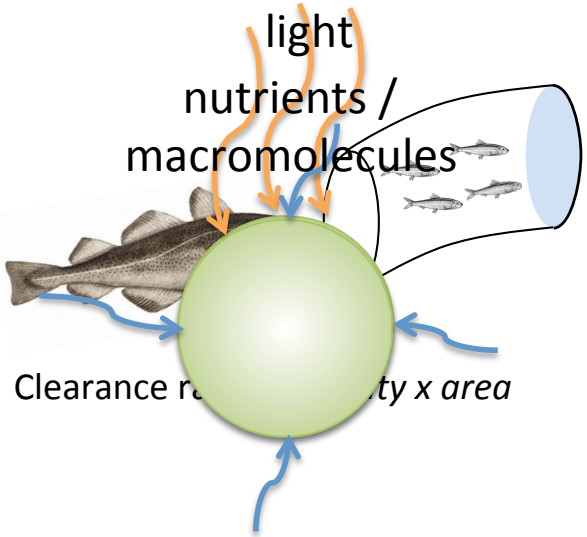


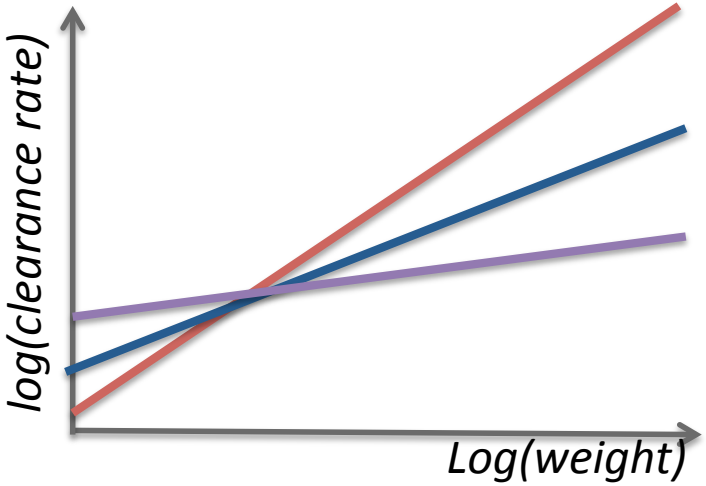
#1: Feeding mode

Clearance rate:

$$\beta(w) = bw^a$$ [Volume per time]

Feeding mode: encounter processes

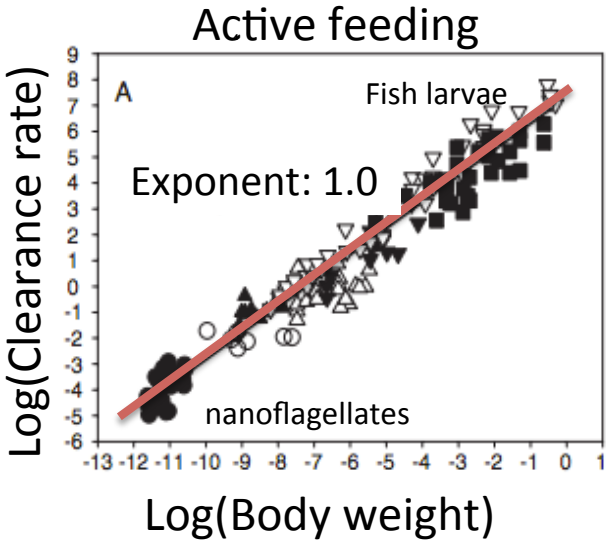




Active feeding: volume^{1}

Surface process: volume$^{2/3}$

Diffusive flux: volume$^{1/3}$

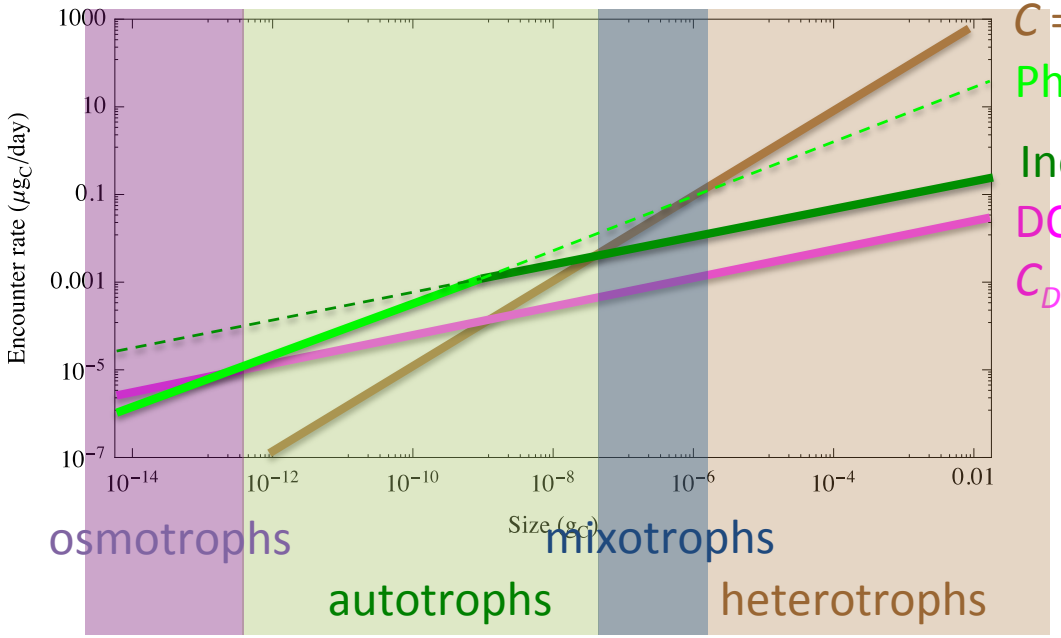


Kiørboe (2011)

Encountered food: $E = bw^a \times C$

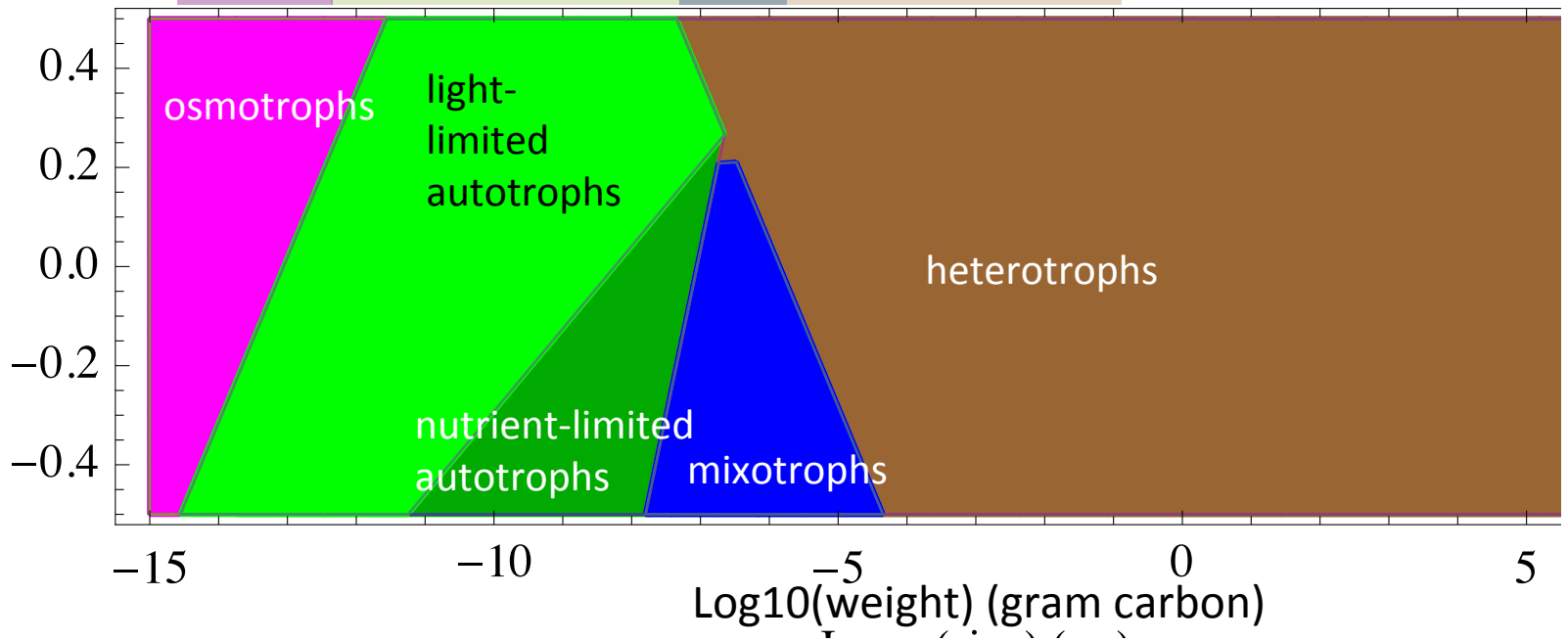
$$\left[\frac{\text{mass}}{\text{time}}\right] = \left[\frac{\text{volume}}{\text{time}}\right] \times \left[\frac{\text{mass}}{\text{volume}}\right]$$

