McGill

# The Biomechanical Model

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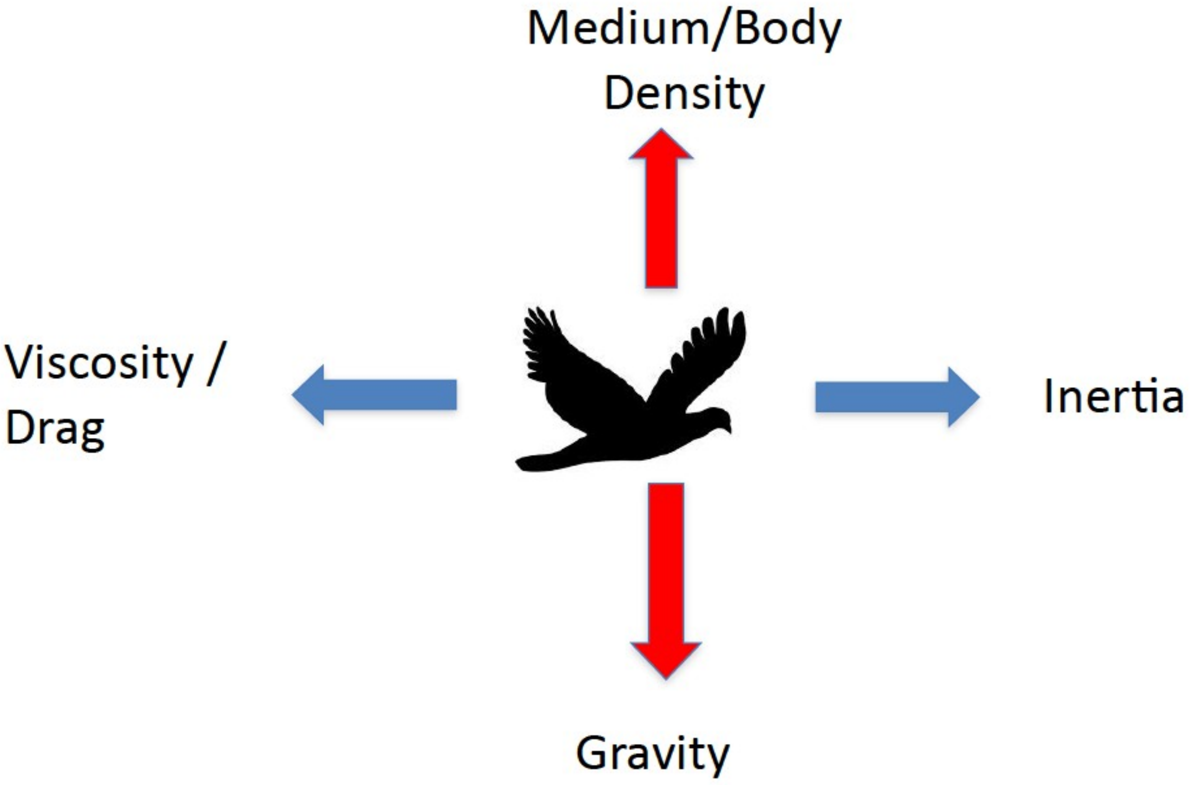
*From* The mechanics of predator-prey interactions:
first principles of physics predict predator-prey size ratios

