Selection –
Consumer-Resource Interactions

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Outline

- Introduction (Why *do* Consumers Exist?)
- The Role of Size
- The Role of Temperature
- Consumer-Resource Dynamics
- Summary, Questions, and Readings

Consumer-Resource Interactions

CONSUMER-RESOURCE INTERACTIONS

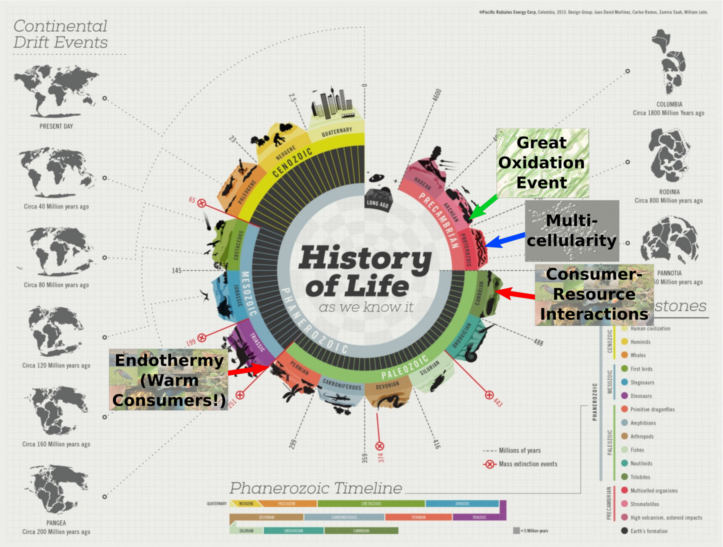
- Consumers ‘live to eat‘ and ‘eat to live‘
- They are ‘heterotrophs‘: harvest energy from other organisms (e.g., Tigers) or from other *organic* sources (e.g., Bacteria)

By Unknown author - Universität Wien, Public Domain, `https://commons.wikimedia.org/w/index.php?curid=867246`

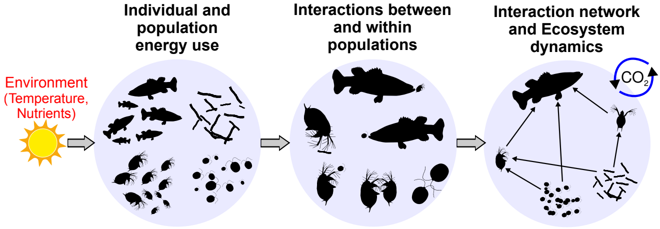
The ’struggle for existence’ of living beings is not for the fundamental constituents of food ... but for the possession of the free energy obtained, chiefly by means of the green plant, from the transfer of radiant energy from the hot sun to the cold earth.

– Ludwig Boltzmann 1886, “The Second Law of Thermodynamics”

WHY *do* CONSUMERS EXIST?

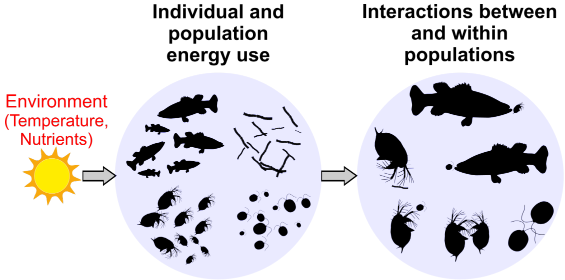


A Metabolic Ecology roadmap



- Individual-level *energy use and metabolic rate* determines:
  - Interaction rates with other individuals, especially, consumption rates
  - Properties of interaction networks (another lecture)

Consumer-Resource Interactions



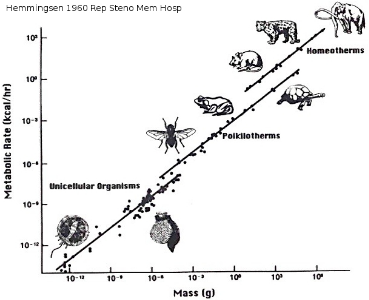
- We will focus on (metabolically-constrained) consumer-resource interactions in this lecture

Energy, Metabolism, and Consumption

- All *living* organisms must be at energy balance:
  - Energy Consumed = Energy Used (for Maintenance + Growth + Movement)
  - Different individuals and organisms invest energy to different degrees in Maintenance vs. Growth vs. Movement
- That is, consumption rate must keep up with metabolic rate (energy use)
- And if you want to do anything other than maintain yourself, you need to consume faster than your metabolic rate
- That is, you need to *invest energy* to *get energy* (find food)
- This is where body size plays a big role

Size and metabolic needs

- (Resting) metabolic rate (B) increases with body size (M)



