Fundamentals of Ecology

Week 9, Ecology Lecture 8

Cara Brook

March 2, 2023

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- The transmission-virulence tradeoff offers an explanation for why pathogens cause disease: virulence is a by-product of the mechanisms (e.g. high growth rates) that help a pathogen transmit to new hosts.
- Pathogens evolve to maximize R_0. Because increasing transmission often increases virulence, balancing these tradeoffs results in the evolution of optimal virulence.

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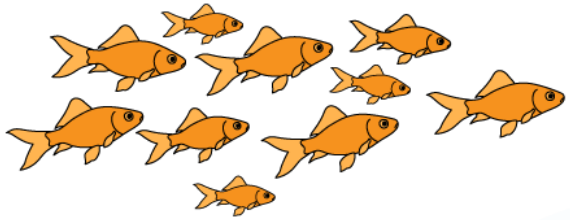
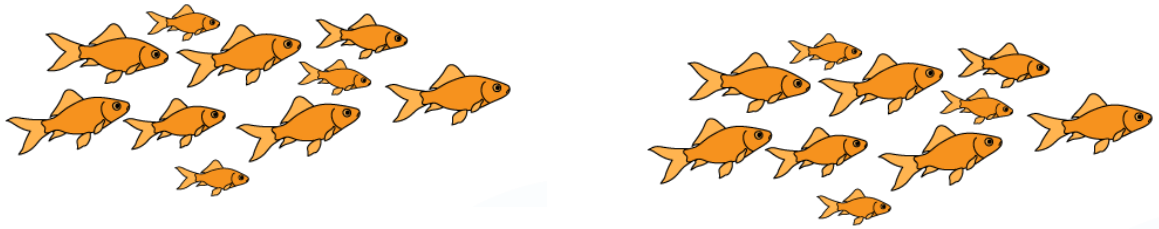
- The result of amplification vs. dilution depends on the ratio of competent to non-competent hosts and the abundance of the vector population.

Ecology is the study of the **interactions** of **organisms** with each other and their **environment**.

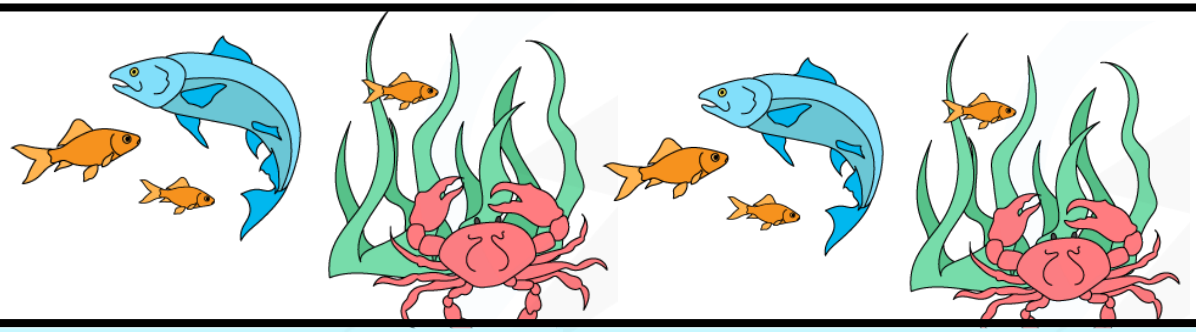
individual



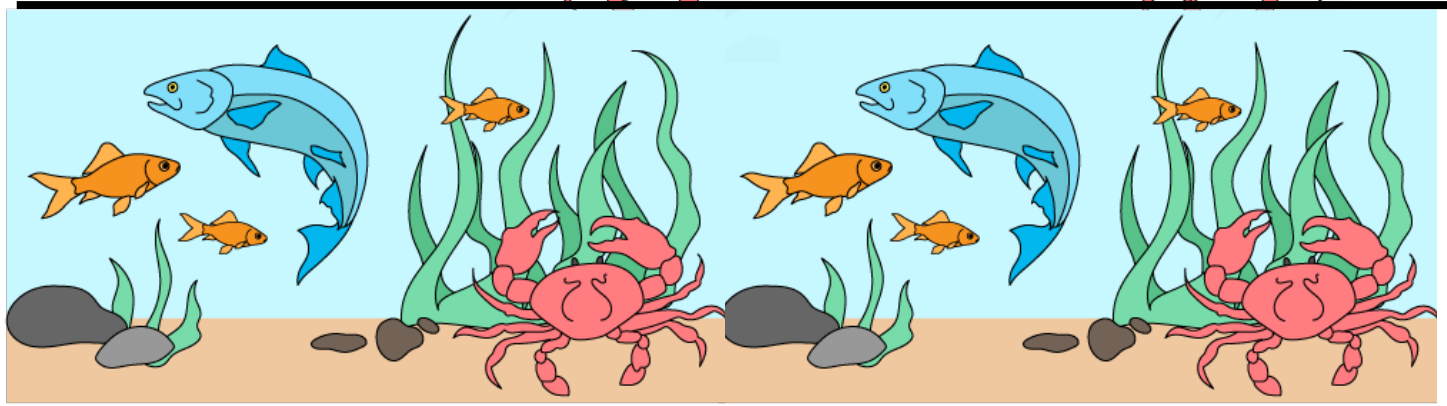
population



metapopulation



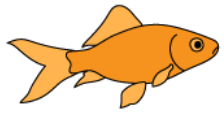
community



ecosystem

Individual:
metabolism, behavior, life history.

interactions of an individual with the environment



individual

population

metapopulation

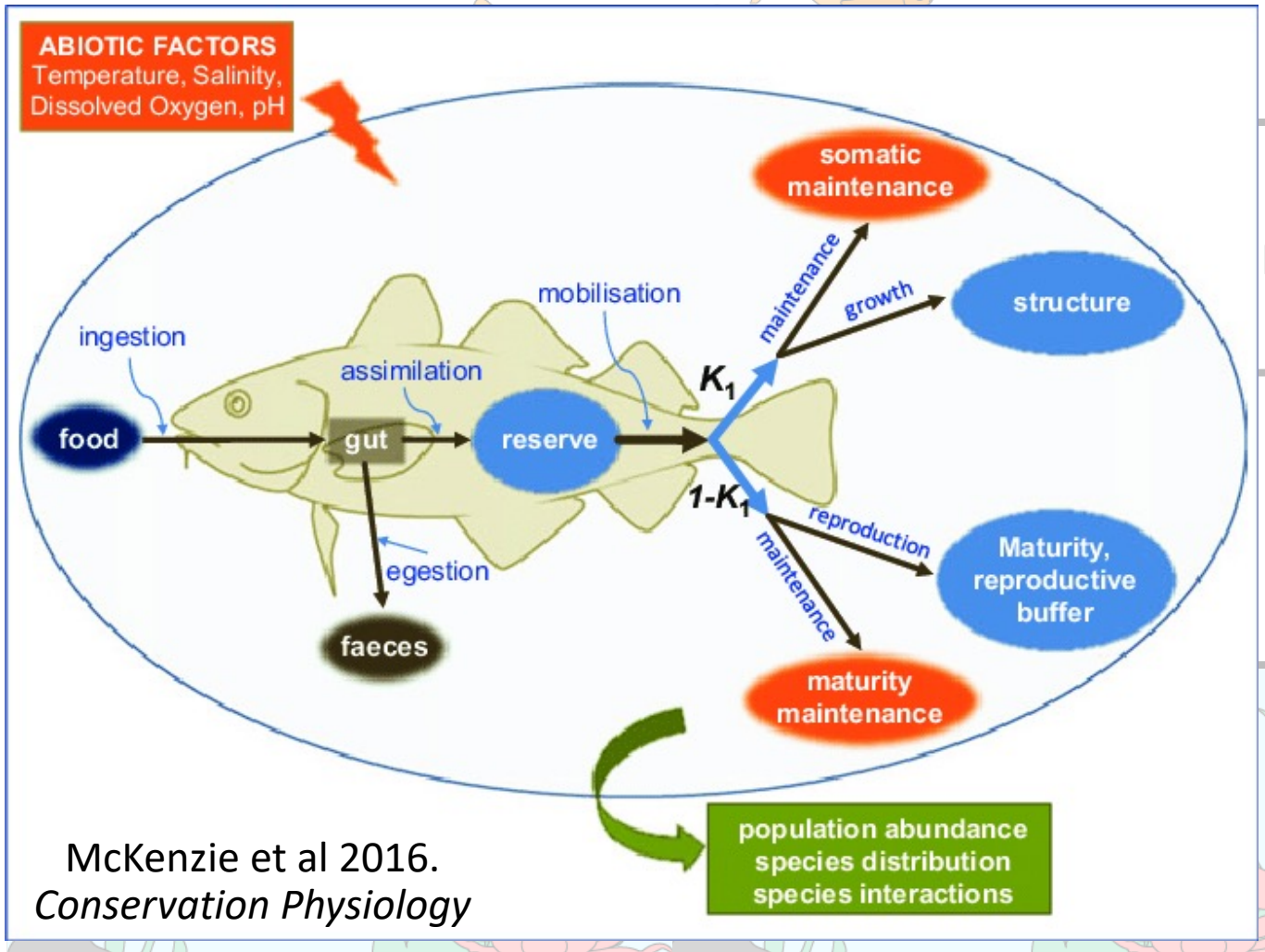
community

ecosystem

Individual: metabolism, behavior, life history.

Dynamic Energy Budget (DEB) Model

*How does a fish's metabolism **change** with temperature?*



McKenzie et al 2016.
Conservation Physiology

individual

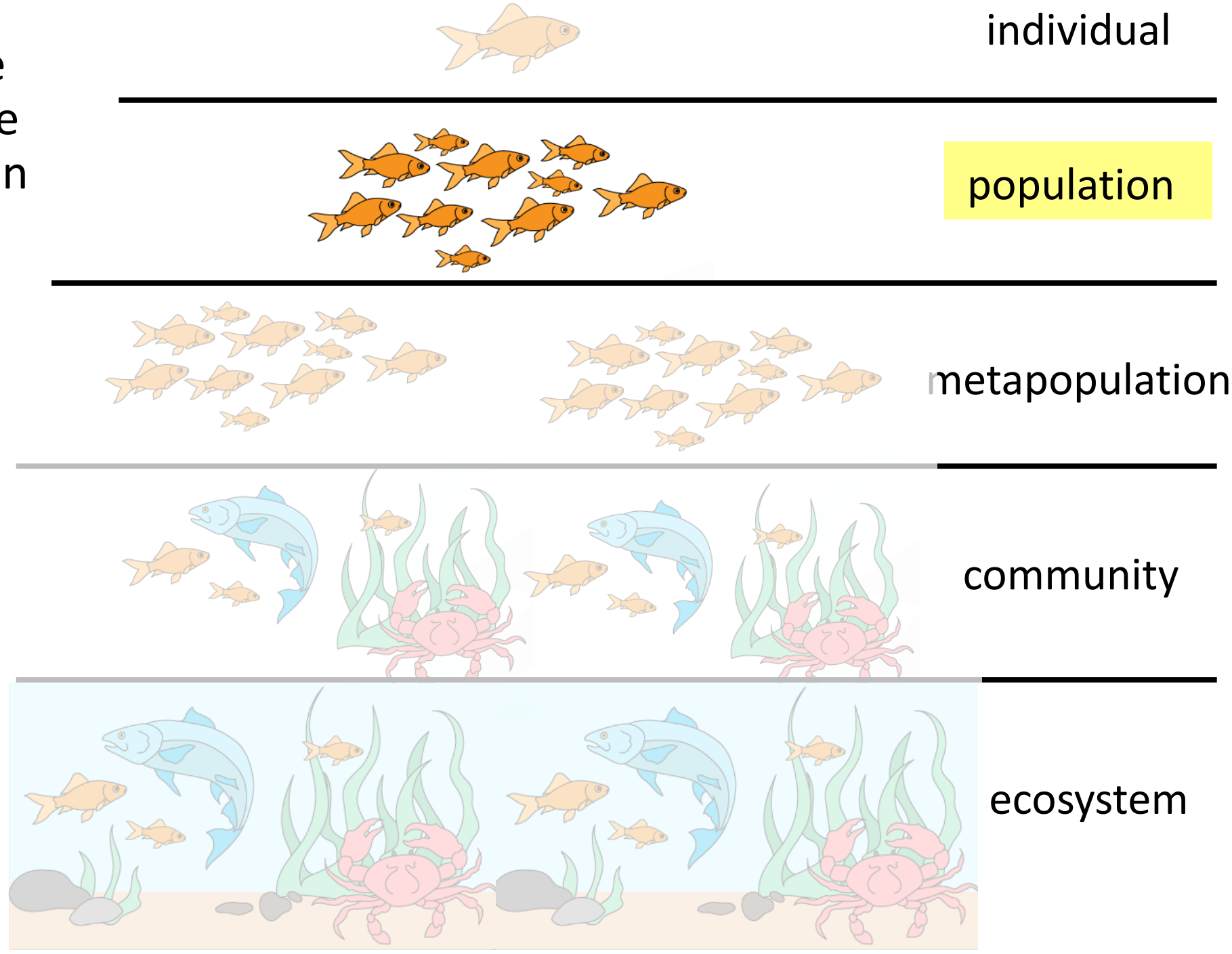
population

metapopulation

community

ecosystem

Population = multiple individuals of the same species (**conspecifics**) in the same habitat



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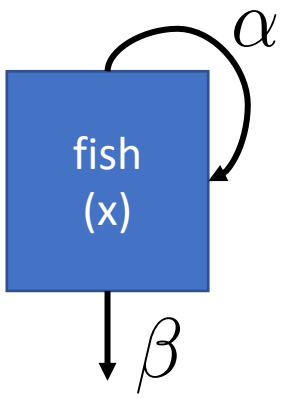


*How does the abundance of fish **change** through time?*

individual

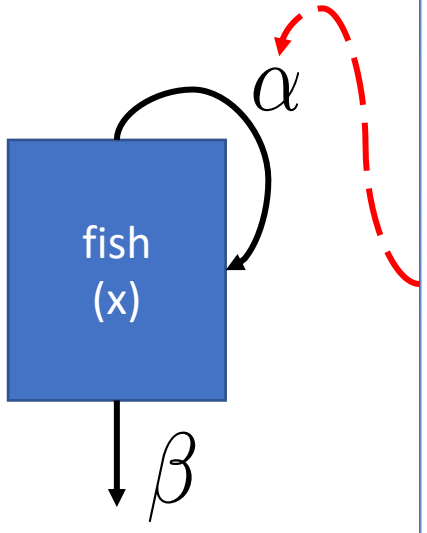
population

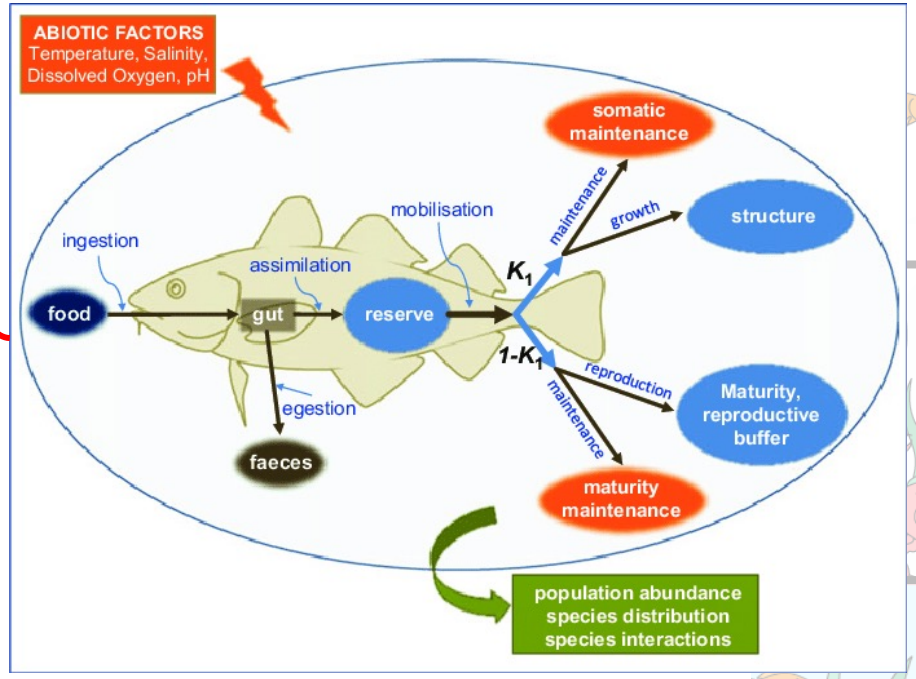
metapopulation

community

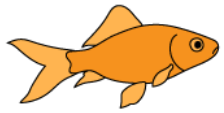
ecosystem

Nested Models, including a class of model known as **Integral Projection Models** (IPMs), link individual- and population-level processes

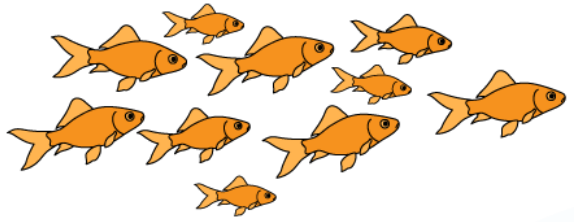




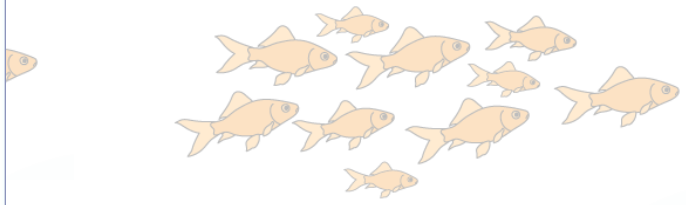
*How does the abundance of fish **change** through time as temperature **changes** metabolism?*



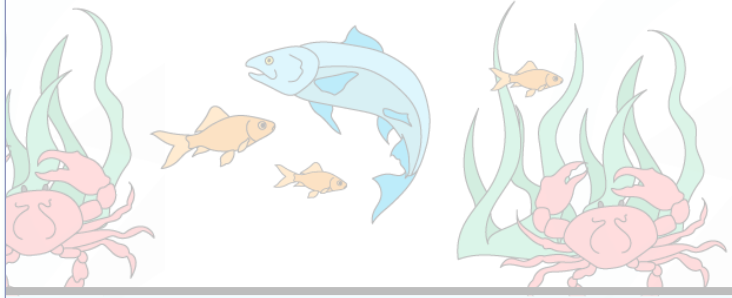
individual



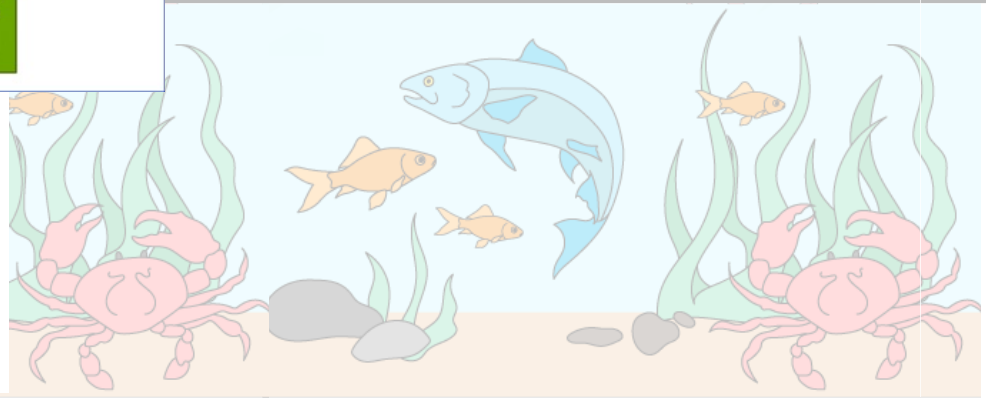
population



metapopulation

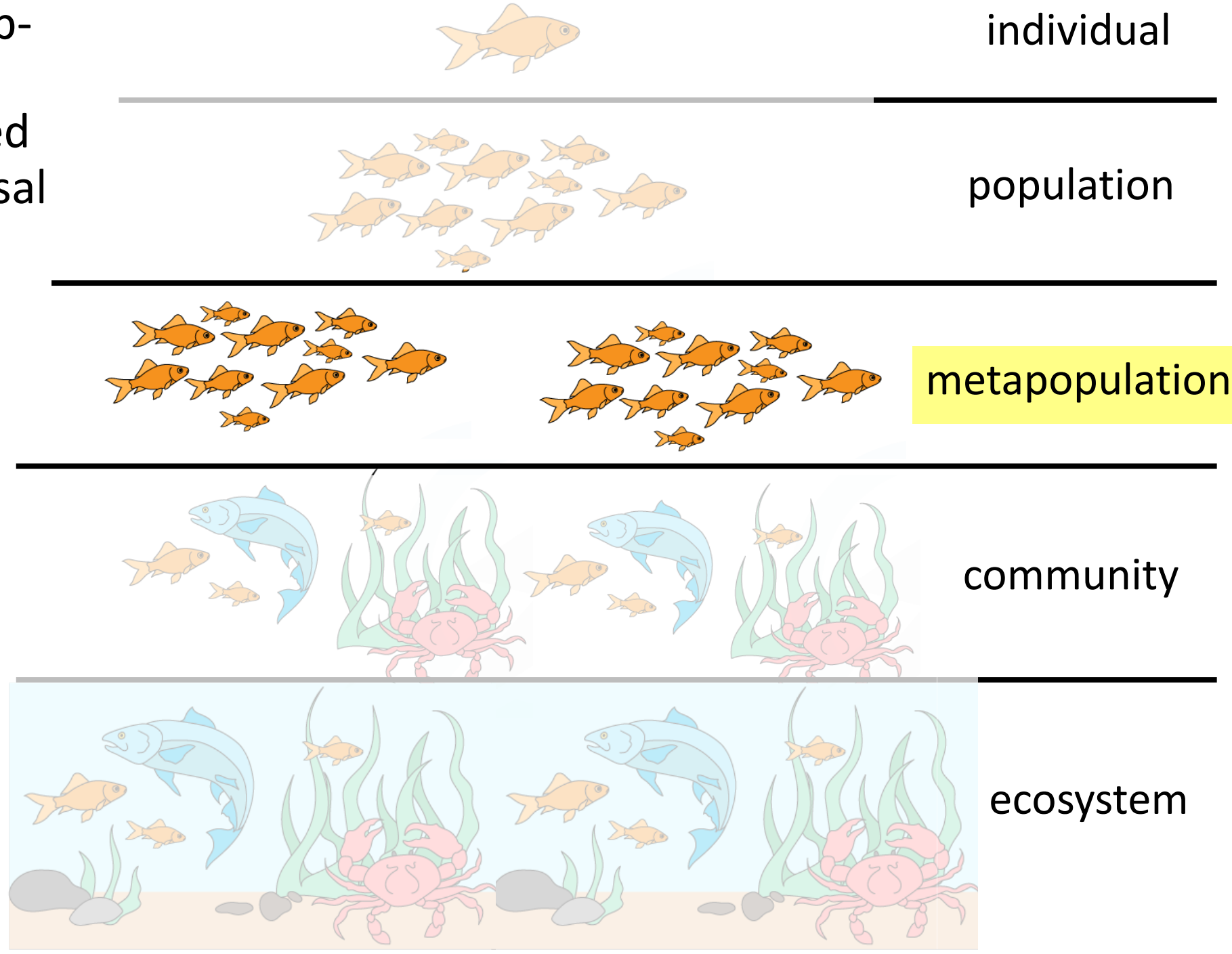


community



ecosystem

Metapopulation = sub-populations of conspecifics connected by migration or dispersal



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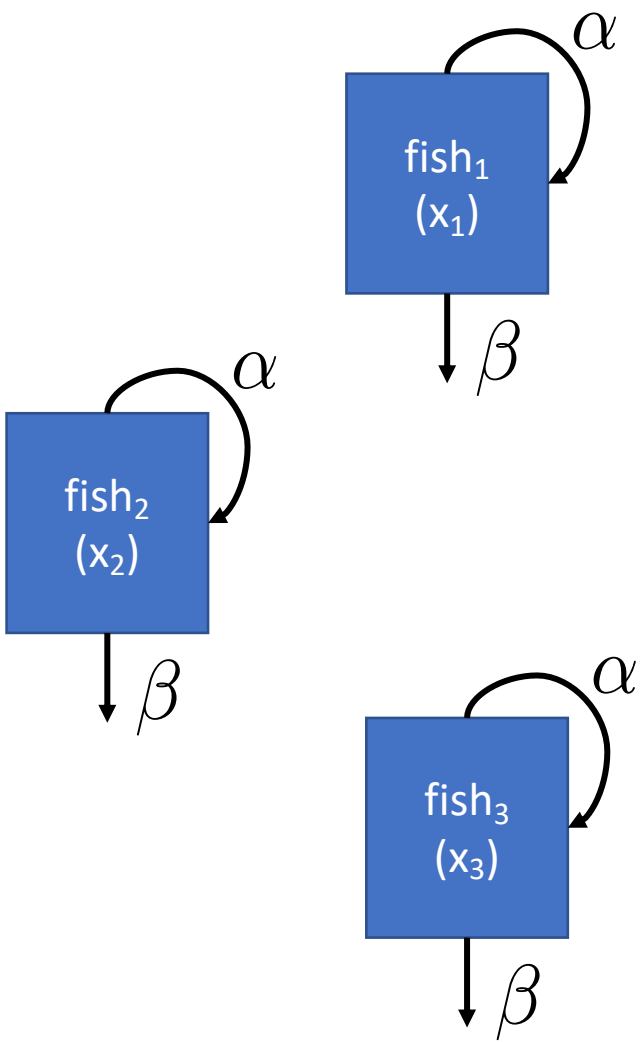