*Portalier S., Fussmann G., Loreau M., & Cherif M.*


*Functional Ecology 33(2)*, 2019


Workshop on the eco-mechanics of food webs, Leipzig, oct 2019

# Mechanical factors



# The model

Search prey

Capture prey

Handle prey

# The model considers physiological and mechanical costs associated to predation

$$G = E - (C_s + C_c + C_h)$$

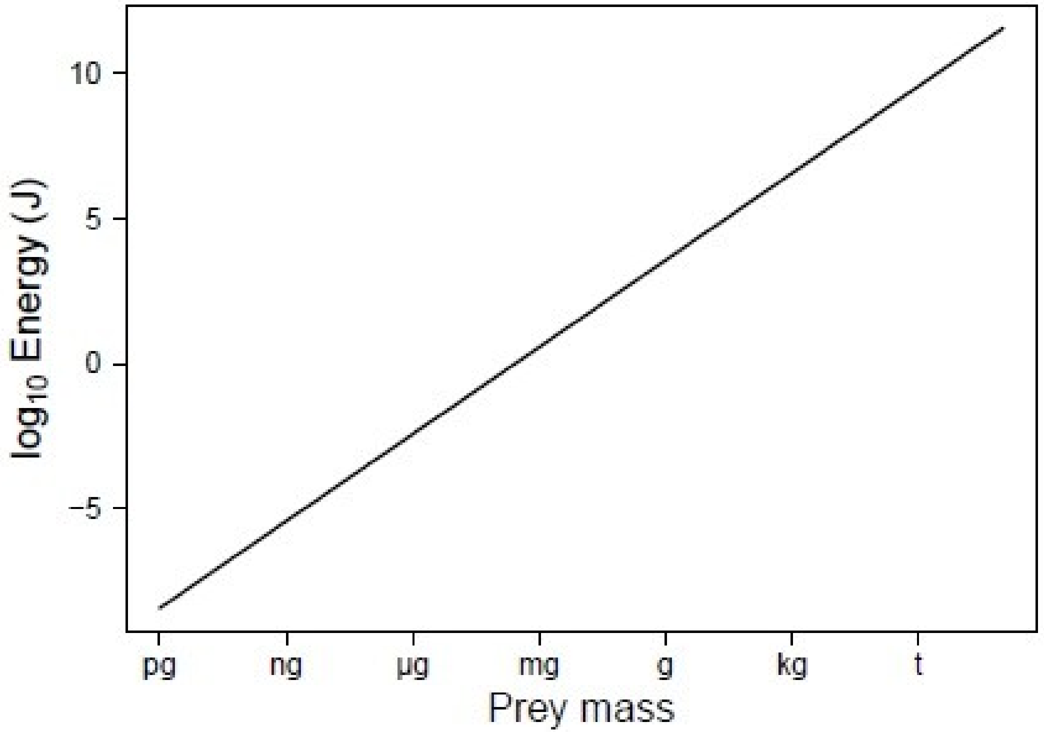
**Where**

$G$: predation gain