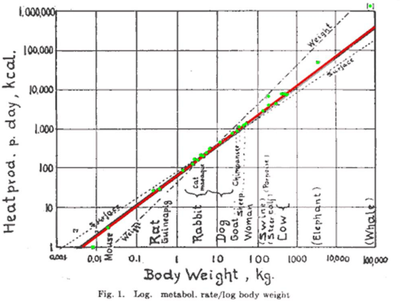


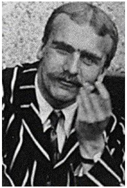
Fig. 1. Log. metabol. rate/log body weight

- Metabolic rate increases with size as a power-law[1]:
  $B = B_0 M^b$
- Therefore, larger organisms also need to *consume* more energy

[1] Review lecture on Energy and Metabolism

Size and consumer-resource interactions

- Size also affects biomechanics—how an organism interacts with the physical environment—, and movement



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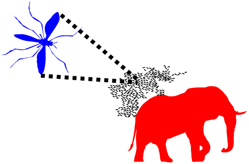
> *You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away, provided that the ground is fairly soft. A rat is killed, a man is broken, a horse splashes.*
>
> *– Haldane 1926, "On being the right size"*

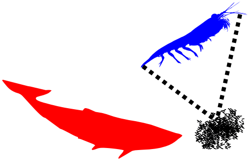
- Watch: `https://www.youtube.com/watch?v=f7KSfjv4Oq0`
- Therefore size also affects consumer-resource interaction, and consumption rate

Size and consumer-resource interactions

- Interaction rates do not always match metabolic needs (biomechanical limitations get in the way)
- Because consumer-resource interaction rates depend on multiple factors other than metabolic rate:
  - Mode of locomotion: Walking? Swimming? Flying?
  - Difference between consumer-resource size and thermal physiology (e.g., endotherm vs ectotherm):



Tiny ectotherm feeding on huge resource



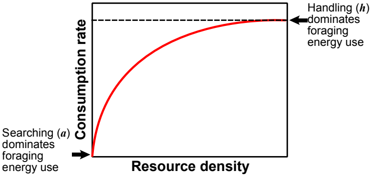
Huge endotherm feeding on tiny resource

- How do we quantify all this?

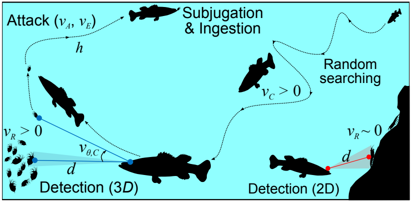
Dissecting consumer-resource interactions

- Components of consumer-resource interactions determine consumption rate (c)
- They together determine the Type II "functional response": $c = \frac{aR}{1+ahR}$

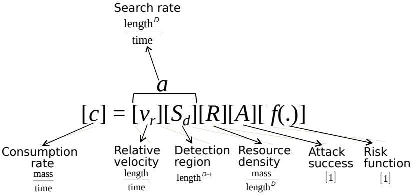
The Type II Functional Response



Holling, Canad. Entomol. (1959).

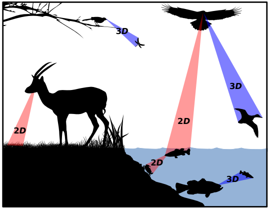


v : Foraging velocity; v_θ: Turning velocity; h : Handling time;
d : Detection distance; v_A : Attack velocity; v_E : Escape velocity



Predicting consumer-resource interactions

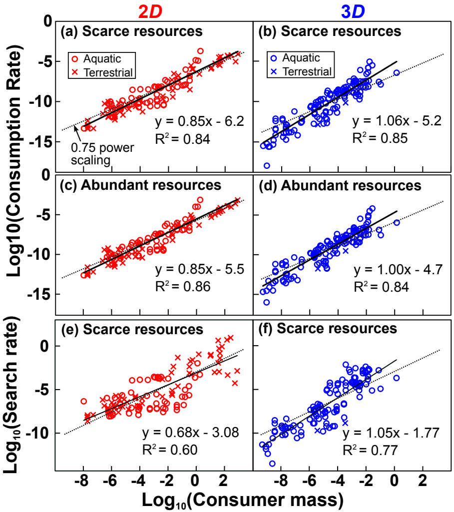
- The key components of species interactions all *scale* with size:
  - Consumer (and resource) Velocity and Detection distance scale positively with consumer size
  - Handling time decreases with size
  - Consumer-resource size-difference also matters
- Therefore, some key theoretical predictions emerge:
  - Consumption rate scales positively with size
  - *Consumption rate increases with (euclidean) dimensionality of interaction*
  - The scaling of consumption rate with size becomes steeper with dimensionality



- Interaction components also depend on temperature (coming up next)

