

NJU Course

# Principles of Paleobiology

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Paleobiological Paleoecology



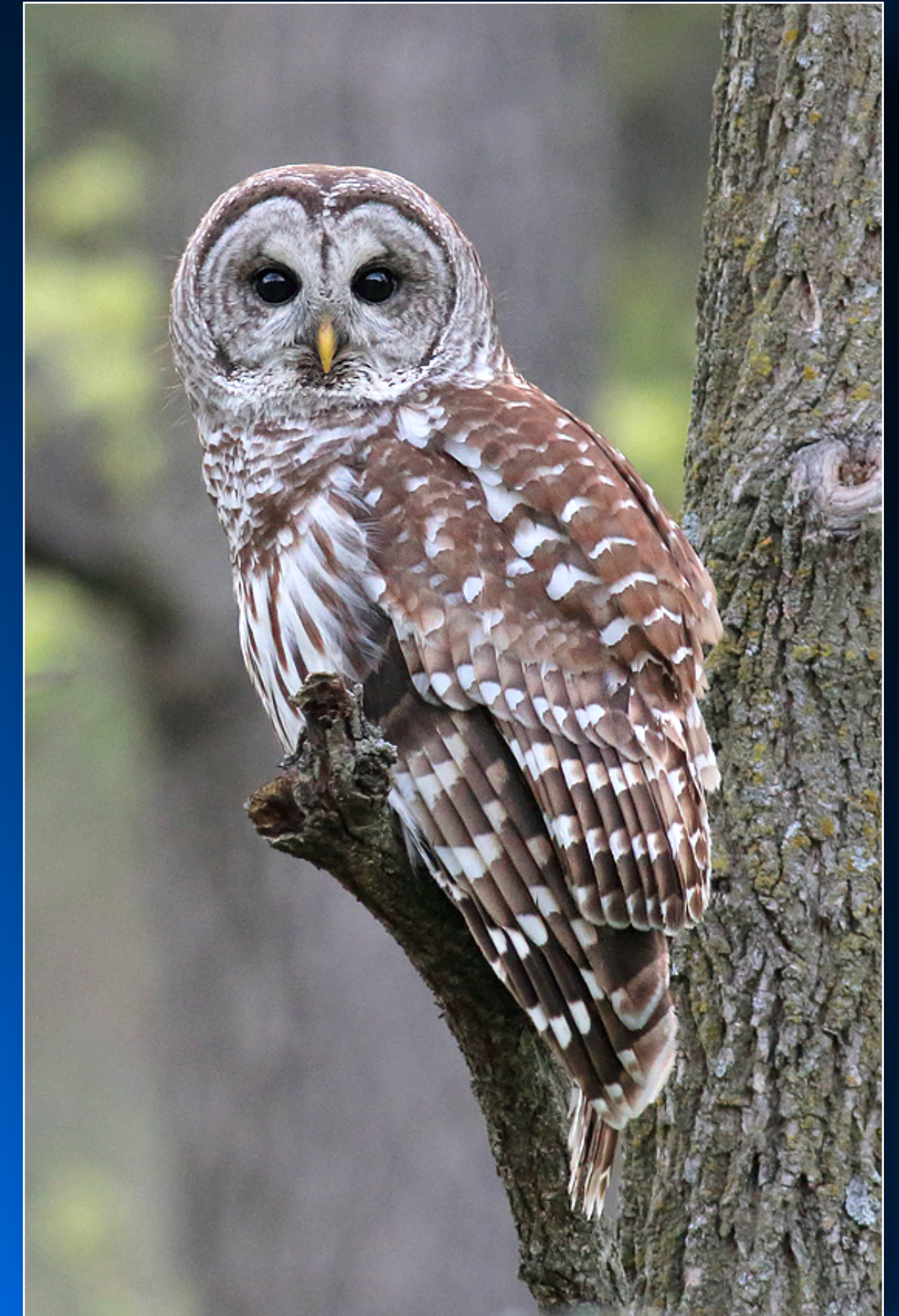


# Paleobiological Paleoecology

## Definitions

**Ecology** - The study of the interactions between living organisms to one another and to their physical environment.

- Like taxonomic and phylogenetic relations, ecological relations are usually represented as nested hierarchies:
  - Species → populations → communities → ecosystems → biomes → biosphere
  - Primary producers → primary consumers → secondary consumers → tertiary consumers → apex consumers





# Paleobiological Paleoecology

## Definitions

**Paleoecology** - The study, and reconstruction, of the interactions between living organisms to one another and to their environment through earth history.

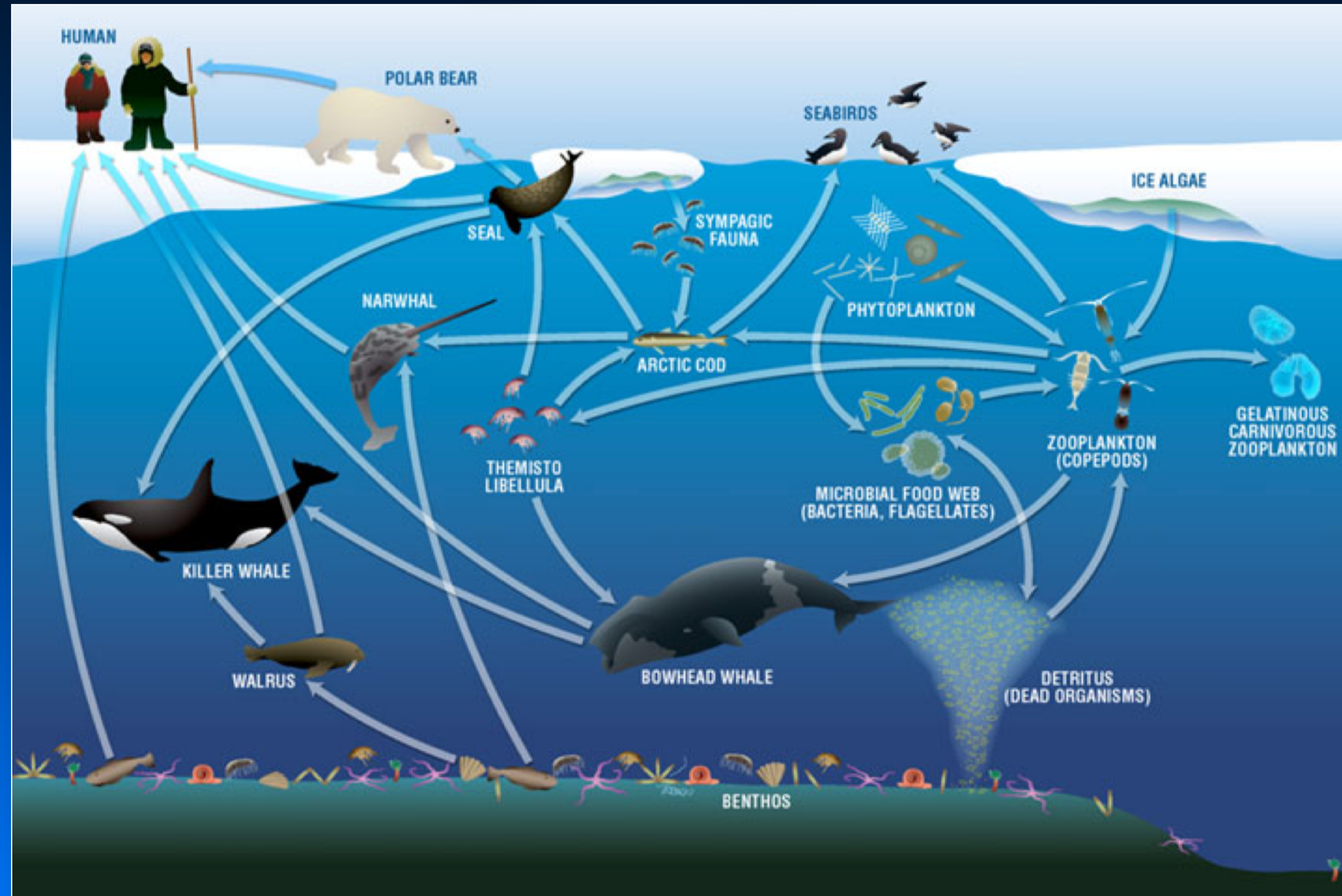
- Accepts the basic principles of ecology, but makes a series of additional assumptions in order to facilitate reconstruction of structures and inference from partial data.
- Adaptation (= optimization) for a particular lifestyle.
- Actualistic approach to the interpretation of data through comparison with recent species.
- An increasing use of phylogenetic data and reasoning.





# Paleobiological Paleoecology

## Ecological Theory & Methods





# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

**Demography** - the quantitative and statistical study of populations, their dynamics and their characteristics.

### Primary descriptive parameters

- Size
- Density
- Age structure
- Fecundity (birth rates)
- Mortality (death rates)
- Sex ratio





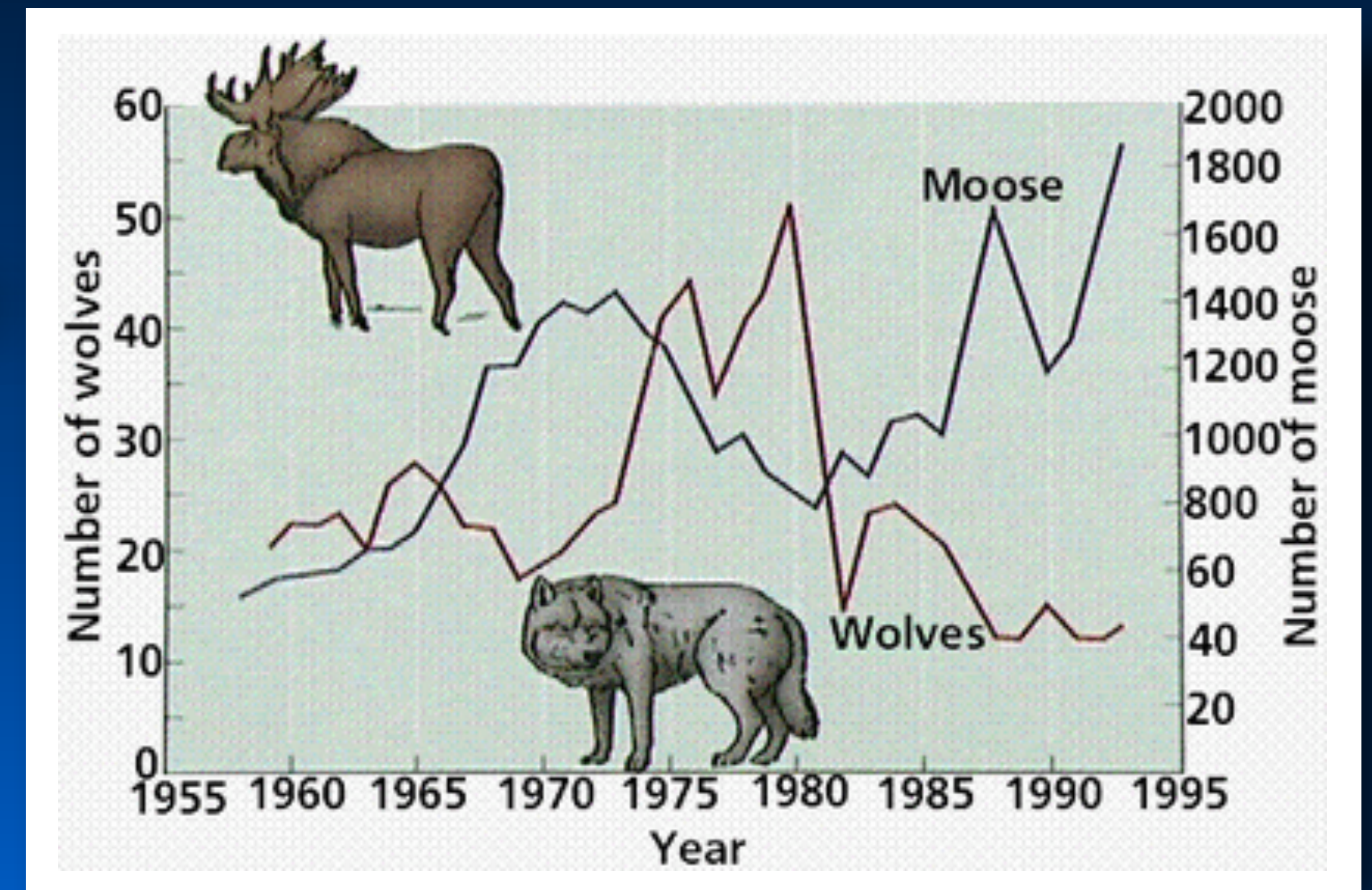
# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

**Size** - the number of individuals within a designated geographic range.

- Appropriate range designations determined (usually) by the hypotheses under evaluation.
- Small populations
  - Higher extinction risk, difficulty finding mates, inbreeding
- Large populations
  - Lower extinction risk, lower fecundity, more intense competition, danger of habitat degradation