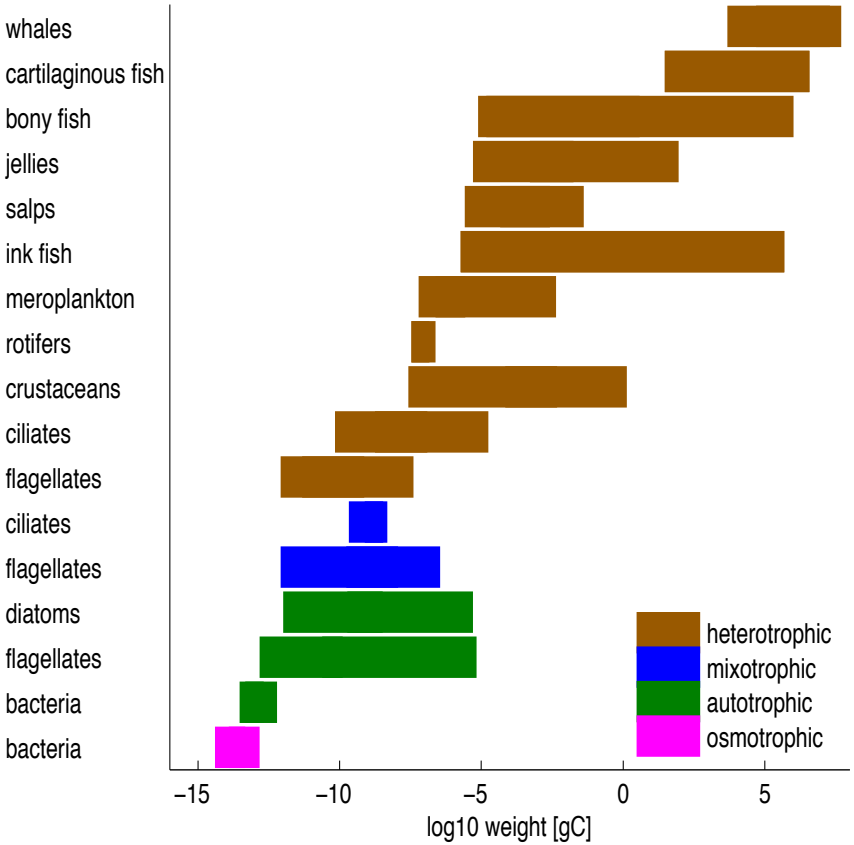
Other organisms
C = 100 µgC/l
Photosynthesis
Inorganic nutrients
DOM
C_{DOM} = 5 µgC/l



Eutrophic
(high nutrients,
low light)

Oligotrophic
(low nutrients,
high light)





heterotrophs

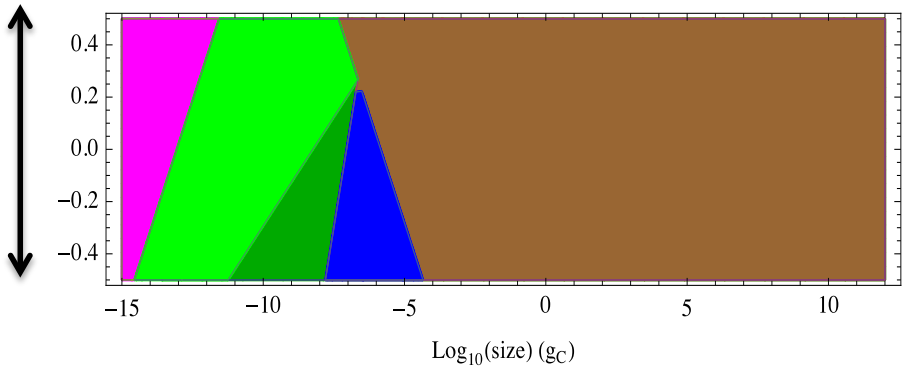
mixotrophs

phototrophs

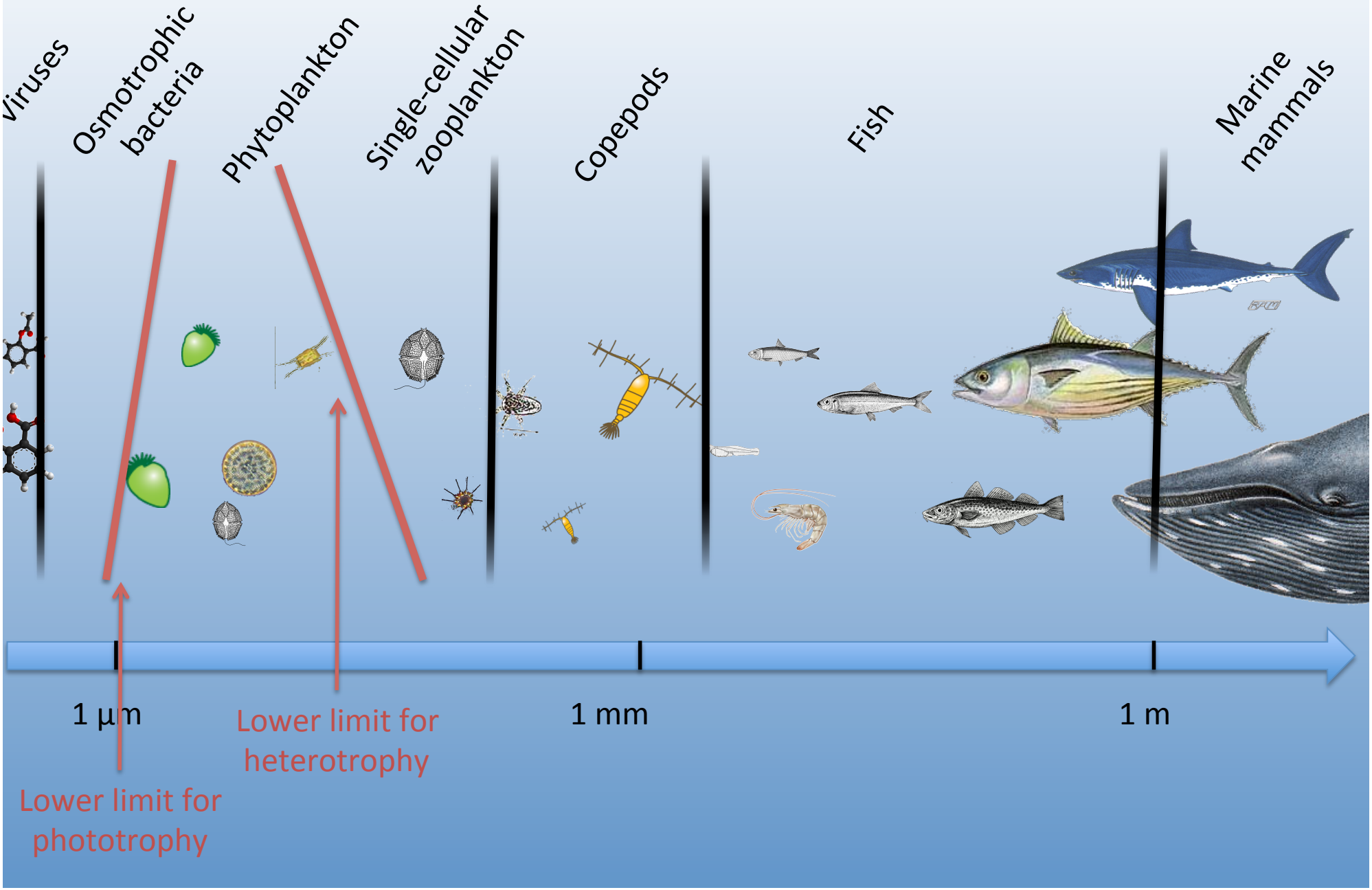
osmotrophic bacteria

Eutrophic
(high nutrients,
low light)

Oligotrophic
(low nutrients,
high light)



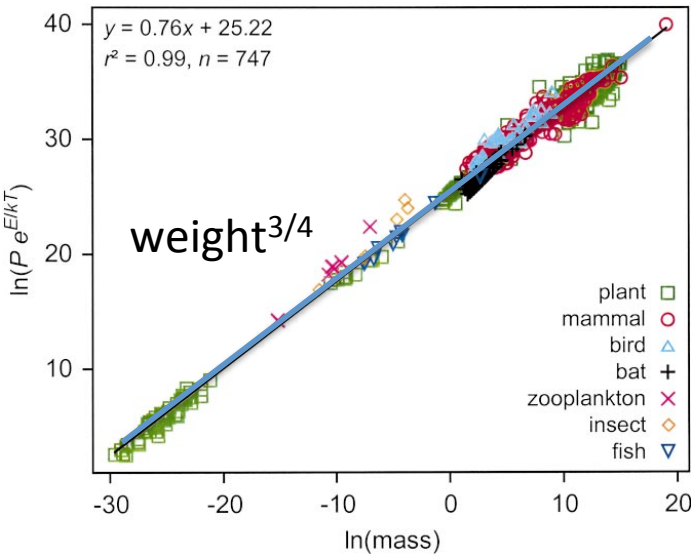
Life in the ocean



#2: Life history - evolution of ontogenetic growth

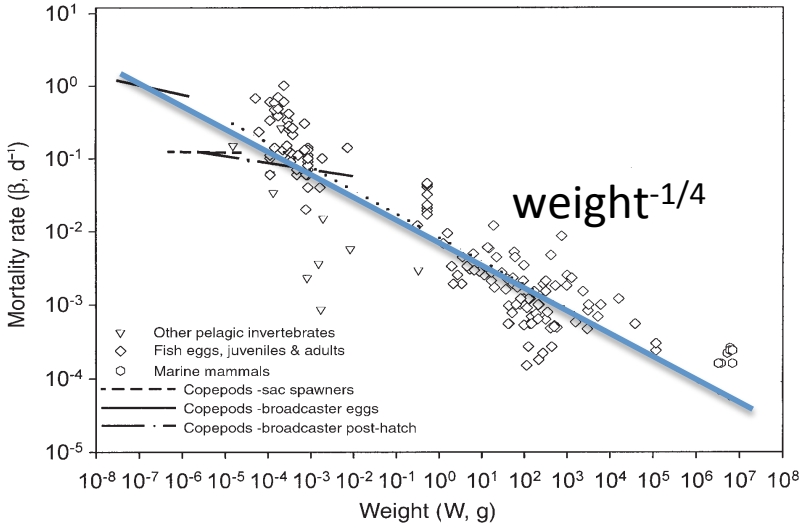
What is the optimal size of offspring and adults?