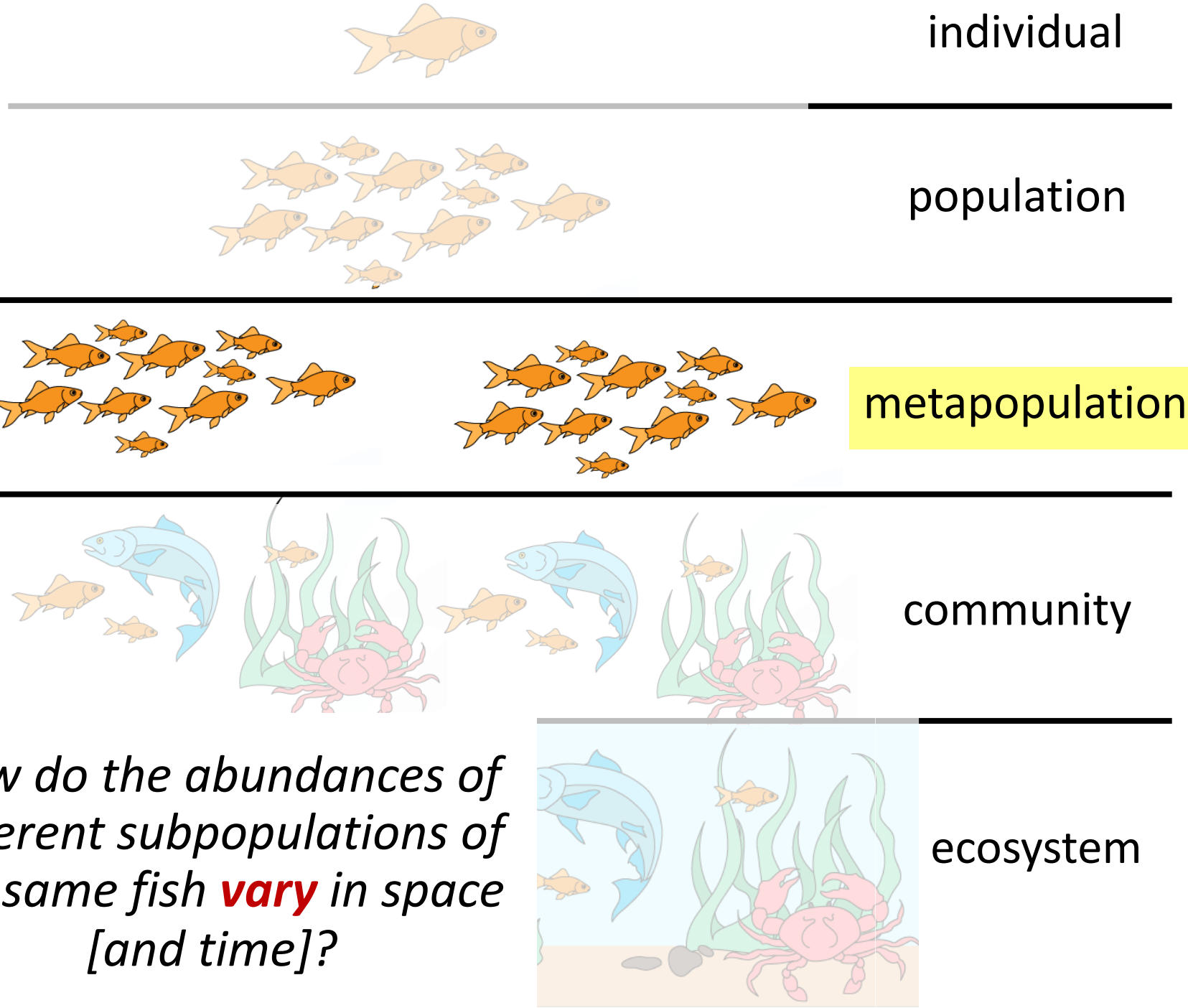

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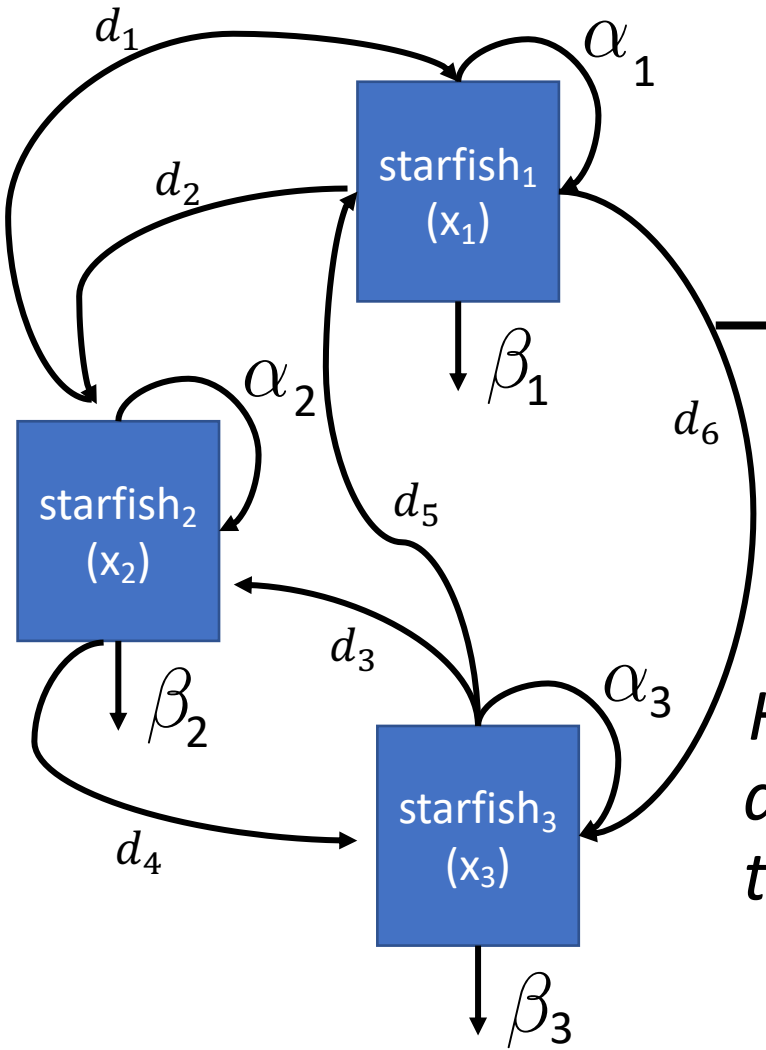
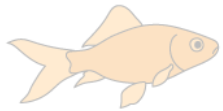
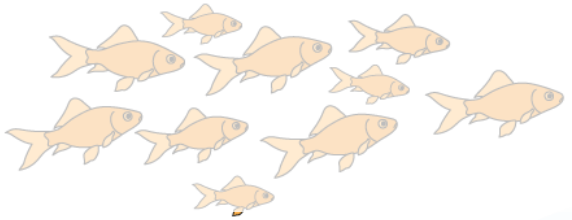
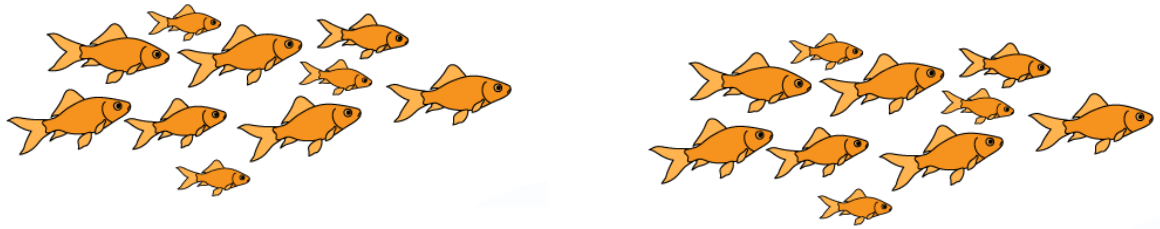




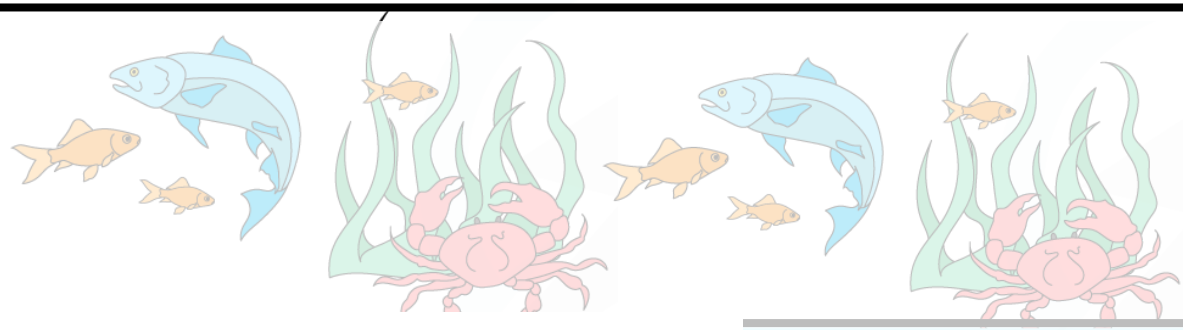
individual



population



metapopulation



community

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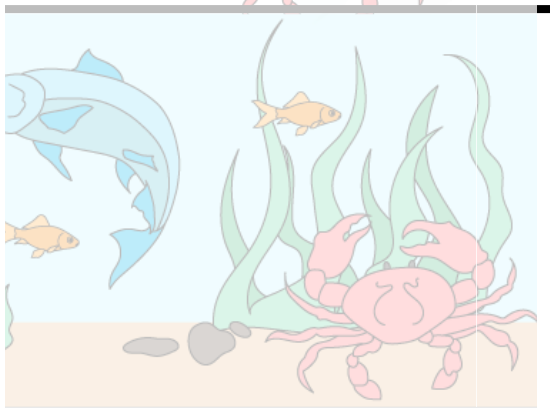
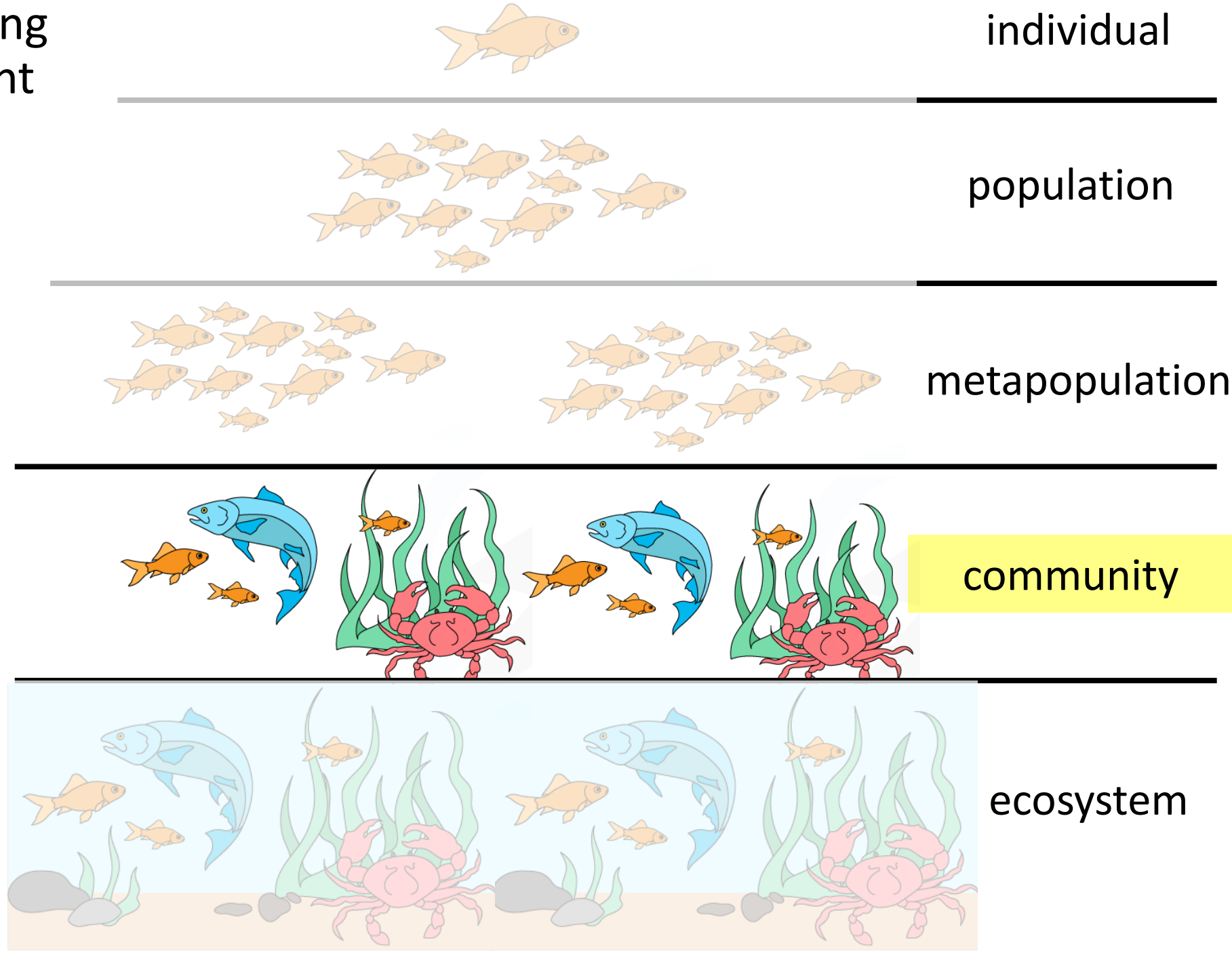


ecosystem

Community = interacting populations of different species



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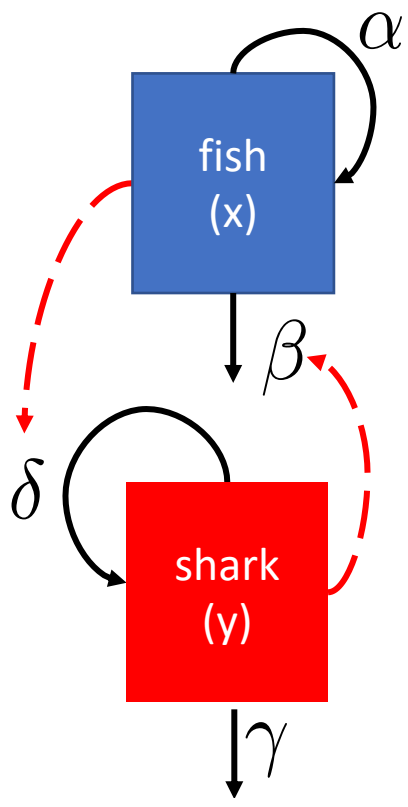
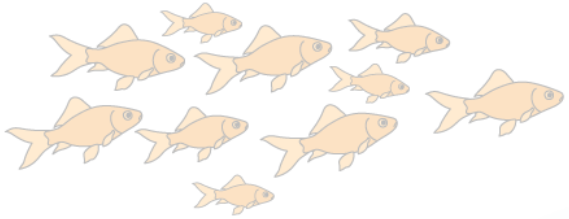
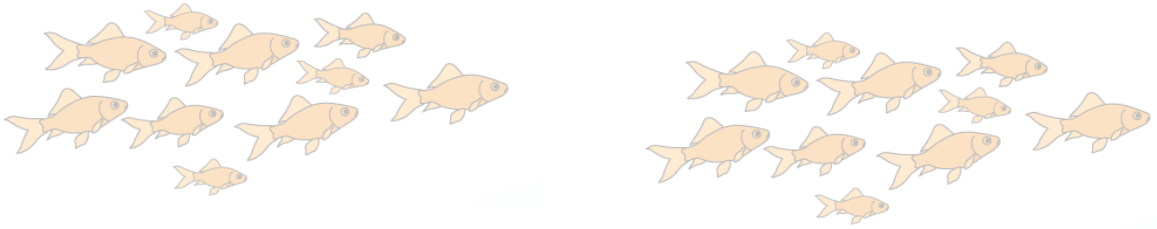
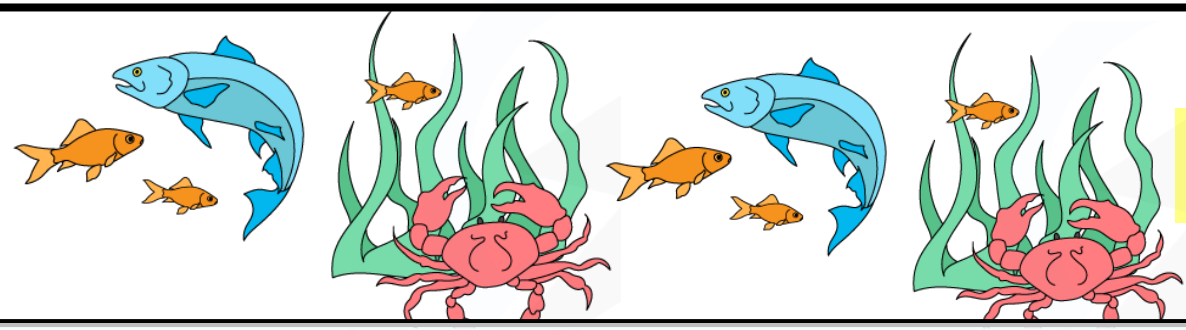


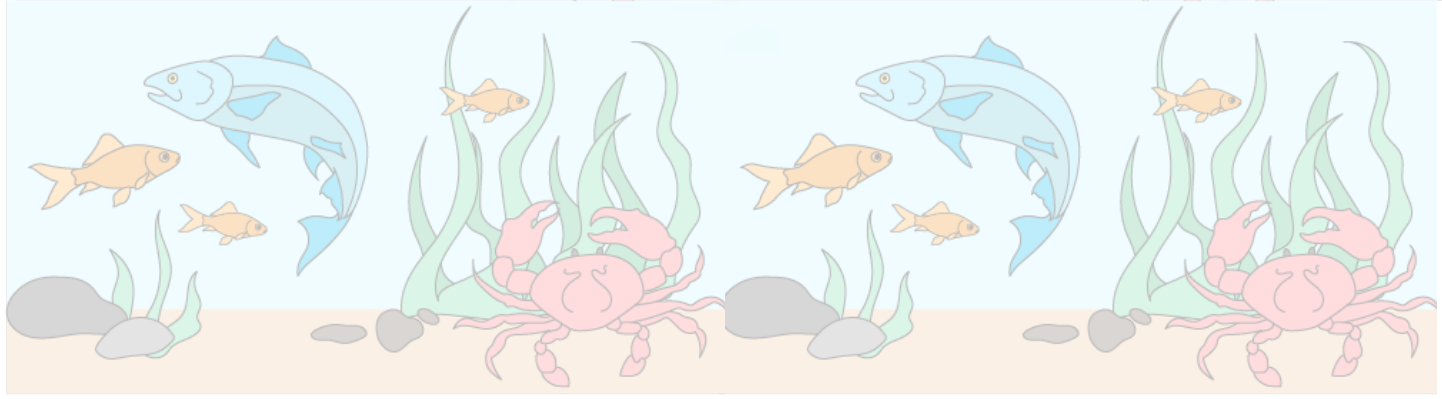
*How does fish abundance **vary** with **changes** in shark abundance?*


individual


population


metapopulation


community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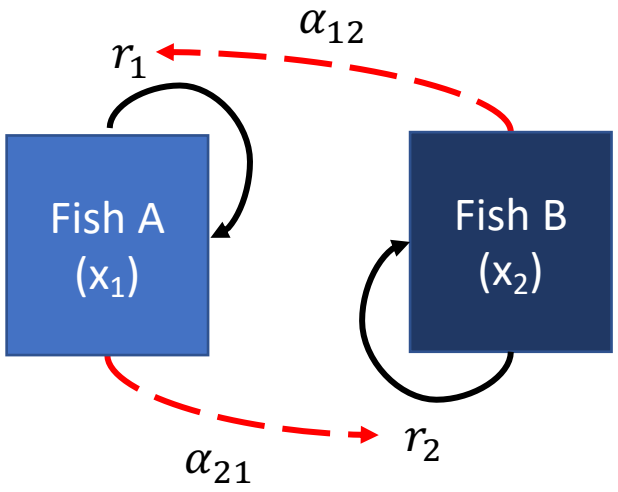
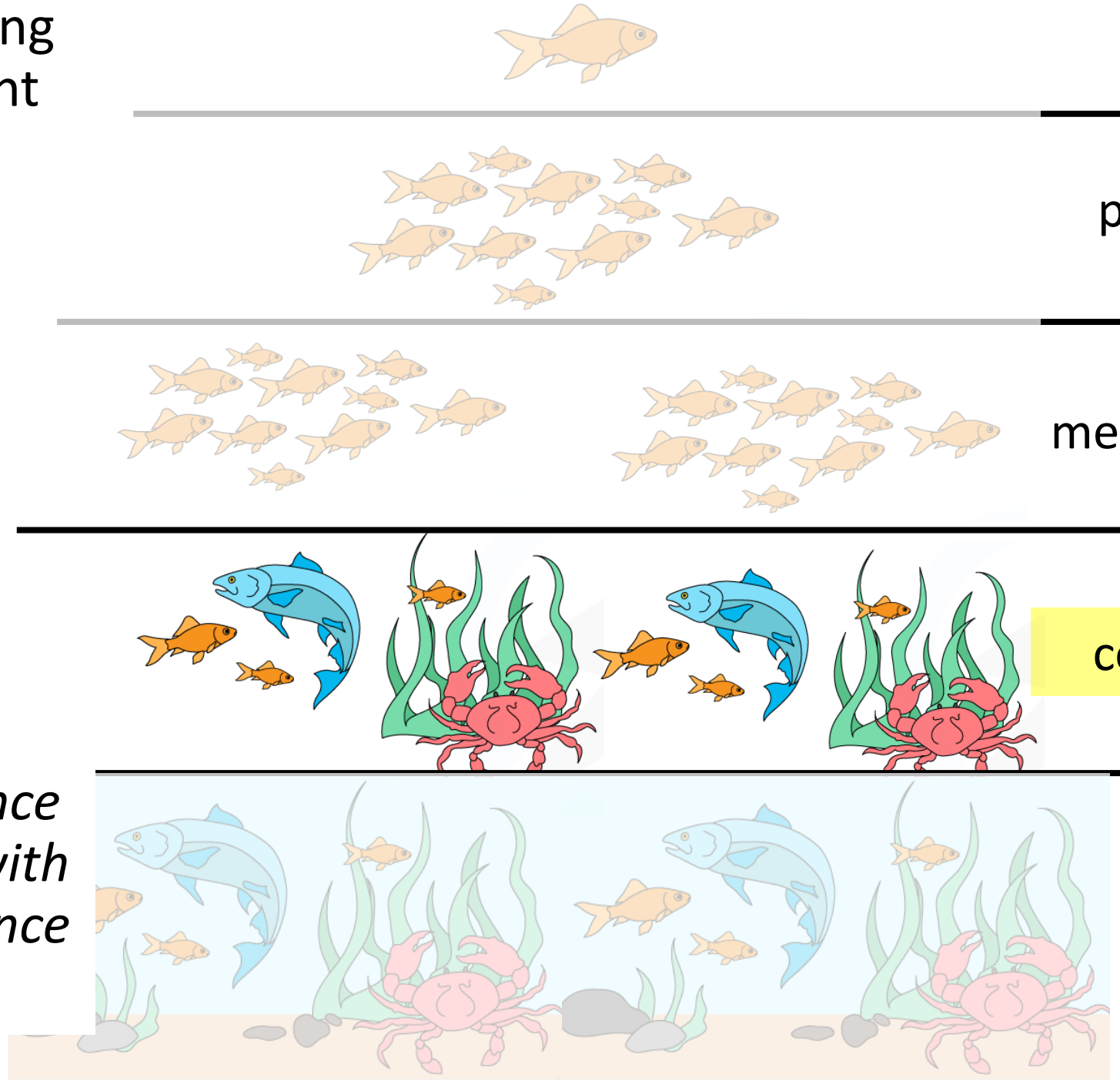


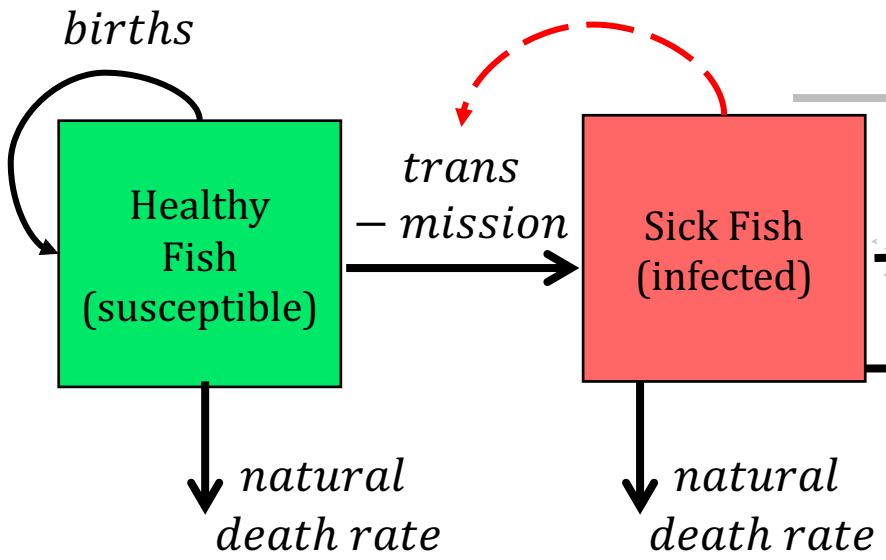
*How does the abundance of **fish species A** vary with changes in the abundance of **fish species B**?*



Community = interacting populations of different species

individual

population



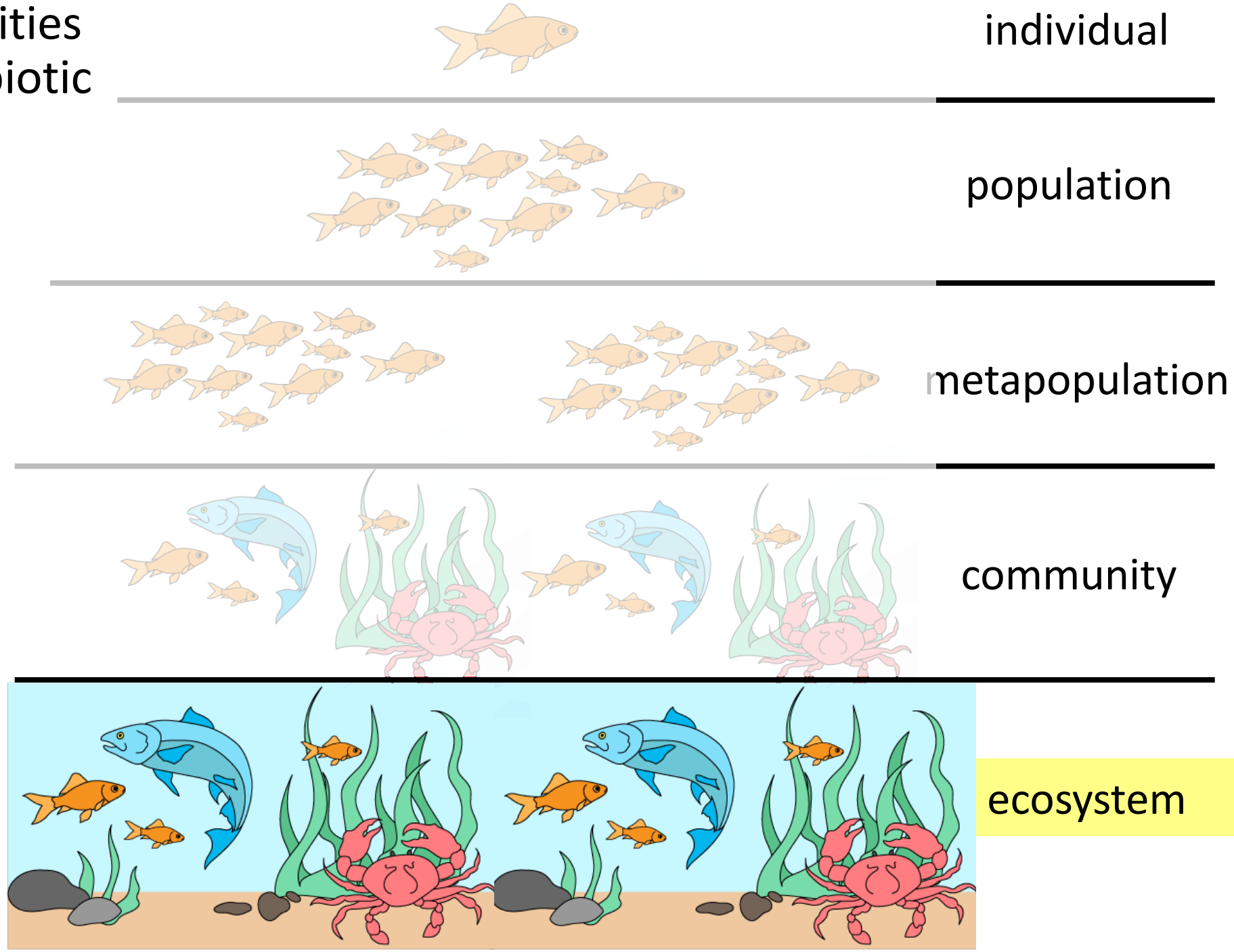
metapopulation

community

ecosystem

*How does the abundance of **fish** change based on **infection with** **Mycobacterium marinum** (wasting disease)?*

