



# **Selection – Ecological Interaction Networks**

Samraat Pawar

[www.pawarlab.org](http://www.pawarlab.org)

*Department of Life Sciences, Silwood Park Campus  
Imperial College London*

January 25, 2022

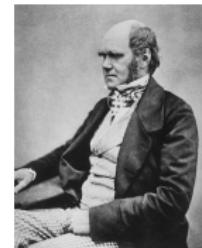
# OUTLINE

- ▶ Introduction
- ▶ Ecological (Interaction) Networks
- ▶ Trophic Networks (including Food webs)
- ▶ Summary, Questions, and Readings

# DARWIN'S *Gedankenexperiment*

*...the presence of a feline animal in large numbers in a district might determine, through the intervention first of mice and then of bees, the frequency of certain flowers in that district!*

– Darwin 1859, “The origin of species”



Public Domain, <https://commons.wikimedia.org/w/index.php?curid=11264065>



- Complex interaction networks between species' populations underpin ecosystems

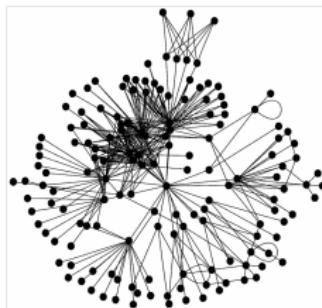
# OBJECTIVES

- ▶ We will learn about Ecological Interaction Networks (henceforth, “Ecological Networks”) in this lecture
- ▶ We will focus on consumer-resource (AKA *Trophic*) interaction-based Ecological Networks (henceforth, “Trophic Networks”), especially, Food webs
- ▶ Mutualistic Networks coming up in next lecture

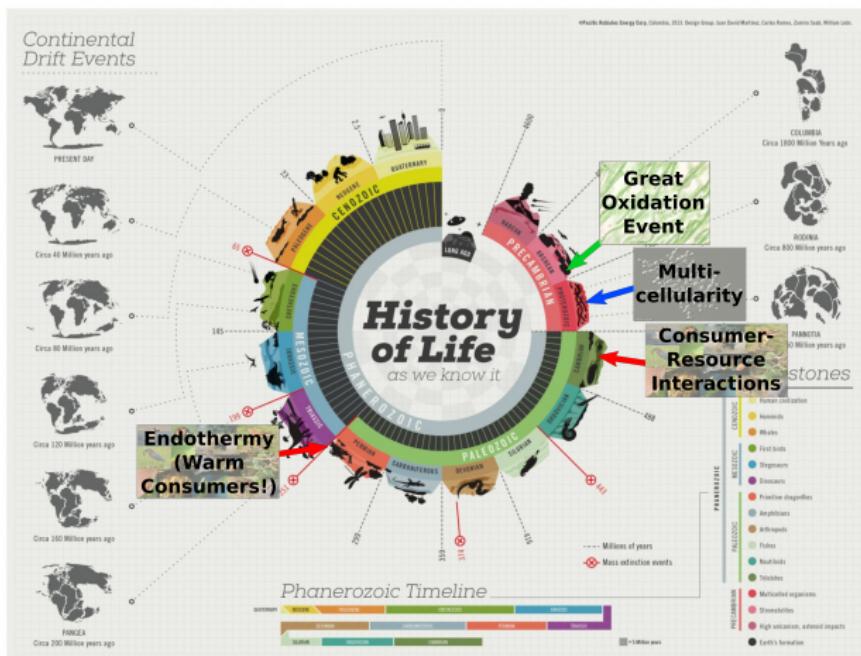
# ECOLOGICAL NETWORKS

- ▶ **Ecological Network:** Network of interactions where *nodes* (•) are individuals or (usually, species') populations, and *links* (—) the interactions between pairs of nodes
- ▶ Types:
  - ▶ Trophic networks (+/-) (e.g., food webs)
  - ▶ Mutualistic networks (+/+) (e.g., plant-pollinator networks) – *next lecture*
  - ▶ Competitive networks (−/−) (e.g., plant-plant or microbe-microbe)
  - ▶ Behavioural networks (+/−, +/+ , +/− ) (e.g., social networks)