Metabolism



Brown et al (2004)

Mortality



Hirst & Kiørboe (2002)

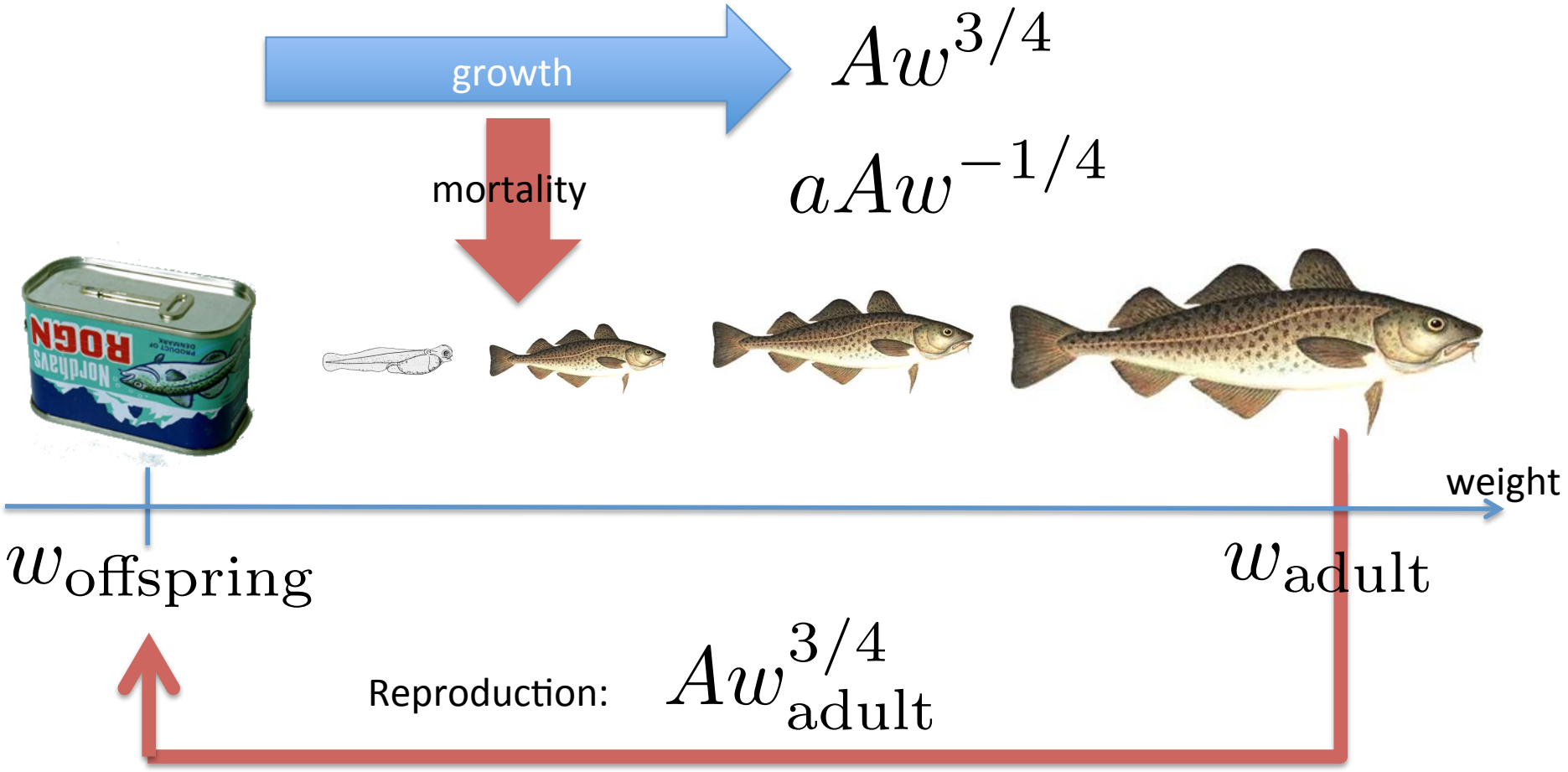
$Assumptions$:

Available energy: Aw^n

Mortality: aAw^{n-1}

Determinate growth

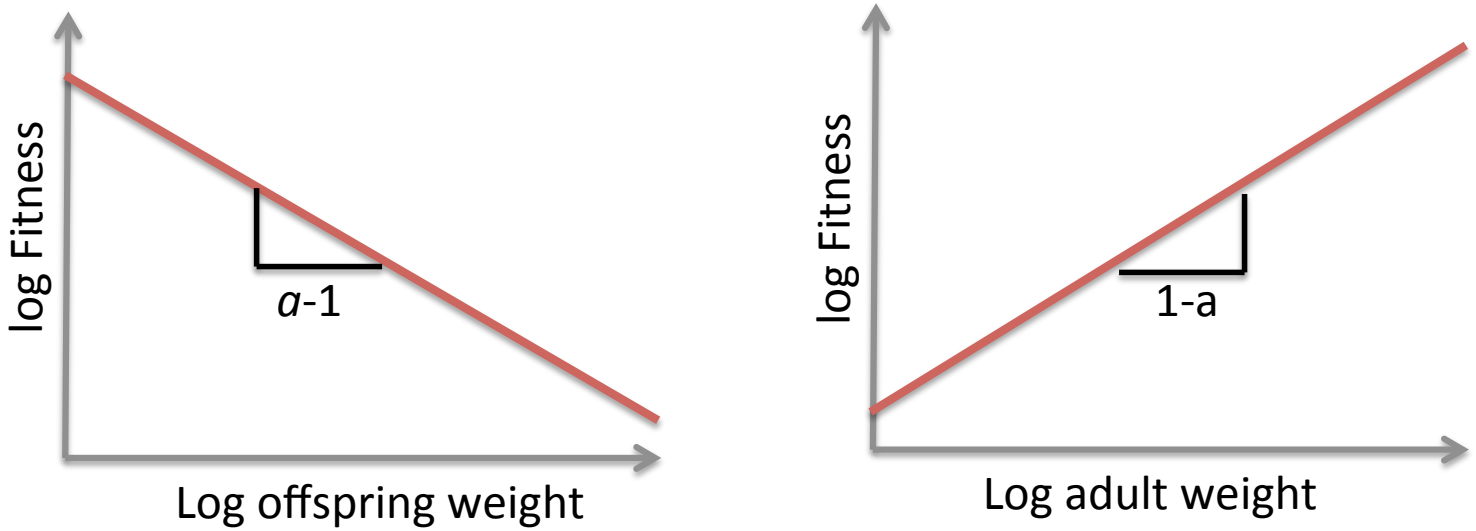
Fitness: (probability to survive to adulthood) x (reproductive rate) x (adult lifespan)



$$R_0 \propto P_{w_{\text{offspring}} \to w_{\text{adult}}} Aw_{\text{adult}}^{3/4} \frac{1}{aAw_{\text{adult}}^{-1/4}}$$