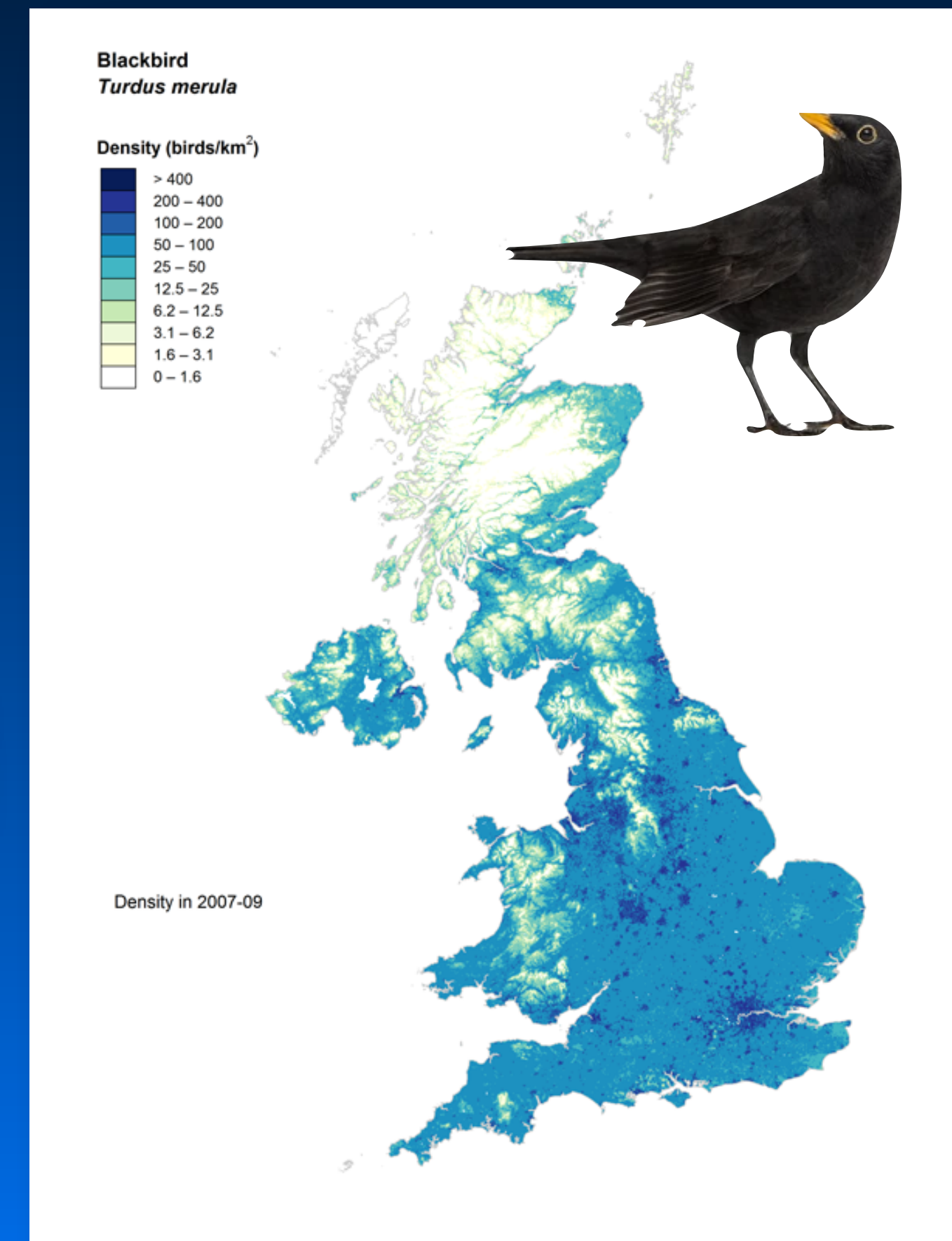
# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

**Density** - the ratio between the population size and the amount of space it occupies at any given time.

- Emigration, mortality and predation reduce population density.
- Immigration, fecundity and adaptation increase population density.
- Overall, population density is expected to be dynamic and, at any given point in time, represents the balance between these factors.





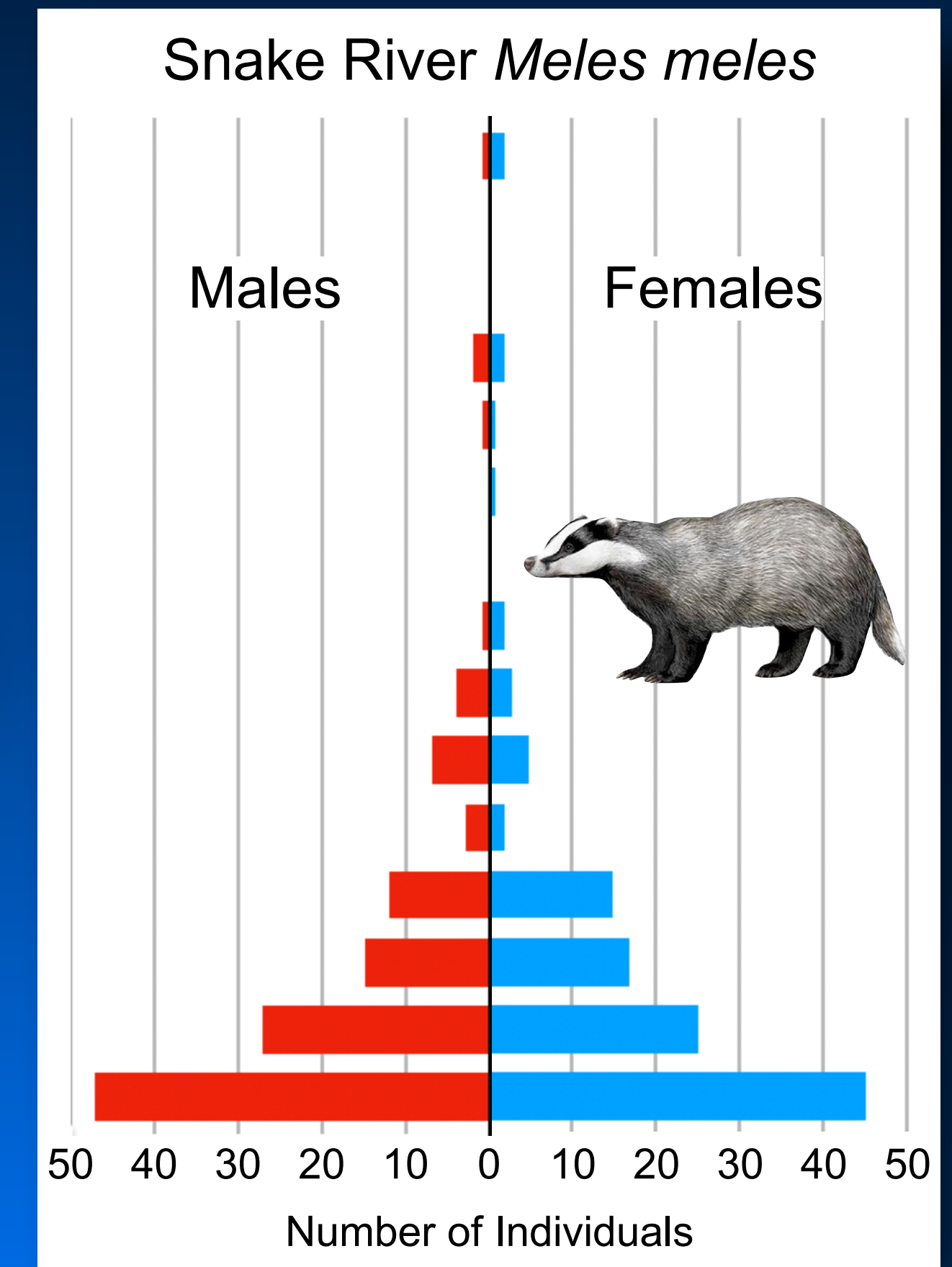
# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

Age structure - the absolute or relative frequencies of the various age cohorts of a population at any given time.

- An age structure-pyramid diagram (right) can be used to estimate whether a population is likely to expand, contract or remain in a steady state over time due to fecundity and mortality.
- Age information can be determined from the morphologies of a wide range of fossil groups.
- Such data is only reliable for biocenoses.



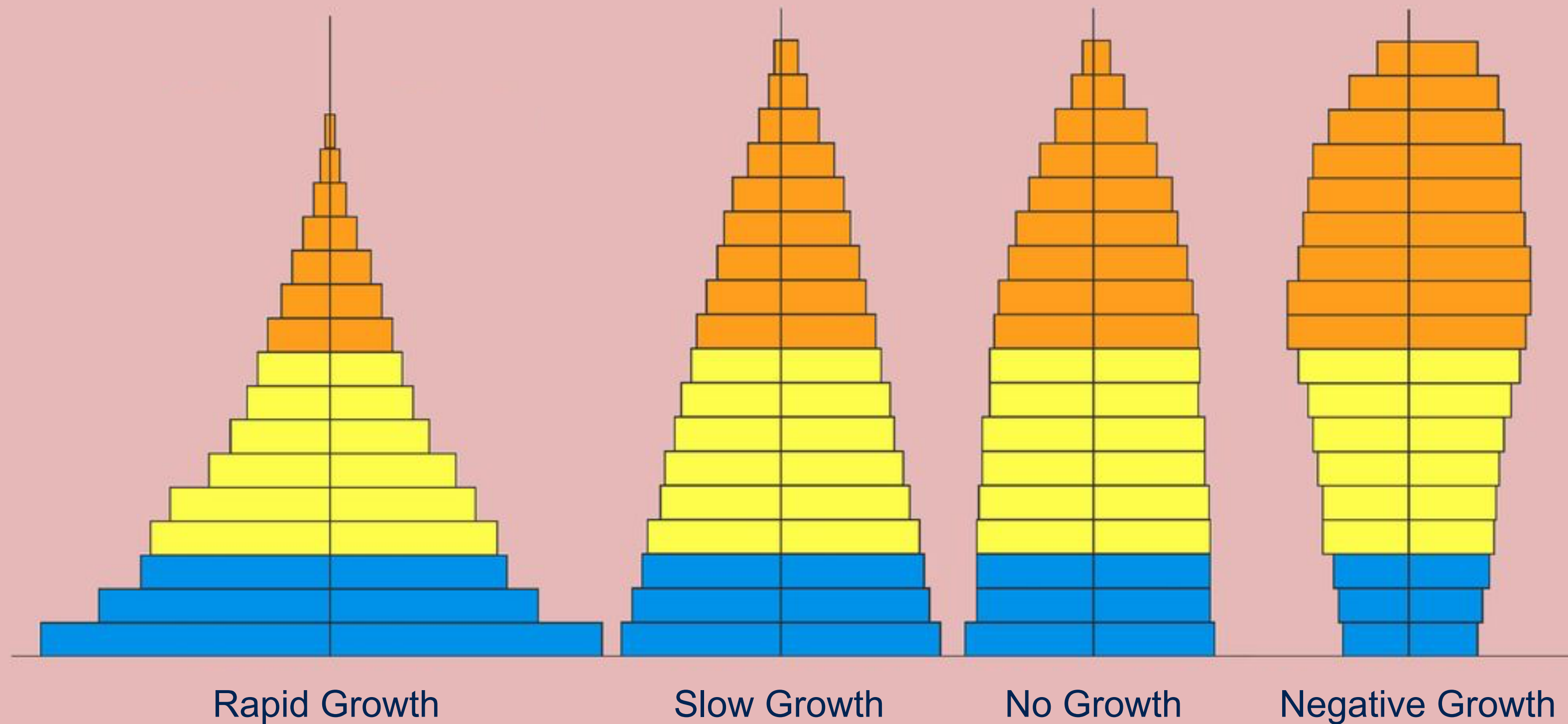


# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

#### Population Age-Structure Profiles





# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

**Fecundity (birth rate)** - the ratio between the number of offspring a population produces and the interval of time over which the birth-count is made.

- Realized fecundity reflects a balance between population size, density, age structure, environmental state and level of intra-group aggression.
- Environmental stress can trigger the release of hormones that suppress mating behavior, delay sexual maturation and/or shrink sex organs.
- Such population-level reactions are examples of density-dependent population regulation.





# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

**Mortality (death rate)** - the ratio between the number of individual deaths a population suffers and the interval of time over which the death-count is made.

- The mortality rate is influenced by many factors, incl. population size, density, age structure, environmental state, frequency and success of predation, disease.
- Under favorable circumstances a life table can be used to quantify the probability of mortality in different age cohorts.