The Silwood Park Food web



# ORIGIN OF ECOLOGICAL NETWORKS



- Ecological networks are almost as old as life itself
  - Ancient microbes had trophic interactions

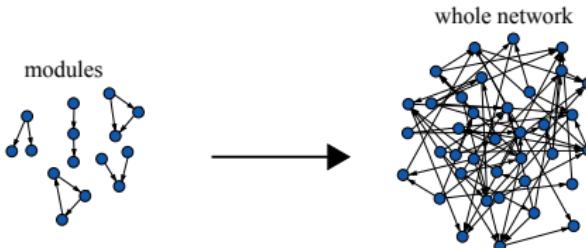
# WHY STUDY ECOLOGICAL NETWORKS?

- ▶ Species invasions (Trophic networks)
- ▶ Biodiversity conservation (Trophic networks)
- ▶ Harvesting (e.g., fisheries) (Trophic networks)
- ▶ Ecosystem function (e.g., carbon cycling) (Trophic networks, Competitive networks)
- ▶ Pollination services (Mutualistic networks) (next lecture)
- ▶ Social change (Behavioural networks)



# STRUCTURE OF ECOLOGICAL NETWORKS

- ▶ Ecological networks are built from *Modules*<sup>1</sup>: groups of few (> 2) inter-connected nodes
- ▶ The modules that are most commonly seen (at an above-random<sup>2</sup> frequency) are called *Motifs*



Bascompte & Stouffer Phil Trans Roy Soc B 2009

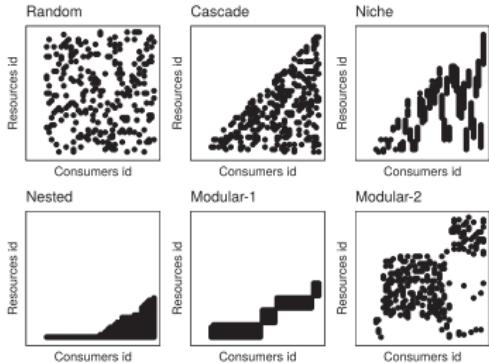
- ▶ Certain modules may be selected (or de-selected) over time because they increase (or decrease) stability of the network / system (species in them go extinct — “species sorting”)

<sup>1</sup>We will learn about specific Modules in next section on Trophic Networks

<sup>2</sup>Because they have been favoured (selected) by some process; read paper by Borrelli et al TREE 2015

# STRUCTURE AND STABILITY OF ECOLOGICAL NETWORKS

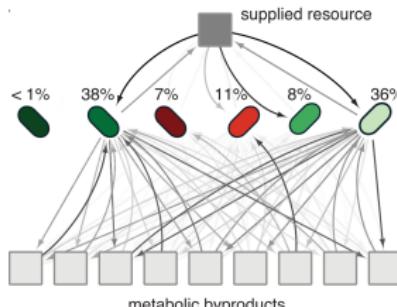
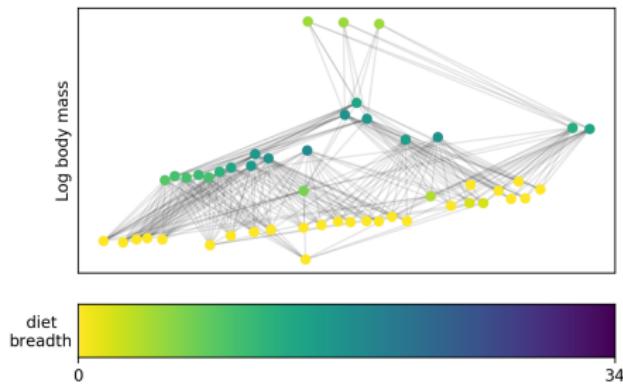
- ▶ Understanding how *structure* (pattern of interconnections) relates to *stability* and resilience of Ecological Networks is a (if not *the*) “Holy Grail” of Ecology
  - ▶ **Network (or System) Stability:** ability of the system to recover (e.g., not lose any species) from disturbances
  - ▶ **Network (or System) Resilience:** ability of the system to buffer/absorb disturbances