Optimal life history

$$R_0 \propto \left(\frac{W_{\text{adult}}}{W_{\text{offspring}}}\right)^{1-a}$$

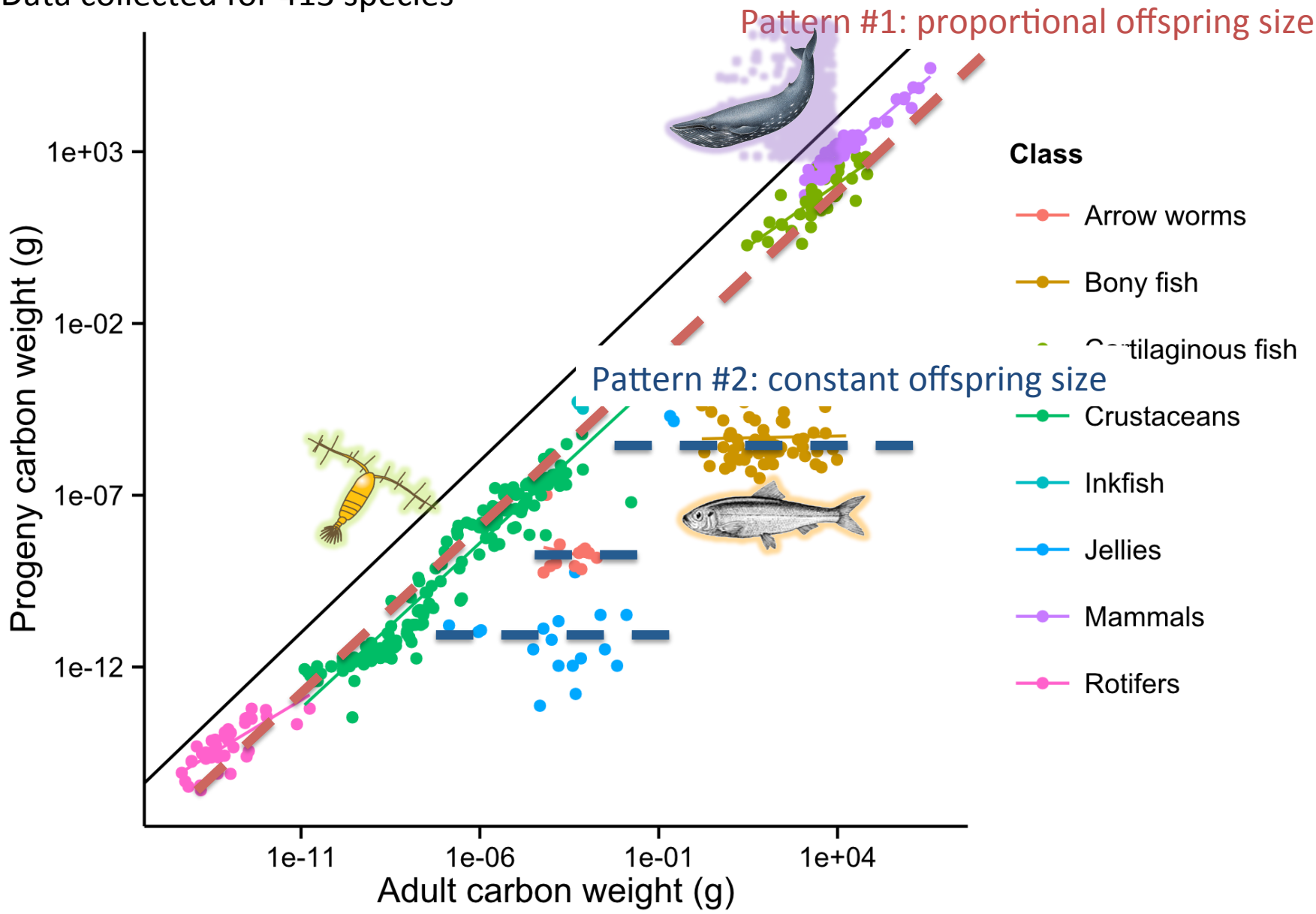


1) Organisms want to minimize offspring size

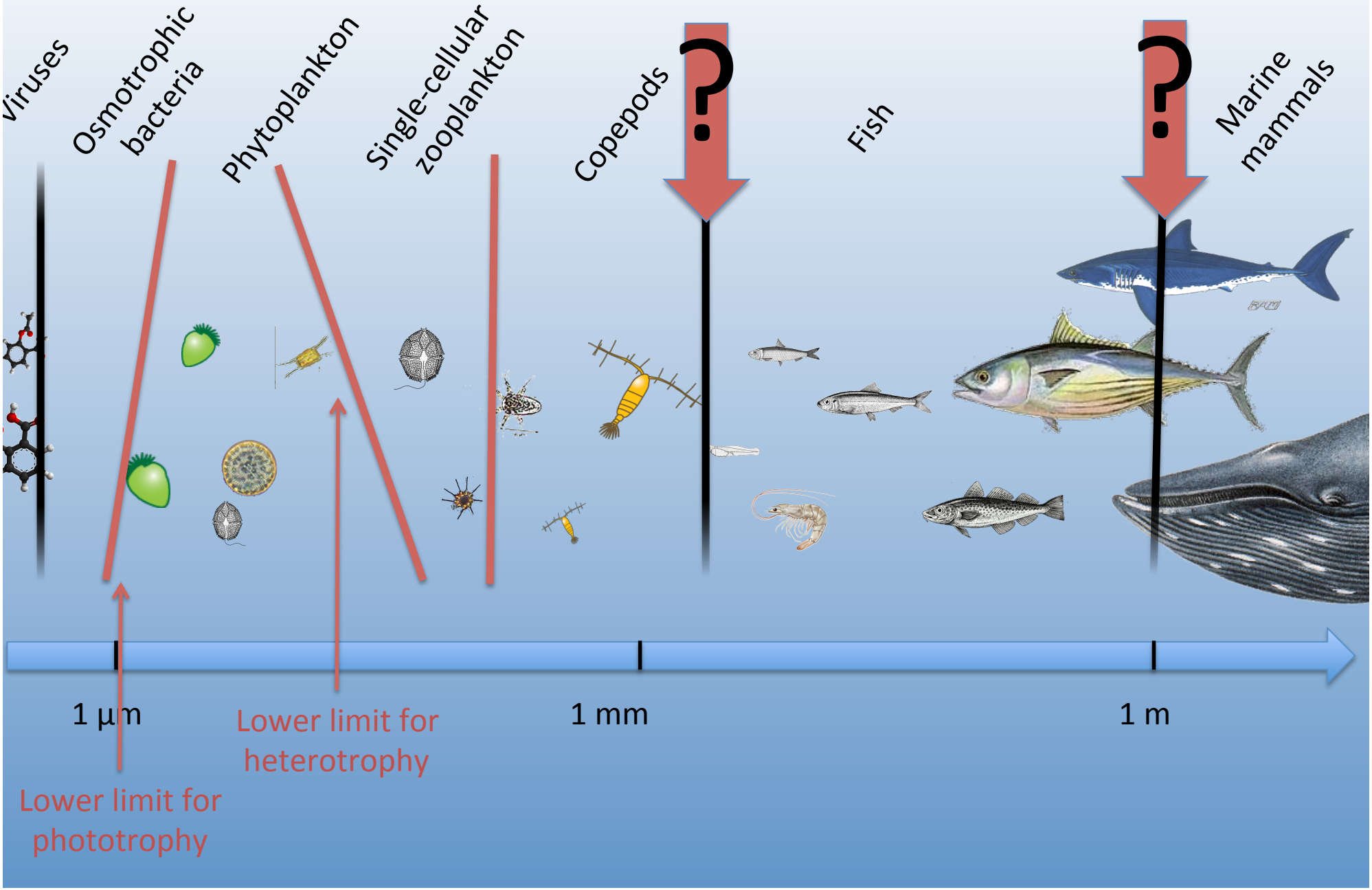
2) Organisms want to maximize adult size