$E$: energy from the prey

$C_s$: search cost
$C_c$: capture cost
$C_h$: handling cost

# Energy given by the prey increases with prey size

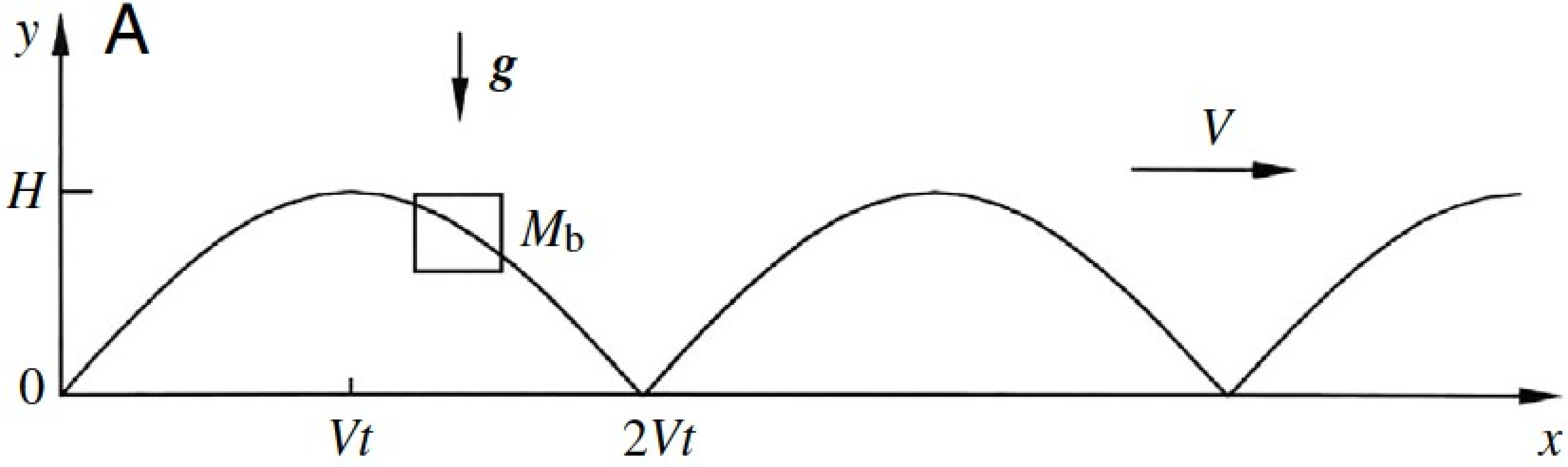
$$E \propto M_b$$



# Search, Capture and handling costs involve cost for motion and cost for metabolism

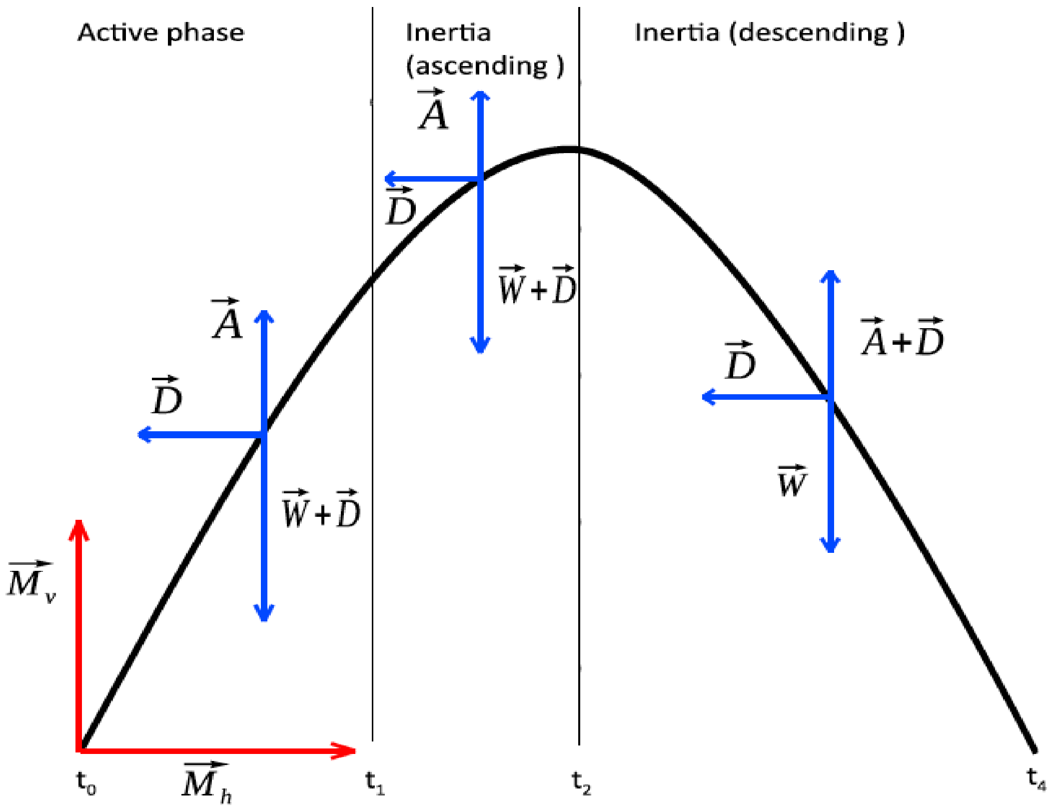
$$\{C_s, C_c, C_h\} = \text{Cost}_{motion} + \text{Cost}_{metabolism}$$