Life Table: *Equus equus*

| Age Cohort<br>(Years) | Survivorship<br>(cum. %) |
|-----------------------|--------------------------|
| Birth                 | 100.00                   |
| 0-3                   | 70.31                    |
| 3 - 6                 | 55.47                    |
| 6 - 9                 | 47.66                    |
| 9 - 12                | 32.03                    |
| 12 - 15               | 17.19                    |
| 15 - 18               | 4.69                     |
| 18 - 21               | 0.78                     |
| 21 - 25               | 0.00                     |



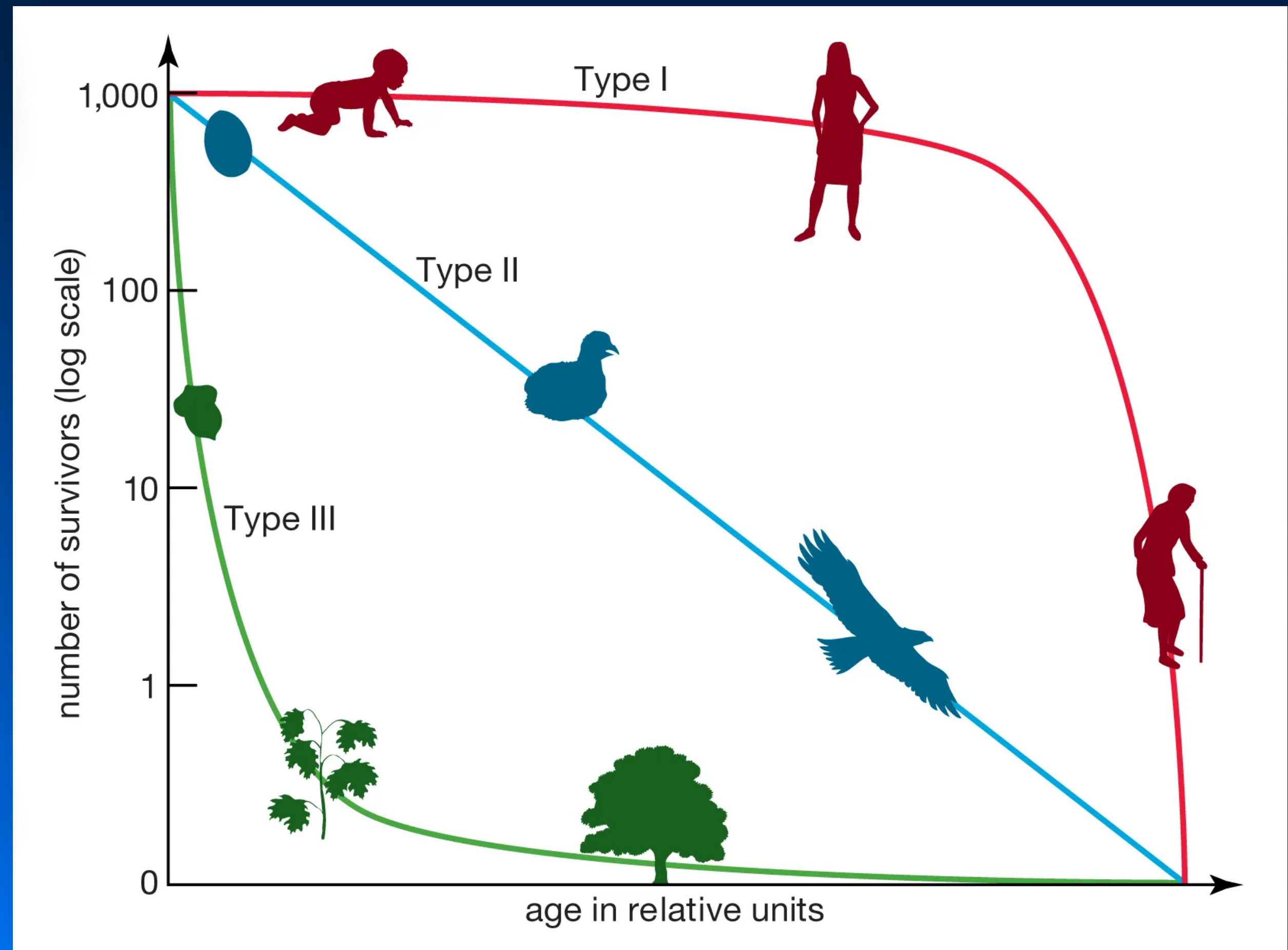
# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Survivorship Curves

**Survivorship (or Survival) Analysis** - A statistical method used to analyse the time until an event of interest occurs.

- Survivorship/Survival curves represent the probability of an individual surviving, or an object remaining in a particular functional state, over time.
- Survivorship/Survival relations can be modeled using either parametric (Weibull, Exponential) or non-parametric (Kaplan-Meier) methods.





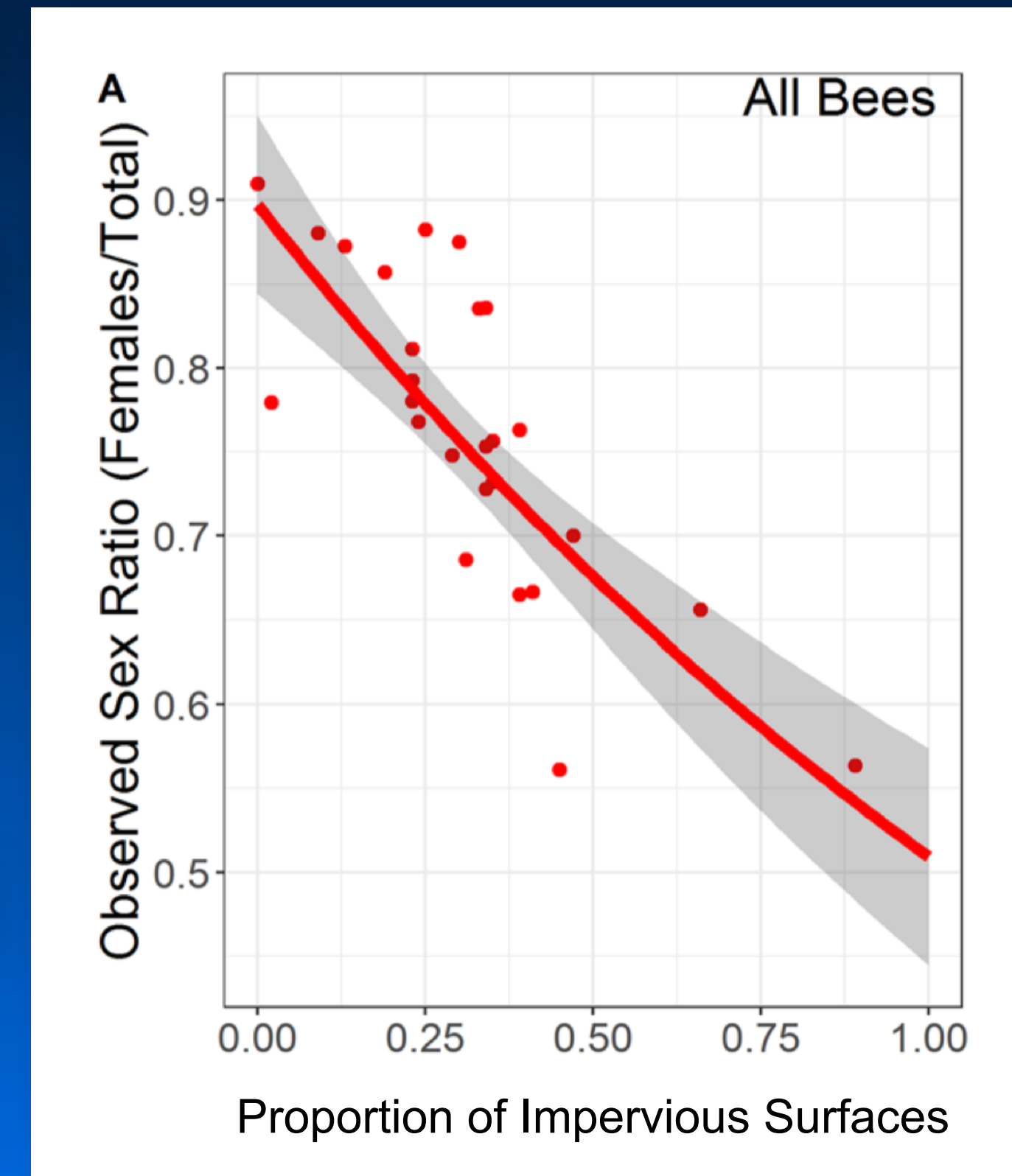
# Paleobiological Paleoecology

## Ecological Theory & Methods: Demographics

### Population Parameters

**Sex Ratio\*** - the ratio between male and female individuals in a population at any given time.

- In most species it is assumed the baseline theoretical sex ratio is 1:1.
- Deviations from this ratio in genuine populations can arise in a number of ways.
- The ecological sex ratio can be used to predict population growth.
- In some species the population ratio can be manipulated based on behavioral and/or environmental factors.

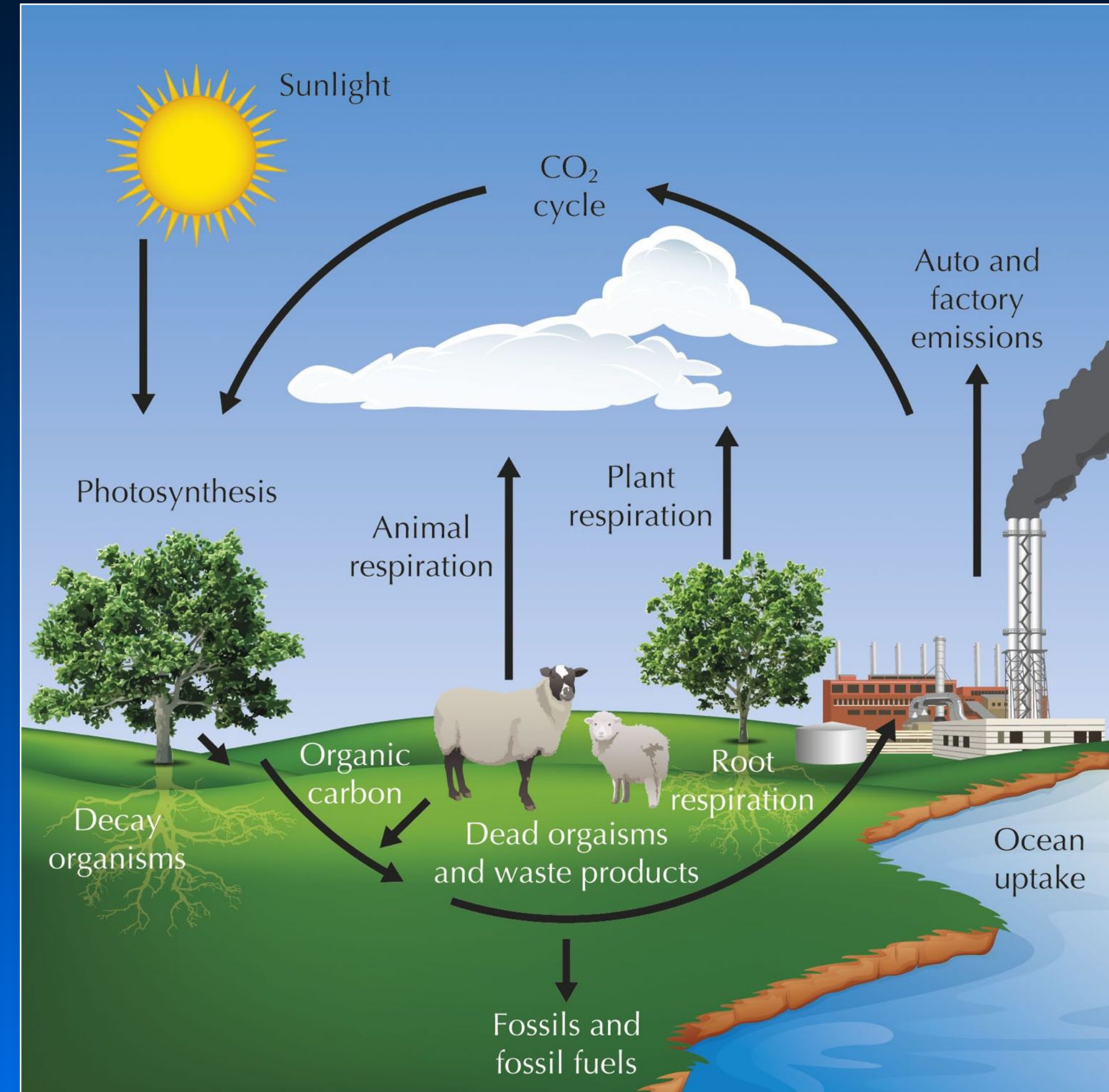
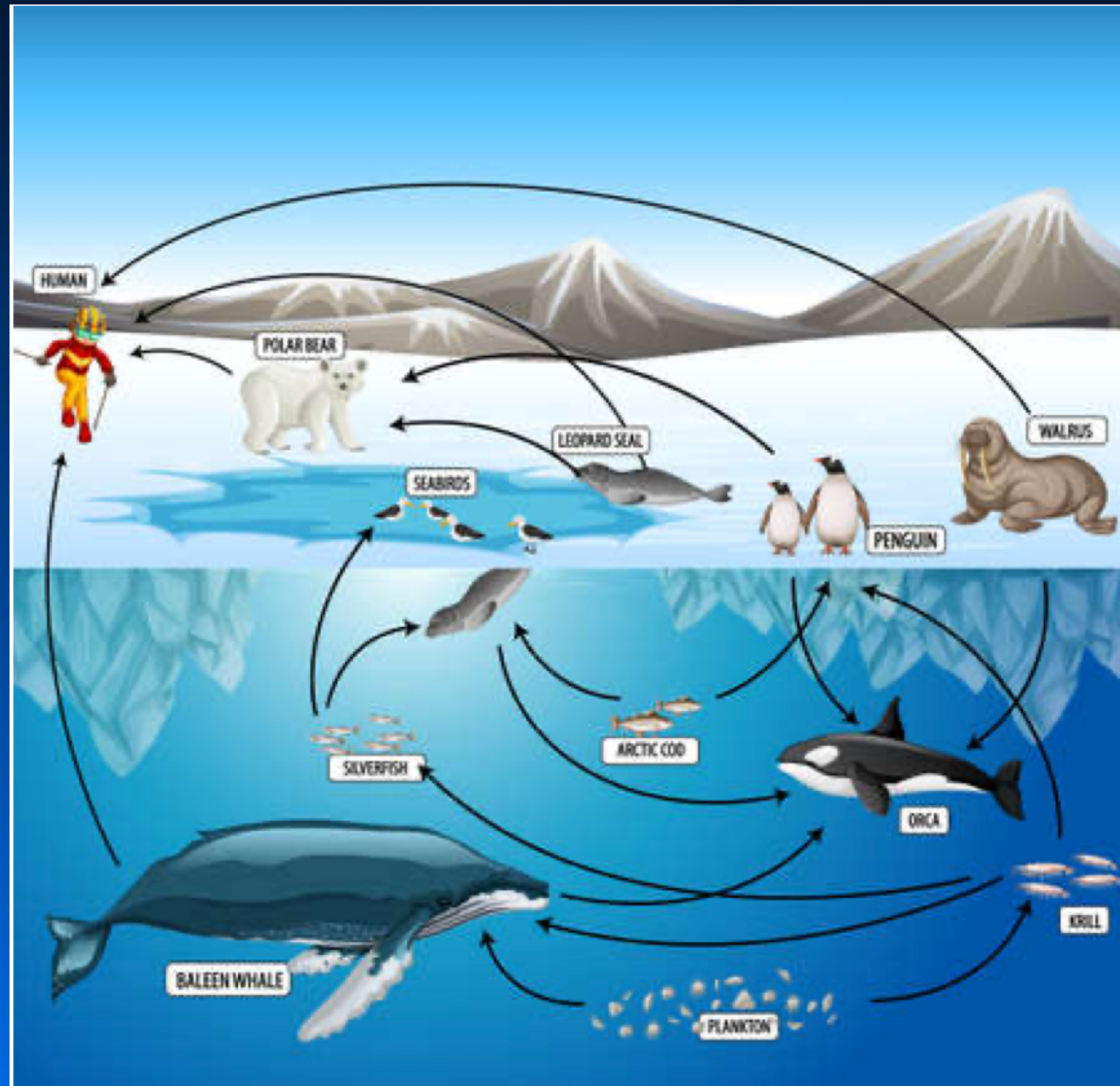