Predicting consumer-resource interactions

Pawar et al. Nature 2012



D	Search rate (Scarce Resources)	Consumption rate	
		Scarce Resources	Abundant Resources
2*D*	0.68 ± 0.12 (0.63)	0.85 ± 0.05 (0.78)	0.85 ± 0.05 (0.78)
3*D*	1.05 ± 0.08 (1.03)	1.06 ± 0.06 (1.16)	1.00 ± 0.06 (1.16)

- 3*D* consumption rates scale much more steeply with consumer size than 2*D*
- 3*D* consumption rate 10× higher at intercept (1 kg organism)

Consumer-Resource interactions have different dimensionalities

Foraging in 3*D*: a school of salema (*Xenocys jessiae*) keep safe distance from a hungry sea lion (*Zalophus wollebaeki*) off the Galápagos Islands, Ecuador

Photo courtesy: David Doubilet

WHAT ABOUT WHALES?!

- Recall Kleiber's (1947) plot:

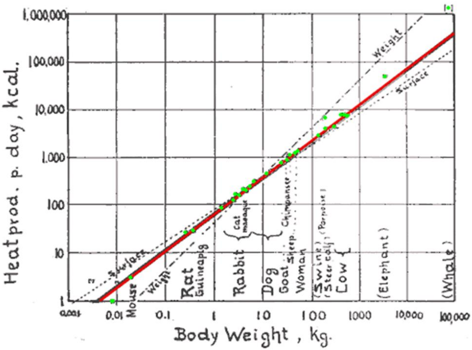
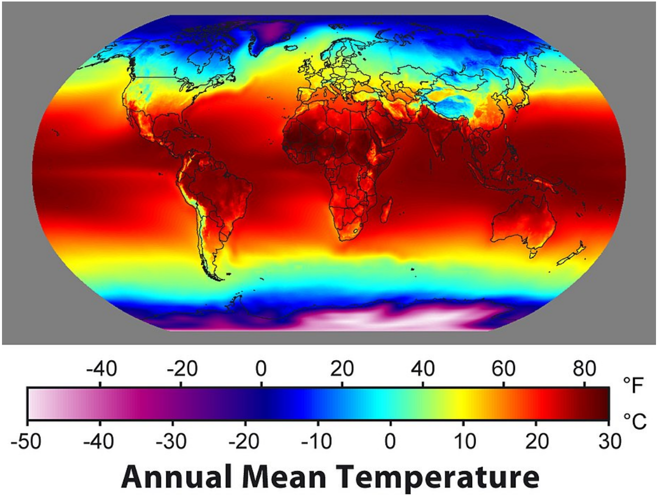


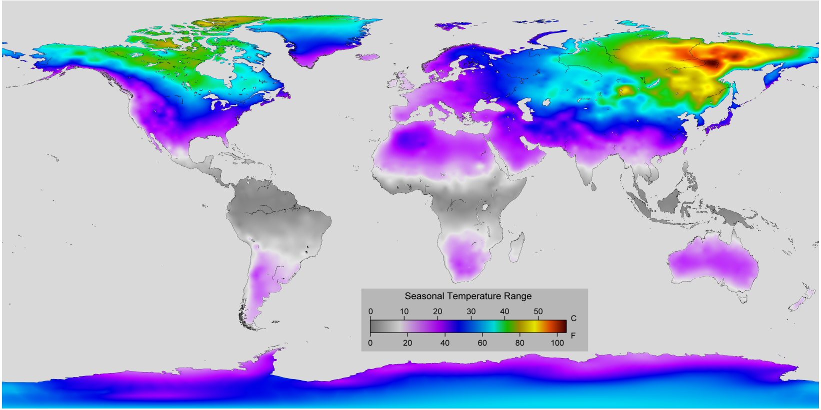
Fig. 1. Log. metabol. rate/log body weight

- **Note the whale ([·])!** (there are more data on this now)
- Perhaps we have explained why whales have higher-than-expected metabolic rates — *because they forage in 3D*

The importance of temperature

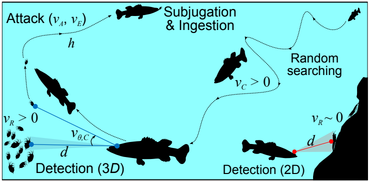


The importance of temperature



Temperature and consumer-resource interactions

- Components of species interactions depend on temperature (following the Boltzmann-Arrhenius response)[2]:
  - Velocity of consumer (and resource) increase with temperature
  - Handling time decreases with temperature



v : Foraging velocity; v_θ : Turning velocity; h : Handling time;
d : Detection distance; v_A : Attack velocity; v_E : Escape velocity

- Therefore, consumption rate increases with temperature (as does metabolic rate)