# Species motion can be represented as an oscillatory process




Bejan and Marden, 2006, *J. Exp. Biol.*

# Motion is split into vertical and horizontal components



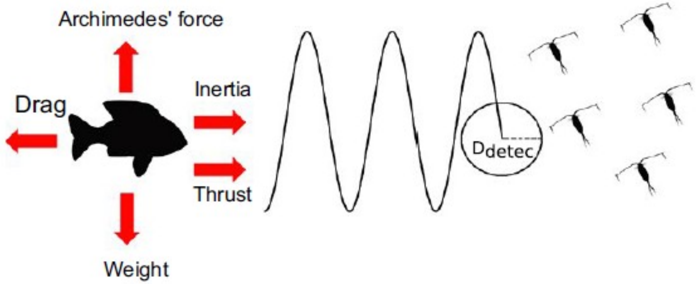
# Three sequences

Search prey

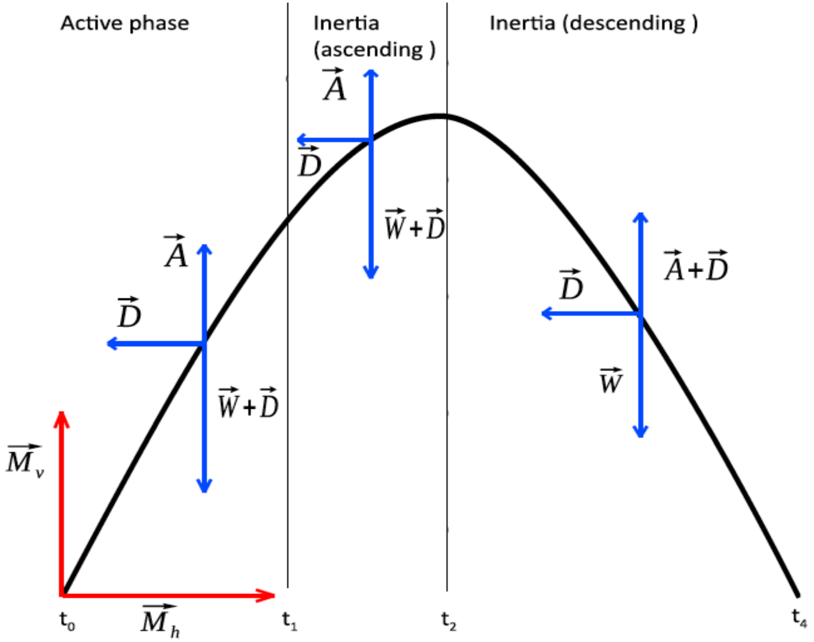
Capture prey

Handle prey

# Search

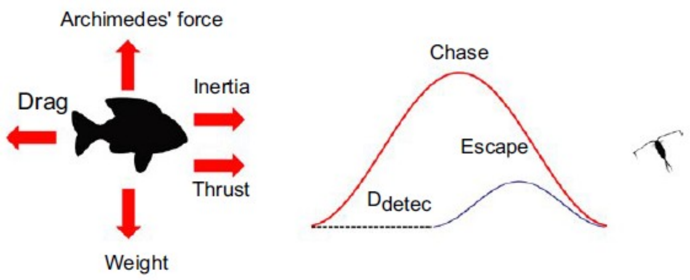


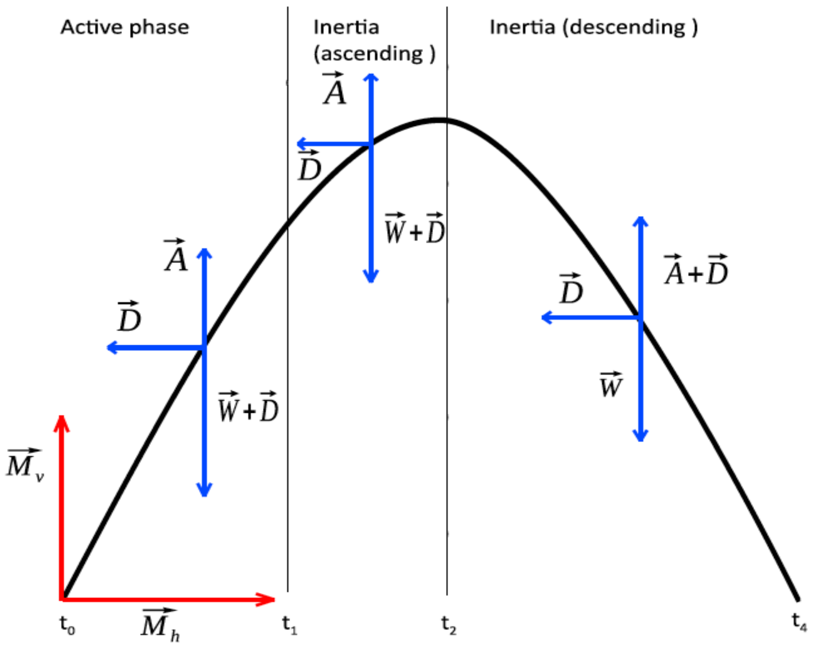

- The predator scans the medium to detect prey
- Motion is done at *species-specific speed*
  - The predator optimizes the Speed/Cost ratio



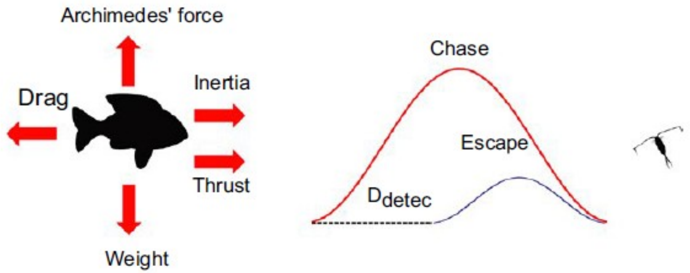