- ▶ A number of structures have been related to stability (e.g., Chain/Path Length, Number of Trophic Levels, Modularity)
- ▶ There is no single measure of structure that holds the answer

# TROPHIC NETWORKS

- ▶ **Trophic Networks:** Networks of populations linked by “who-eats-whom” or “who-eats-what” interactions
- ▶ **Food webs:** “who-eats-whom” interactions (animal-eat-animal or animal-eat-plant)
- ▶ **Microbial networks:** “who-eats-what” interactions of Consumers feeding on organic carbon sources



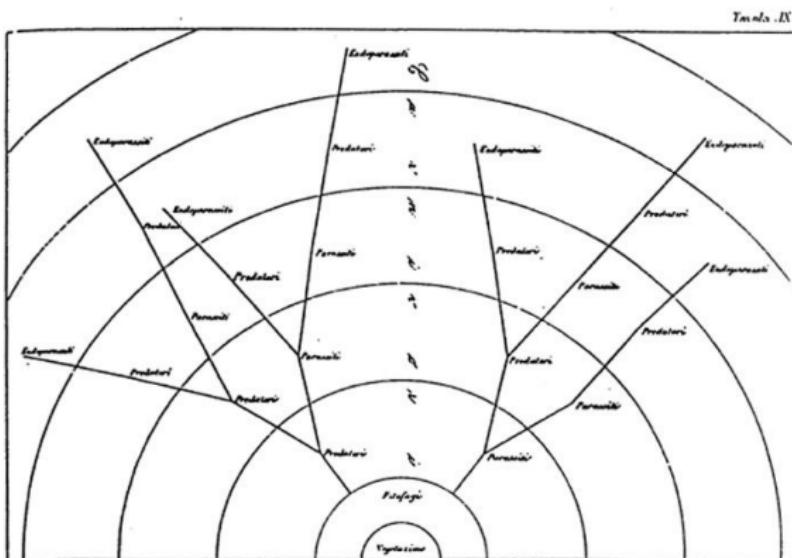
# EARLY WORK ON TROPHIC NETWORKS

**Plate I**

vegetazione = vegetation  
predatori = predators  
parassiti = parasites  
endoparassiti = endoparasites  
carnivori = carnivores

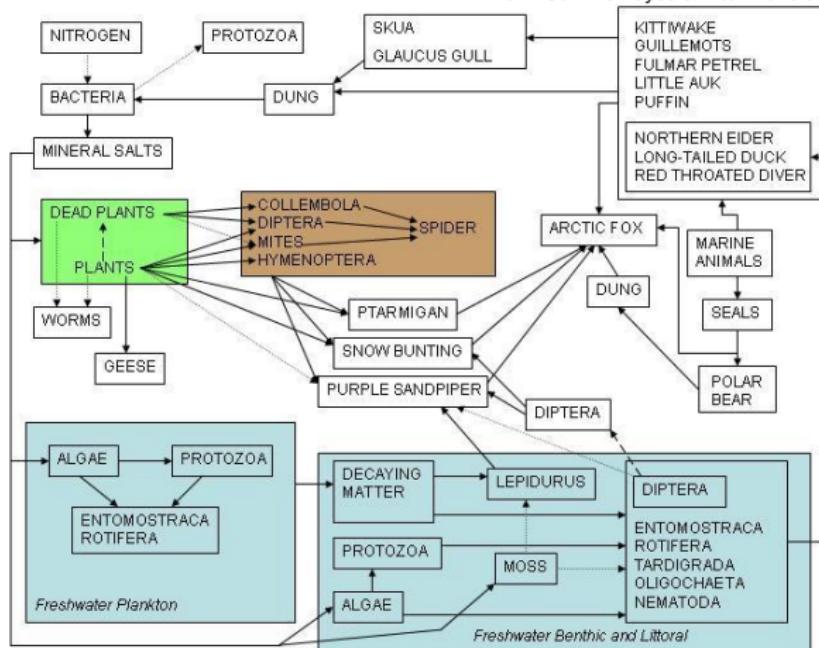
From:

Camerano 1880 Atti Reale Acc Scienze Torino 1880

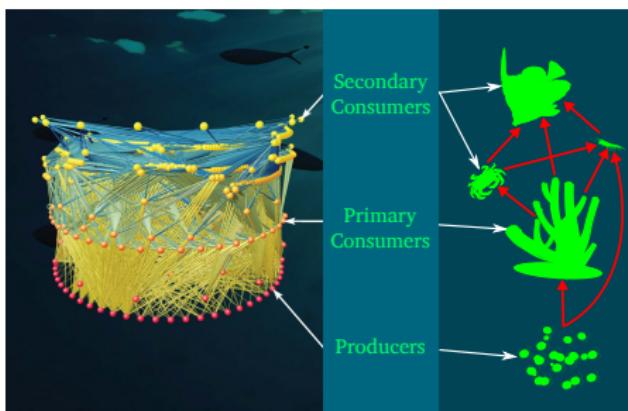


# EARLY WORK ON FOOD WEBS

From: Summerhayes & Elton 1923 J Ecol



# MODERN UNDERSTANDING OF FOOD WEBS



- ▶ Certain structural features can predict food web stability<sup>1</sup>
- ▶ Food webs have systematic body size structure (e.g., size increases with trophic level)<sup>2</sup>
- ▶ There are consistent efficiencies of energy transfer across trophic levels (only  $\approx 10 - 20\%$  per level)

<sup>1</sup>Everything you learned about this in the previous section applies to food webs

<sup>2</sup>Review lecture on Energy and Metabolism, and the effect of size on trophic/biomass/ecological pyramids

## FOOD WEB MODULES

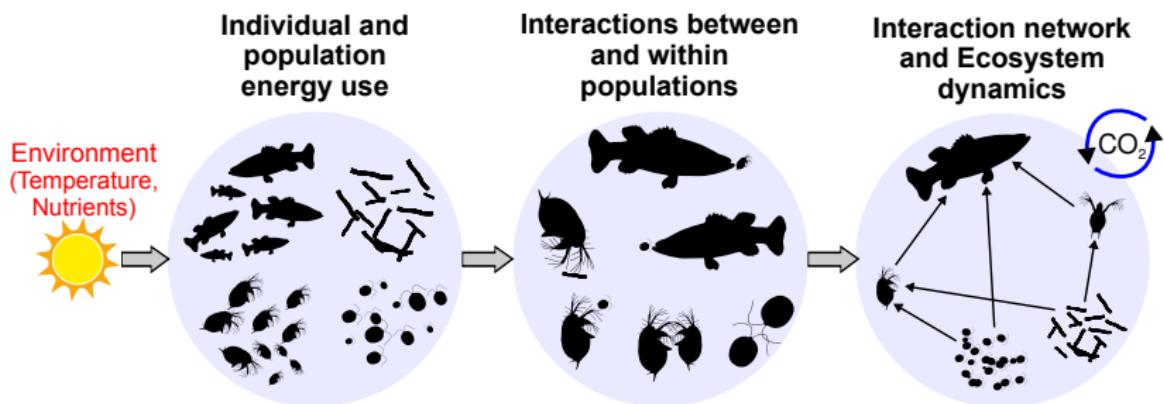
- ▶ Food webs are also made of modules (like other Ecological networks); three key modules are,
  - ▶ Resource competition (two consumers, one resource)
  - ▶ Apparent competition (two resources, one consumer)
  - ▶ Food chains (one resource and atleast two consumers)



- ▶ Play EcoBuilder to understand these modules (and more)
- ▶ <https://ecobuildergame.org> (to play in web browser:  
<https://ecobuildergame.org/Beta>)
- ▶ Try out as much of the *Learning World* as you can<sup>1</sup>
- ▶ Think about the role of *indirect interactions*, and *trophic cascades*