Ecosystem = communities interacting with the abiotic environment



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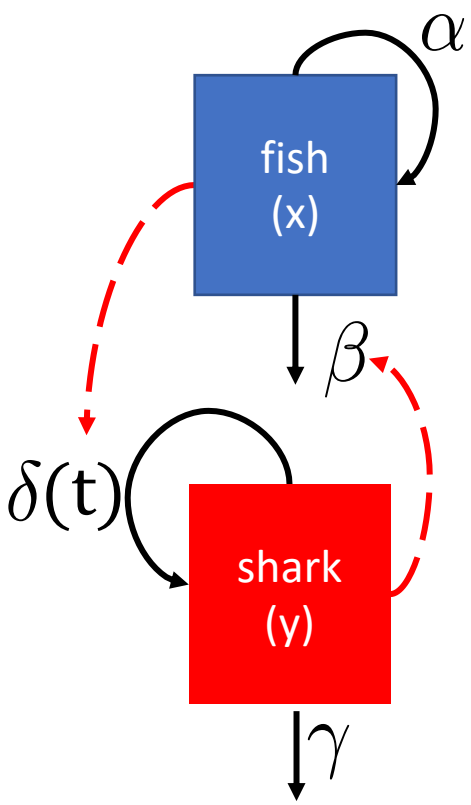
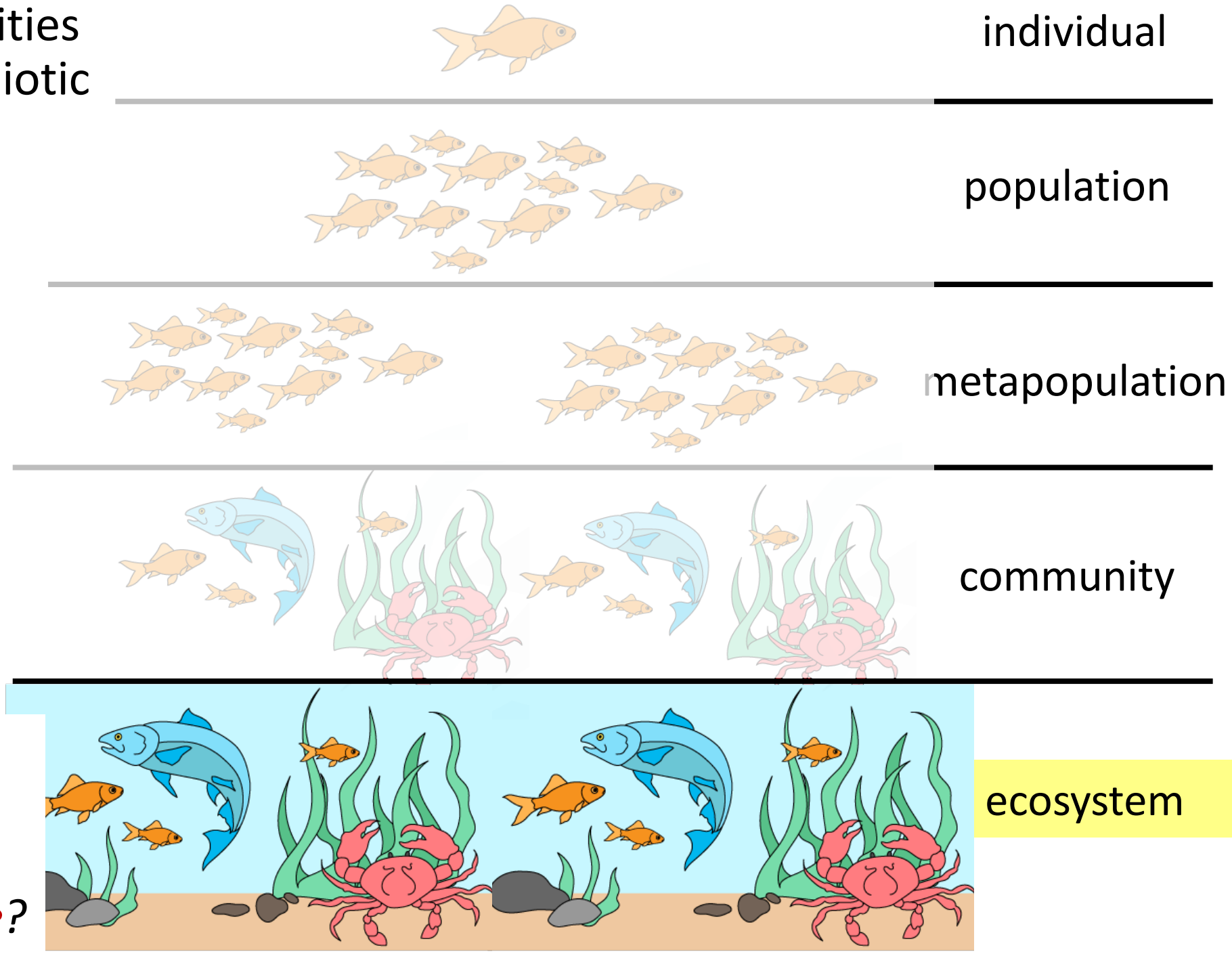
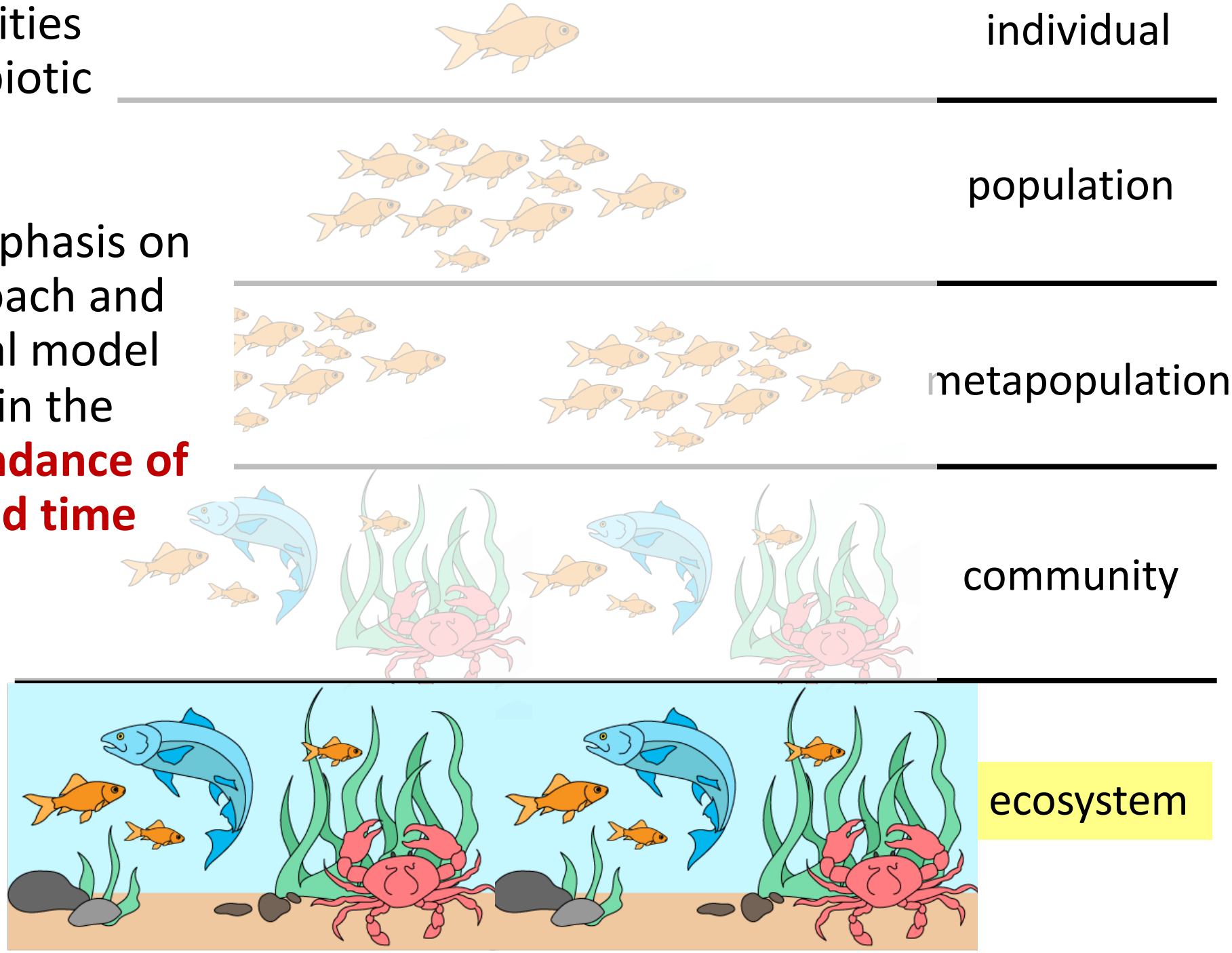


*How does fish abundance **vary** with **changes** in shark birth rates with **temperature**?*



Ecosystem = communities interacting with the abiotic environment

There is often less emphasis on the box model approach and more of a conceptual model approach to explain the **distribution and abundance of species in space and time**



Ecosystem = communities interacting with the abiotic environment

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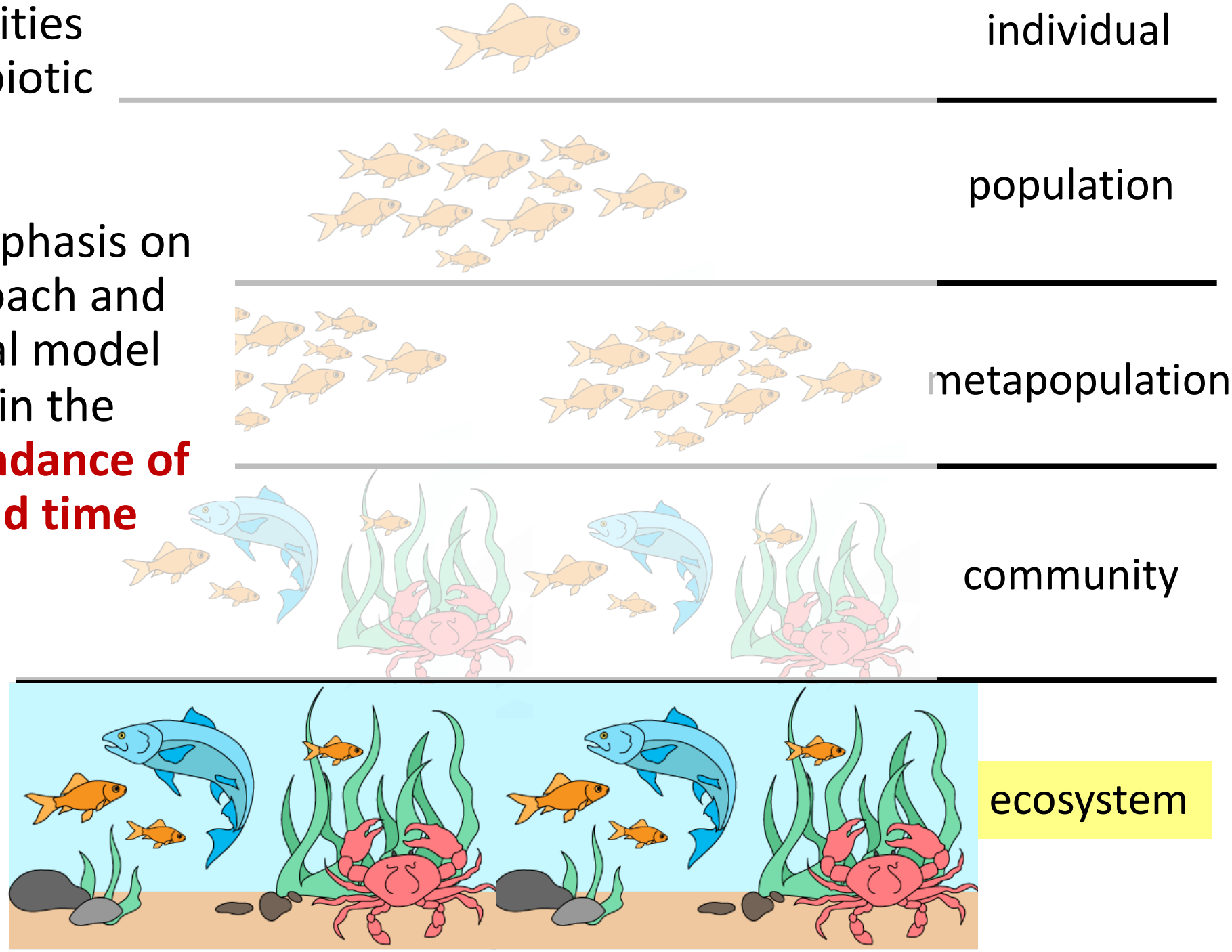
How do communities assemble?

Do they end up the same in different environments?

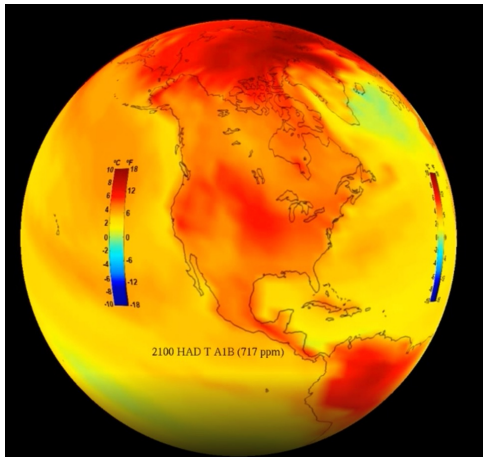


What is a model? an abstract representation of a phenomenon

Human

Solar System

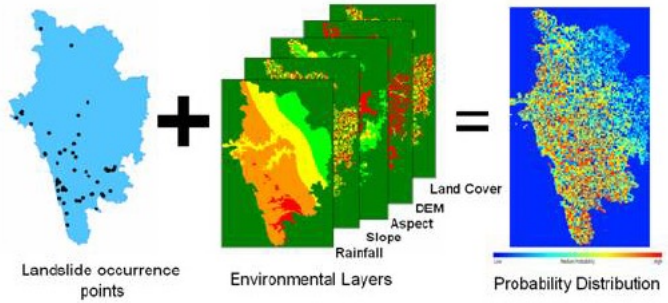
Climate



Human Genetics

Human Disease

Species Distribution



What is a model? an abstract representation of a phenomenon

Human

Solar System

Mathematical

$$\frac{dS}{dt} = -\beta SI$$

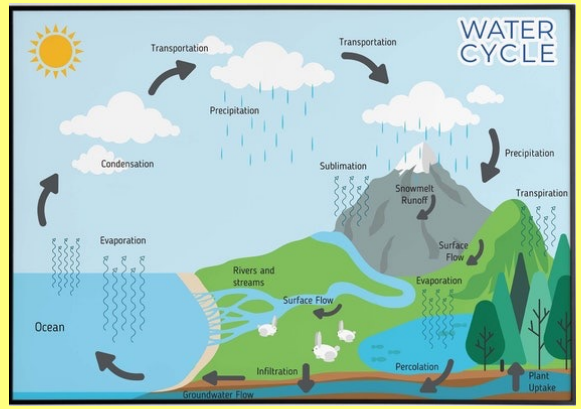
$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

Human Genetics

Human Disease

Conceptual



Community assembly is the study of the **processes** that shape the **identity and abundance** of species within ecological communities.

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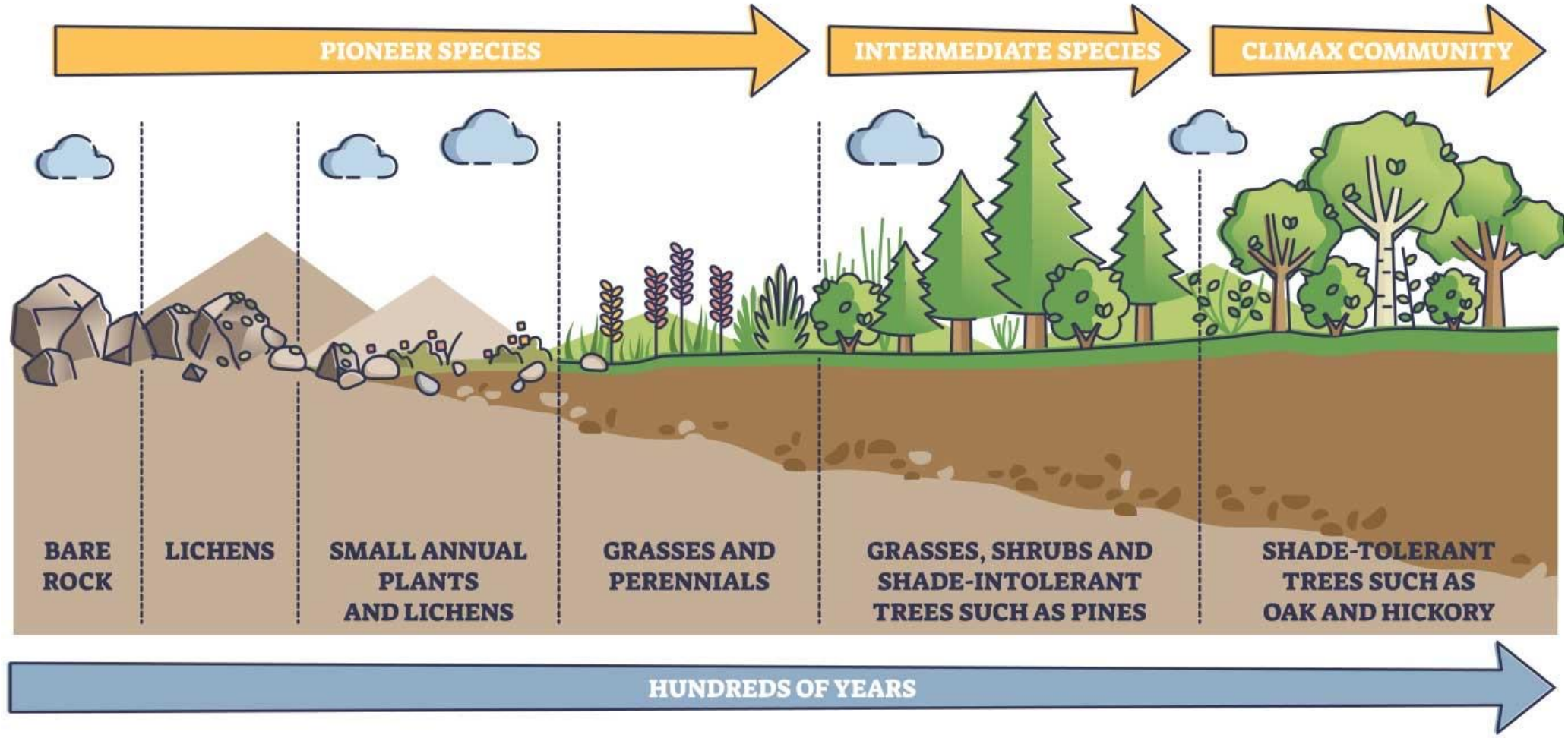
- Henry Chandler Cowles, a professor at the University of Chicago, developed the first formal concept of succession while observing **vegetation on dunes of different ages at the Indiana Dunes**. Differently aged dunes offered a proxy for time.

Primary succession occurs when species colonize a bare substrate.



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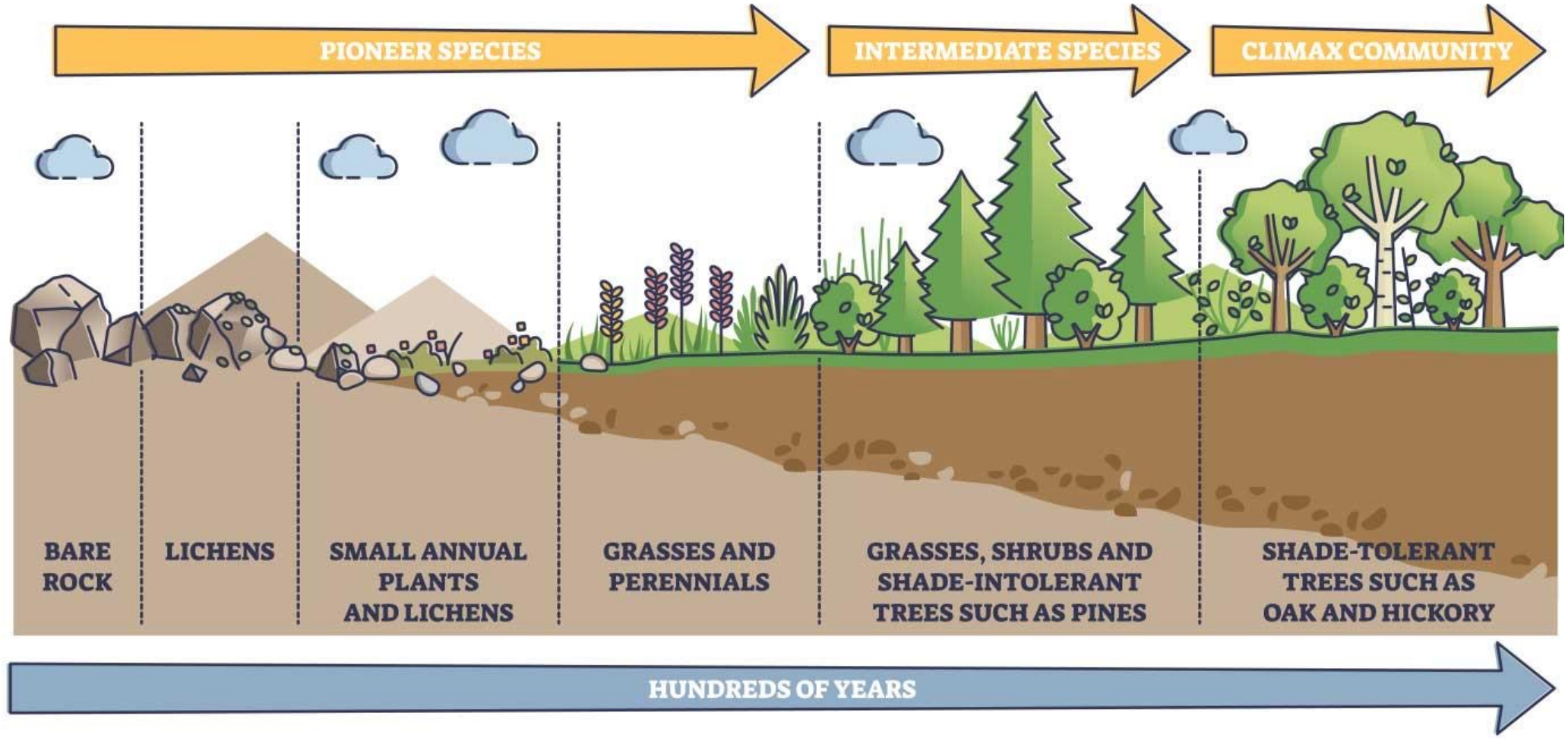
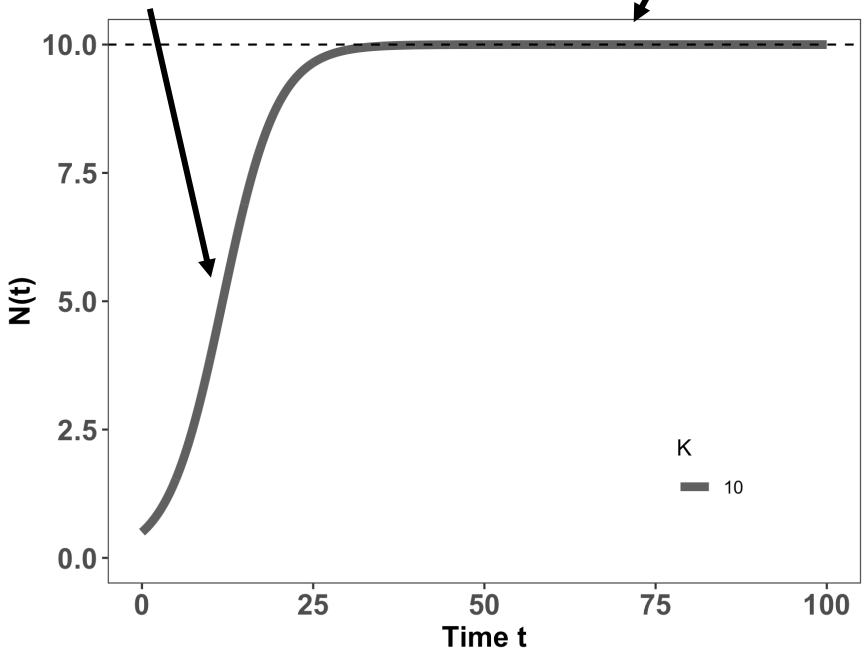


*Continuum from "**r-selected**" → "**K-selected**" species.*

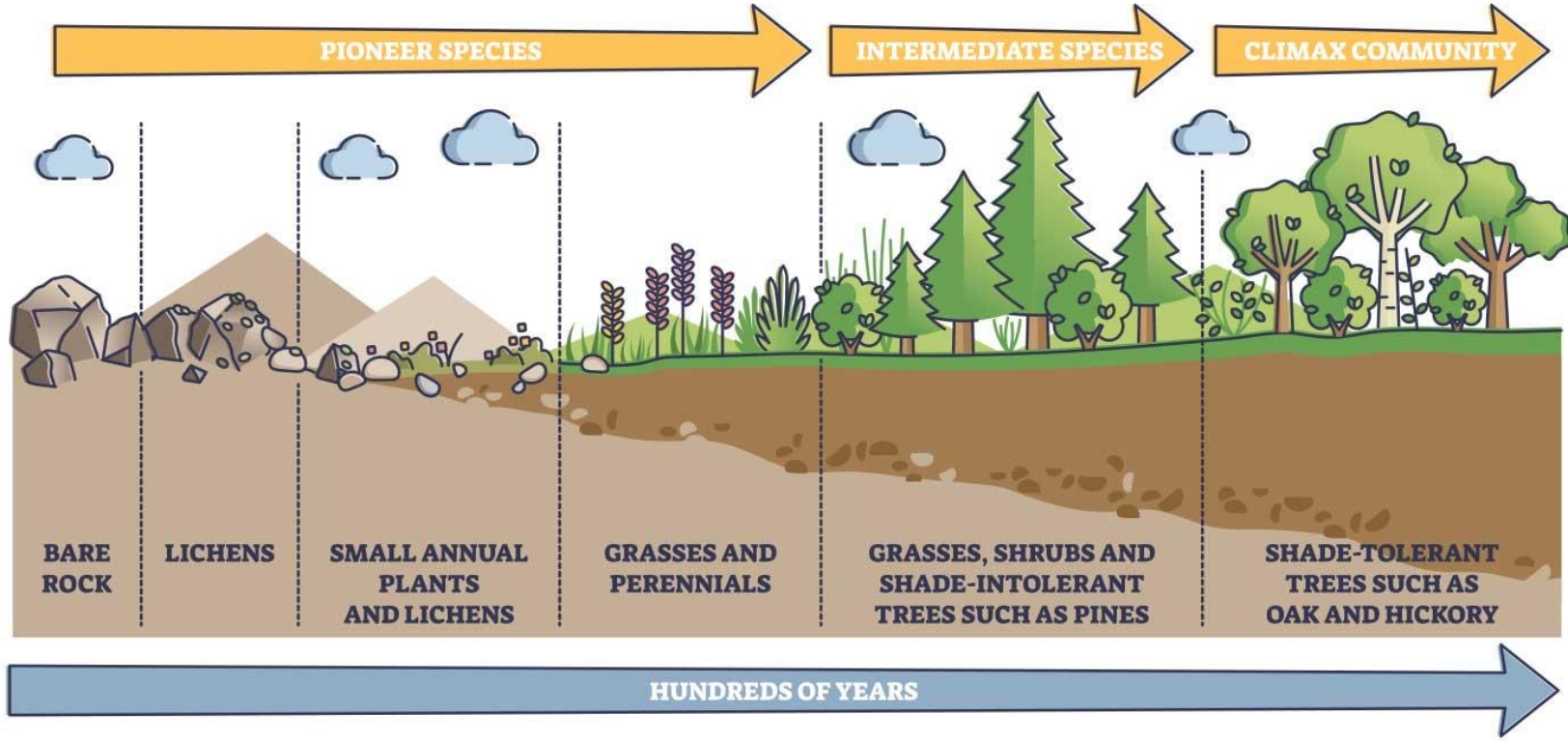
Primary succession occurs when species colonize a bare substrate.