\* Pertains to sexually-reproducing species only.



# Paleobiological Paleoecology

## Ecological Theory & Methods: Energy Flow & Nutrient Cycling



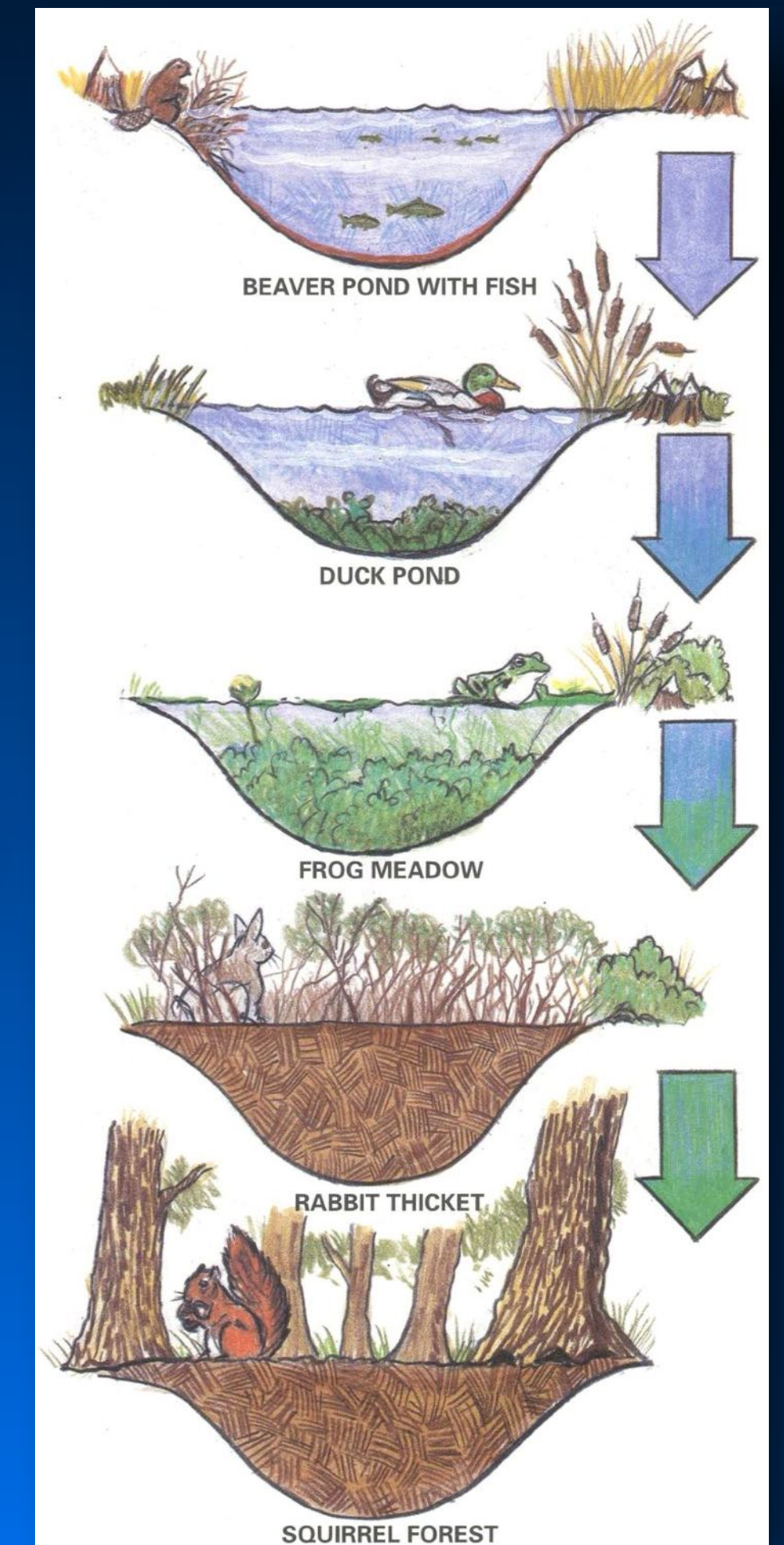


# Paleobiological Paleoecology

## Ecological Theory & Methods: Energy Flow & Nutrient Cycling

**Succession (ecological ontogeny)** - the process by which the structure of an ecological community or ecosystem changes over time owing its ability to attract and retain and increasingly diverse biota that create new ecological opportunities.

- Succession is a dynamic and continuous process involving immigration and colonization, but well-studied successions have been subdivided into named stages.
- Primary succession - a successional sequence that begins with a lifeless surface.
- Secondary succession - a successional sequence that results from the resetting of a community/system back to an earlier successional stage, usually through disturbance.





# Paleobiological Paleoecology

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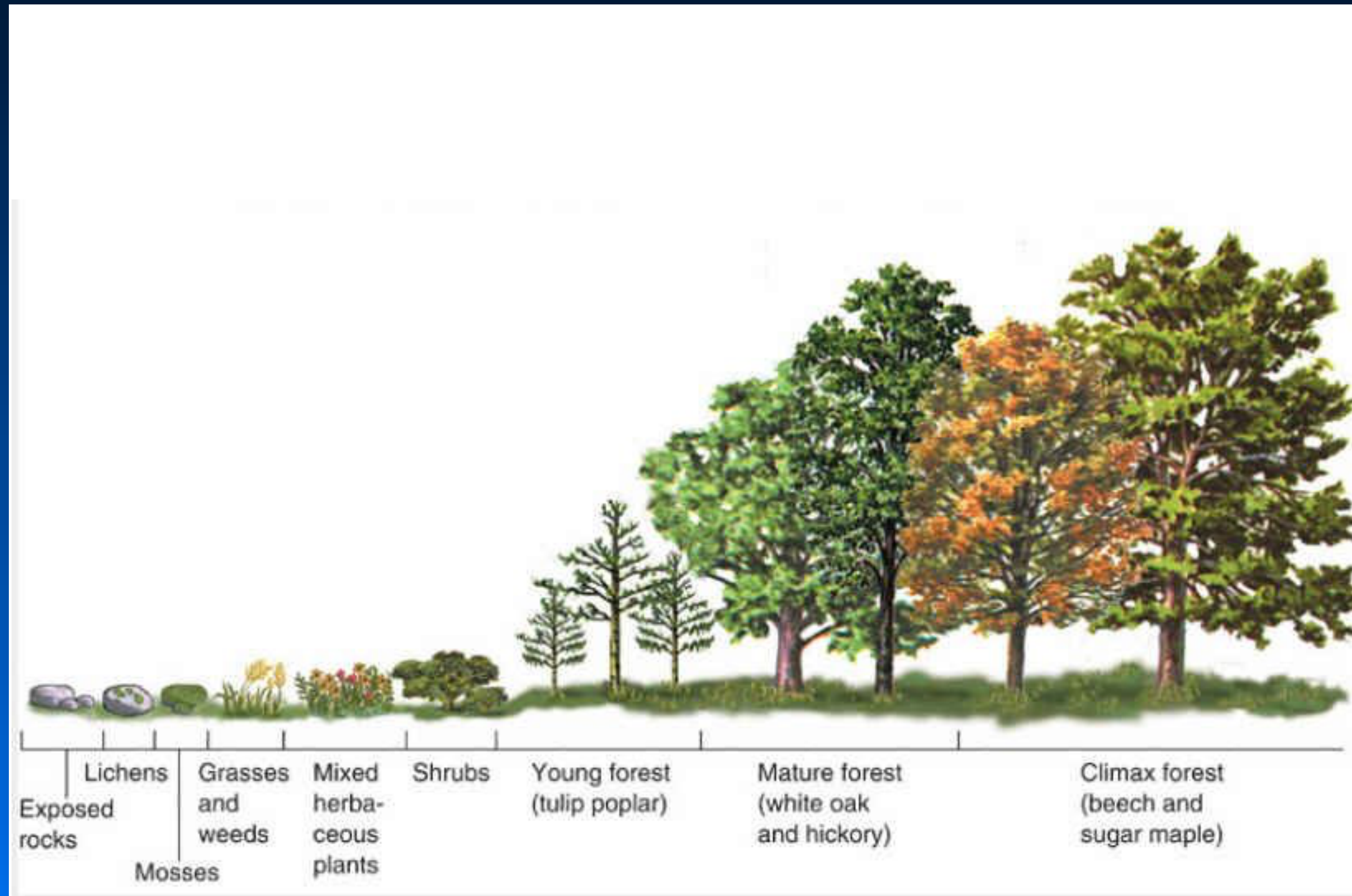
## Ecological Theory & Methods: Succession





# Paleobiological Paleoecology

## Ecological Theory & Methods: Succession





# Paleobiological Paleoecology

## Ecological Theory & Methods: Succession





# Paleobiological Paleoecology

## Ecological Theory & Methods: Succession

- **r/K Selection Theory** - the variables  $r$  and  $K$  refer to the distinction between the growth rate and intrinsic amount of parental investment species invest in their offspring.
- **r-Selected species** have a large number of offspring that grow and become independent quickly. These species tend to occupy broad niches and suffer high mortality.
- **K-Selected species** have a small number of offspring that grow and become independent slowly. These species tend to occupy narrow niches and suffer low mortality.
- Succession is largely driven by the replacement of  $r$ -selected species by  $K$ -selected species.
- $r$  and  $K$  selection are end-members of a continuum.