# Capture

- The predator jumps and tries to catch the prey
- The predator uses its maximal *muscular* output and maximizes the distance covered



# Capture

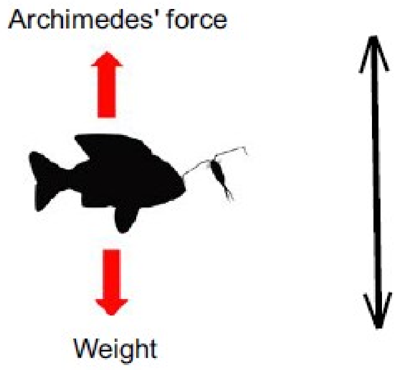


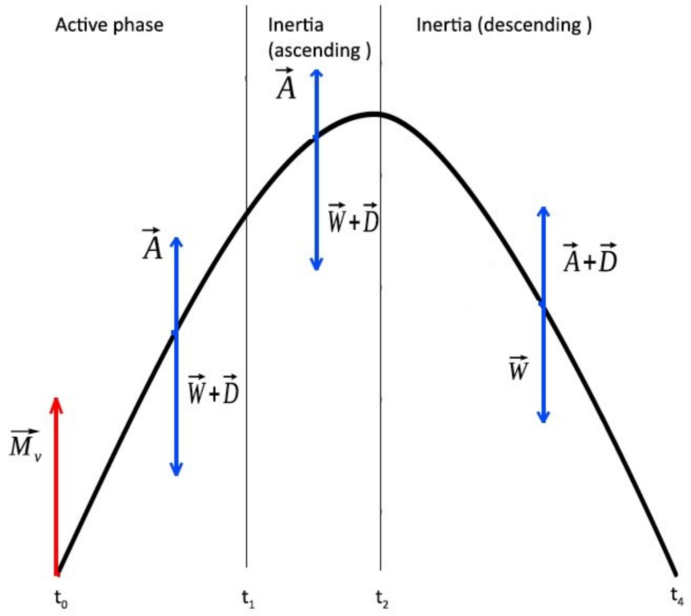

- The prey jumps and tries to escape
- If the prey is reached:
  - Capture probability depends on the ratio between predator/prey speeds (at that moment)

$$P_{suc} = \frac{1}{1 + \frac{v_{Prey}}{v_{Pred}}}$$

# Handling

- The predator tries to maintain its position in the column
- The predator moves only along the vertical plan, with the minimal cost