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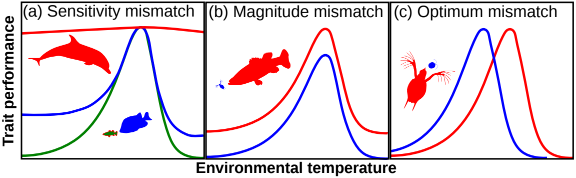
[2]Review Energy and Metabolism Lecture

Temperature and consumer-resource interactions

- Consumer-resource interaction (and consumption) also depend on *physiological "mismatches"* between the consumer and resource traits (e.g., body velocity)



- For example,
  - Panel (a): an endothermic dolphin will be able to feed on a fish species over a much wider temperature range than a fish feeding on another fish
  - Panel (c): If both species and ectothermic are adapted to the different temperatures, the prey can escape from the predator at certain temperatures

Consumer-Resource population dynamics

- The metabolic basis of of consumer-resource interaction rate can also be used to predict population dynamics
- For example, by using the Lotka-Volterra model[3]:

$$\frac{dN}{dt} = r_m N \left(1 - \frac{N}{K}\right) - aNC$$
$$\frac{dC}{dt} = eaNC - zC$$

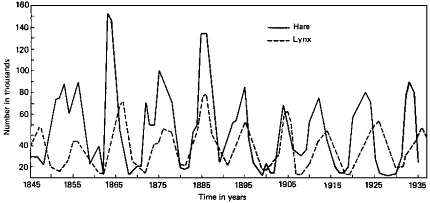
  - r_m = Resource's maximum growth rate
  - K = Resource's carrying capacity
  - a = Consumer's *search rate* (or "attack coefficient")
  - e = Consumer's biomass conversion efficiency
  - z = Consumer's mortality rate
- All these parameters can be defined to be size- and temperature- dependent

[3] You will be playing with this model in one of your practicals

CONSUMER-RESOURCE DYNAMICS

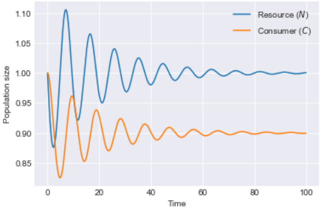
- Such metabolically-constrained models can yield useful predictions:

Data



source: `https://www.cds.caltech.edu/~murray/amwiki/images/8/8f/LHgraph.gif`

Model



- Population cycles are partly driven by *size difference* between the two species and *temperature variation* over time
- The Lotka-Volterra model with metabolic constraints can also predict Damuth's law[4]

[4] Review Lecture on Energy and Metabolism

Consumer-Resource dynamics

- Play the EcoBuilder game to see how such metabolically-informed consumer-resource models work

- Play: `https://ecobuildergame.org` (can also play in web browser: `https://ecobuildergame.org/Beta/`
- Try out the *Learning World*, starting with Tutorial I and II, and upto Level 4 atleast (we will revisit this game in the next Lecture)

Summary

- Metabolic rate and biomechanics drive species consumer-resource interactions, and therefore consumption rate (through the functional response)
- Consumer size, consumer-resource size difference, and interaction dimensionality influences consumer-resource interaction (and consumption) rate
- Mismatches between species’ thermal physiologies also determine consumer-resource interaction (and consumption) rate
- Consumer-resource population dynamics depend on the metabolic properties of the species (and environmental factors like dimensionality)

Discussion Questions

1. What are the main advantages of a consumer (heterotrophic) lifestyle compared to an producer (autotrophic) one? What are the disadvantages?
2. Which is the most common and diverse organisms on planet earth[5]? Why? Think in terms of what type of consumer they are, and what their size is.
3. What did you learn about the role of body size in the coexistence of consumers and resources from the EcoBuilder game? What is the largest consumer on Earth? What is the smallest? In what respects is their "struggle for existence" similar? In what respects is it different?
4. Which consumer(s) on earth operate(s) at the hottest temperatures? Which operate at the coldest? How is their "struggle for existence" similar or different?

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[5] See Bar-On et al, "The Biomass Distribution on Earth" PNAS 2018

Readings

1. Holling, C. S. Some Characteristics of Simple Types of Predation and Parasitism. Can. Entomol. 91, 385–398 (1959)
2. Pawar, S., Dell, A. I. & Savage, V. M. Dimensionality of consumer search space drives trophic interaction strengths. Nature 486, 485–489 (2012).
3. DeLong, J. P. & Vasseur, D. A. A dynamic explanation of size-density scaling in carnivores. Ecology 93, 470–476 (2012).
4. Dell, A. I., Pawar, S. & Savage, V. M. Temperature dependence of trophic interactions are driven by asymmetry of species responses and foraging strategy. Journal of Animal Ecology 83, 70–84 (2014).
5. Grady, J. M. et al. Metabolic asymmetry and the global diversity of marine predators. Science. 363, (2019).