# Paleobiological Paleoecology

## Ecological Theory & Methods: r / K Species Theory

### R selected species





# Paleobiological Paleoecology

## Ecological Theory & Methods: r / K Species Theory

### K selected species



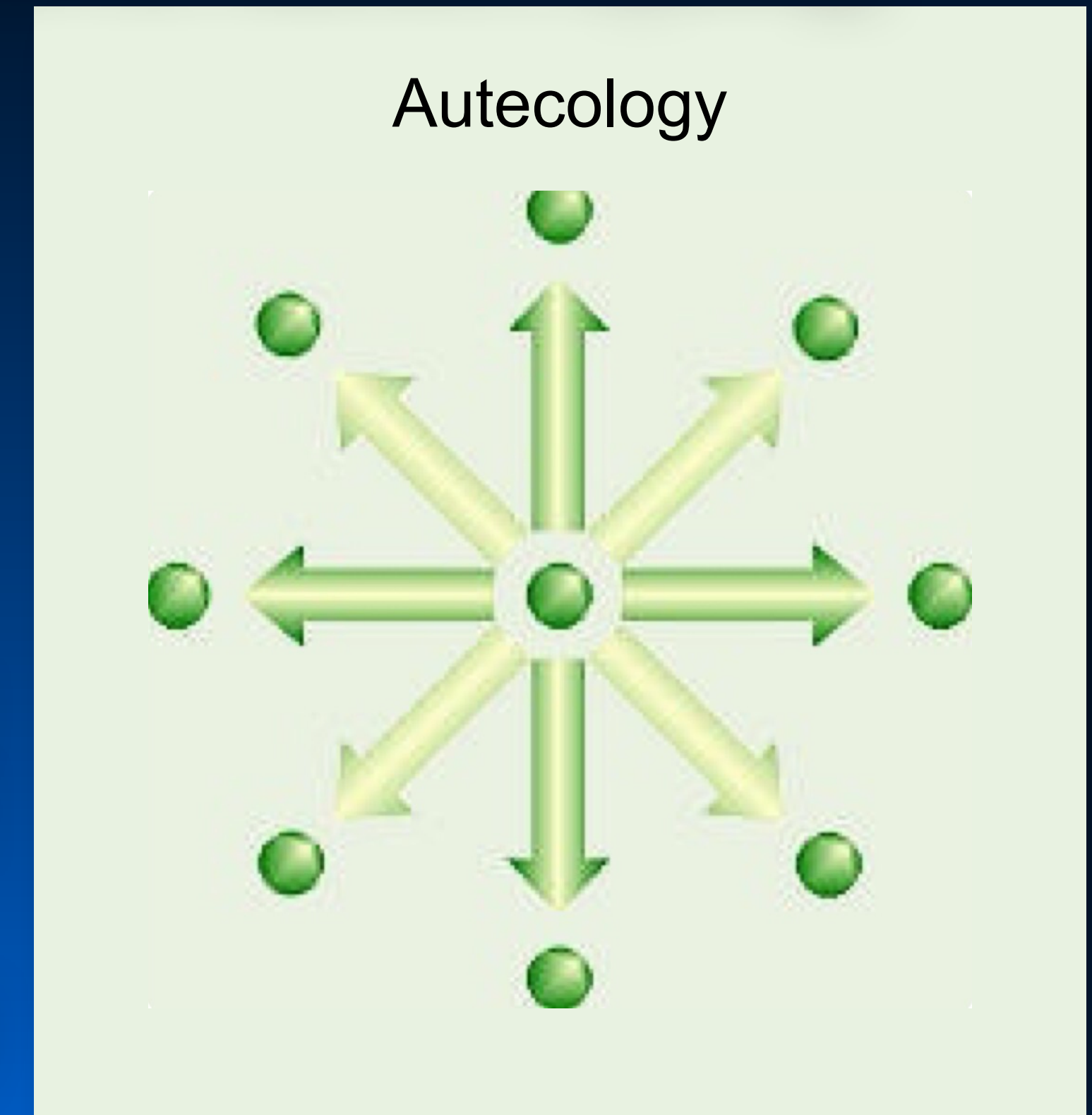


# Paleobiological Paleoecology

## Ecological Theory & Methods: Energy Flow & Nutrient Cycling

**Population Ecology (Autecology)** - an approach to ecology and seeks to explain the distribution and abundance of species by studying the interactions of individual species with their biotic and physical environment.

- Environmental matching can be used to explain species' distribution patterns and predict how they will respond to environmental changes, extinction events, etc.
- Functional morphology is an aspect of autecology that can be accessed from the fossil record.
- When environmental variation exceeds a species' tolerance it usually becomes extinct through reproductive failure rather than excess mortality.



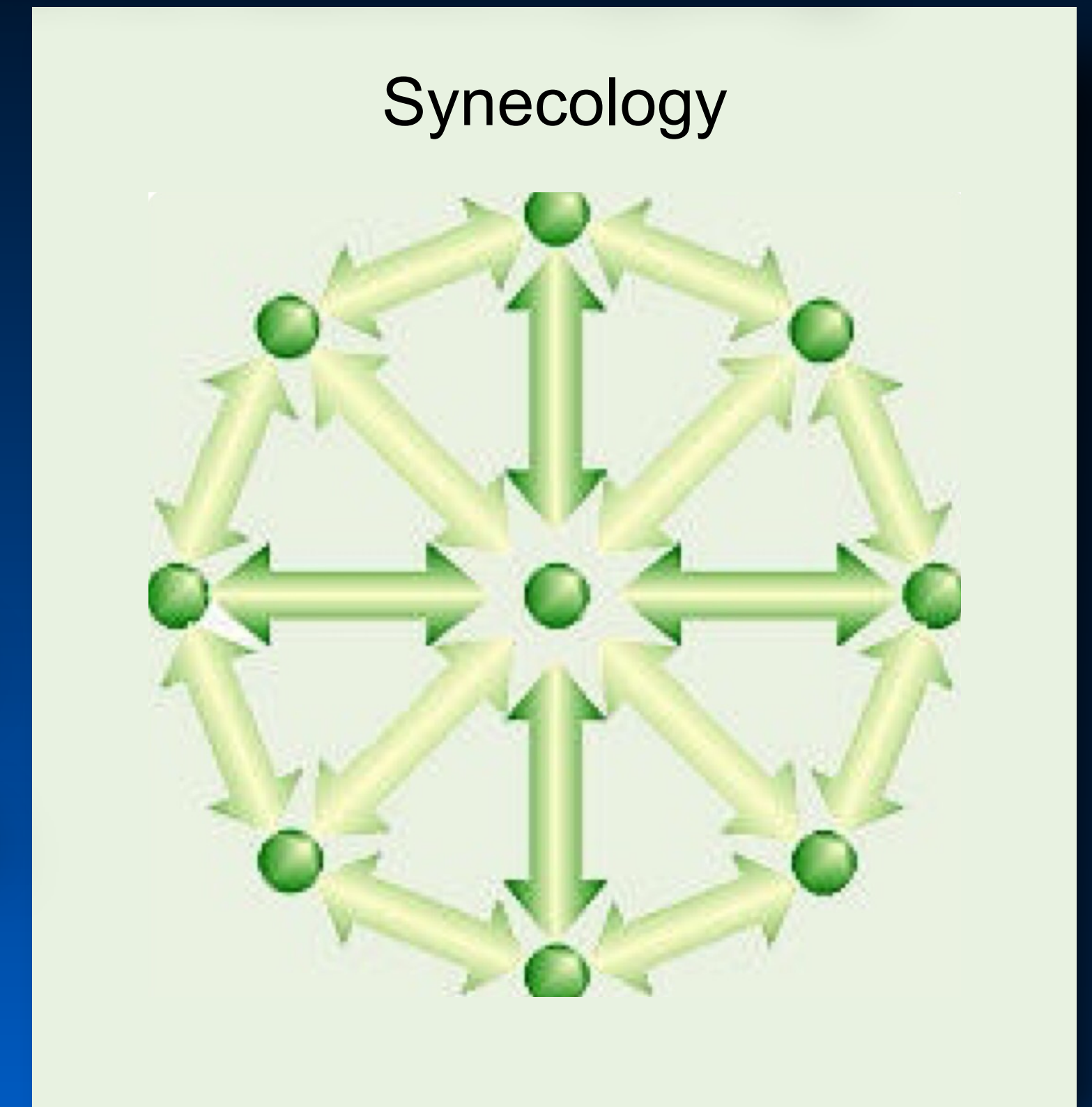


# Paleobiological Paleoecology

## Ecological Theory & Methods: Energy Flow & Nutrient Cycling

**Population Ecology (Synecology)** - an approach to ecology and seeks to explain the distribution and abundance of species by studying the interactions between whole plant and/or animal communities.

- Often referred to as “community” ecology.
- Synecology takes both biotic and abiotic factors into consideration, but its focus is on understanding the structure of relations between aggregates of species, their origin, maintenance, and level of stability.
- Since the definition of what does, and does not, constitute a “community” is so imprecise, debate continues around the issue of what the fundamental unit of synecology is and, indeed, whether so-called communities constitute a real level of ecological structure.



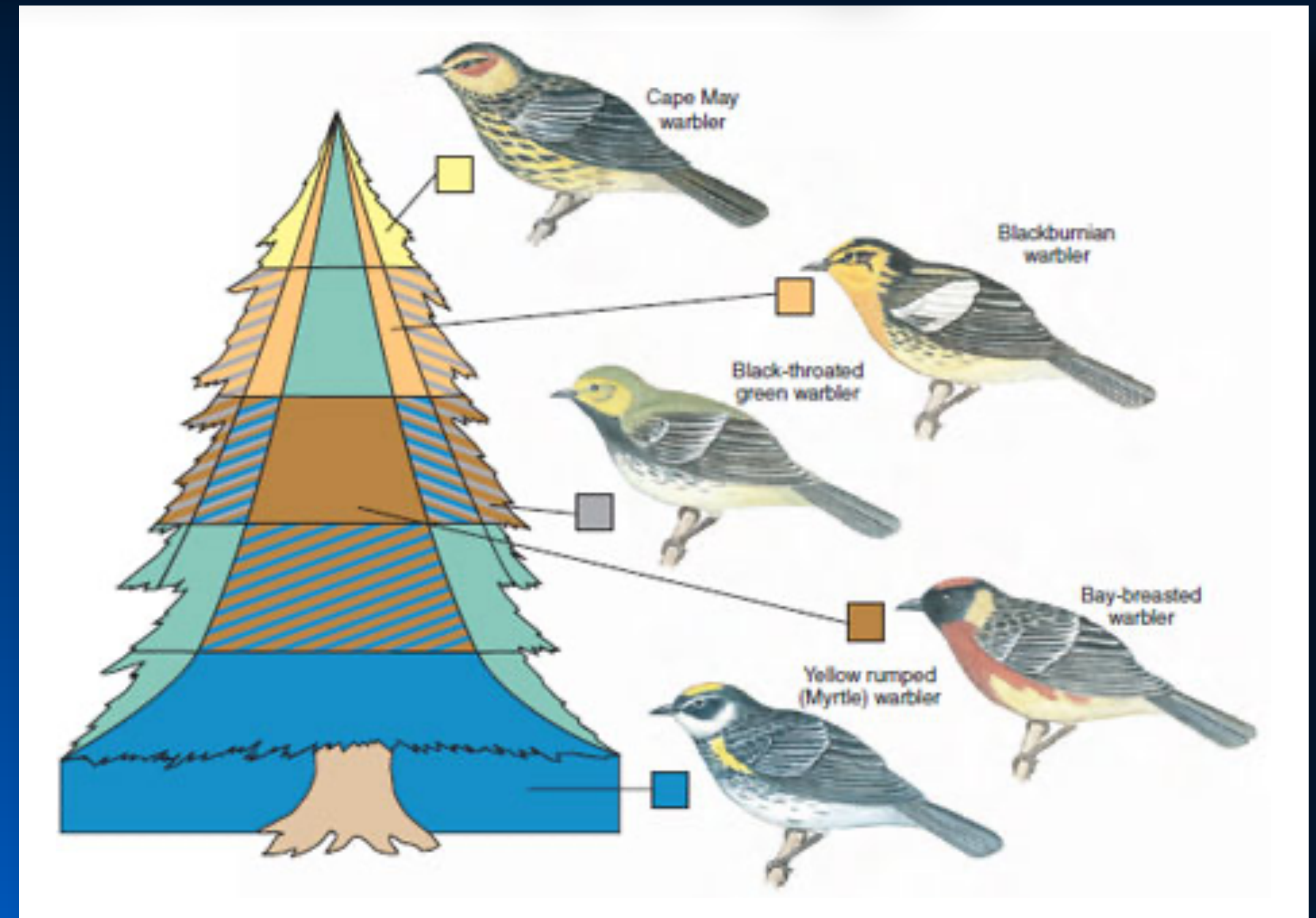


# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

**Niche** - the manner in which a species interacts with other species in its community and the physical environment.

- Niche partitioning allows similar species to exist within the same community by reducing inter-specific competition.
- Neo-Darwinian evolutionary theory predicts that, if two species occupy the same niche one will eventually exclude the other. However, Hutchinson argued that co-occupation was possible if different species achieved a competitive advantage at different times of year (e.g., seasons).
- Controversy surrounds the questions of whether niches exist independently of the species that fill them and the degree to which species construct their own niches.