Patterns of offspring size

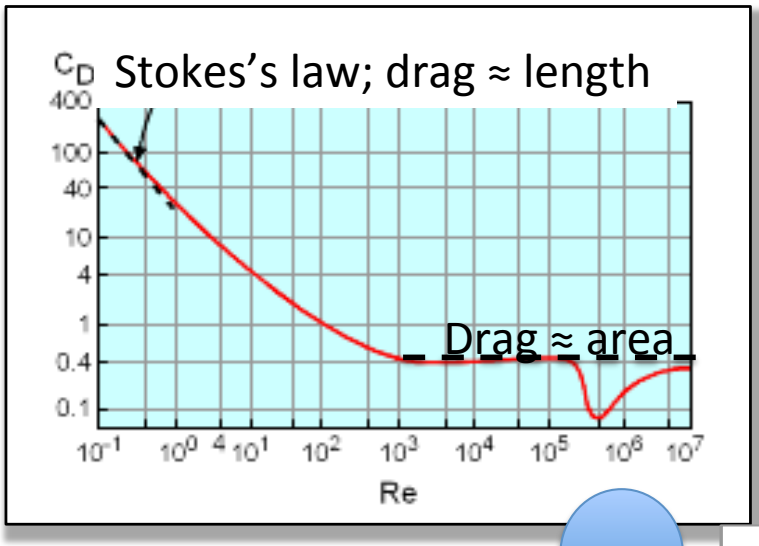
Data collected for 413 species

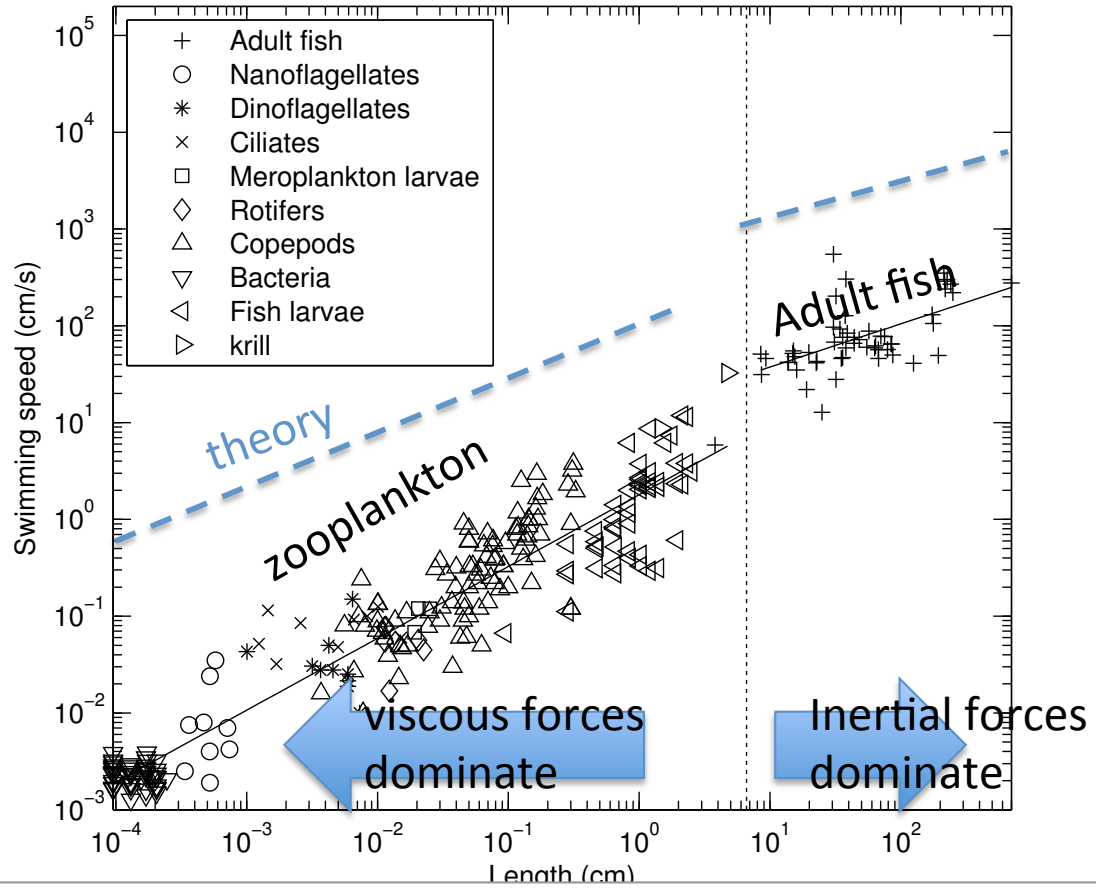


Life in the ocean



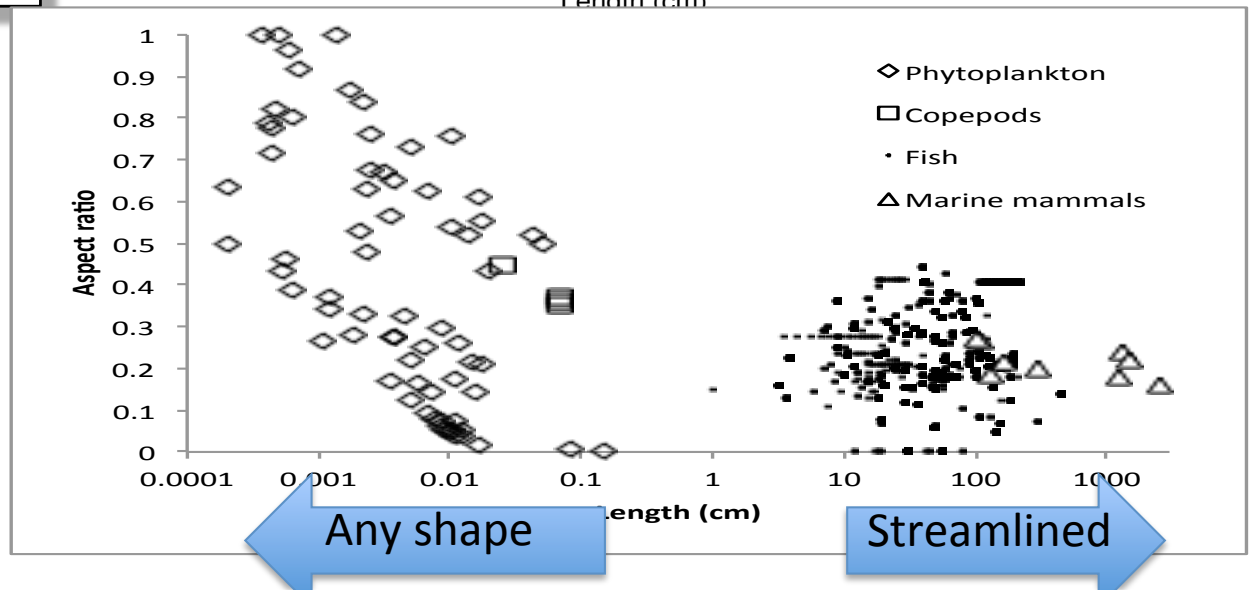
#3: Mobility





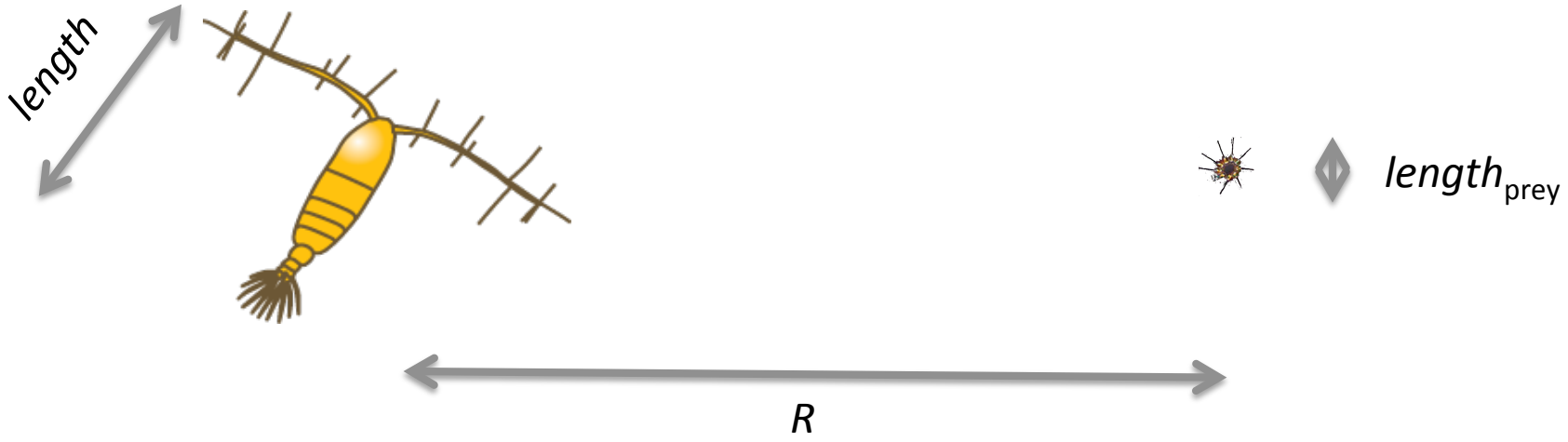
Spherical

Streamlined

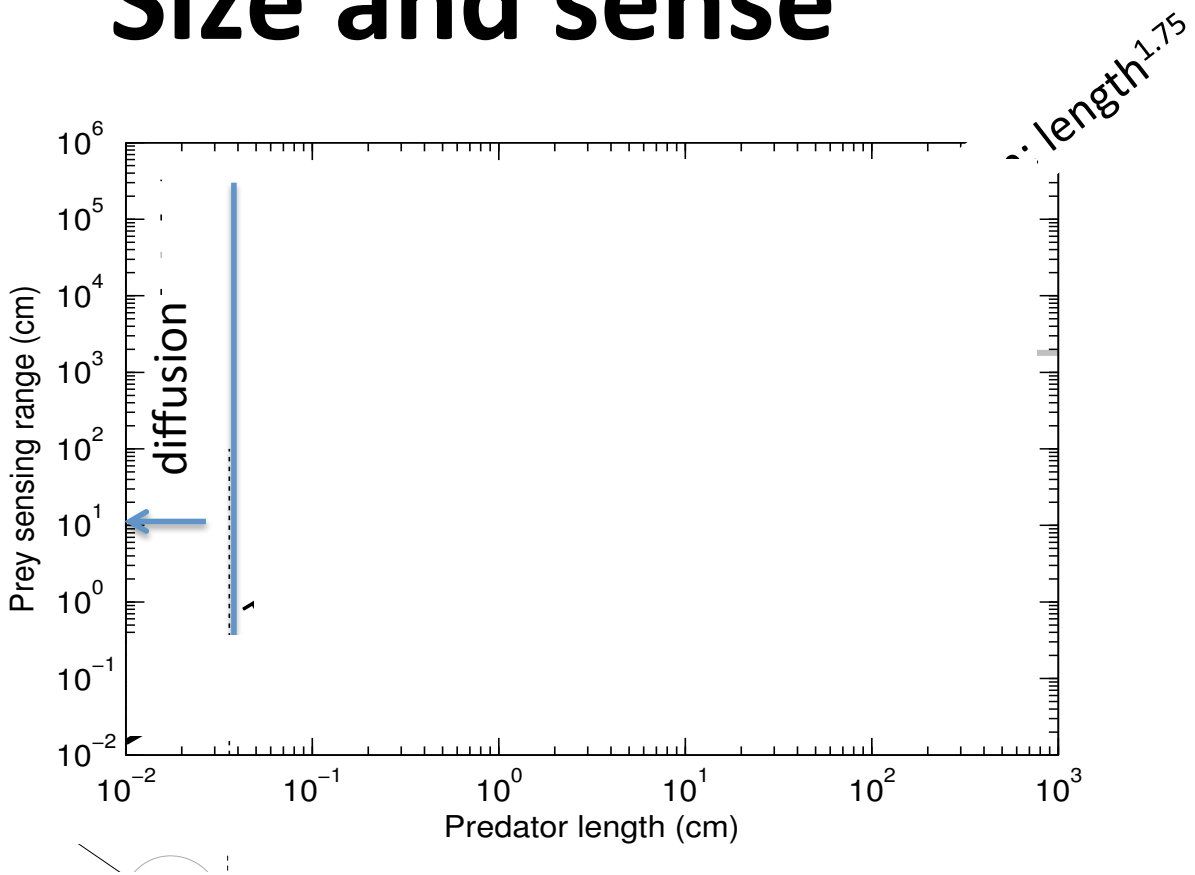


#4: Size and Sense

Within which range can an organism sense a prey?