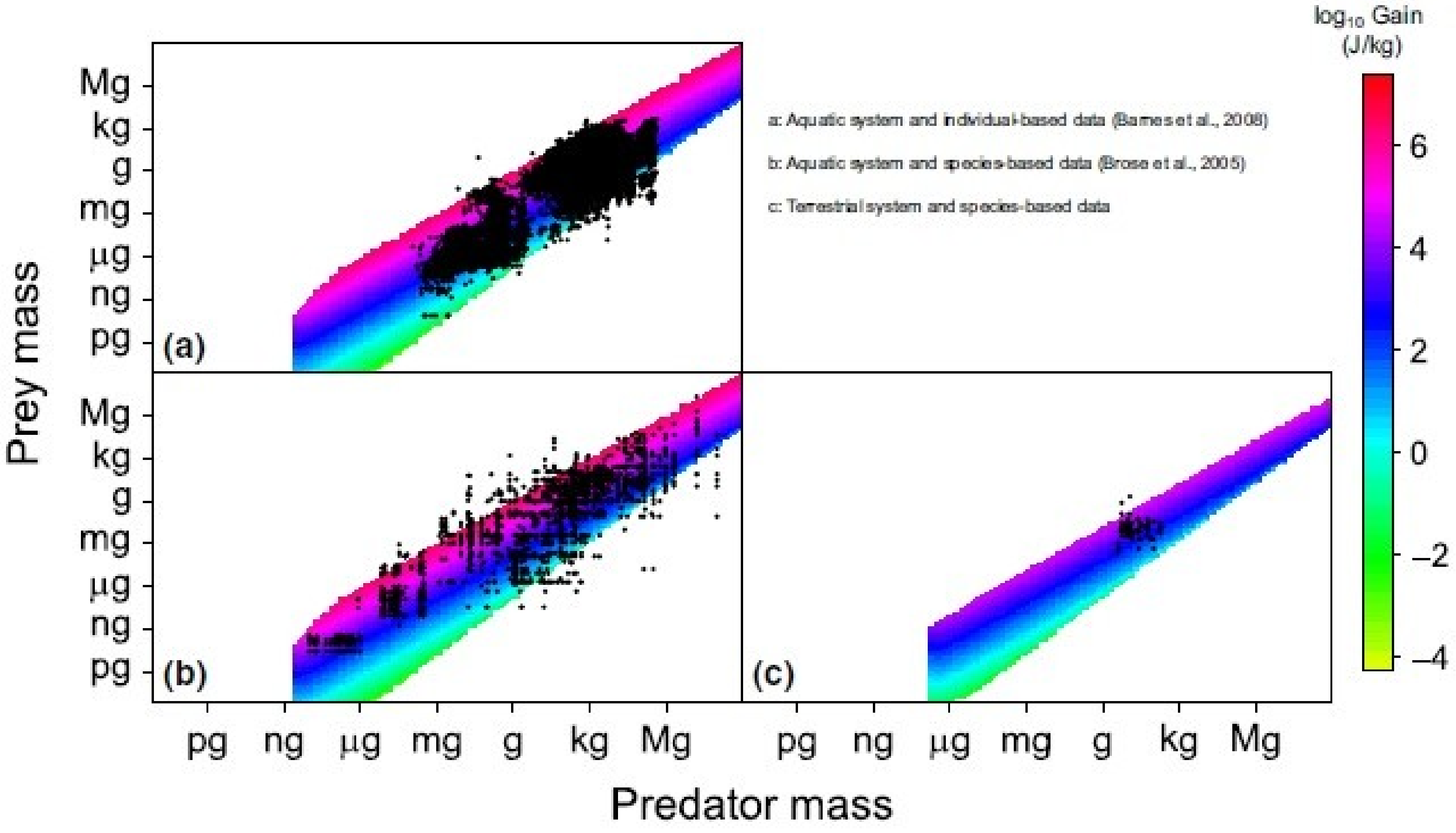


# Main assumptions

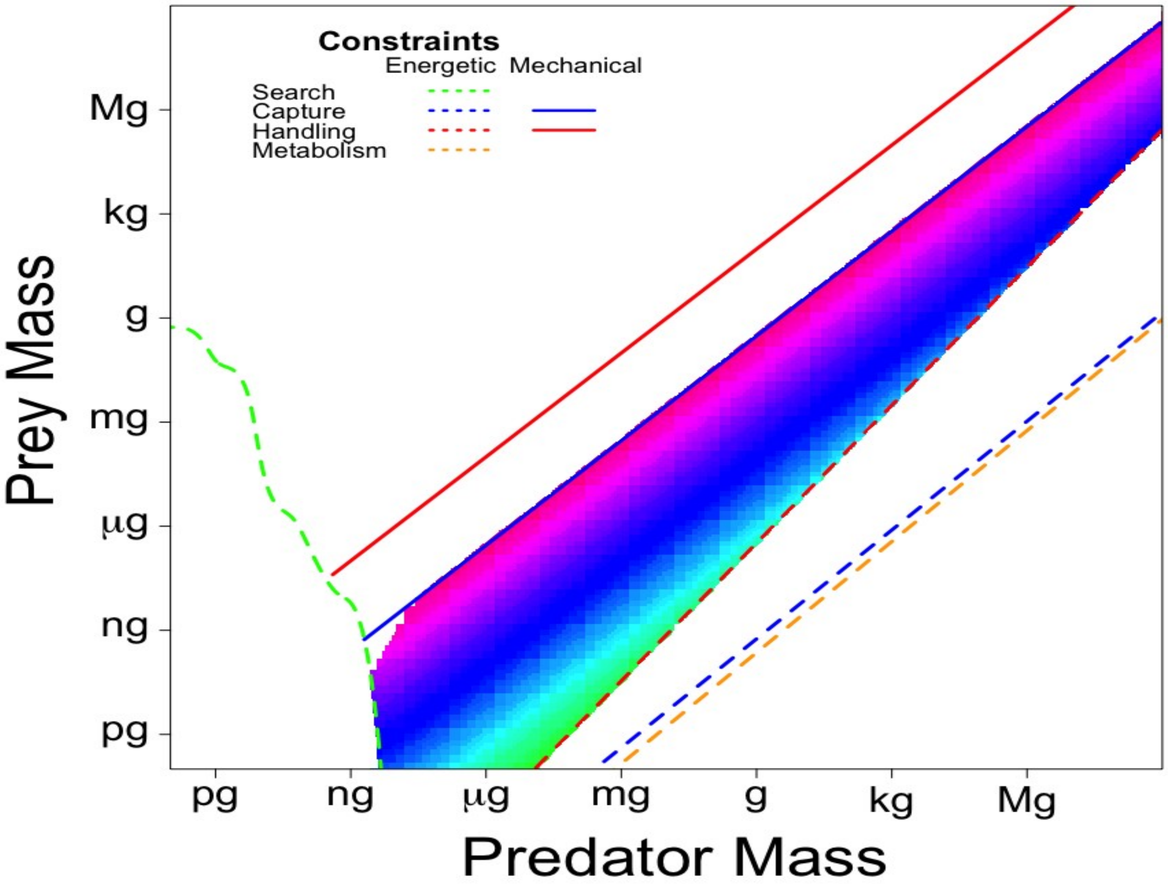
- Predators consume one prey at a time
- Prey try to escape
- Speed is only determined by body size
- Predators stay in the column during all predation phases