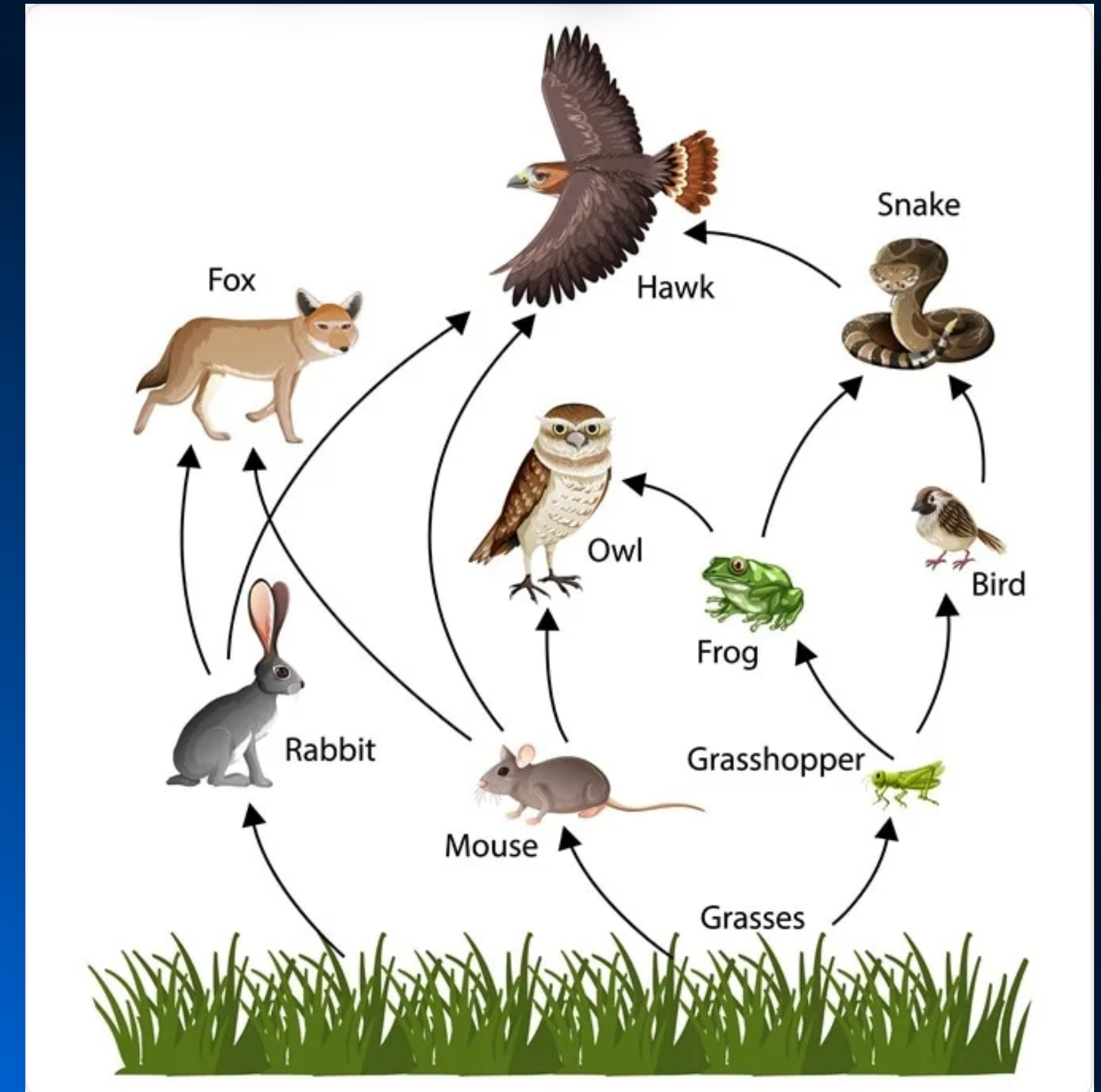


# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

**Food Webs** - a network diagram that traces feeding relations among the species of an ecological community.

- Food webs are an important, but limited, representation of ecological community structure.
- Communities with few and/or single chain links are less stable than communities with many and/or multi-furcating links.
- Food webs can be used to identify foundation and keystone species.
- Allometric scaling relations can be used to compare the food webs of different sized communities and relate food-web complexity to species richness in a regional, biome and/or global context.



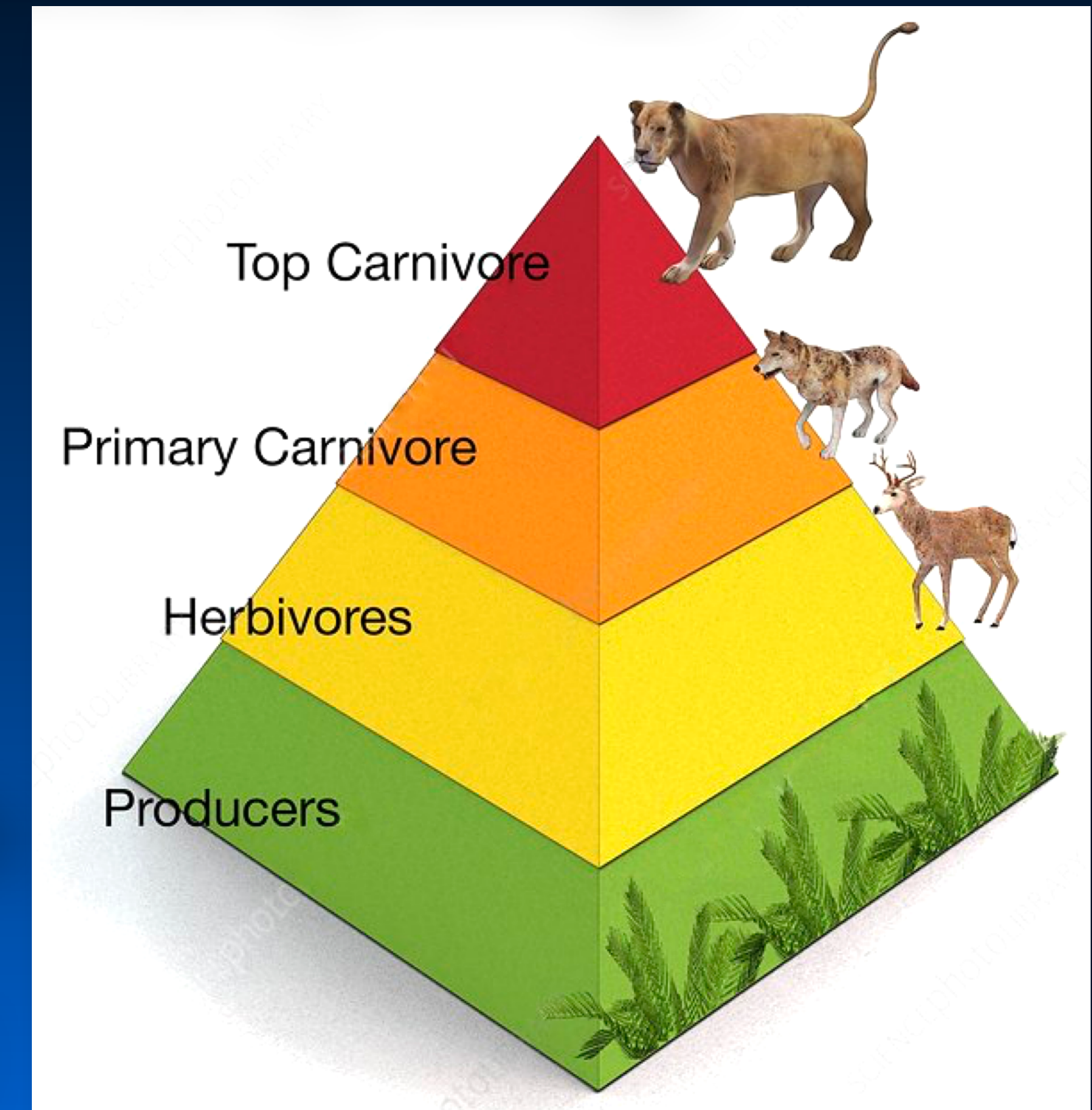


# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

**Trophic Pyramid** - A manner of analyzing the structure of ecological communities (developed by Charles Elton) that organizes species into categories based on the feeding (= energy transfer) criteria.

- Represents a view of communities as thermodynamic structures.
- Trophic structure is dynamic and can change if the species composition changes.
- Energy is lost at each trophic level (usually in the form of heat).
- Decomposers are integral to trophic structure, but (typically) not represented on trophic pyramid diagrams.





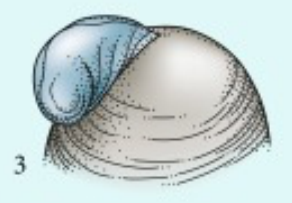
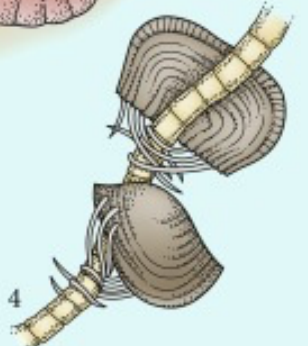
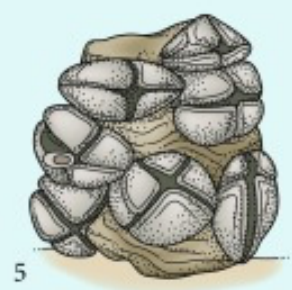
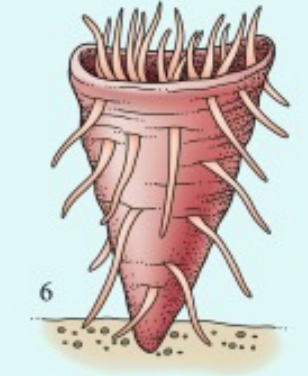
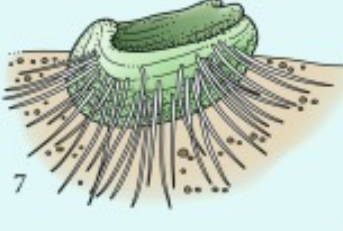

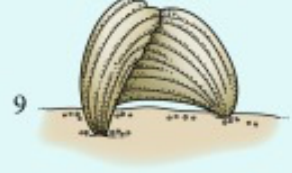
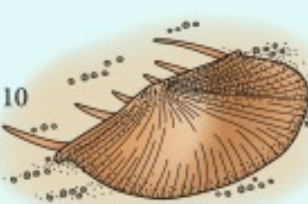
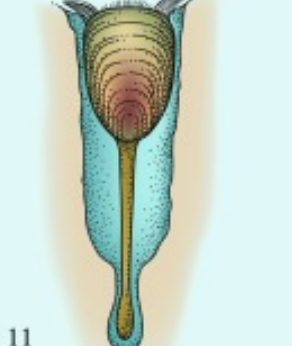
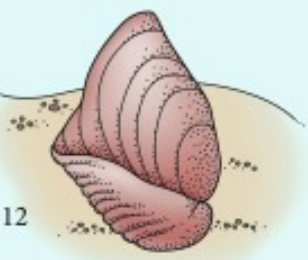





# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

**Ecological Guilds** - an ecological classification system that places species which use the same resources in the same way in the same category, which is called a “guild”.

- Guild is a flexible concept that can be focused on locations, attributes, activities, or any combination of these.
- The number of guilds existing in a community is referred to as its “disparity”.
- Phylogenetically related species tend to be members of the same guild, but morphological convergence can also be a factor in guild membership.

| LIFESTYLE   | BRACHIOPOD TAXA   | ADAPTATIONS   |
|---|---|---|
| Attached by pedicle<br>Epifaunal – hard substrate (1)<br>(plenipedunculate) | Orthides, rhynchonellides,<br>spiriferides and terabratulides                 |    |
| Epifaunal – soft substrate (2)<br>(rhizopedunculate)                        | <i>Chlidonophora</i> and <i>Cryptopora</i>                                    |    |
| Cryptic   | <i>Argyrotheca</i> and <i>Terebratulina</i>                                   |    |
| Interstitial  | Acrotretides and <i>Gwynia</i>  |    |
| Cemented  | <i>Craniops</i> and <i>Schuchertella</i>                                      |   |
| Encrusting (3)  | Craniids and disciniids   |   |
| Clasping spines (4)   | <i>Linoproductus</i> and <i>Tenaspinus</i>                                    |  |
| Mantle fibers   | Orthotetoids  |  |
| Unattached<br>Cosupportive (5)  | Pentamerids and trimerellids  |  |
| Coral-like (6)  | Gemmellaroids and<br>richthofeniids   |  |
| Recumbent   | Strophomenides  |  |
| Pseudofaunal (7) and inverted (8)   | <i>Waagenoconcha</i> and <i>Marginifera</i>                                   |  |
| Free-living (9, 10)   | <i>Cyrtia</i> , <i>Chonetes</i> , <i>Neothyris</i><br>and <i>Terebratella</i> |  |
| Mobile<br>Infaunal (11)   | Linguloids  |  |
| Semi-infaunal (12)  | <i>Camerisma</i> and <i>Magadina</i>  |  |



# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

### Community Identification

Because ecological communities are defined as associations between species Q-mode ordination analyses of species-occurrence data has been used to identify modern and paleo. communities.