K-selected species

r-selected species



$$\frac{dN}{dt} = \boldsymbol{r}N\left(1 - \frac{N}{\boldsymbol{K}}\right)$$



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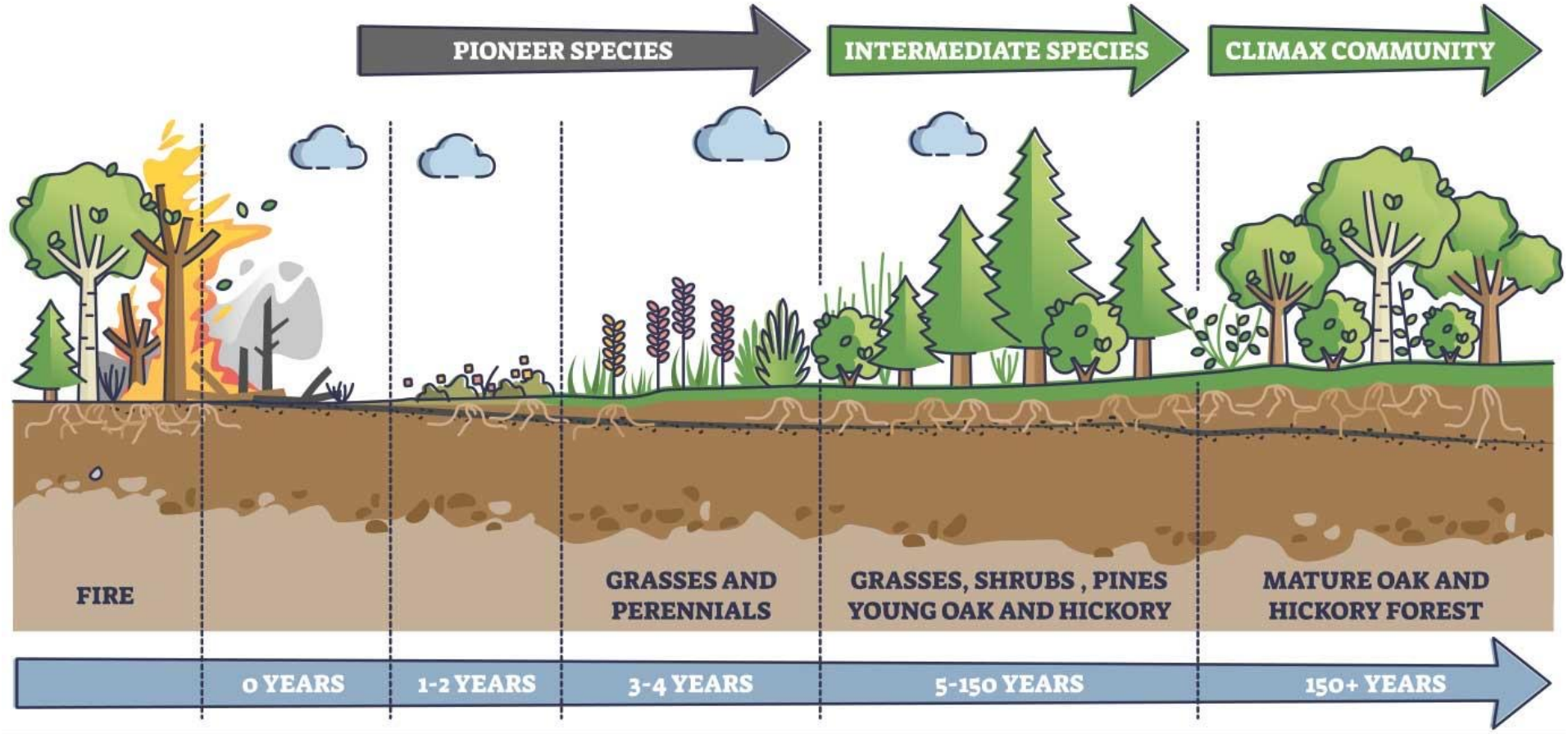
Secondary succession occurs when an environmental disturbance displaces a climax community, but soil and nutrients are still retained.



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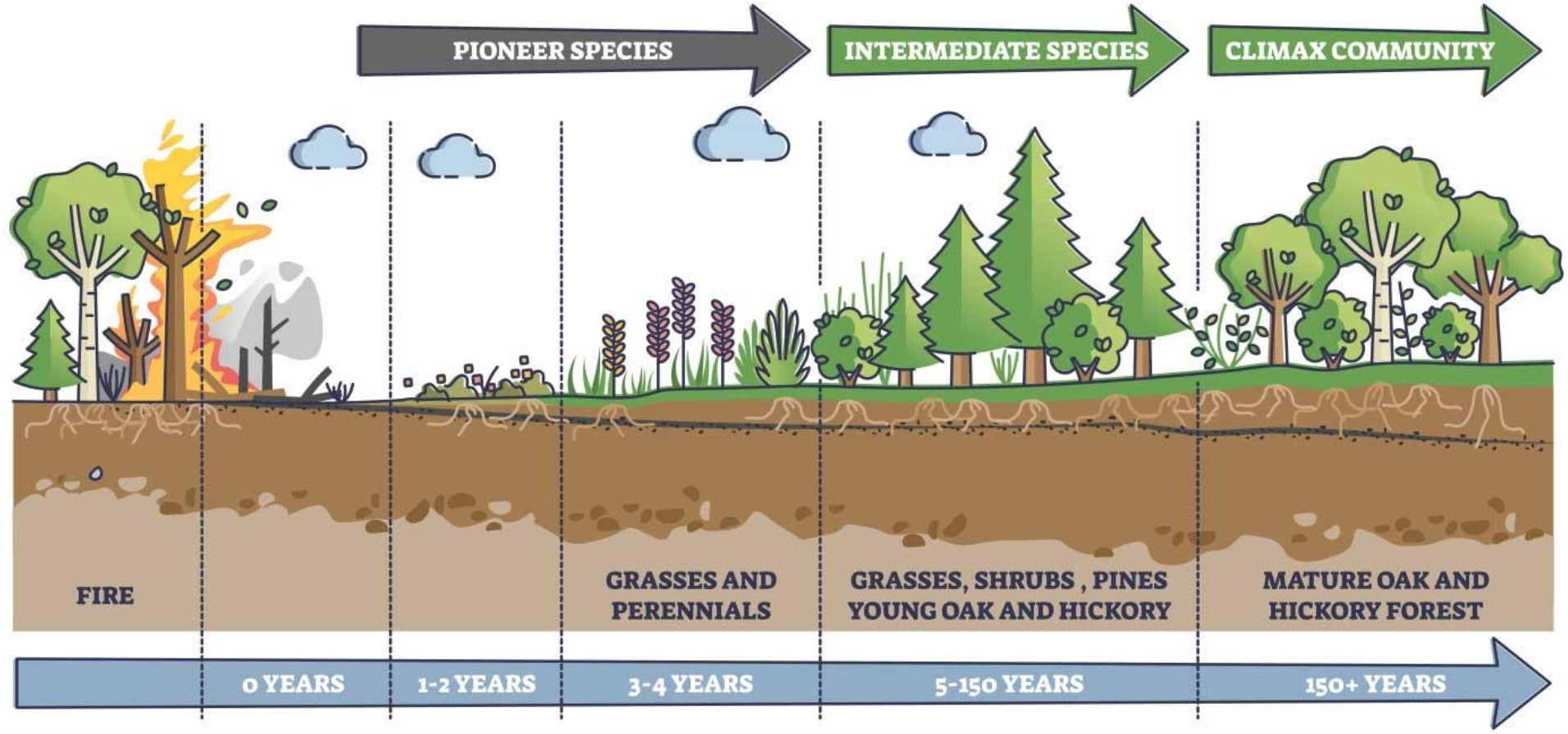

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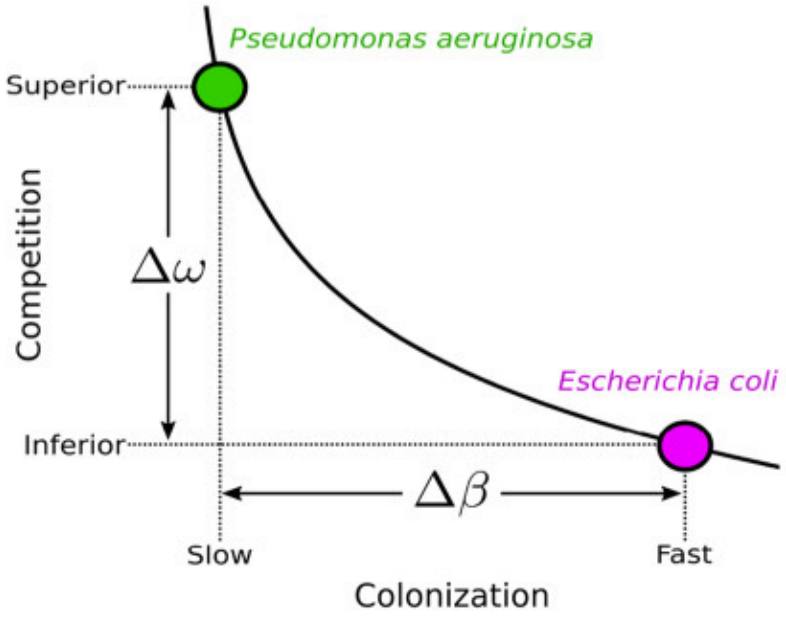
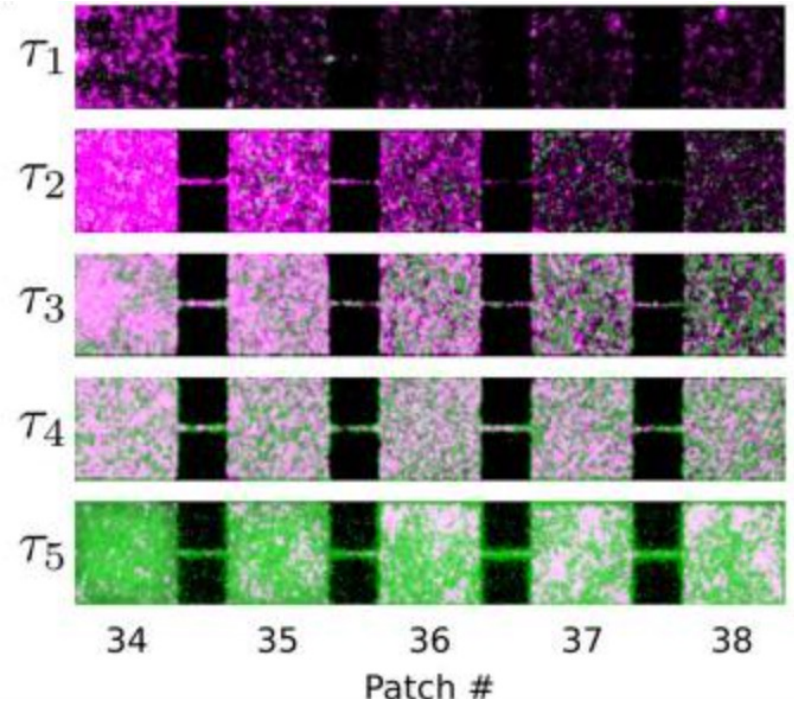
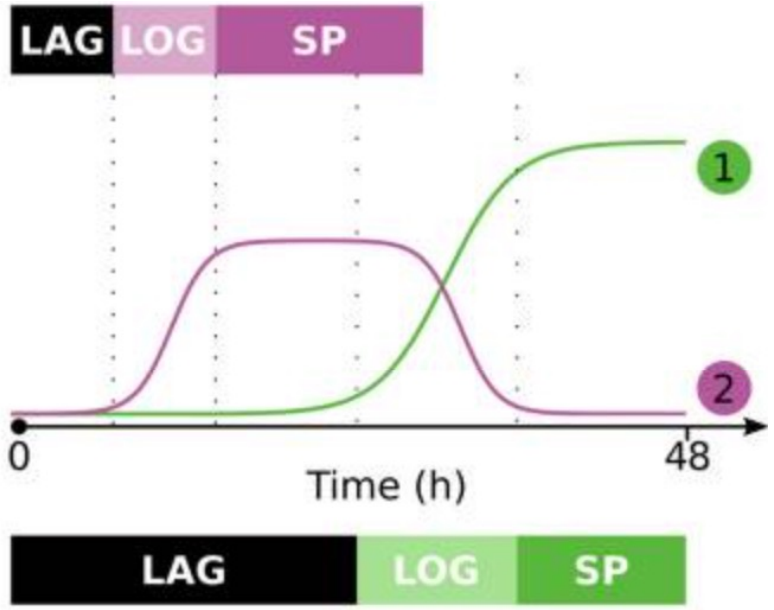
Succession also occurs in microbial systems.

Here, the "***K-selected***" superior competitor eventually replaces the "***r-selected***" fast colonizer.







Wetherington et al. 2022. *BMC Biology*

Superorganisms vs. **Loose Collections** of Species

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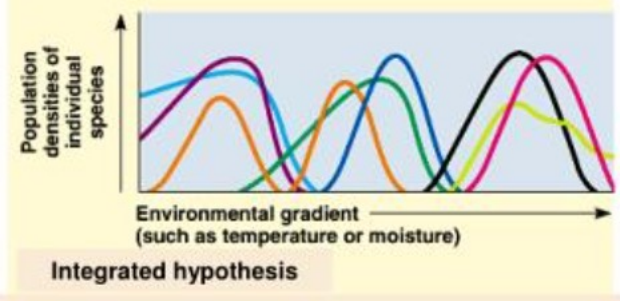

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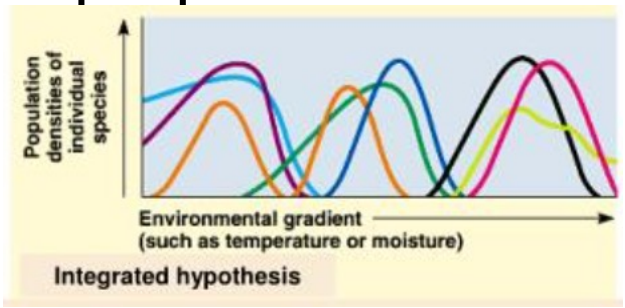
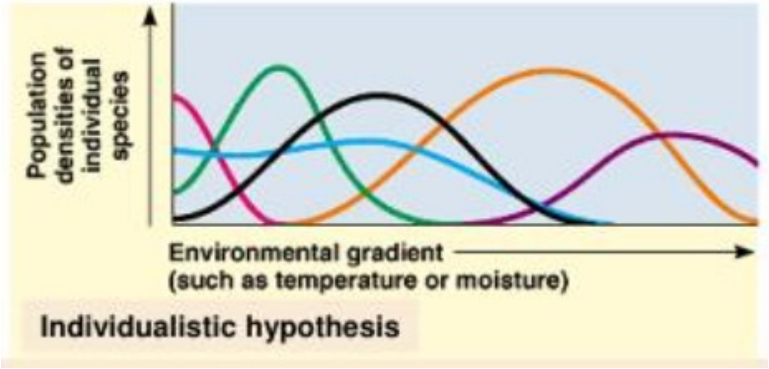
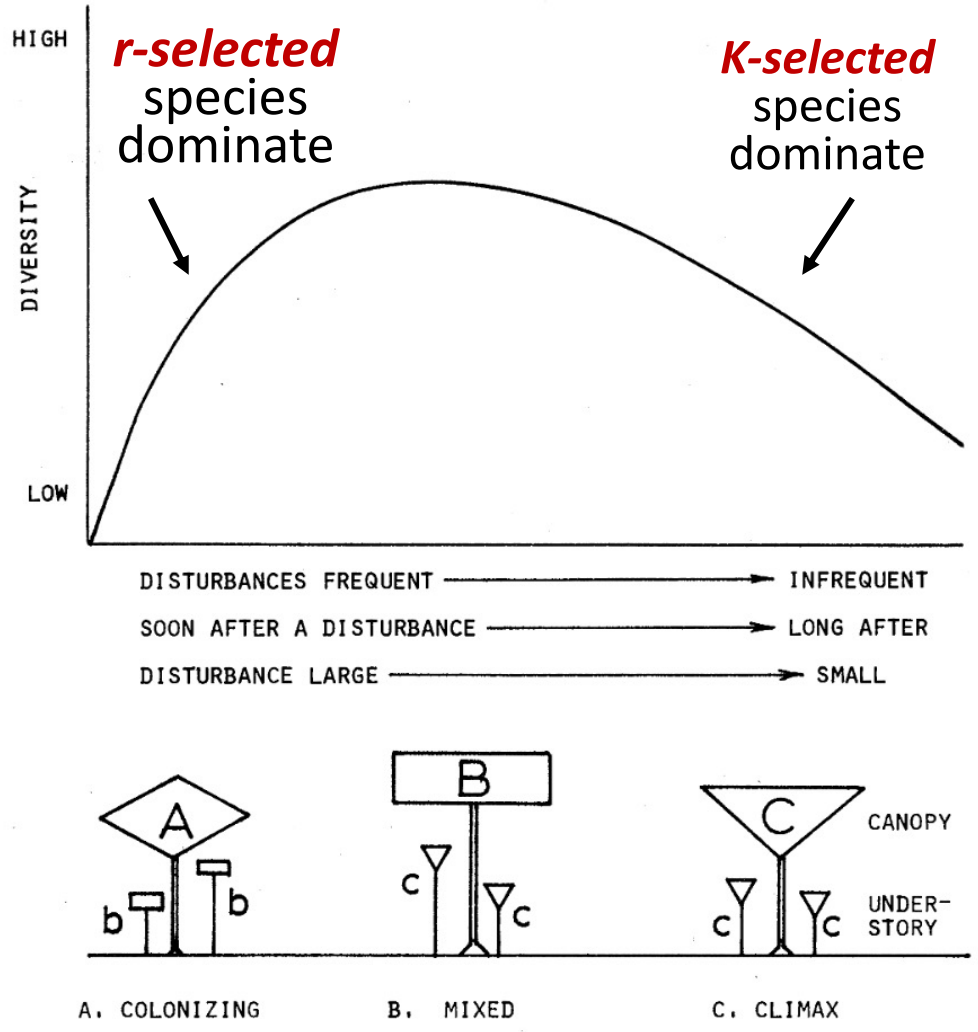


- Henry Gleason (1926) argued instead that chance favored the dispersal of nearby species into available habitat for succession, leading to **stochastic** assembly of communities
- Closer to Cowles’ original thinking



The **Intermediate Disturbance Hypothesis** states that species diversity should be maximized at levels of intermediate disturbance in which both r-selected and K-selected species can coexist.



Connell 1978. *Science*.

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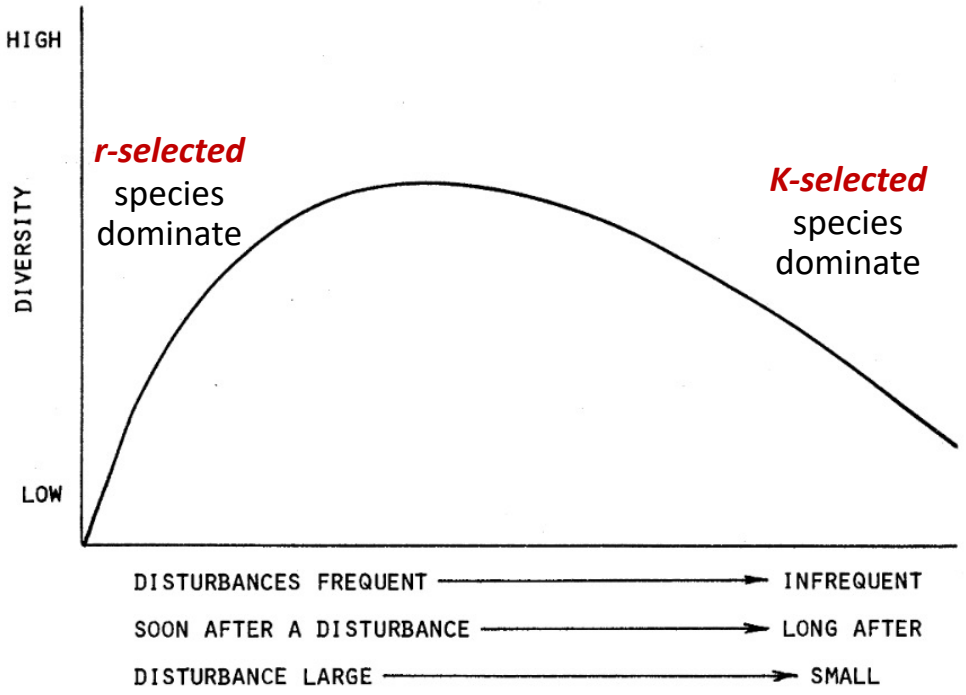

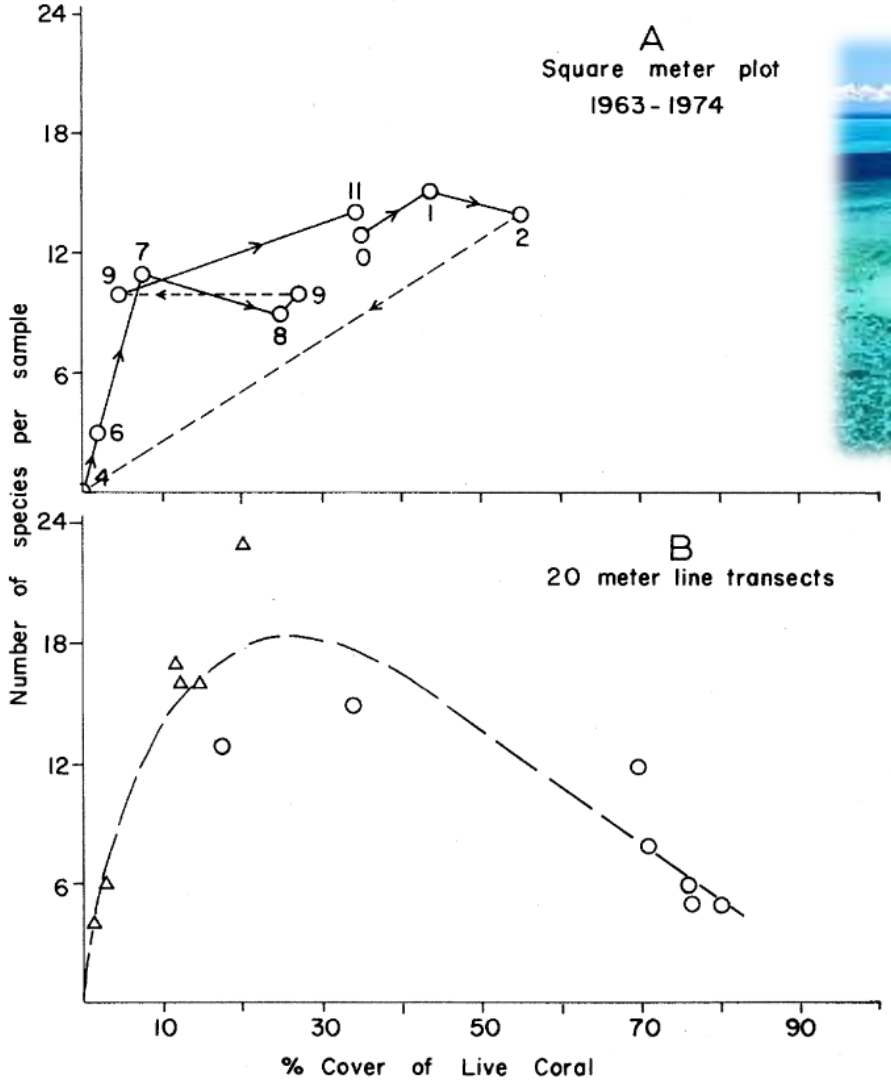

Heron Island, Australia

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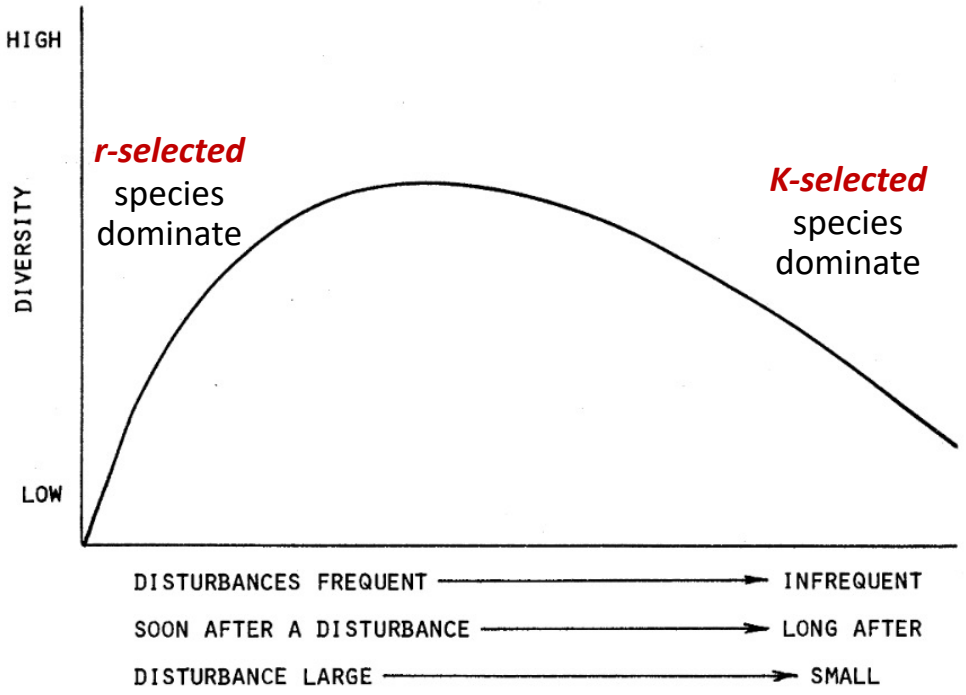
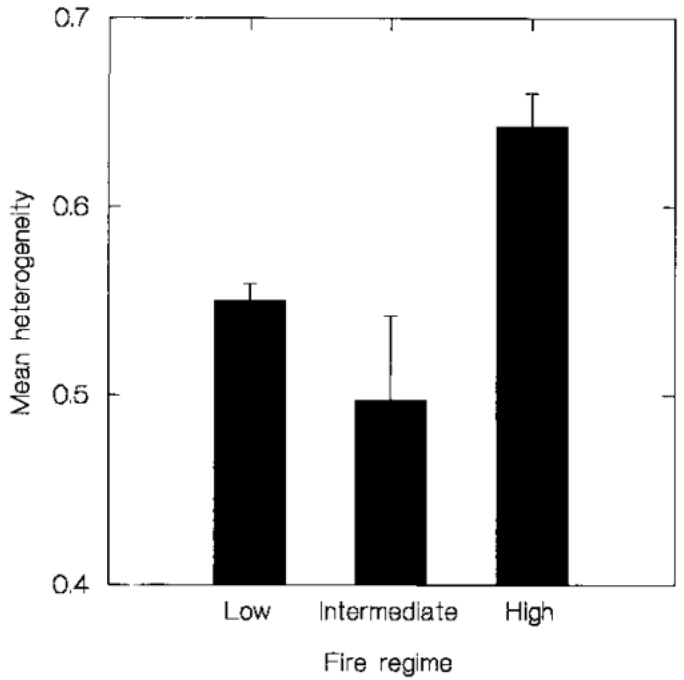


Sometimes it is not so well-supported empirically!



Schwik et al. 1997. *Plant Ecology*

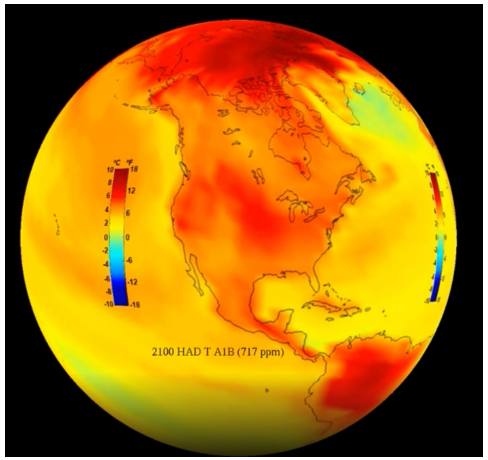
The **IDH** gives an example of a model that is often wrong but still useful in generating testable hypotheses.