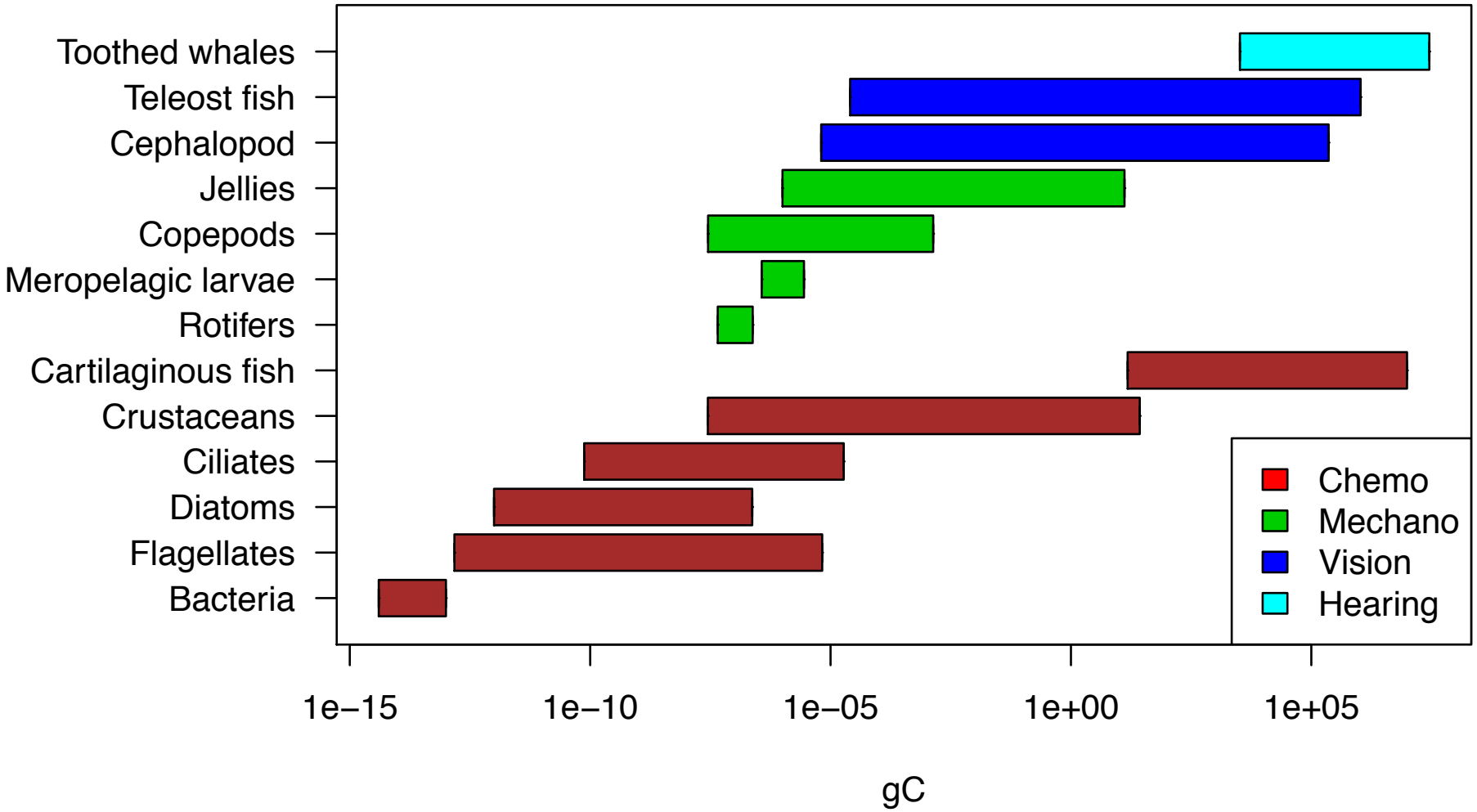
Size and sense



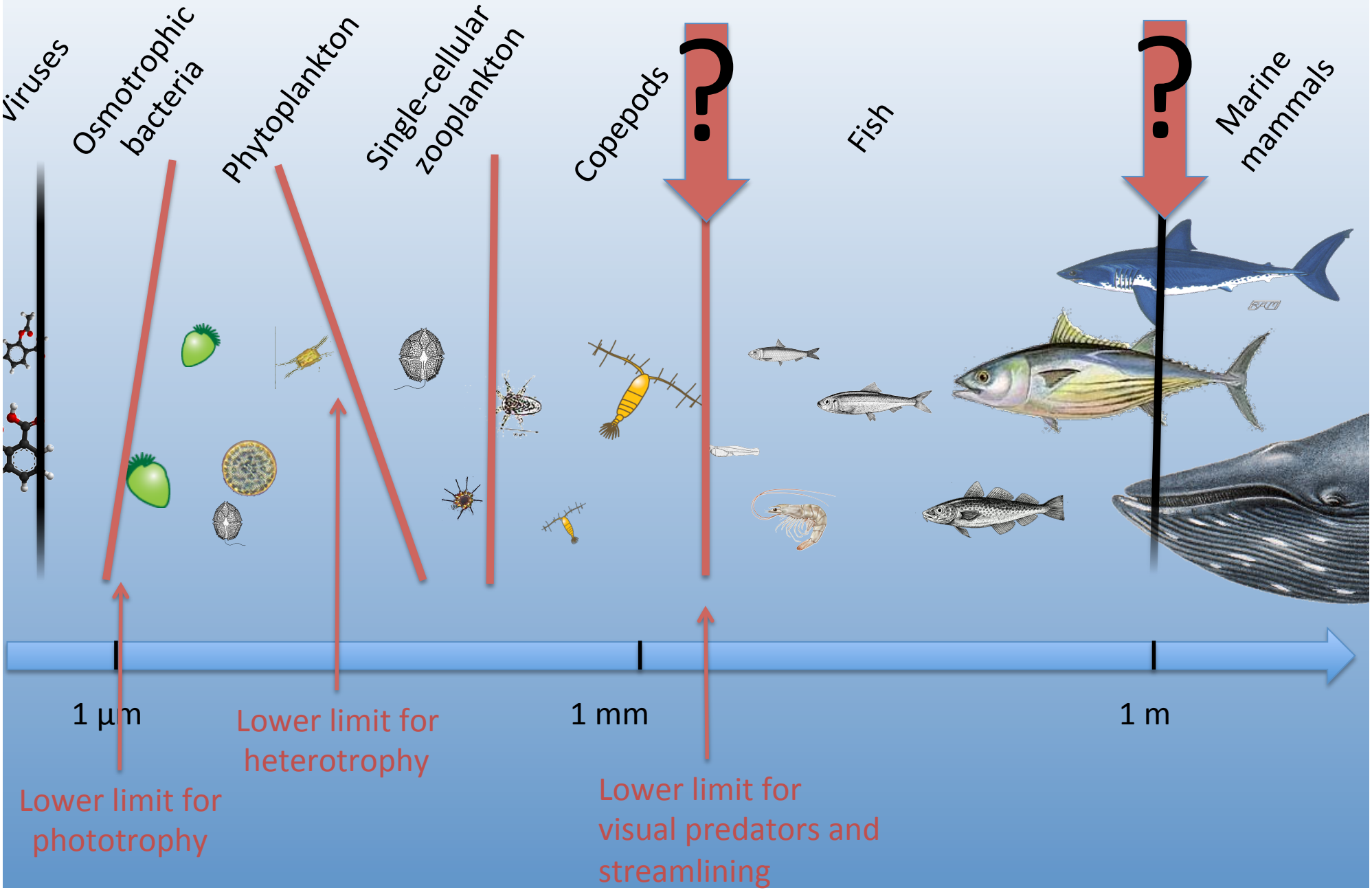
Conclusions:

1) Small animals achieve the longest sensing range by tactile sensing
2) There is a transition between tactile and vision at a size between 1 mm and 1cm
3) Organisms larger than about 1 m (or at depth) echolocate