<sup>1</sup> Assuming you have already played to Level 4 at least; see preceding lecture on Consumer-Resource Interactions

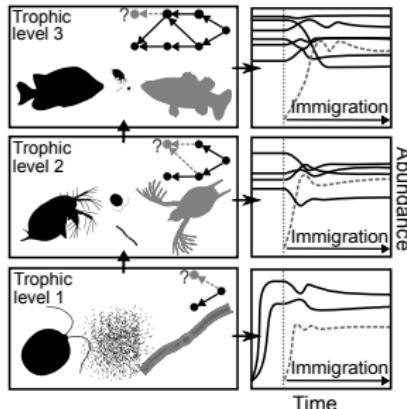
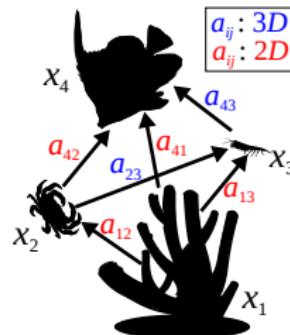
# METABOLIC BASIS OF TROPHIC NETWORKS



- ▶ Individual-level metabolism, through species interactions, determines trophic network structure and dynamics

# METABOLIC BASIS OF FOOD WEB DYNAMICS

- ▶ The effect of metabolism on network structure and dynamics is mediated by
  - ▶ Body size[1]
  - ▶ Size difference (ratio) between species pairs[1]
  - ▶ Temperature<sup>1</sup> and Nutrients
  - ▶ Spatial dimensionality<sup>1</sup>
- ▶ These factors also influence community assembly/recovery rate



<sup>1</sup>Review lecture on Consumer-Resource interactions

# THE FINAL ECOBUILDER CHALLENGE

- ▶ How complex a network can you build?
- ▶ Who can get the highest score in the class?



- ▶ <https://ecobuildergame.org> (to play in web browser:  
<https://ecobuildergame.org/Beta>
- ▶ You will have to get through the *Learning World* to get to the *Research World*
- ▶ In the *Research World*, try and maximize your score!

# SUMMARY

- ▶ Darwin's *Gedankenexperiment* — every ecosystem is more than the sum of its parts (species's populations) because of underlying interaction networks
- ▶ Network motifs (small sub-networks) are the building blocks of Ecological networks
  - ▶ They can be selected/favoured by stability
- ▶ Trophic networks are arguably the most important type of ecological network
  - ▶ Important for understanding the many effects of global change
- ▶ Metabolism is key for understanding trophic networks and the emergent ecosystem dynamics

## DISCUSSION QUESTIONS

1. What sorts of interactions might ancient microbes have had?  
What type(s) of Ecological Network(s)?
2. What are the differences and similarities between microbial networks (who-eats-what type) and food webs (who-eats-whom type)?
3. What did you learn about types of building blocks of food webs from the EcoBuilder game? What types of trophic interaction modules?
4. What role do indirect interactions play in trophic network / food web dynamics?
5. How are trophic/biomass/ecological pyramids related to body size structure in food webs?
6. How do you think climatic temperature (and warming) affects trophic networks / food webs?

## READINGS

1. Bascompte, J. & Stouffer, D. B. The assembly and disassembly of ecological networks. *Philosophical Transactions of the Royal Society (B: Biological Sciences)* 364, 1781–1787 (2009).
2. Borrelli, J. J. et al. Selection on stability across ecological scales. *Trends in Ecology and Evolution* 30, 417–425 (2015).
3. Pawar, S., Dell, A. I. & Savage, V. M. From metabolic constraints on individuals to the dynamics of ecosystems. In: *Aquatic Functional Biodiversity: An Ecological and Evolutionary Perspective*, 3–36 (Academic Press, 2015).
4. Ho, H. C., Tylianakis, J. M. & Pawar, S. Behaviour moderates the impacts of food-web structure on species coexistence. *Ecology Letters* 24, 298–309 (2021).
5. Goldford, J. E. et al. Emergent simplicity in microbial community assembly. *Science* 361, 469–474 (2018).