What is a model? an abstract representation of a phenomenon

Human

Solar System

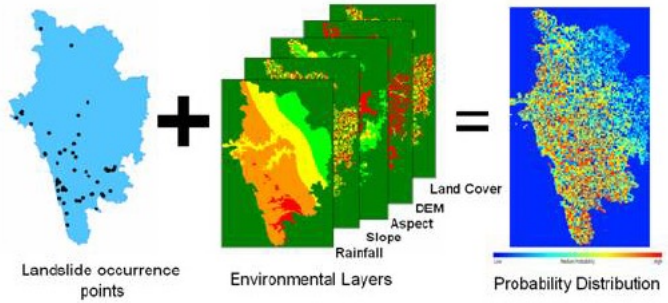
Climate



Human Genetics

Human Disease

Species Distribution



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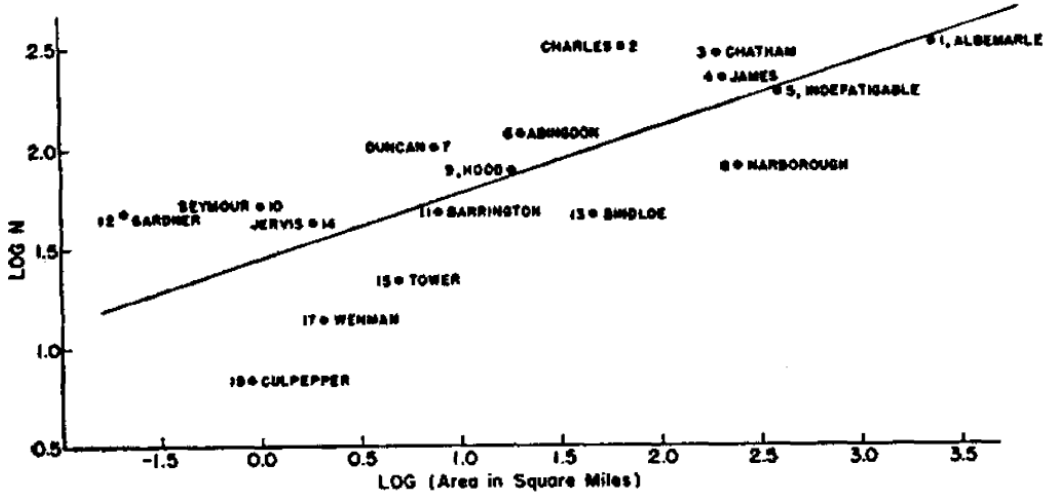
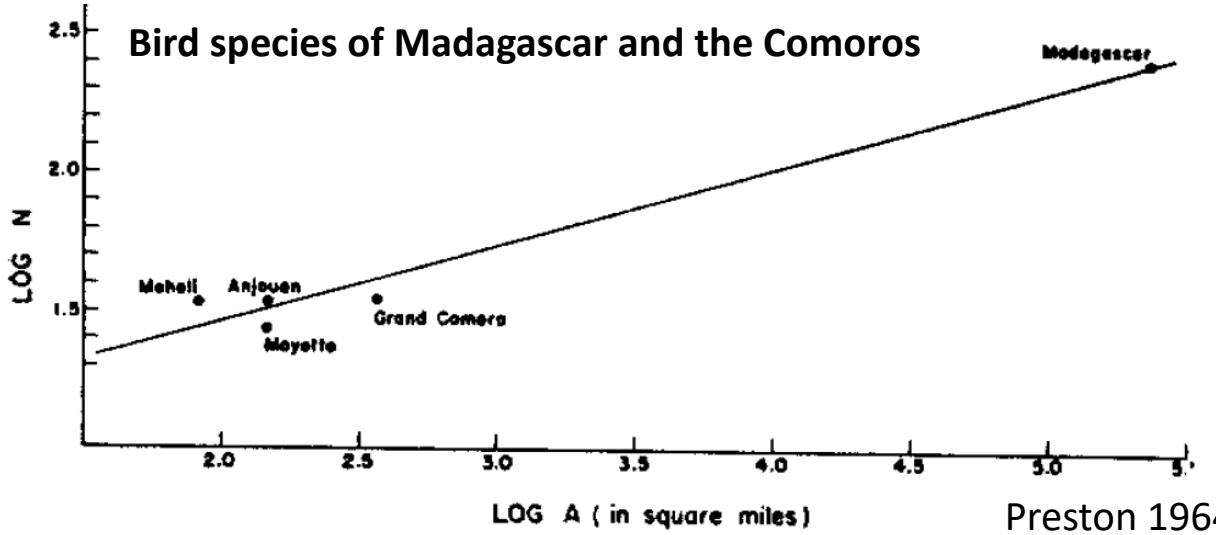
Plant species of the Galapagos islands



Bird species of Madagascar and the Comoros



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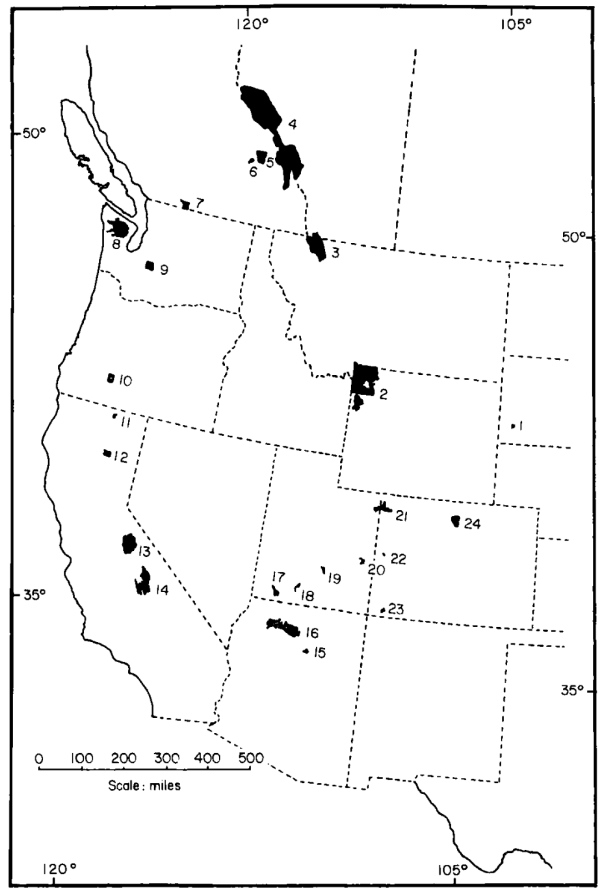
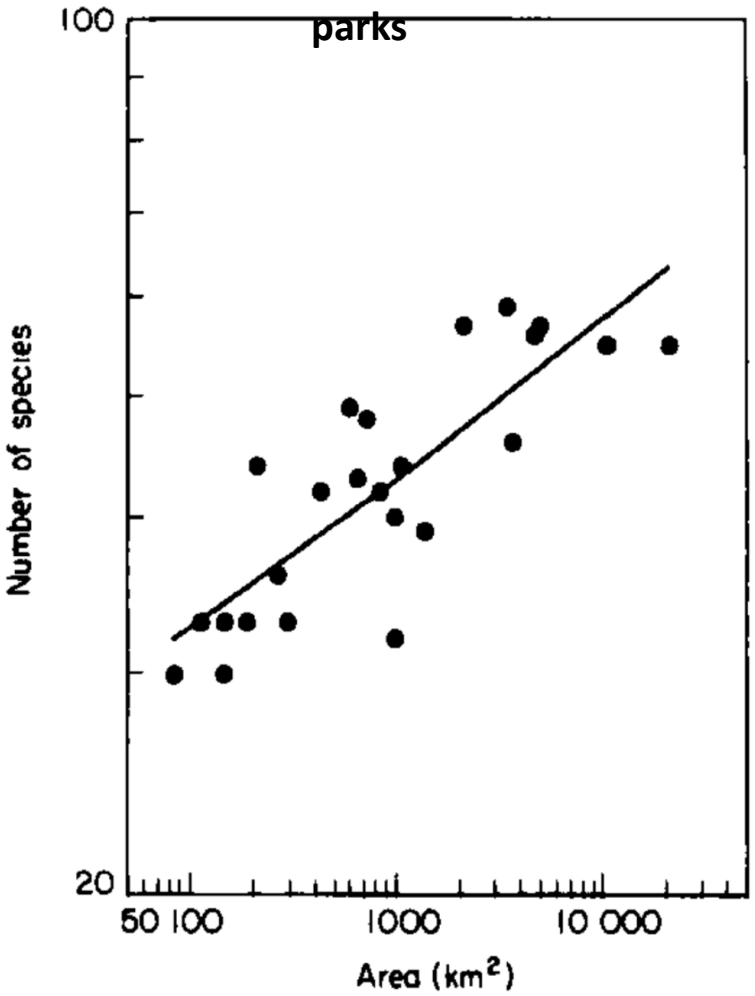
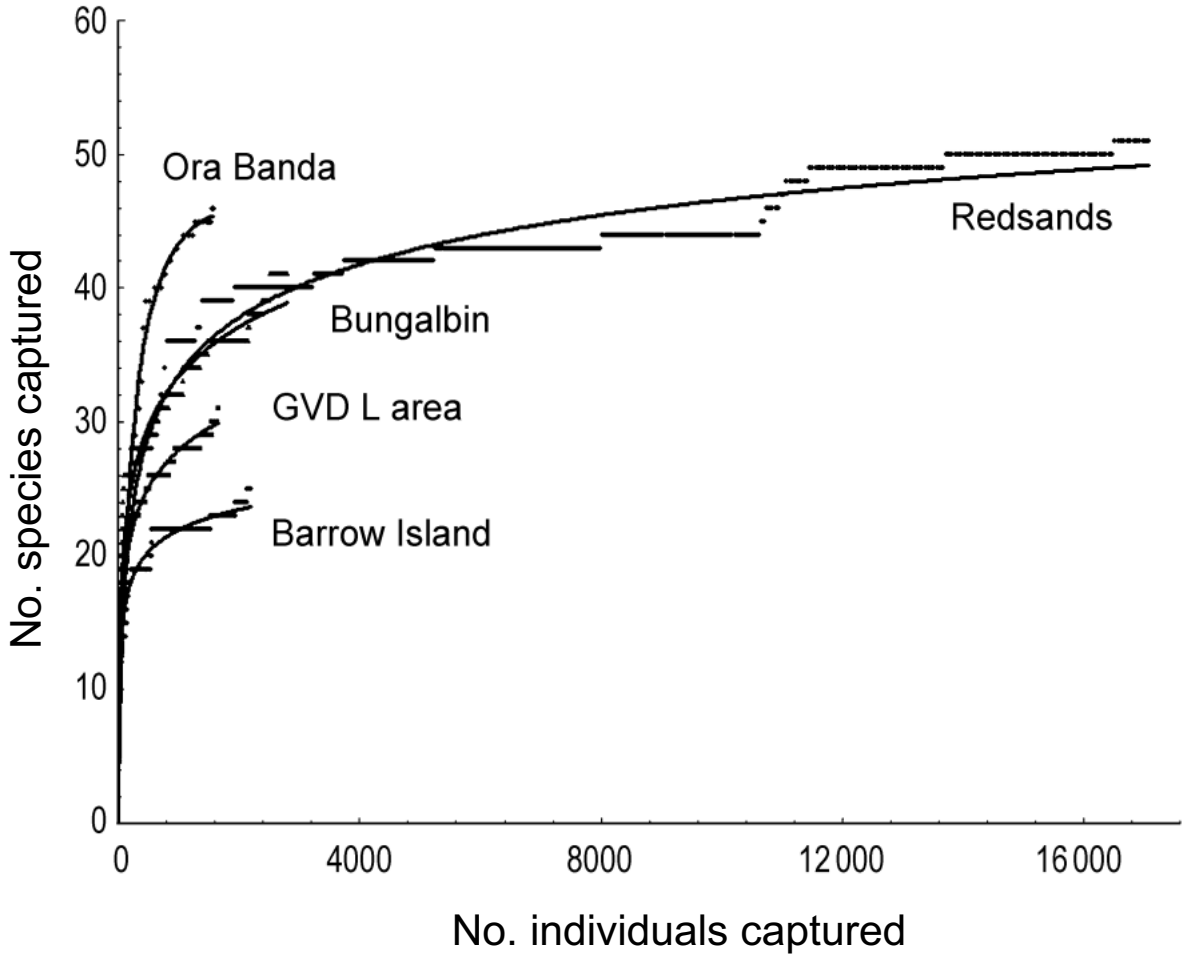
Mammal species of western US national parks





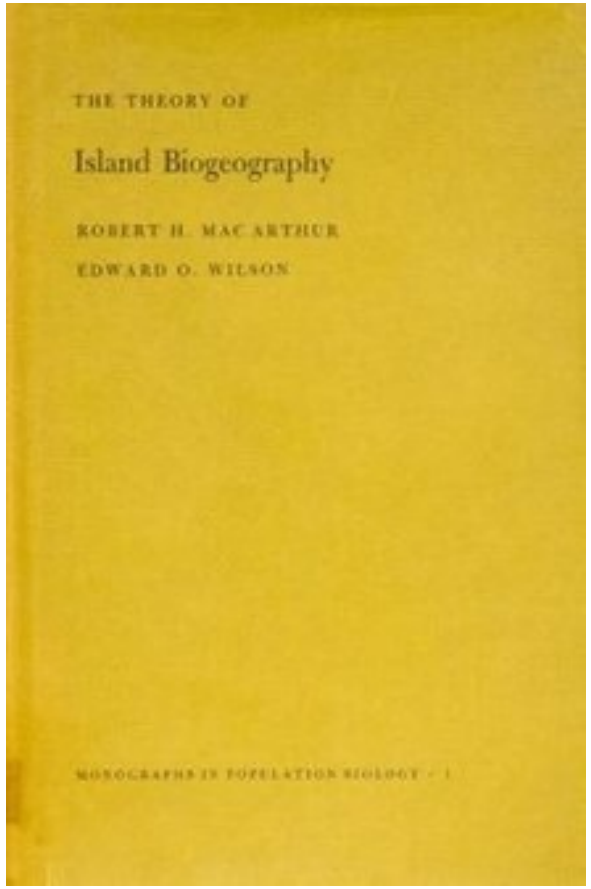
Newmark 1986. *Biological Journal of the Linnean Society.*

We can use the **species-area relationship** (**SAR**) to build **species accumulation curves** to understand if we have representatively sampled a population in field studies.



Thompson 2003. *Animal Ecology.*

Building on the species-area relationship (SAR), MacArthur and Wilson proposed the **theory of island biogeography**.



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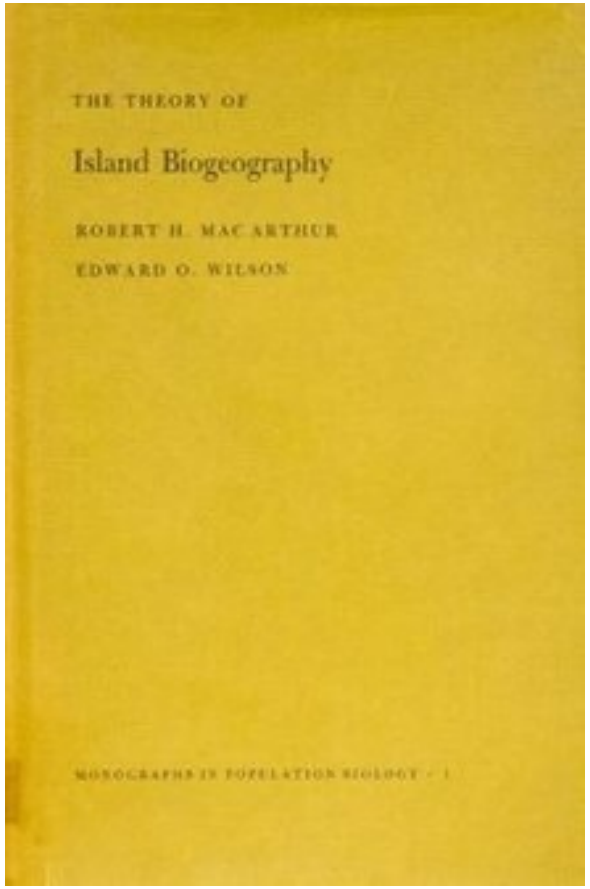

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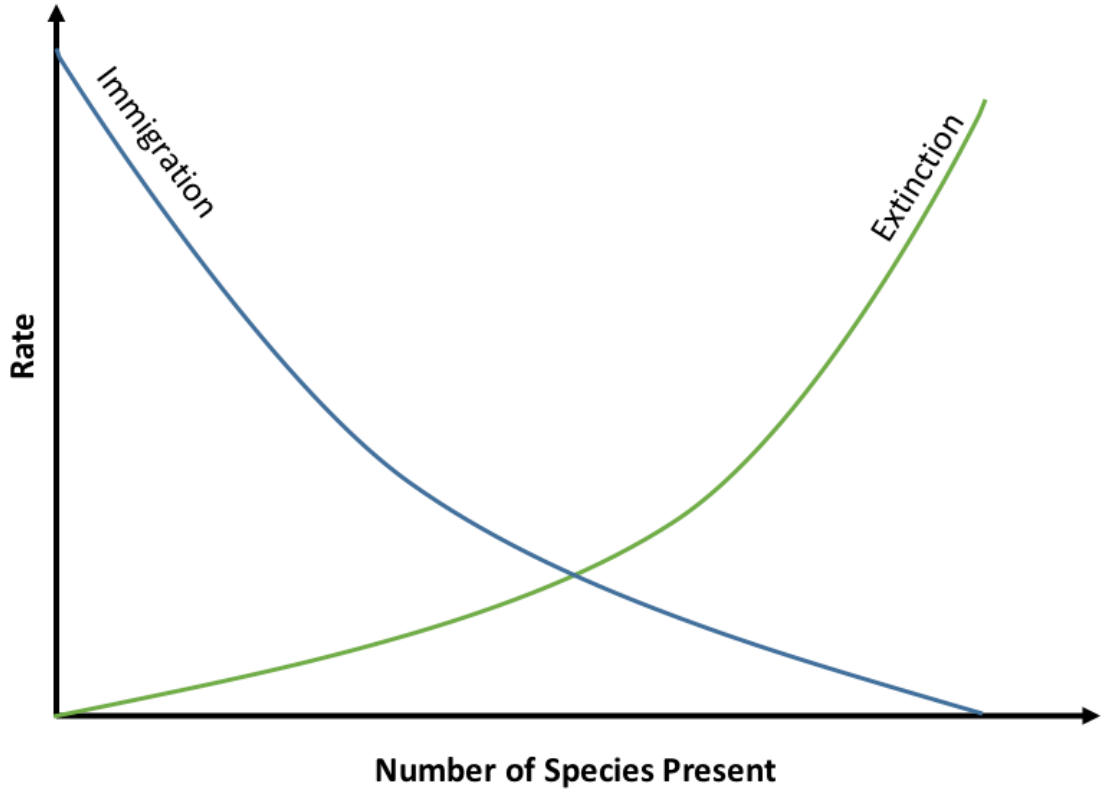
The equilibrium number of species in an "island" habitat is reached when:
the rate of immigration = the rate of extinction



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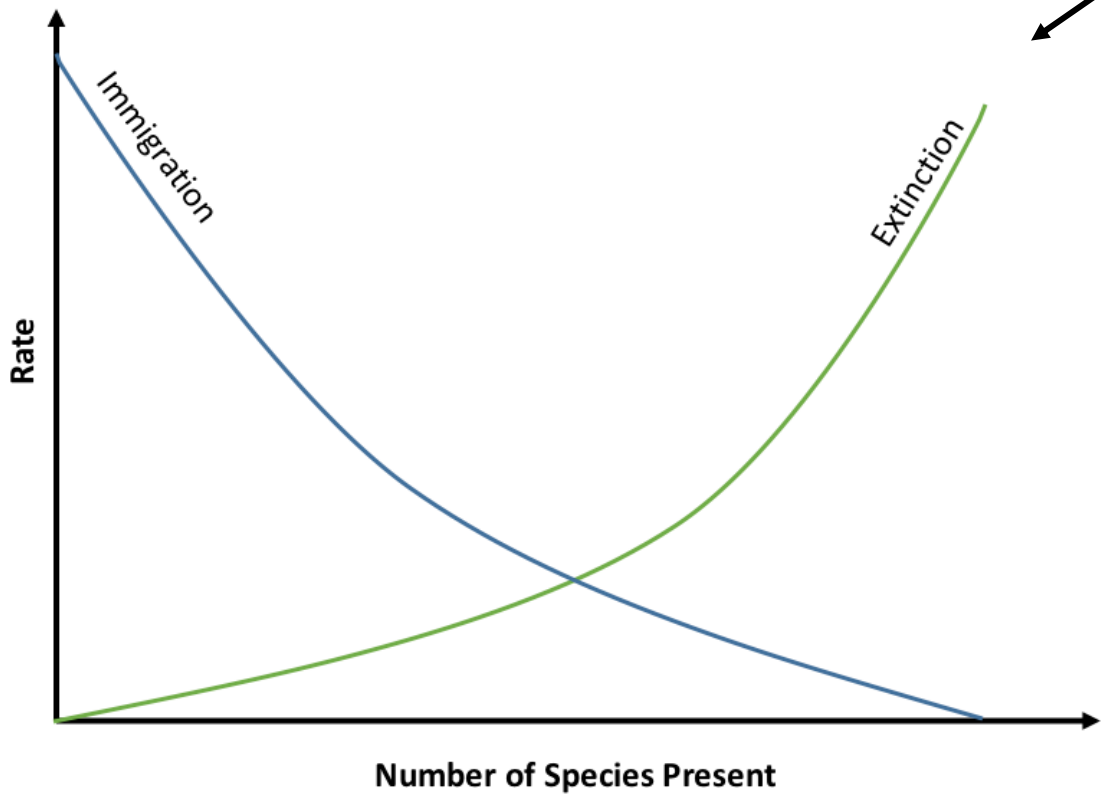

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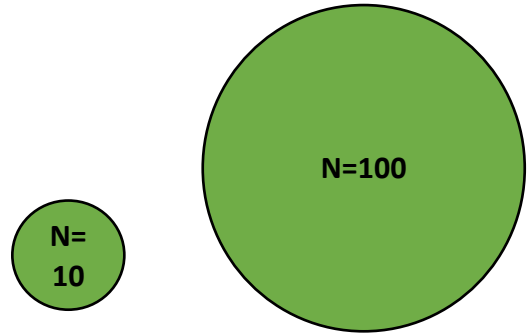

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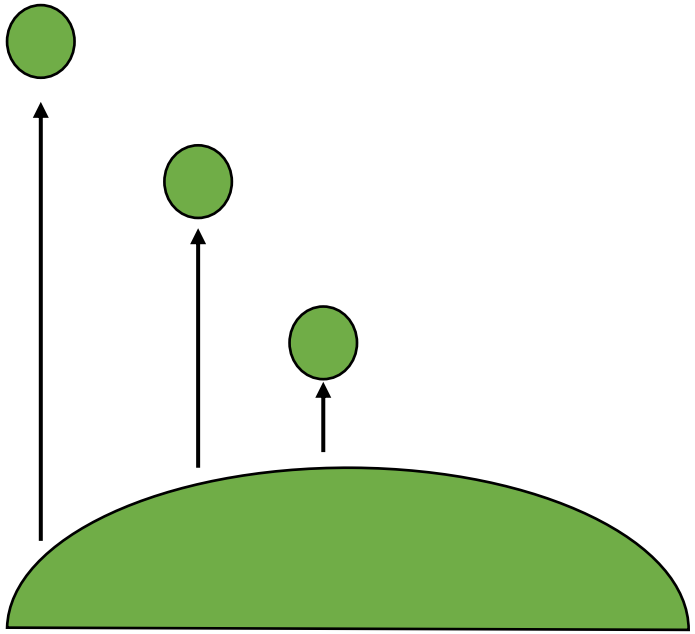

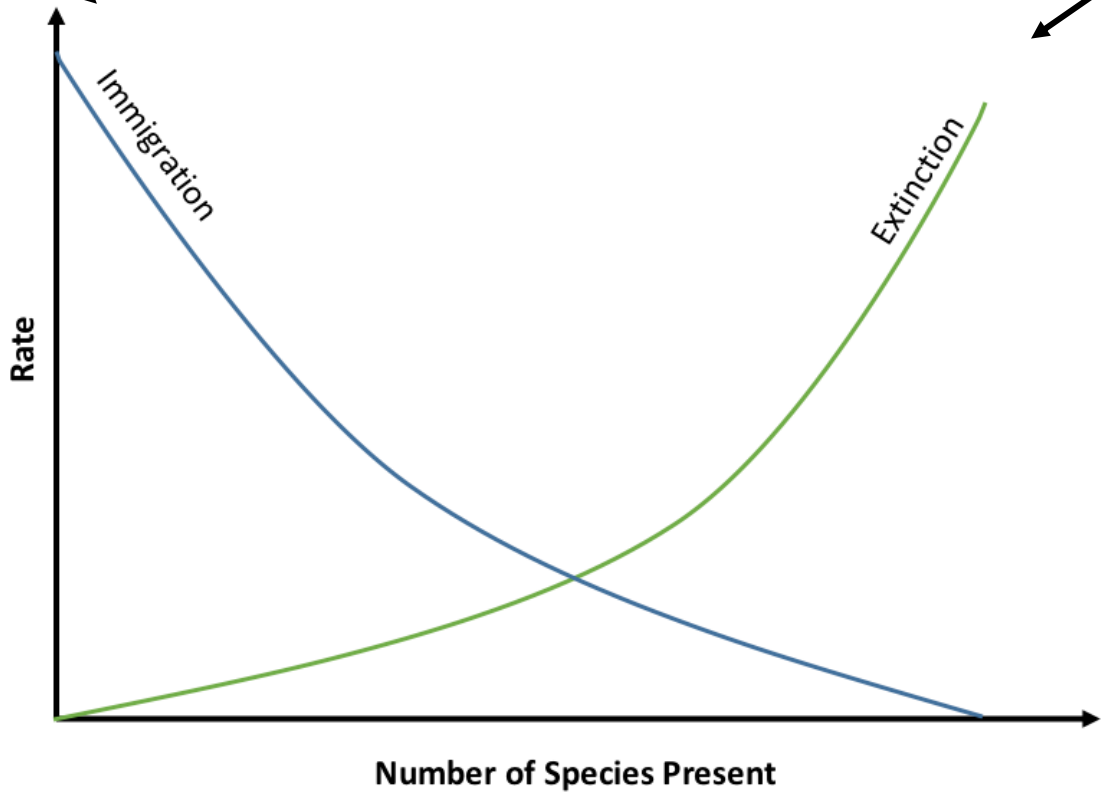

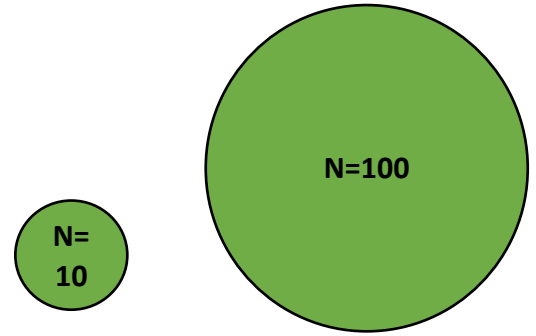

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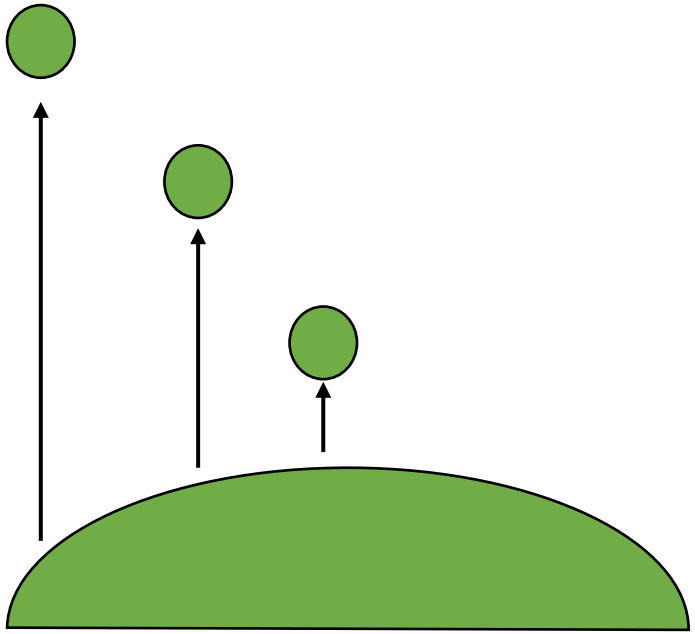