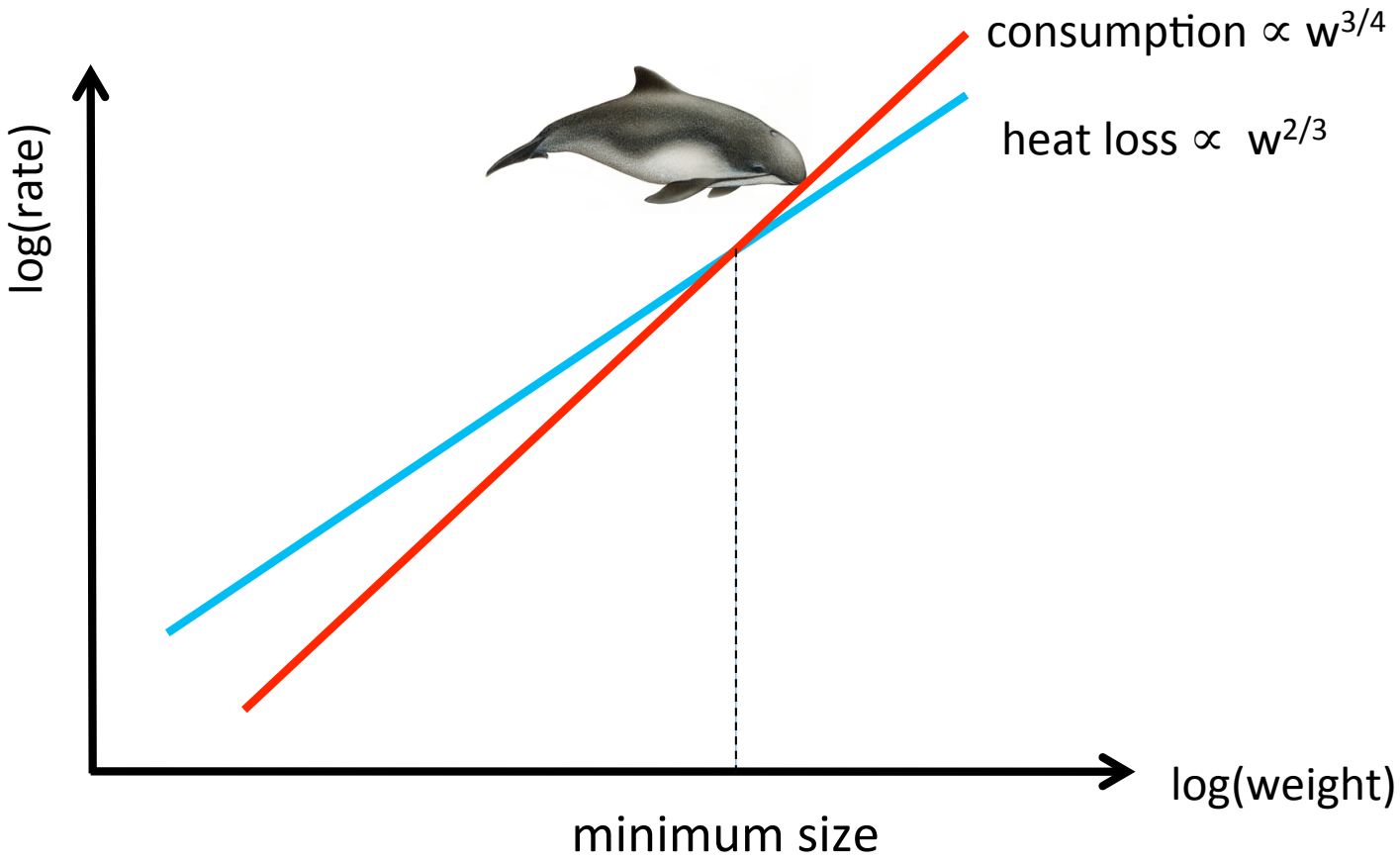
Size and sense



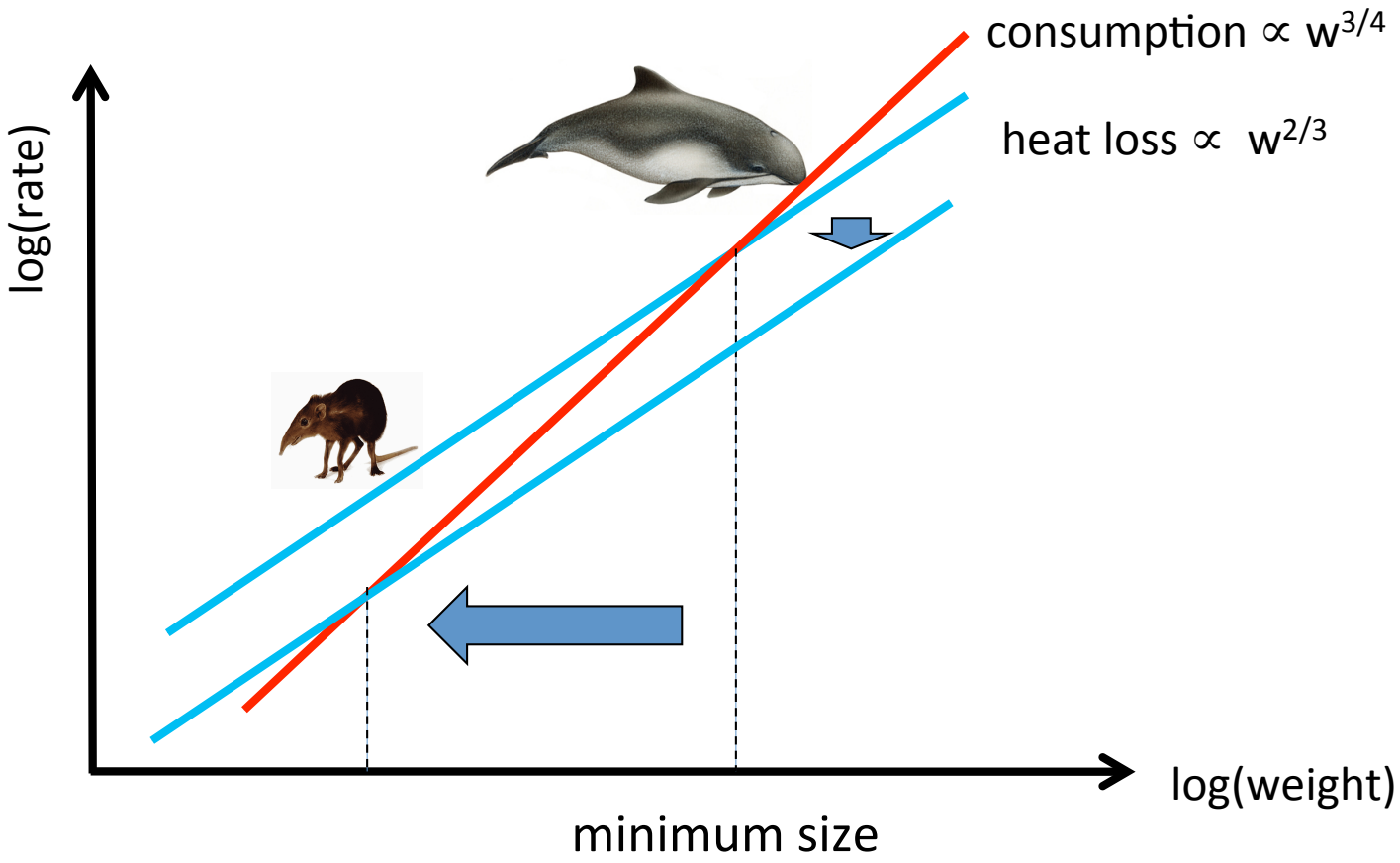
Life in the ocean



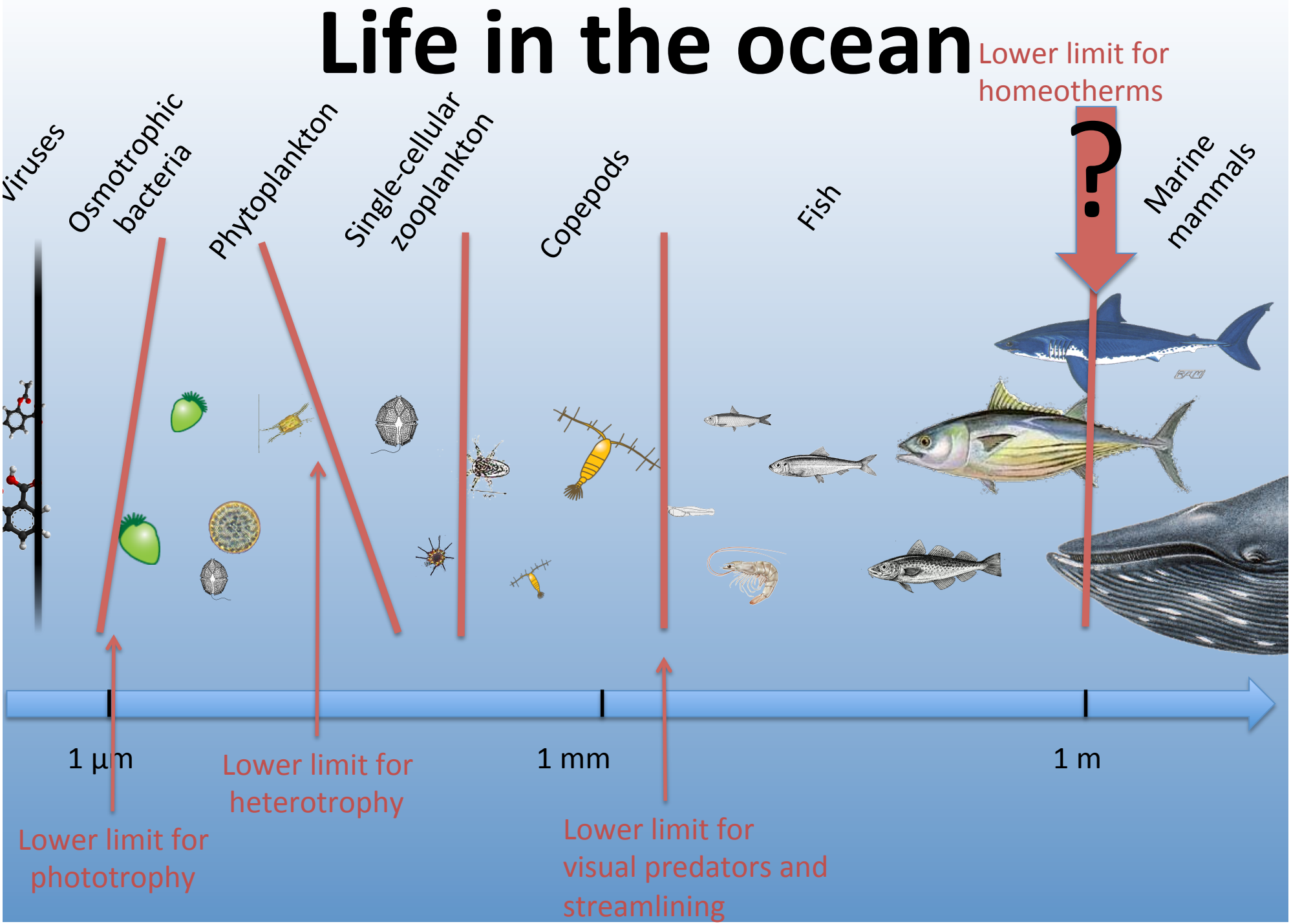
Energy budget

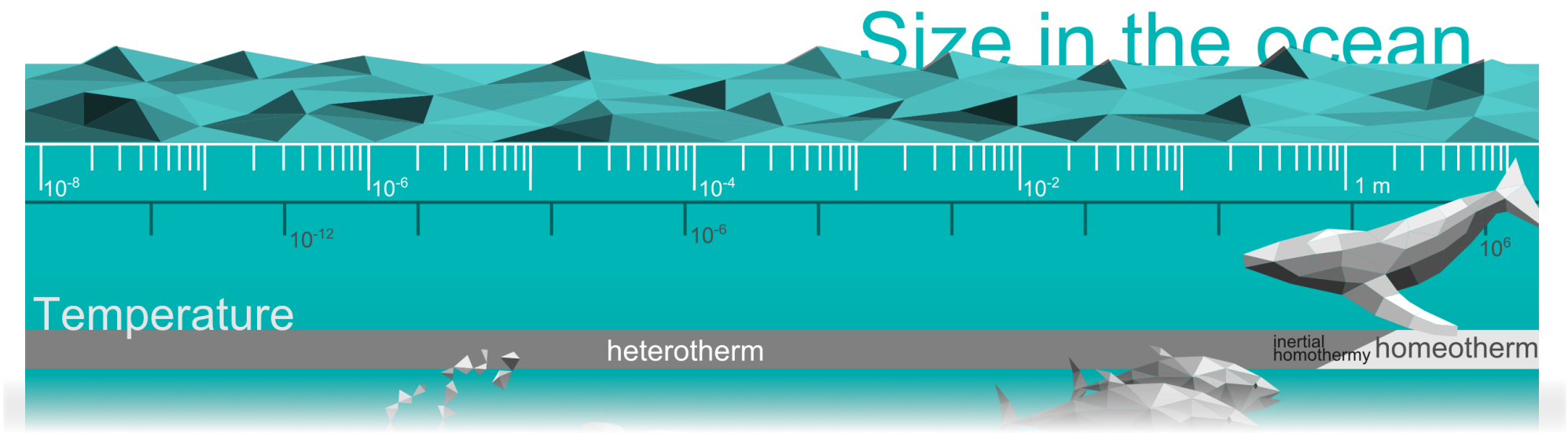


Energy budget



Life in the ocean

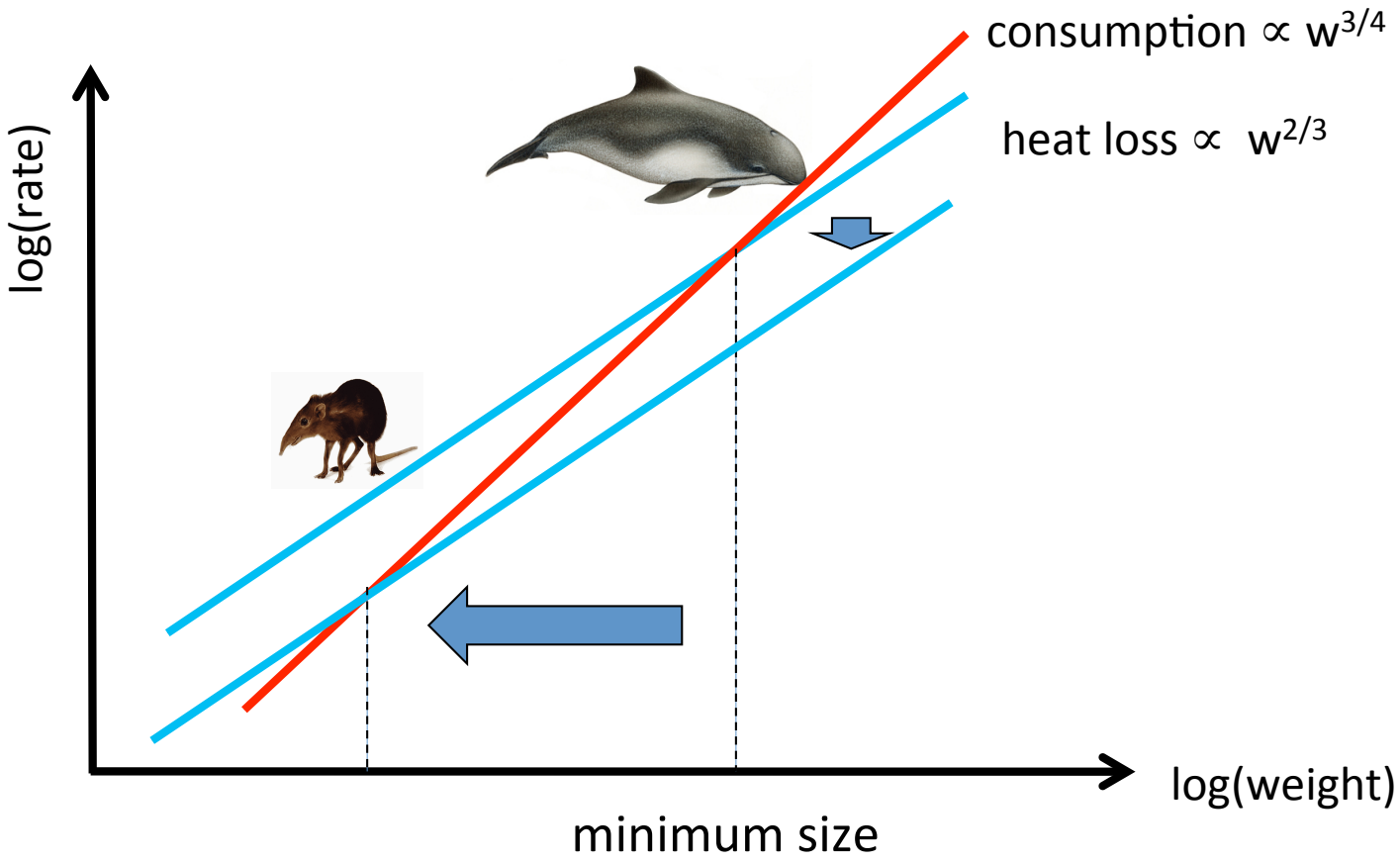



Size in the ocean
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1 m
10^{-12}
10^{-6}
10^{6}
Temperature
heterotherm
inertial homothermy
homeotherm

Life on land