- Cluster analysis
- Principal coordinates analysis
- Linear discriminant analysis
- Network analysis

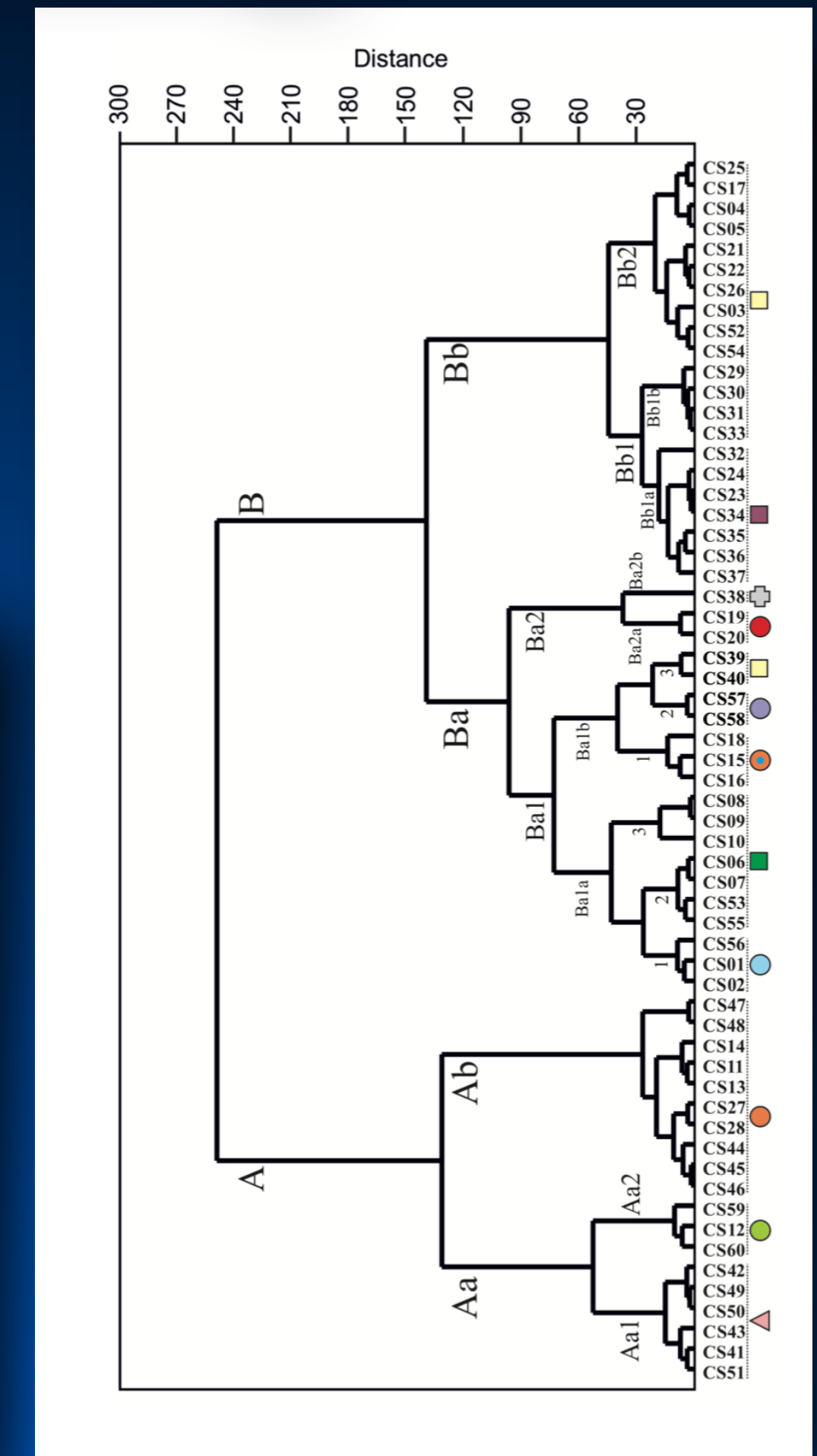
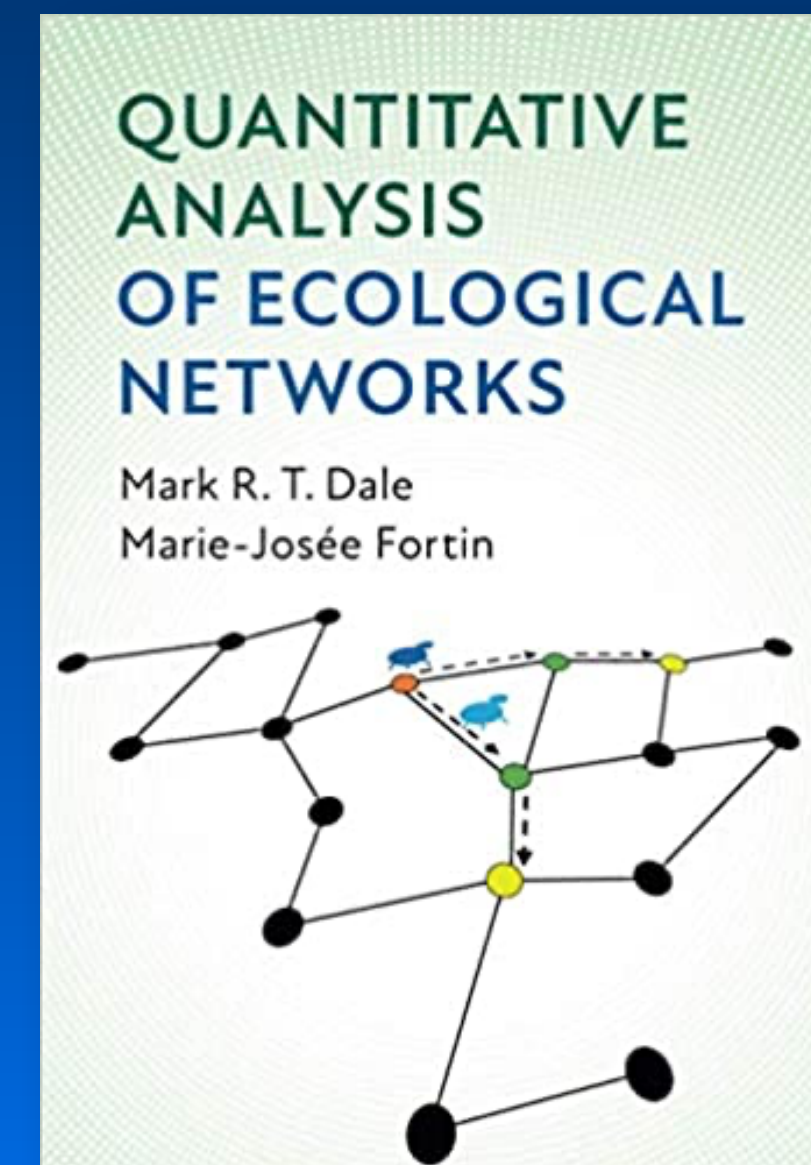


Diagram from López Sáez et al. (2019)

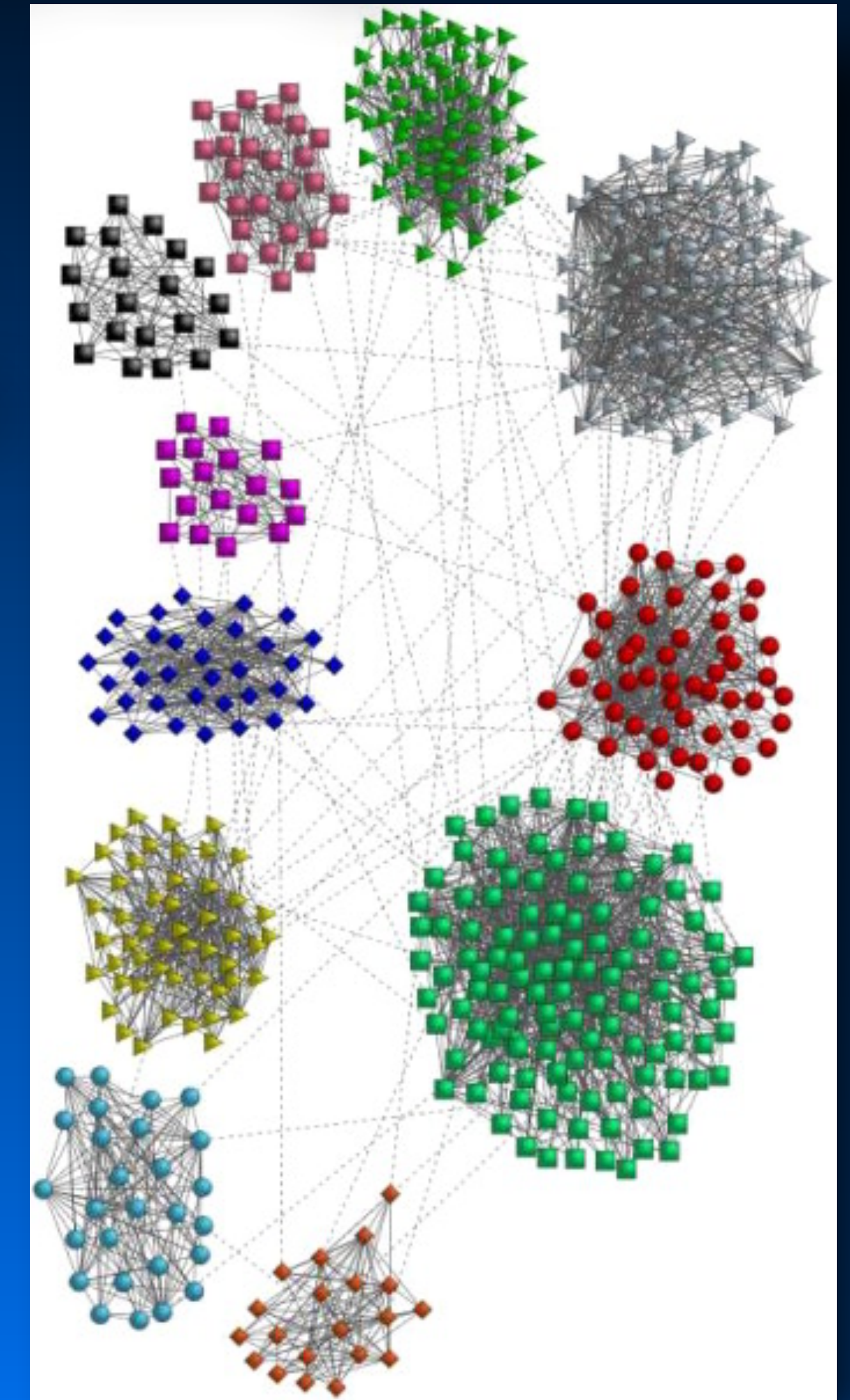


# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

### Community Structure Theories

- **Holistic (Organism) Theory** - regards ecological communities as “superorganisms” that exhibit well-defined structures, semi-obligate interdependencies mechanisms to resist perturbation, and definite environmental ranges.
- **Individualistic (Epiphenomenon) Theory** - regards ecological communities as coincidental and opportunistic associations of functionally independent species.
- **Neutral Theory** - regards ecological communities as associations of functionally equivalent species with the same adaptive value to the community as a whole. Under this model community composition can change due to random ecological drift.





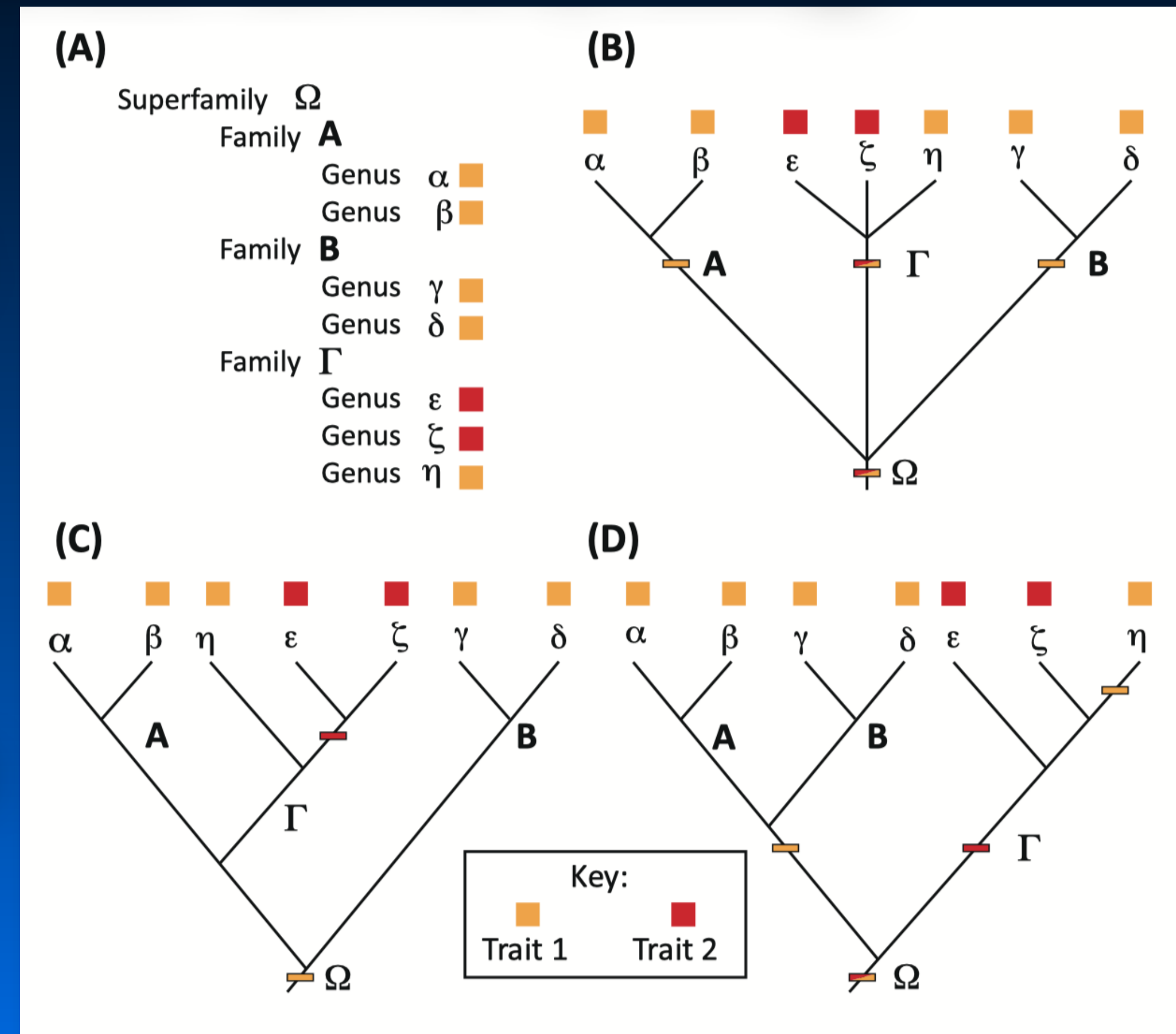
# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology

### Phylogenetic Paleoecology

A new trend in (paleo)ecology is the incorporation of a phylogenetic perspective. This approach is derived from comparative method analysis and allows associations and changes due to environmental factors to be distinguished from those due to common ancestry.