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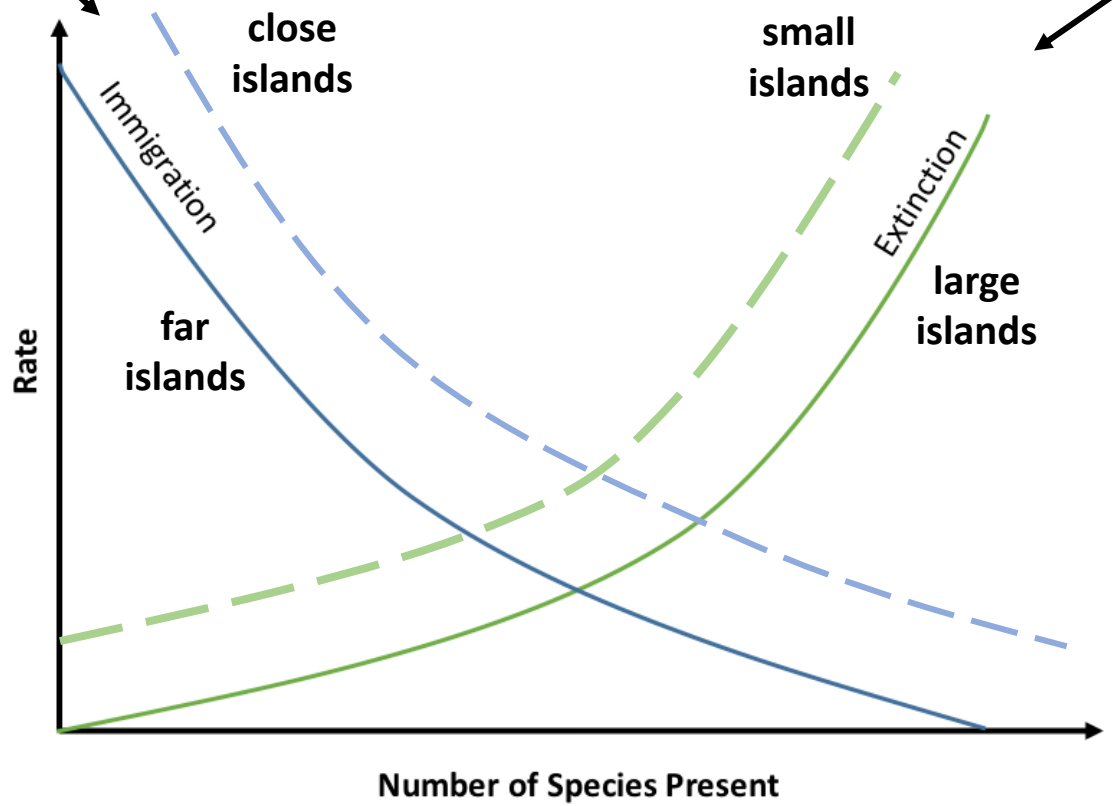

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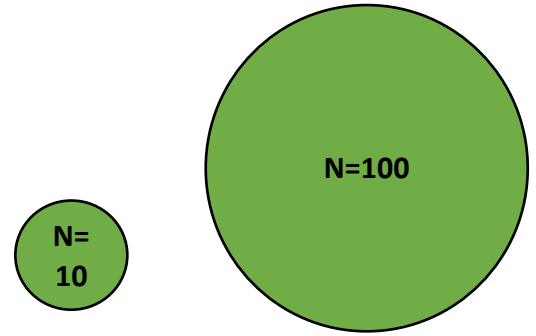

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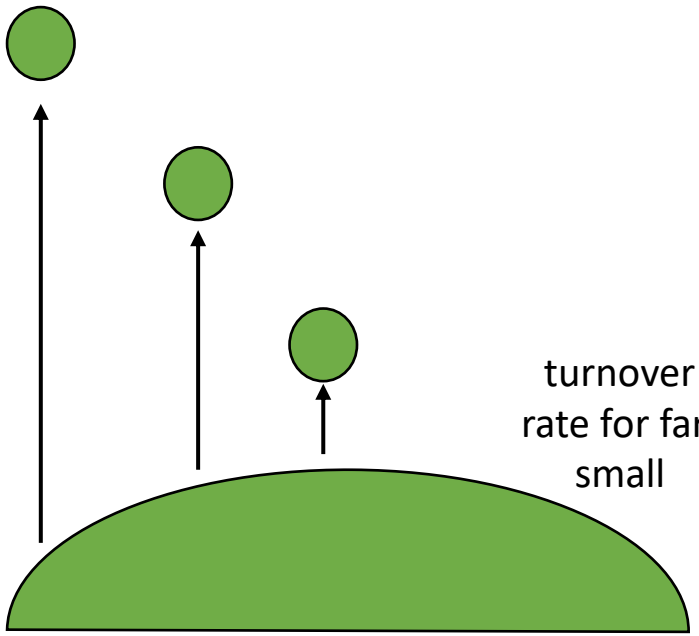

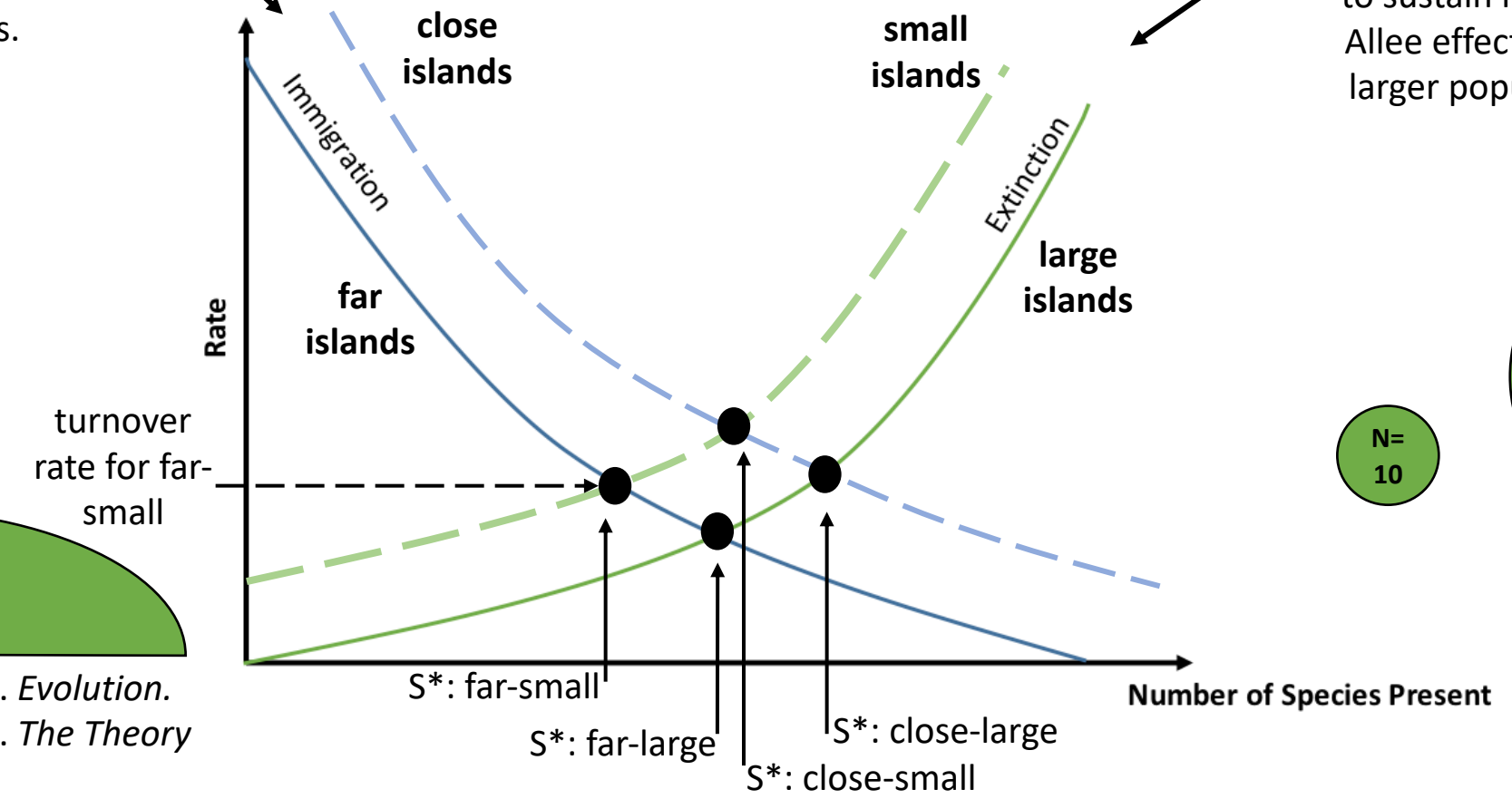

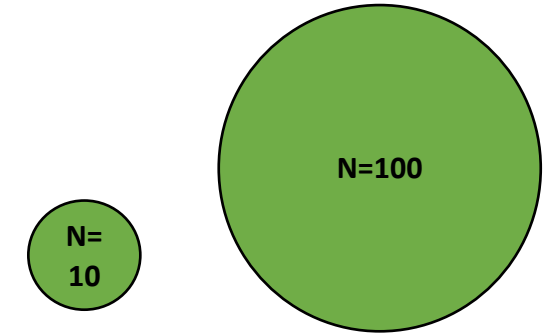

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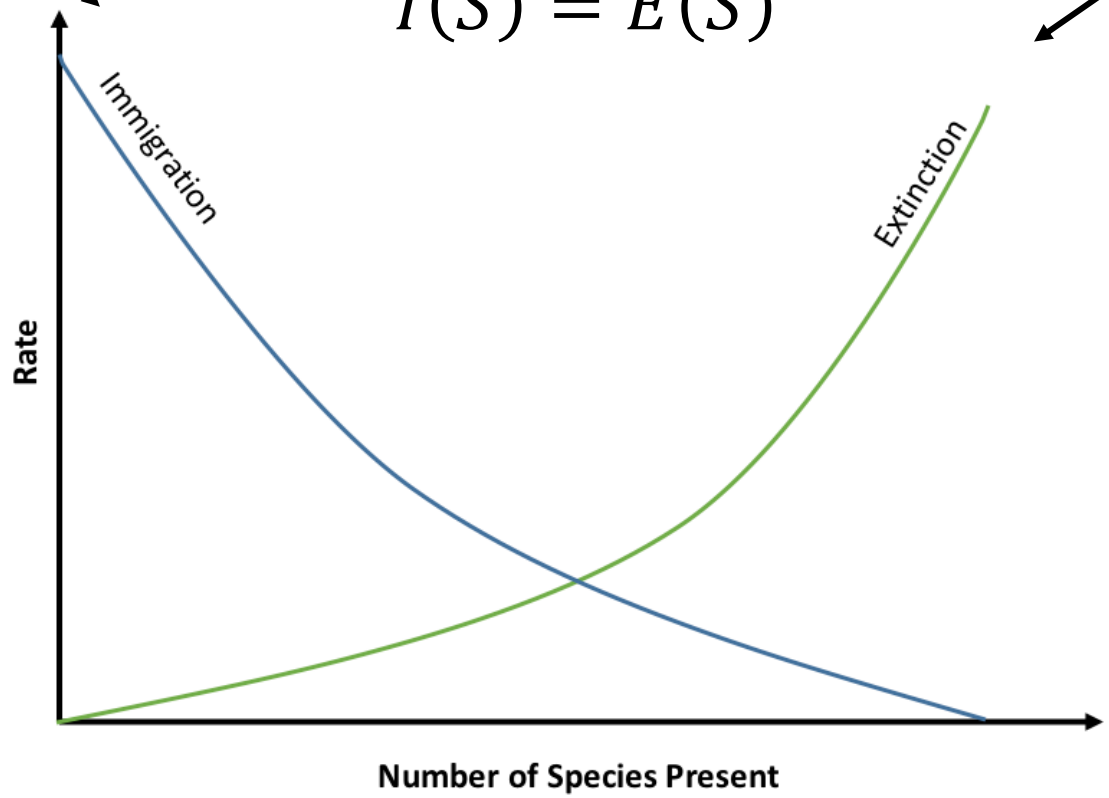

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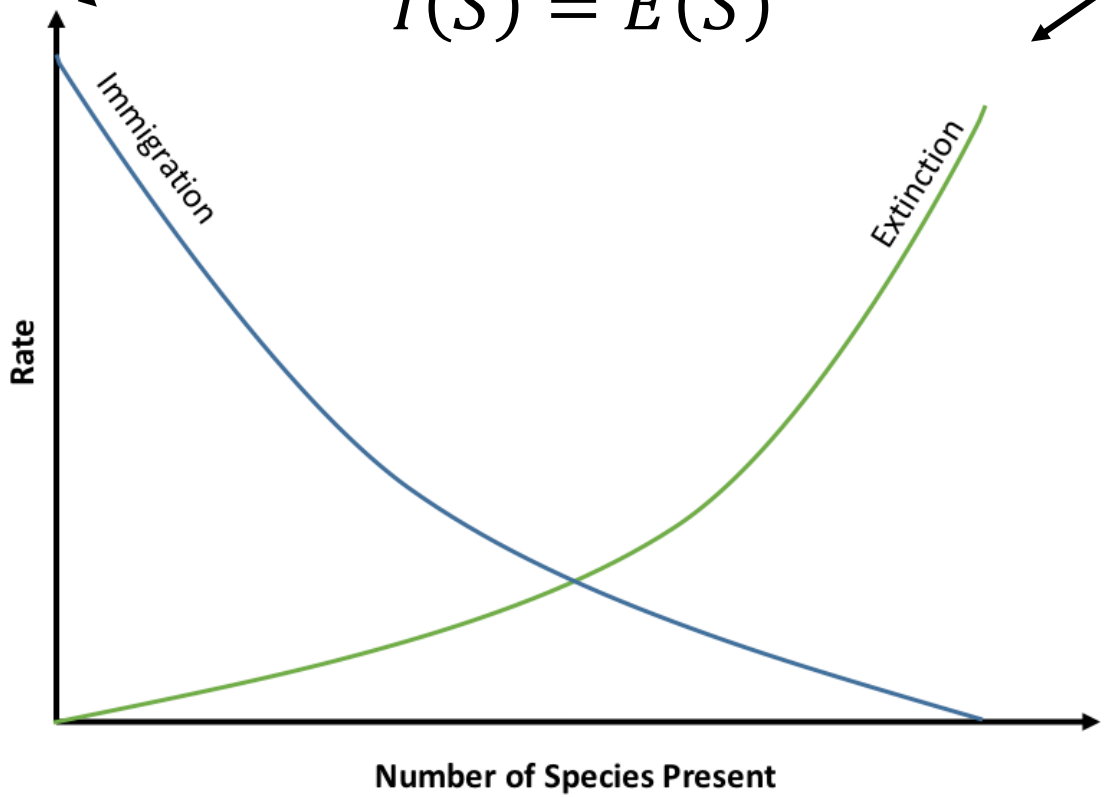

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$$E(S) = Se^{-\varepsilon A}$$

number of species on island

fit parameter scaling effect of area on extinction

area of habitat

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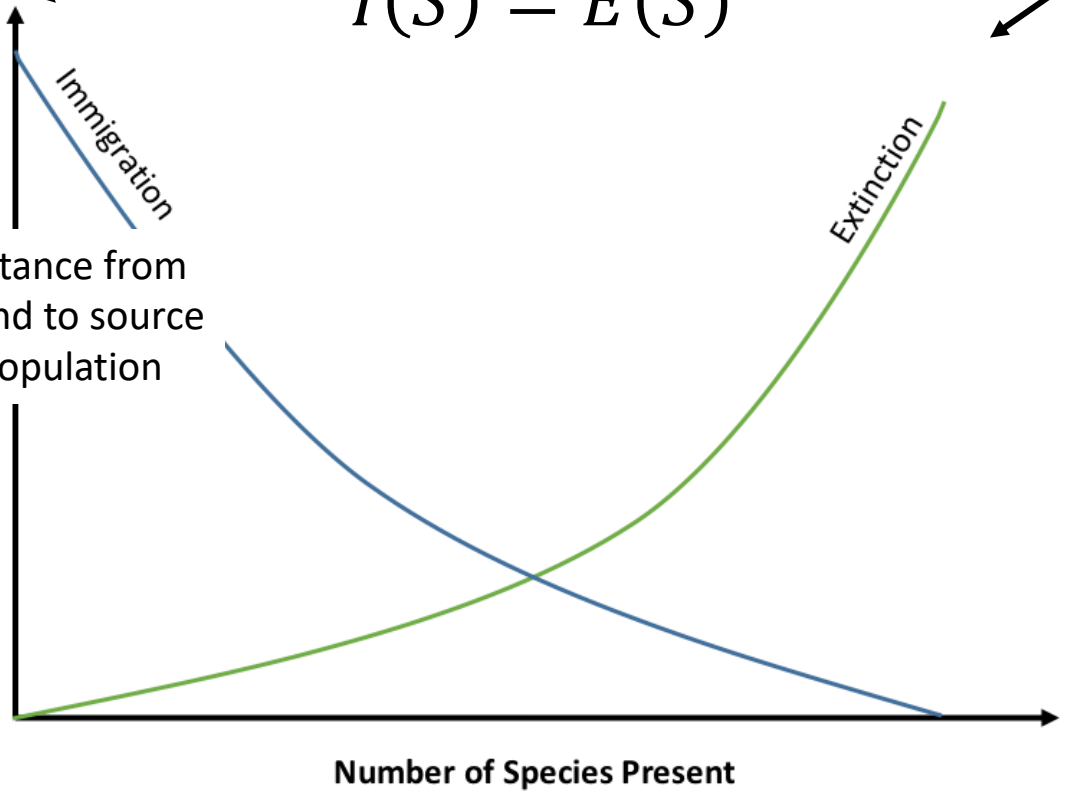
$$I(S) = i(P - S)e^{-\phi d}$$

- i: immigration rate
- P: total number of species in pool
- S: number of species on island
- ϕ: fit parameter governing distance decay on immigration rate
- d: distance from island to source population

The equilibrium number of species in an "island" habitat is reached when:
the rate of immigration = the rate of extinction

$$I(S) = E(S)$$



Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.

$$E(S) = Se^{-\varepsilon A}$$

- S: number of species on island
- ε: fit parameter scaling effect of area on extinction
- A: area of habitat

MacArthur and Wilson. 1963. *Evolution.*
MacArthur and Wilson. 1967. *The Theory of Island Biogeography.*

The **theory of island biogeography** offers a null model for the number of species found in a given habitat, predictable from both the **size** of the habitat and its **distance** from a source population.

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$$I(S) = i(P - S)e^{-\phi d}$$

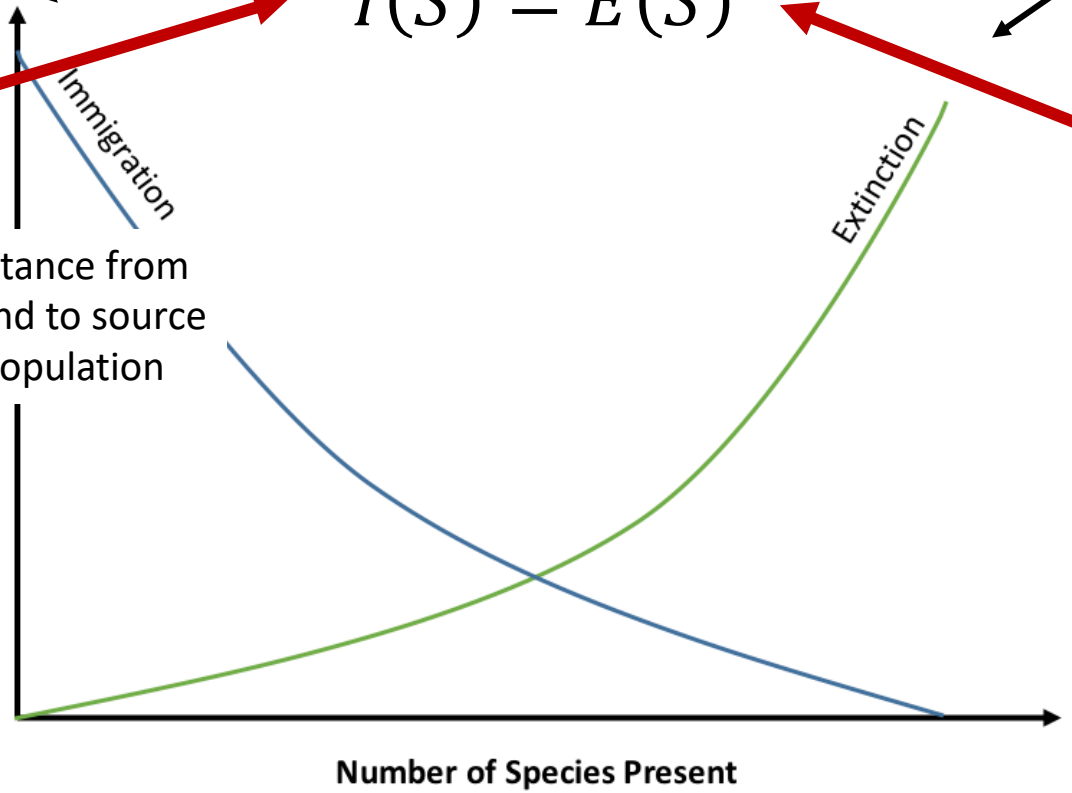
immigration rate

total number of species in pool

number of species on island

fit parameter governing distance decay on immigration rate

distance from island to source population



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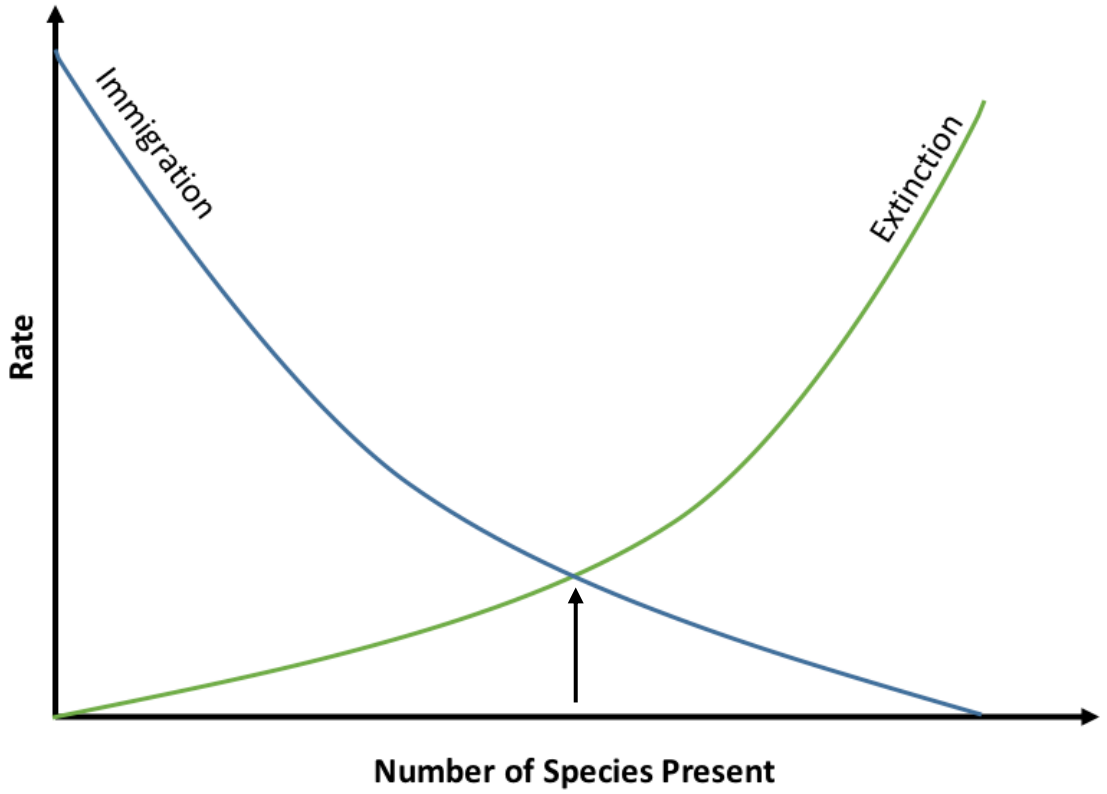

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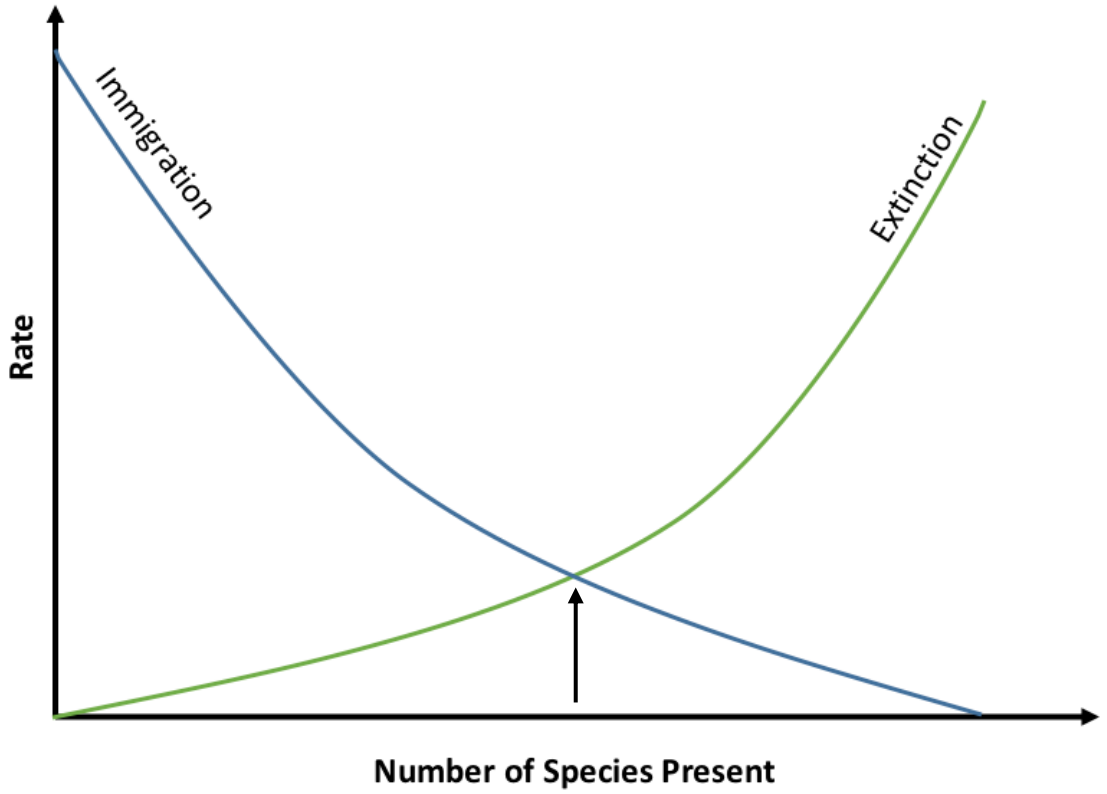
$$S^* = \frac{iPe^{\varepsilon A}}{ie^{\varepsilon A} + e^{\phi d}}$$

- S^*: equilibrium number of species
- $iPe^{\varepsilon A}$: increases with number of species in source pool
- εA: increases with area of island
- $ie^{\varepsilon A} + e^{\phi d}$: decreases with distance from with distance from mainland



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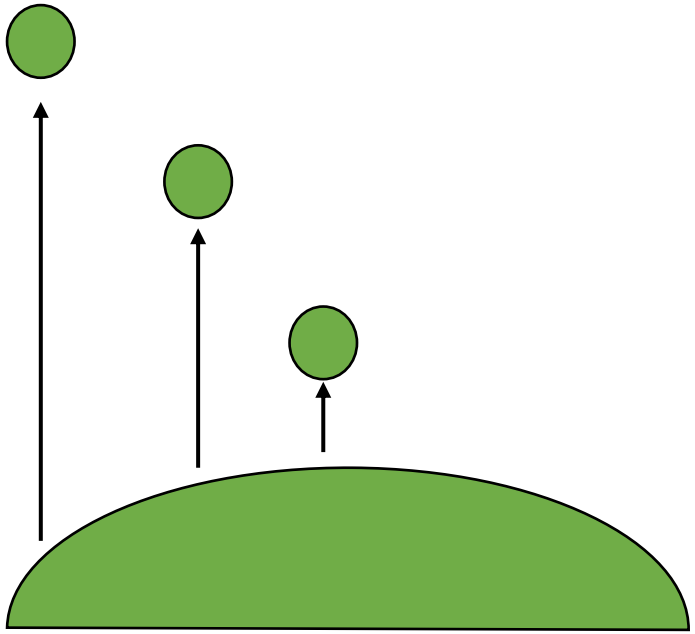

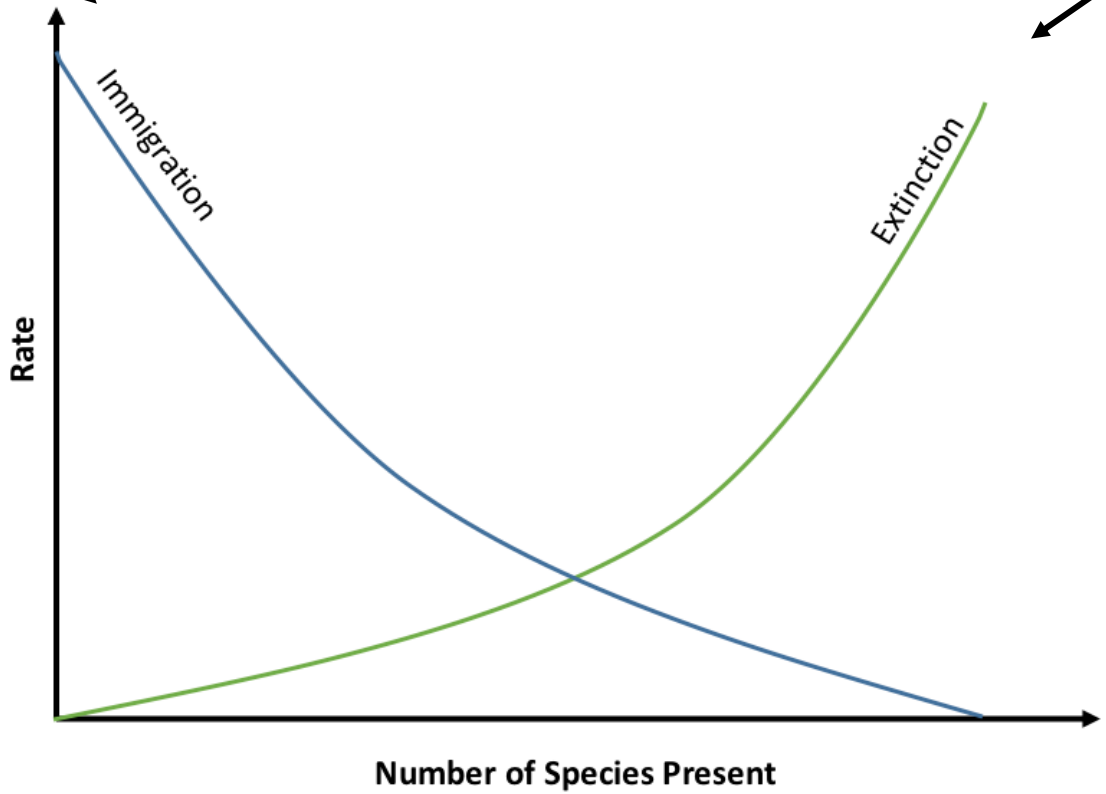

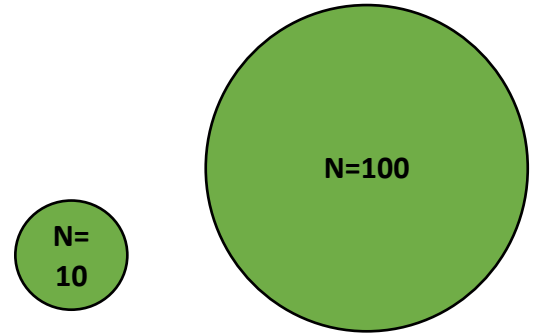

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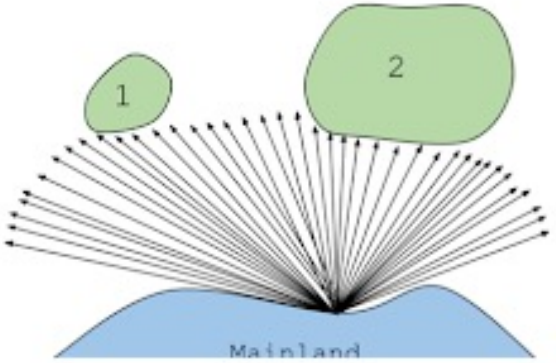
Extensions to the **theory of island biogeography**…

Distance effect: **Closer islands have higher immigration rates** because it's easier for organisms to disperse across short distances.