- Why does the many-small-eggs strategy not exist on land?

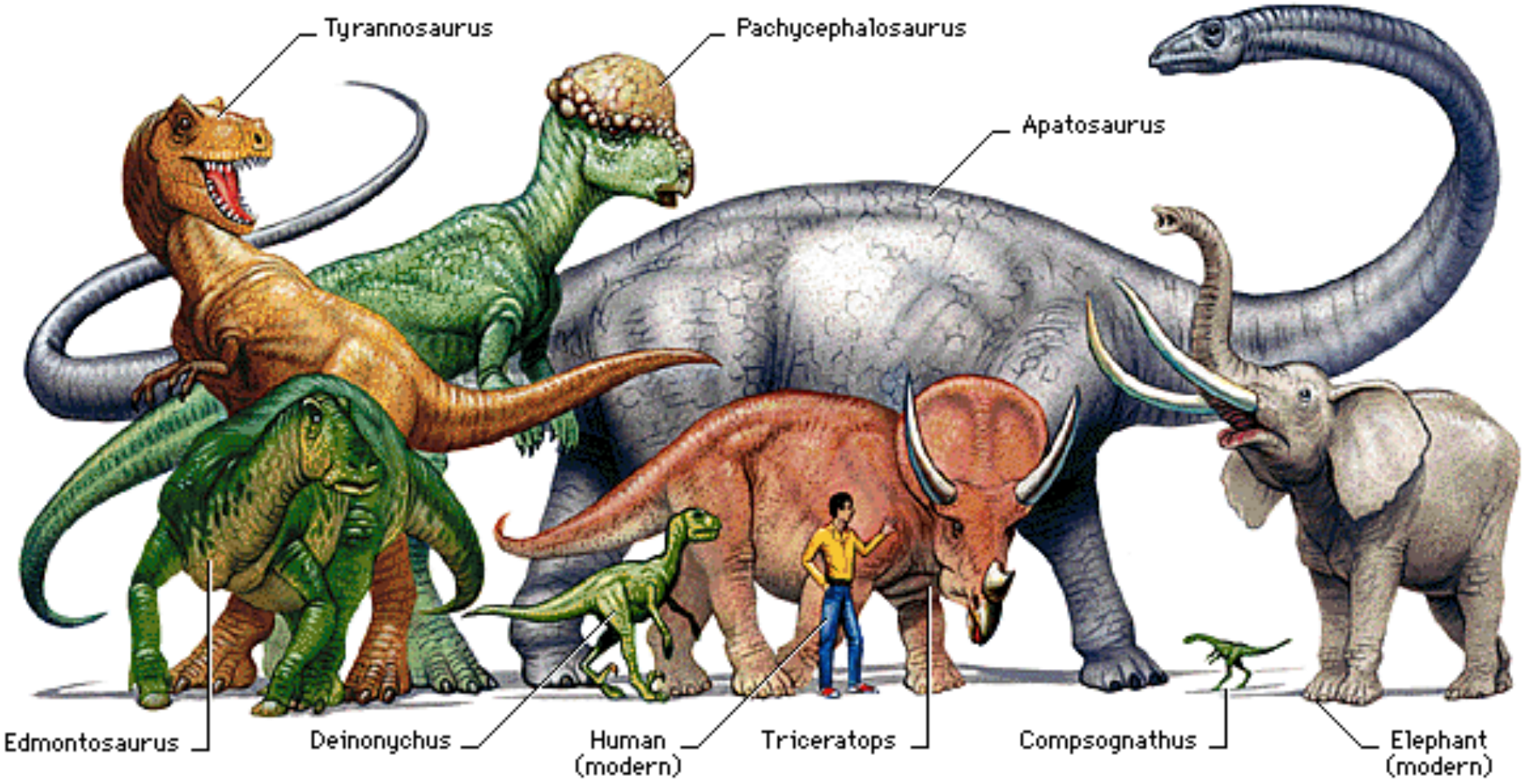
Energy budget



Life on land

- Why does the many-small-eggs strategy not exist on land?

- Could the many-small-eggs strategy exist on land?


Tyrannosaurus
Pachycephalosaurus
Apatosaurus
Edmontosaurus
Deinonychus
Human
(modern)
Triceratops
Compsognathus
Elephant
(modern)

What cannot be explained by size?

- Gelatinous zooplankton
- Elasmobranchs
- Large filter-feeders