# Results



log10 Gain (J/kg)
6
4
2
0
−2
−4
a: Aquatic system and individual-based data (Barnes et al., 2008)
b: Aquatic system and species-based data (Brose et al., 2005)
c: Terrestrial system and species-based data
Prey mass
Mg
kg
g
mg
µg
ng
pg
(a)
(b)
(c)
pg
ng
µg
mg
g
kg
Mg
Predator mass

# Mechanical limit sets upper prey size,
# Energetic limits set lower prey size

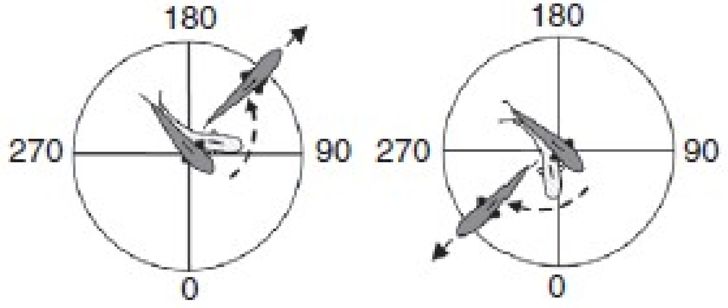


# Other assumptions

- The model focuses on motion and metabolism
  - What about other physiological functions (e.g., growth, reproduction, excretion)?
- Temperature is constant
  - Temperature affects both mechanical factors and metabolism

# Other assumptions

- Capture success is determined by predator-prey relative speed at capture time, while many studies emphasized the role played by ability to change direction during chase



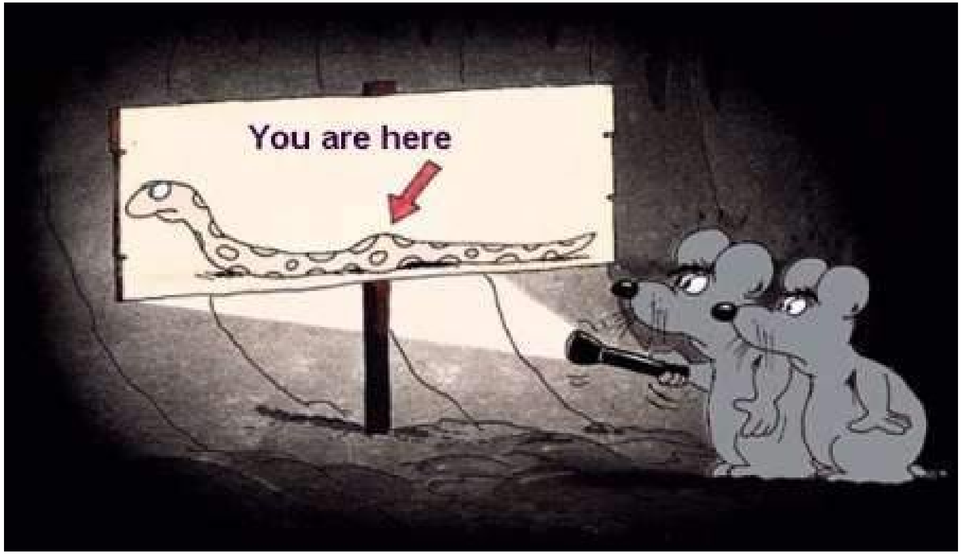

Dominici *et al.*, 2011, J. Exp. Bio.

# Other assumptions

- Predators stay in the column (water/air) during search, capture and handling times: pelagic predators and insectivorous birds/bats
- Open water/air are open spaces: predator and prey can detect each other without interference

# Next step(s)?

- Change assumptions about capture efficiency?
- Develop a more detailed *energy budget* model?
- Consider the *bottom* of the system (benthic, ground)?
- Consider other factors acting on speed (other than size)?
- Include temperature?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