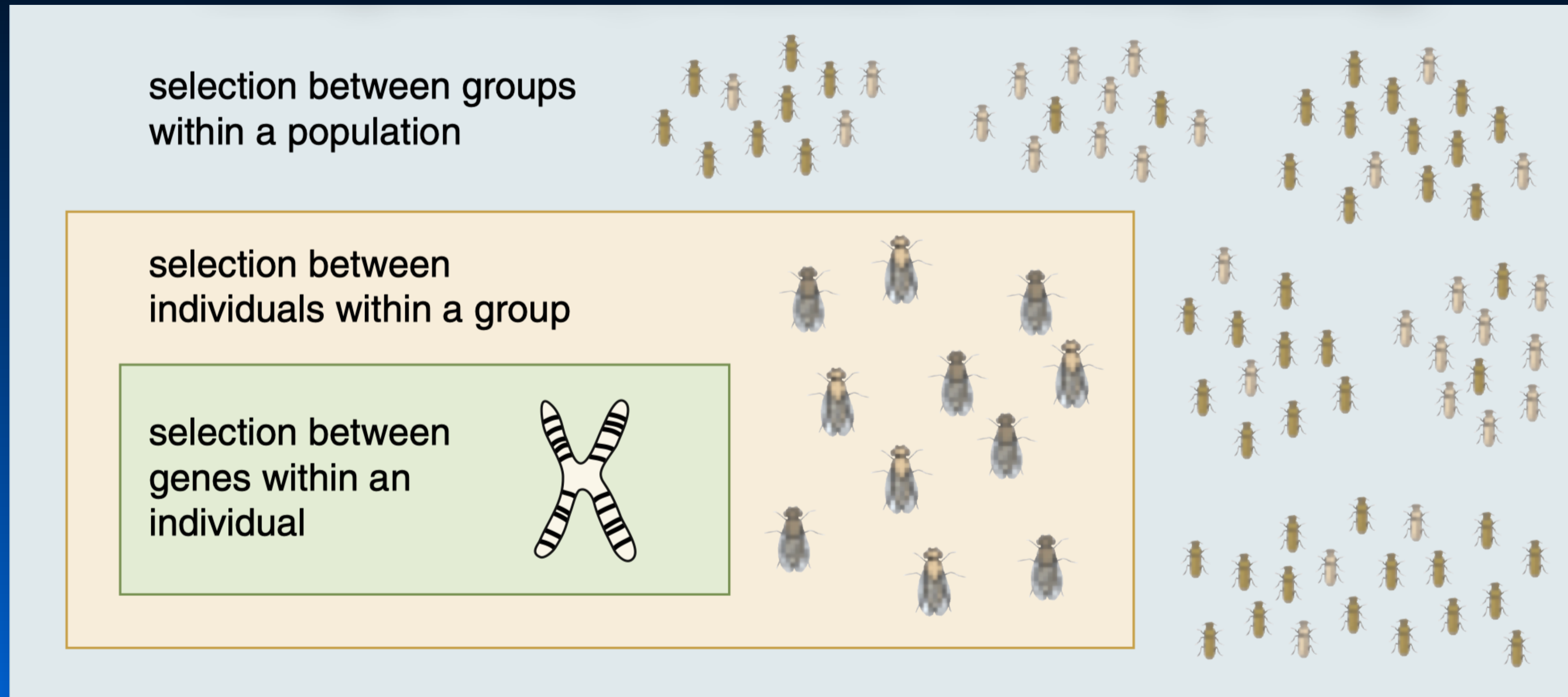
Appreciation of the important role phylogeny plays in (paleo)ecological studies has long been missing from this approach and, while its introduction is just now being explored, it is a welcome development.





# Paleobiological Paleoecology

## Ecological Theory & Methods: Community Ecology



**Multilevel Selection Theory** suggests that Darwinian natural selection can operate and a variety of organizational levels, including those above the level of the species.

Diagram from Wilson & Wilson (2008)

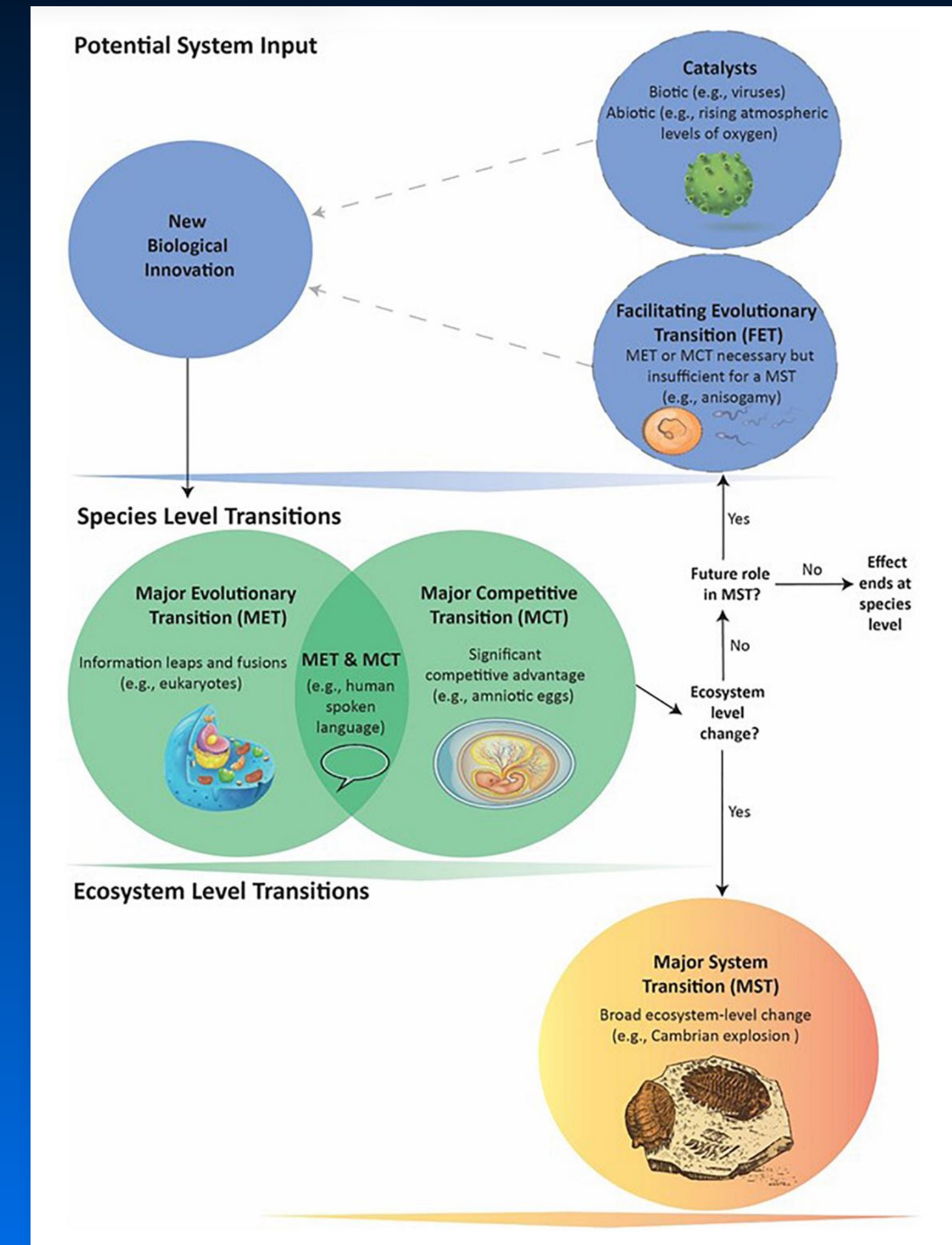


# Paleobiological Paleoeecology

## Ecological Theory & Methods: Eco-Evolutionary Transitions

### Major Evolutionary-Ecological Transitions

- Independently replicating molecules to cells
- RNA to DNA
- Prokaryotes to eukaryotes
- Acquisition of plastids
- Single celled to multi-celled individuals
- Origin of phyla
- Solitary individuals to eusocial groups
- Primate societies to human societies





# Paleobiological Paleoecology

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## Ecological Theory & Methods: Island Biogeography

### Theory of Island Biogeography

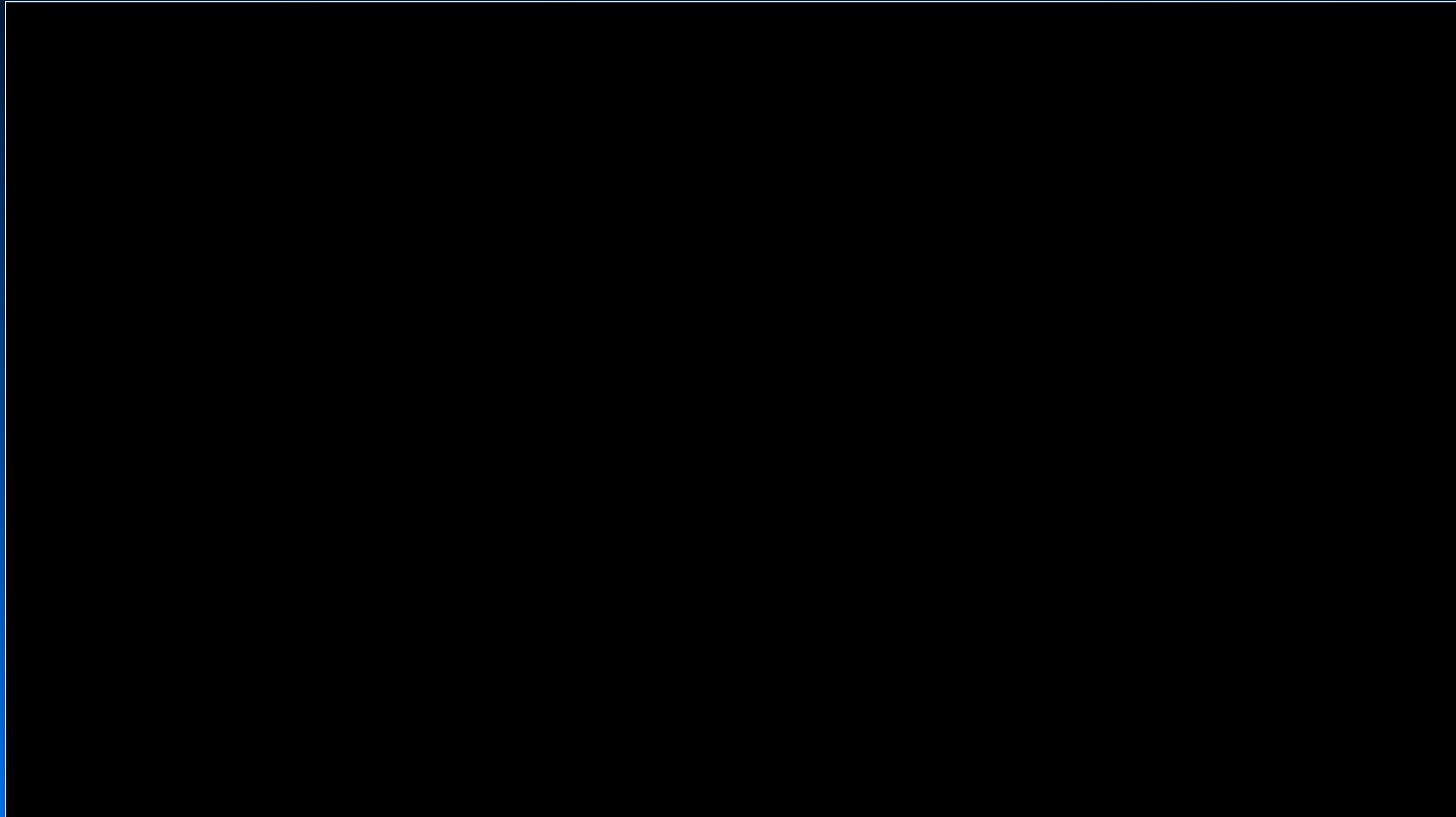
Chrissy Spencer  
School of Biology  
Georgia Tech



# Paleobiological Paleoecology

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## Ecological Theory & Methods: Island Biogeography





NJU Course

# Principles of Paleobiology

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Paleobiological Paleoecology