Target effect: **larger islands have higher immigration rates** because they offer a bigger target to land on!



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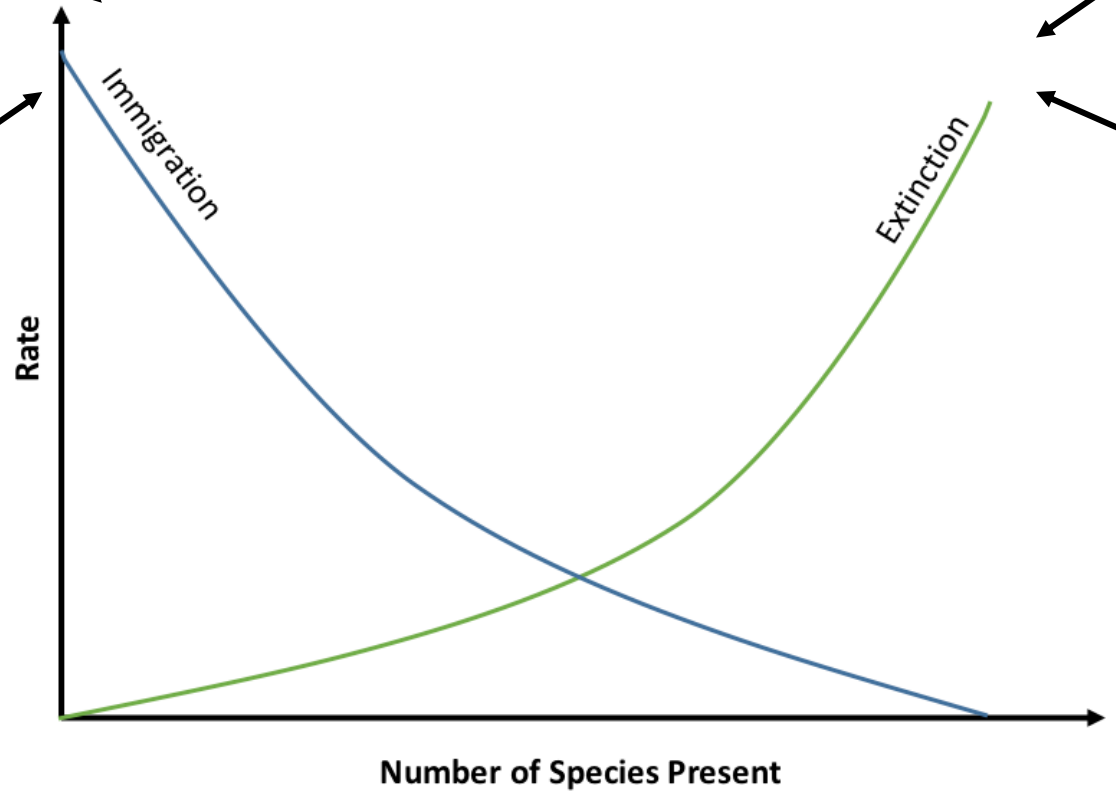
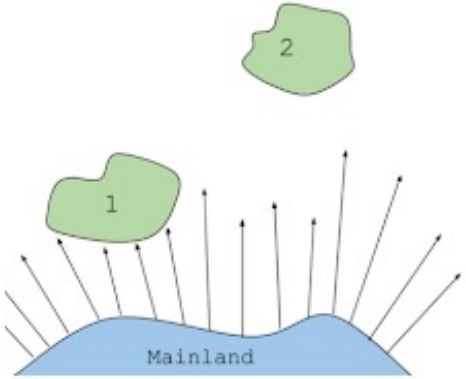


Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.

Rescue effect: **Closer islands have lower extinction rates** because they can be repopulated from the mainland!



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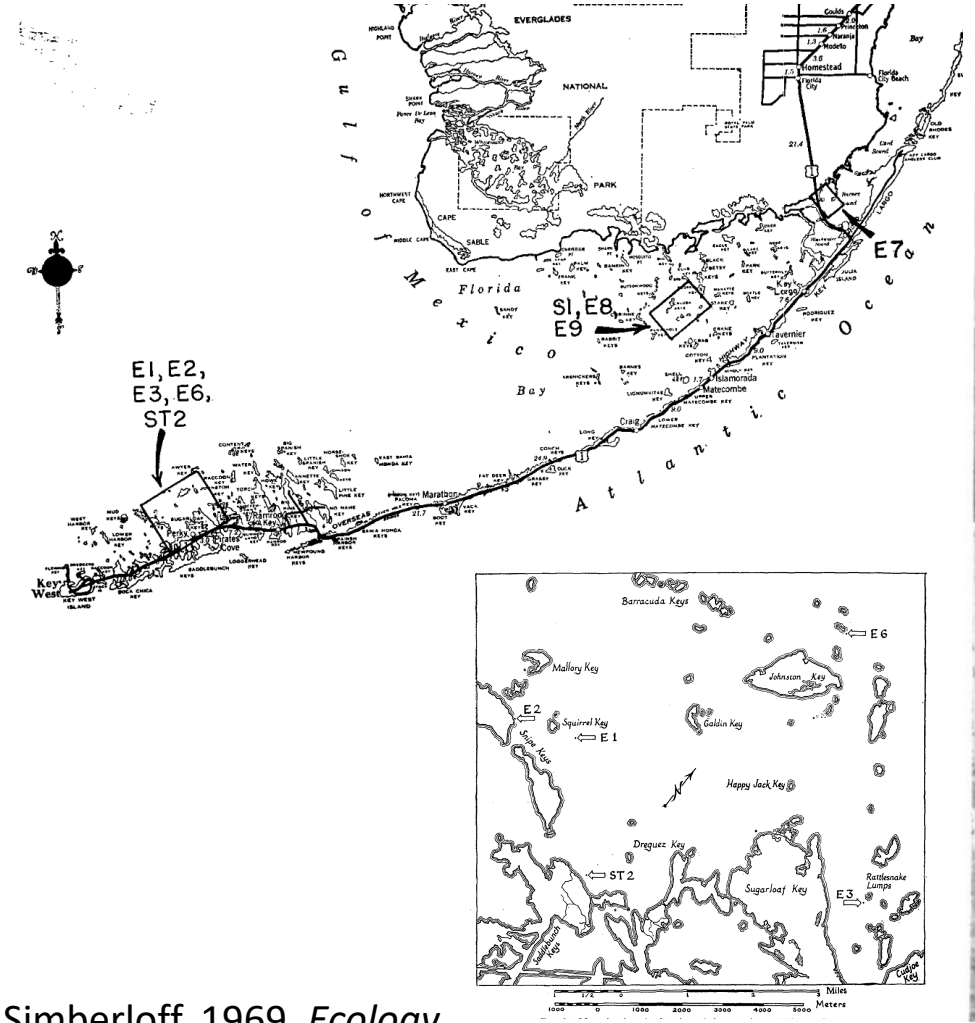
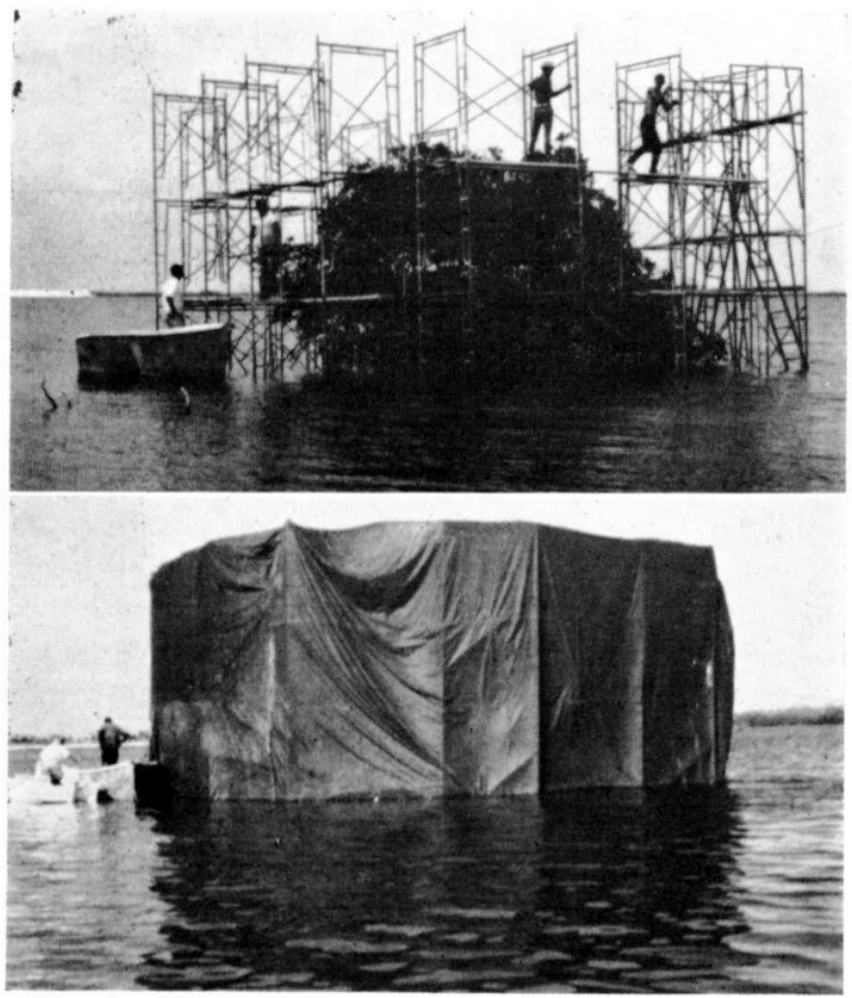
Wilson and Simberloff field-tested this theory in the Florida Keys!





- Wilson and Simberloff identified seven mangrove islands in the Florida Keys varying in size from 11-18m in diameter and catalogued their fauna (all arthropods).
- They also conducted surveys across the keys to quantify the entire possible “source” pool to the islands.
- The experimental islands were then fumigated with methyl bromide at levels lethal to arthropods but not to plants.
- They catalogued their progressive recolonization after fumigation, tracking its predictability based on size and distance of these islands to the source pool.

Simberloff. 1969. *Ecology.*
Wilson and Simberloff. 1969. *Ecology.*
Simberloff and Wilson. 1969. *Ecology.*

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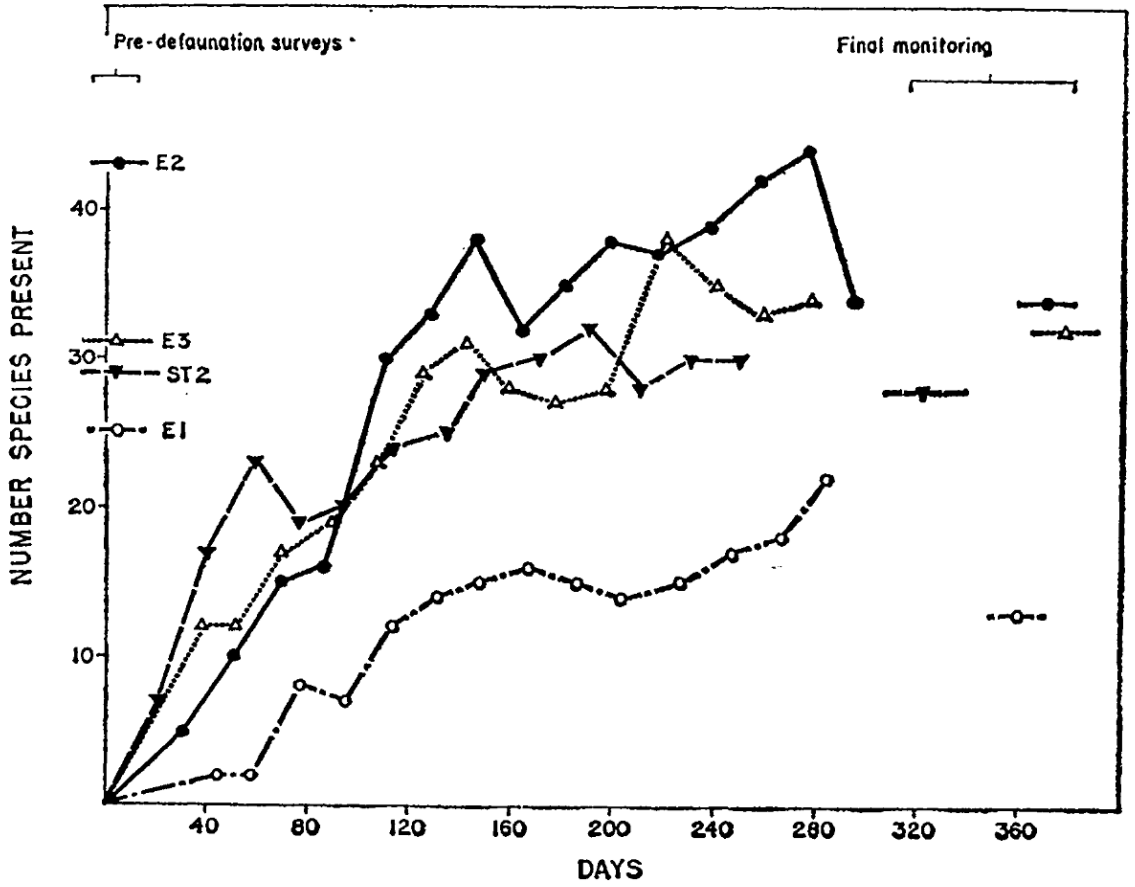

- Islands were recolonized to pre-defaunation levels rapidly, within a year!
- Though the equilibrium number of species was the same, the identity was quite different – only about 40% similar to the original censuses.
- Strong flyers recolonized first but were eventually replaced (outcompeted) by better competitors (typically ants) – in keeping with theories of faunal succession.
- The islands farthest from the mainland were the slowest to recolonize.

Simberloff. 1969. *Ecology.*
Wilson and Simberloff. 1969. *Ecology.*
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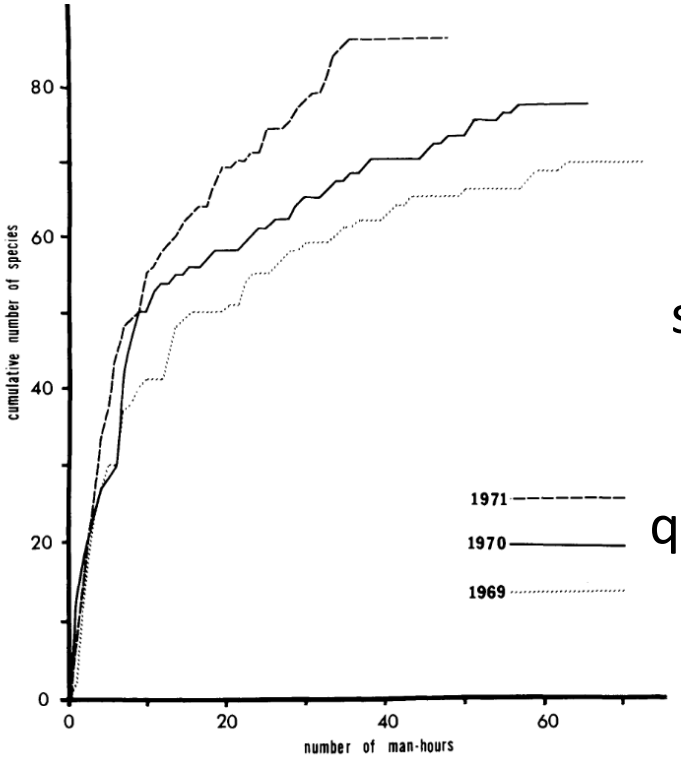
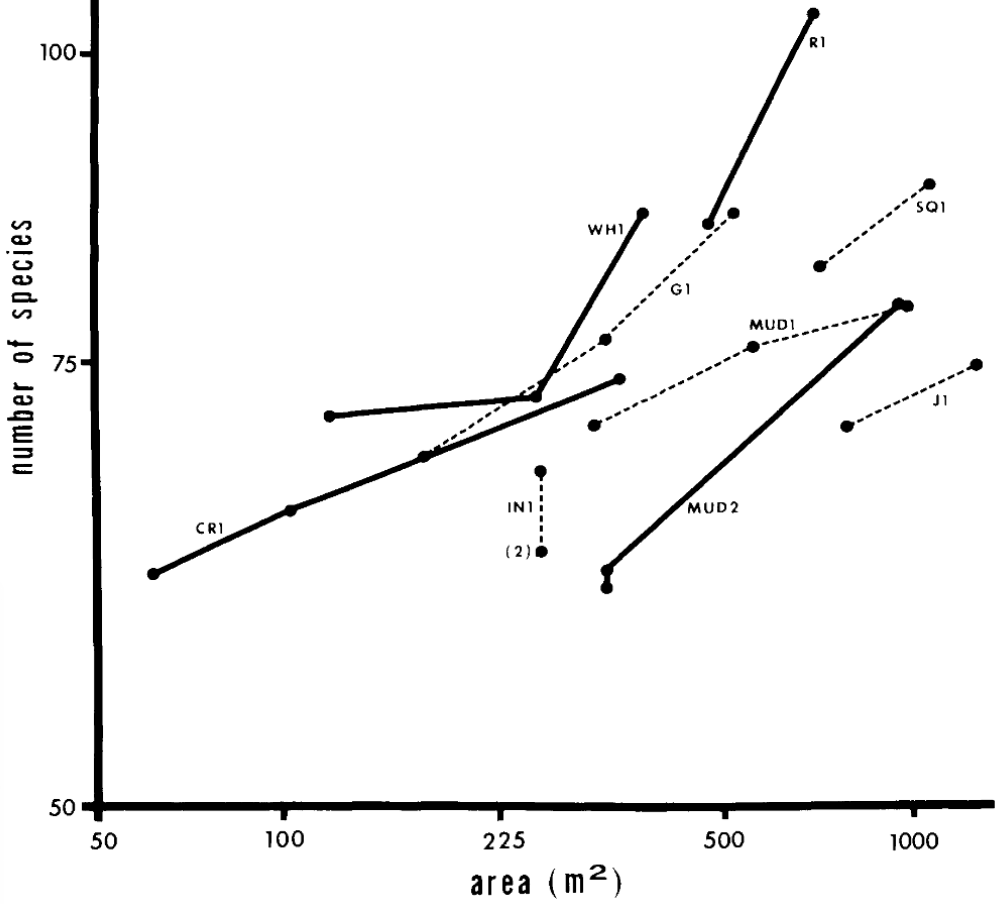
In subsequent work, Simberloff demonstrated the area effect by actually removing entire chunks out of islands and censusing species!



Pre-land removal species accumulation curves demonstrate that a sufficient quantity of biodiversity was sampled.

log-log plot of island area and species count before and after land removal!

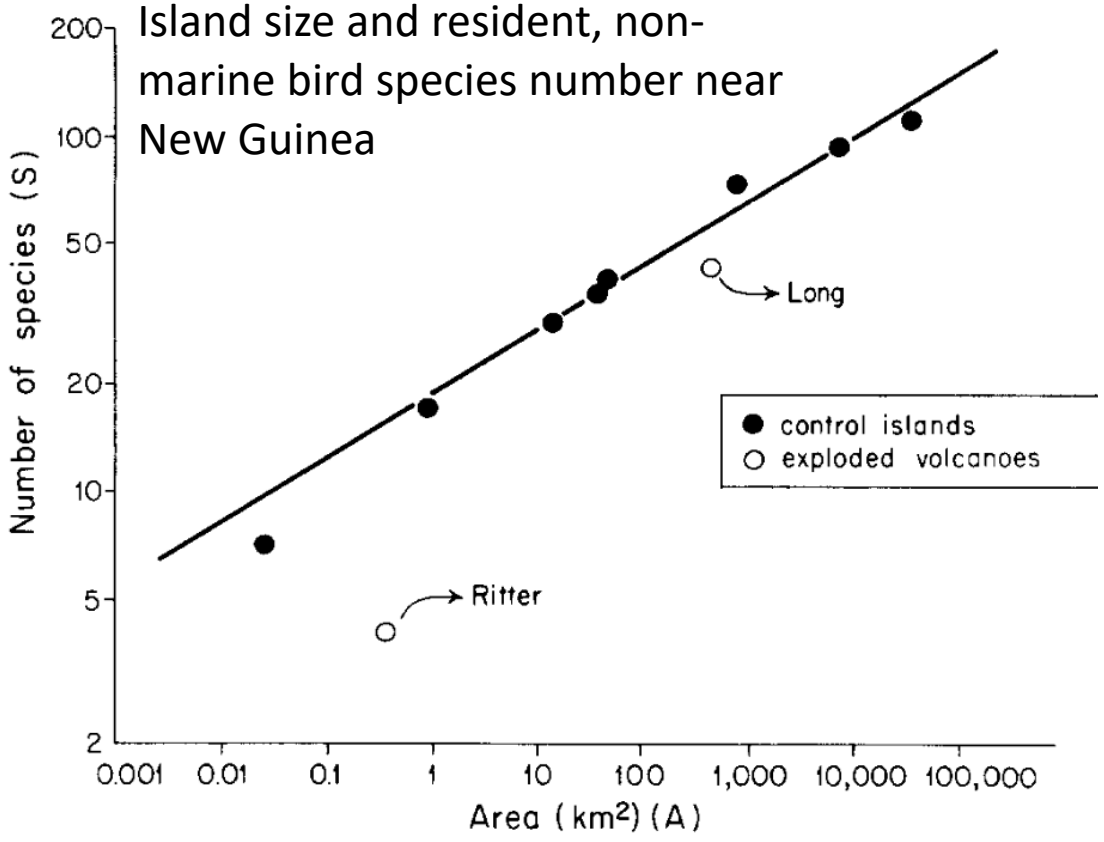


Simberloff. 1976. *Ecology.*

Island biogeography has greatly influenced the design of **protected area reserves**

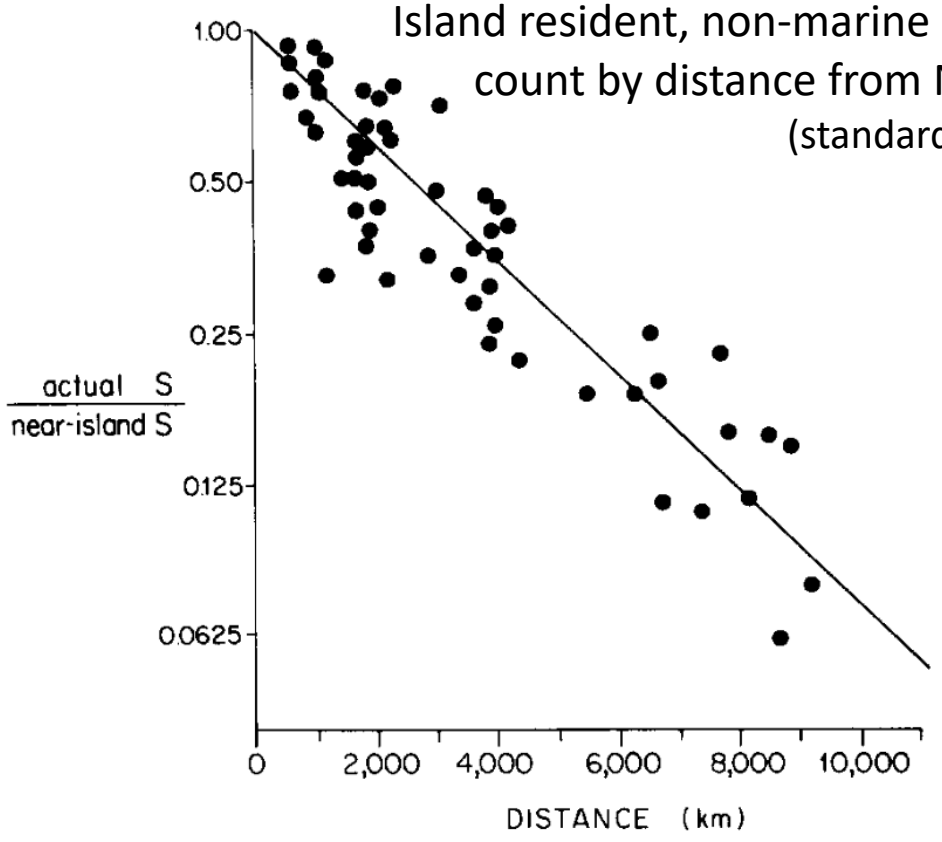
Area effect:

Island size and resident, non-marine bird species number near New Guinea



Distance effect:

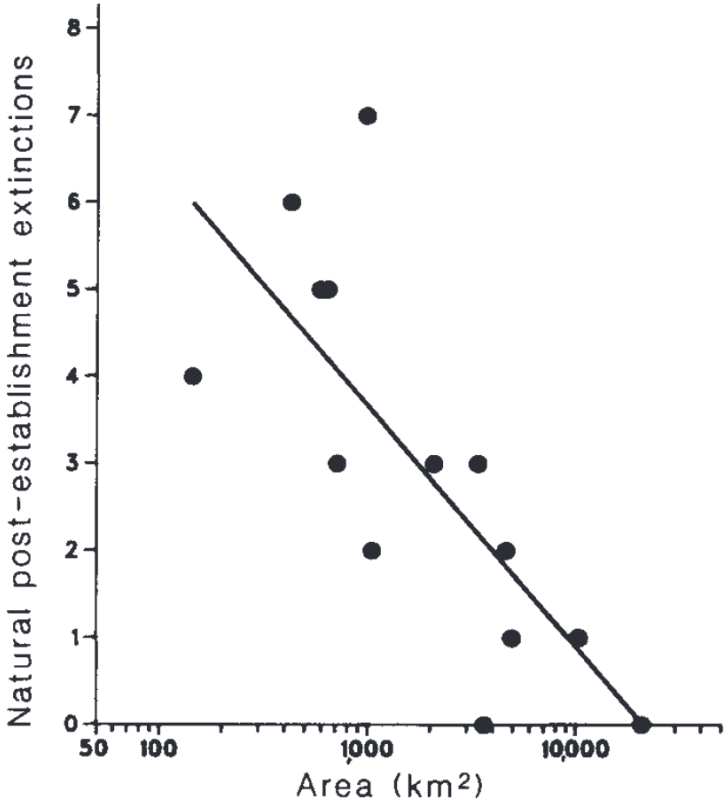
Island resident, non-marine bird species count by distance from New Guinea (standardized by area)



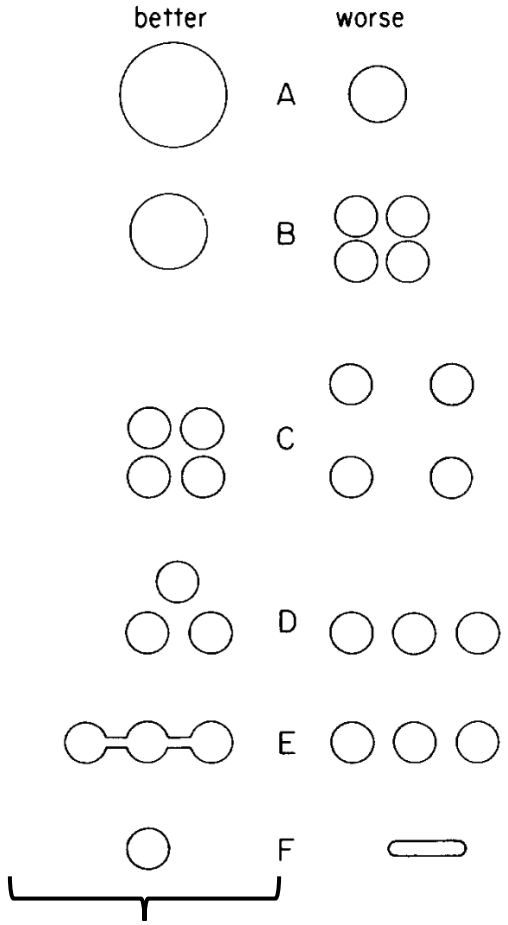
Diamond. 1975. *Biological Conservation.*

Island biogeography has greatly influenced the design of **protected area reserves**

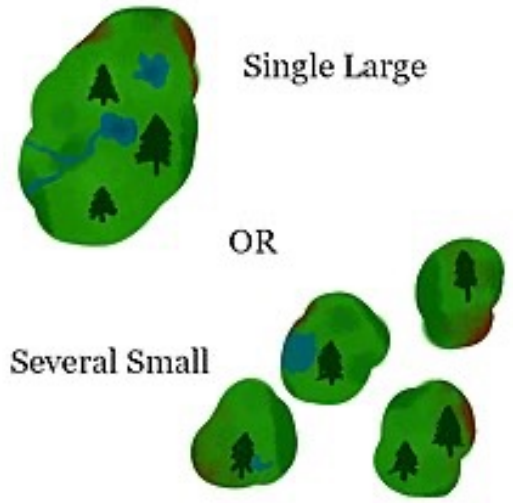
Mammalian extirpations post-establishment by area size in western North American national parks



Newmark. 1987. *Nature.*



Reserve design estimated to protect the largest number of species based on island biogeography theory



"**SLOSS**" debate
(1970s-1980s)

Diamond. 1975. *Biological Conservation.*

Biodiversity can be measured in several ways!

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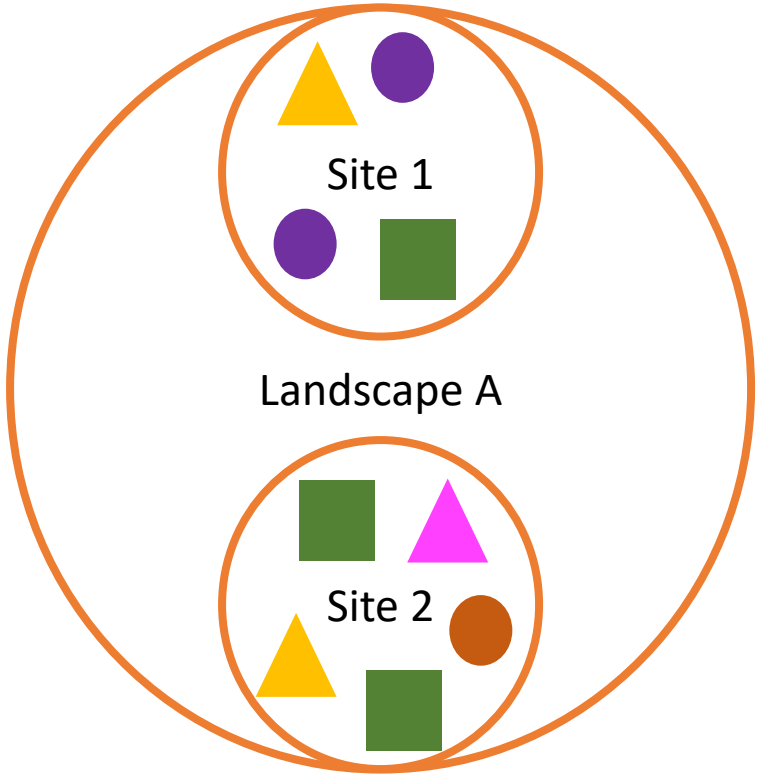
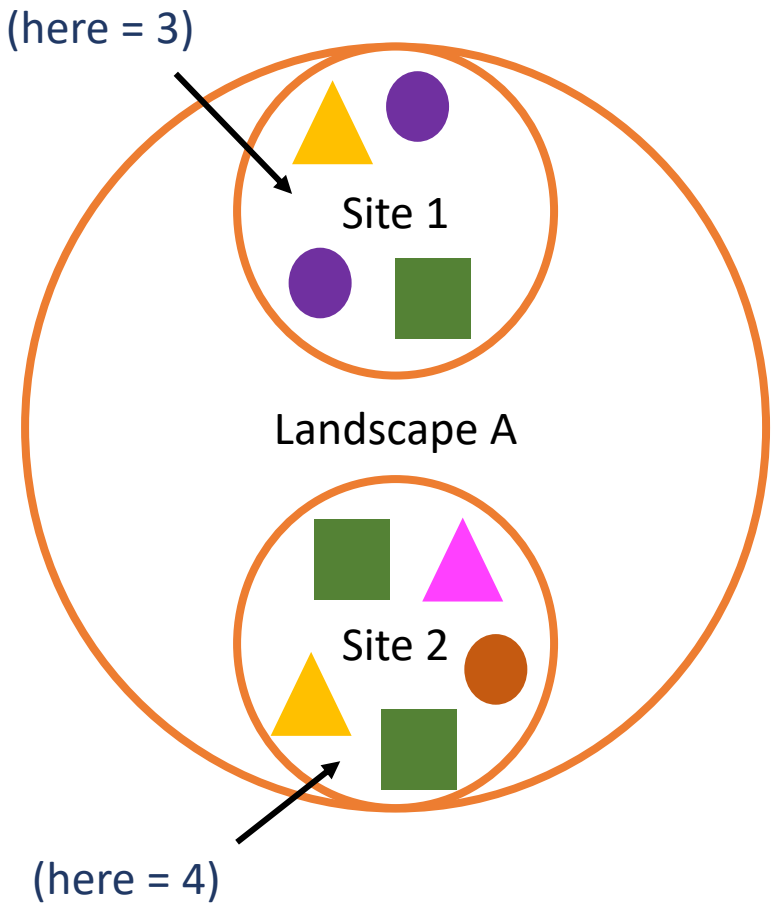


Whittaker. 1960. *Ecological Monographs.*

Biodiversity can be measured in several ways!

α – diversity = species richness, typically within a small specified region



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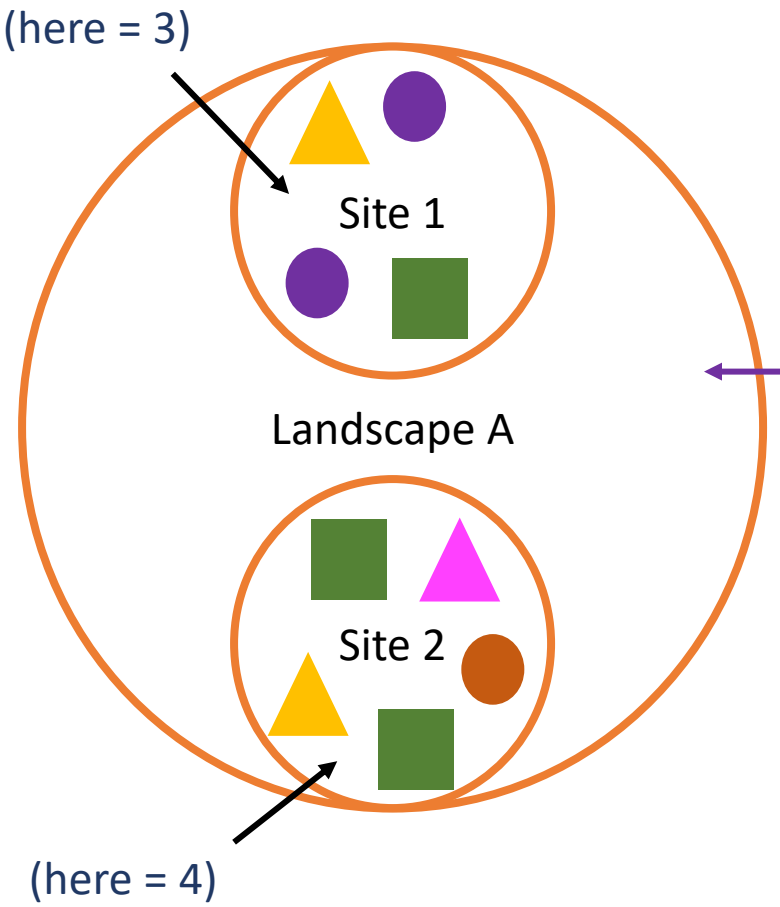

γ – diversity = total species diversity in a the landscape (here = 5)

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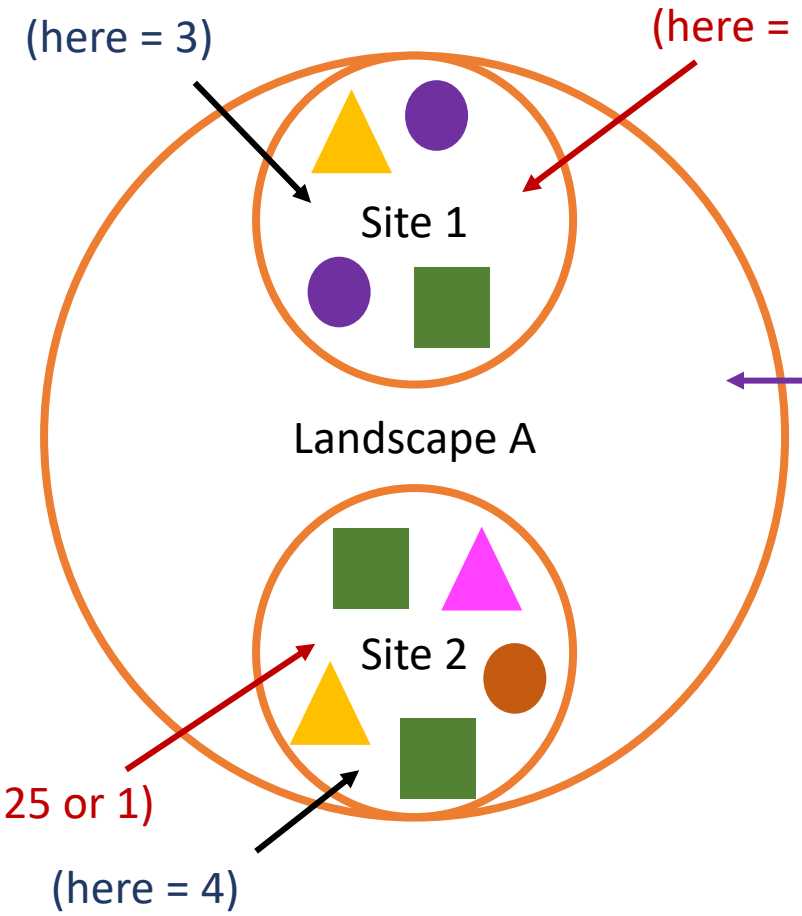


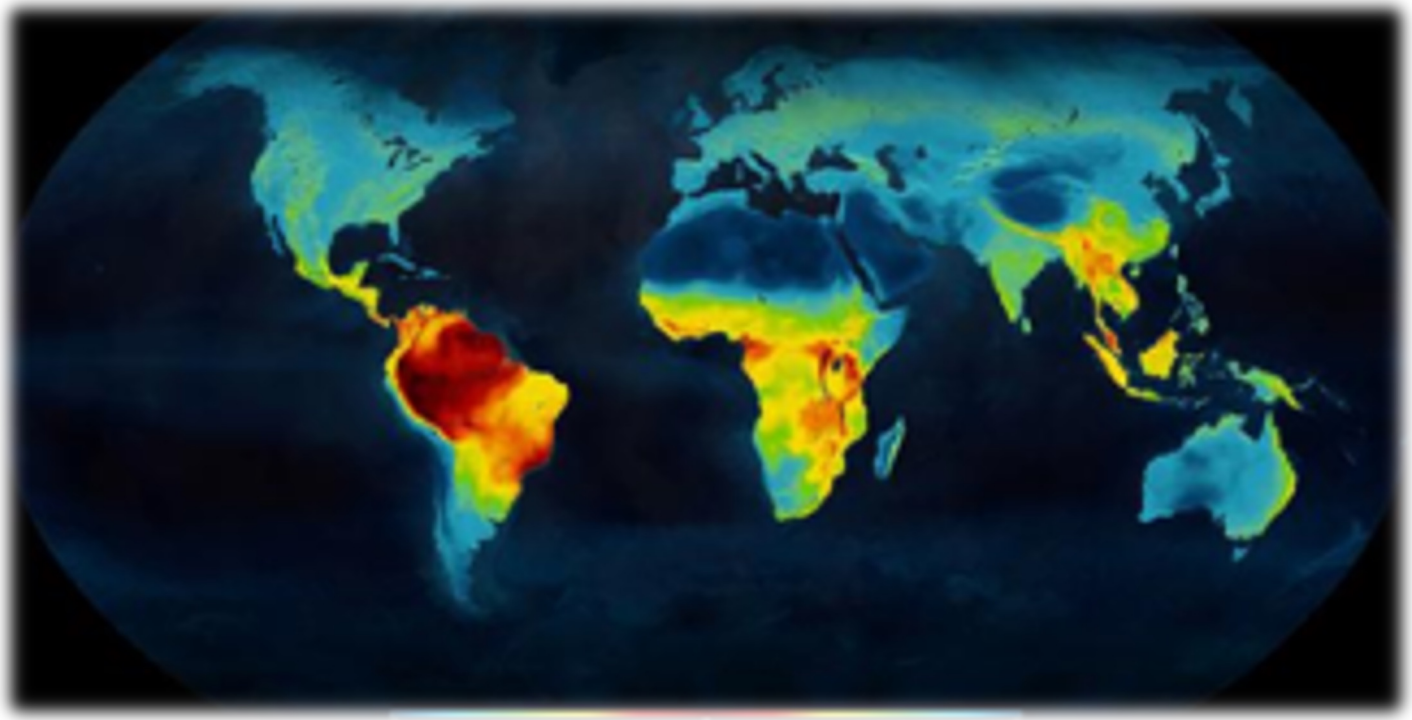
γ – diversity = total species diversity in a the landscape (here = 5)

β – diversity = ratio between landscape and local species diversity, either $\left(\frac{\gamma}{\alpha}\right)$ or $(\gamma\text{-}\alpha)$

Site 1 has lower α – diversity but higher β – diversity than site 2. Both are important!

Whittaker. 1960. *Ecological Monographs.*

Biodiversity is concentrated in the tropics.



(terrestrial vertebrate diversity)

Mannion. 2014. *Trends in Ecology & Evolution.*

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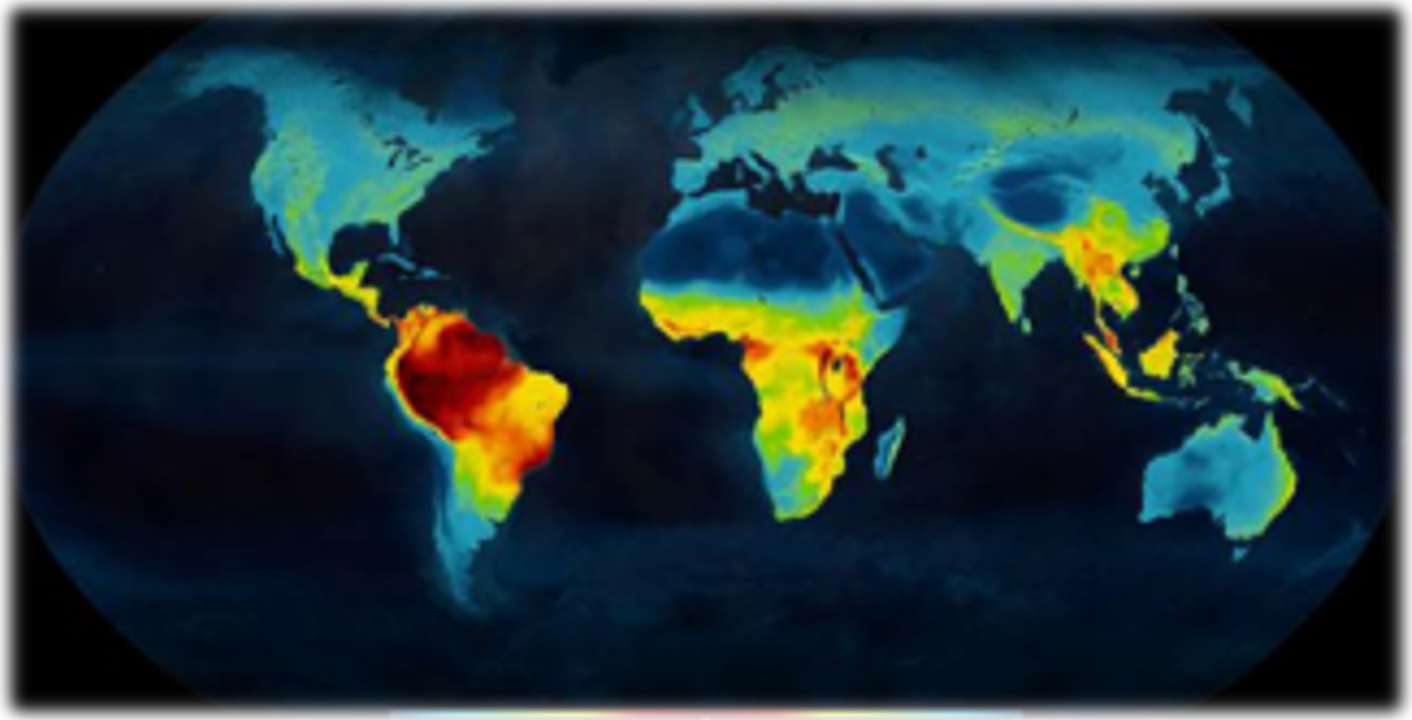

We still lack a satisfying model to explain why.

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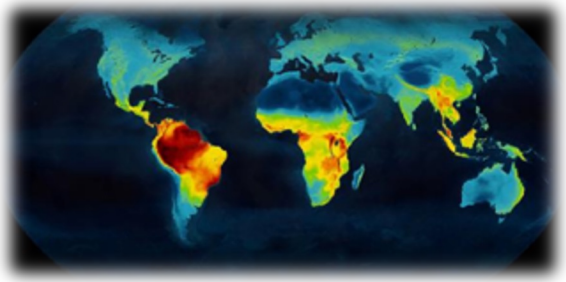

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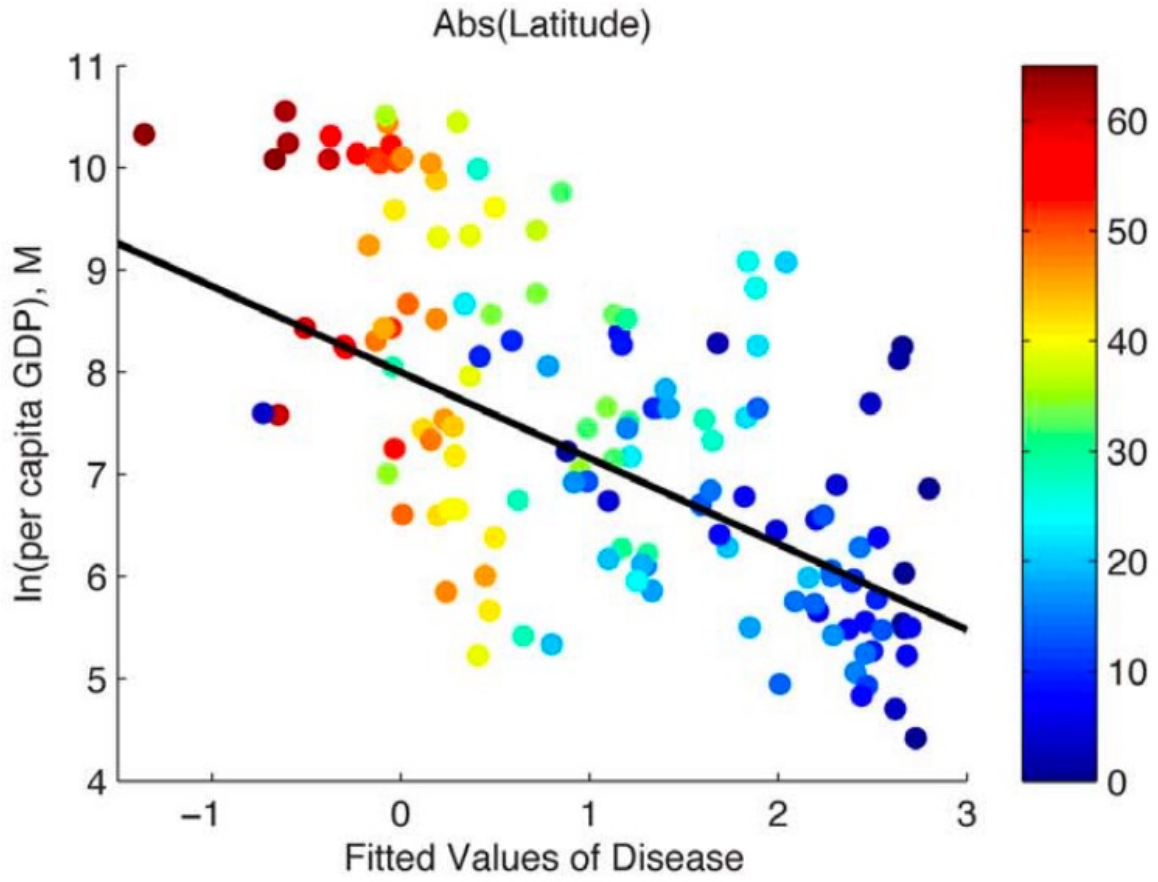
We still lack a satisfying model to explain why.

<u>Some candidate hypotheses:</u>

1. **Geographical area hypothesis.** More area in the tropics = more species… *but there's just as much area north of the tropics and fewer species!*
2. **Species-energy hypothesis.** Increased solar energy at low latitudes causes increased net primary productivity (or photosynthesis) and drives accumulation of species up the food web…*but offers a better prediction for abundance and biomass than for numbers of species.*
3. **Historical perturbation hypothesis.** Polar regions have not yet recovered equilibrium species numbers after glaciation… *but does not hold for marine systems, where the latitudinal gradient still exists…*
4. **Biotic interactions hypothesis.** More species yield more species as processes of competition, predation, etc. are intensified in the tropics… *but cannot provide the basal cause for the accumulation of more species to begin with!*

Mannion. 2014. *Trends in Ecology & Evolution.*

Vector-borne and parasitic diseases are also **concentrated in the tropics** - where income is correspondingly low.



Bonds et al. 2012. *PLoS Biology.*

Why do we care about biodiversity?

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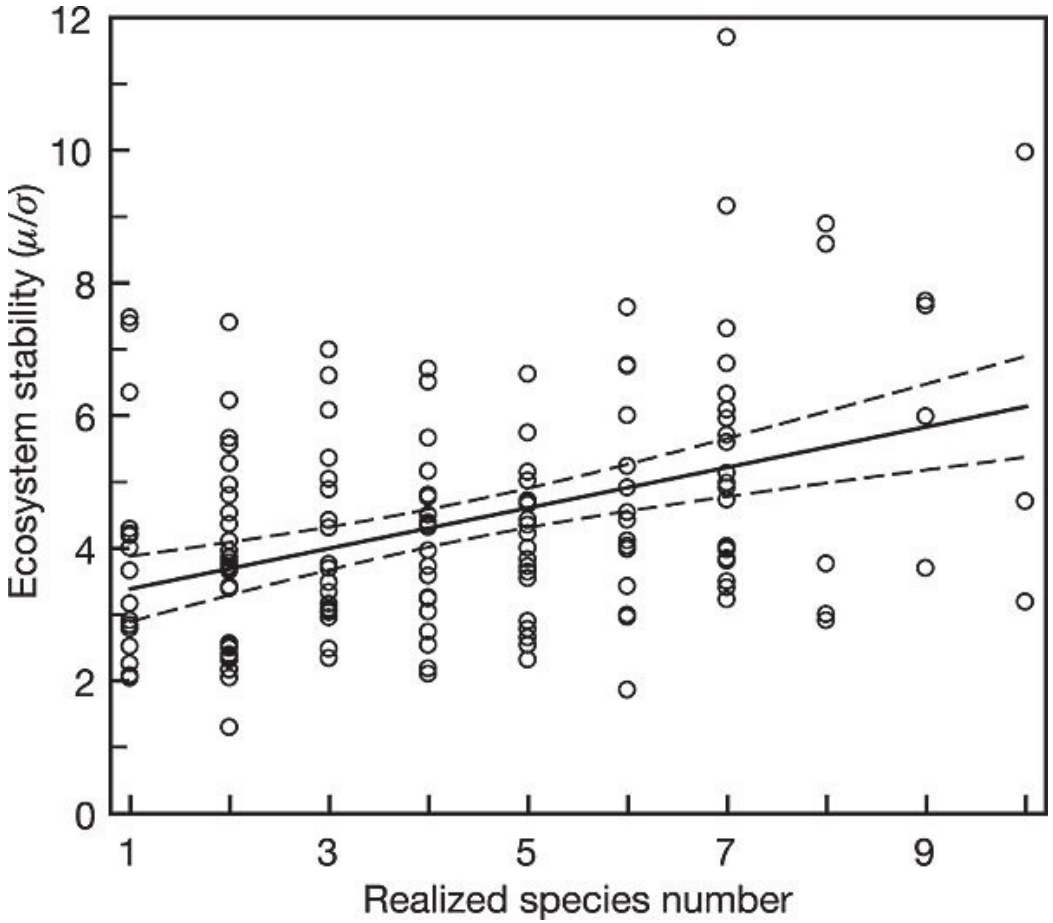
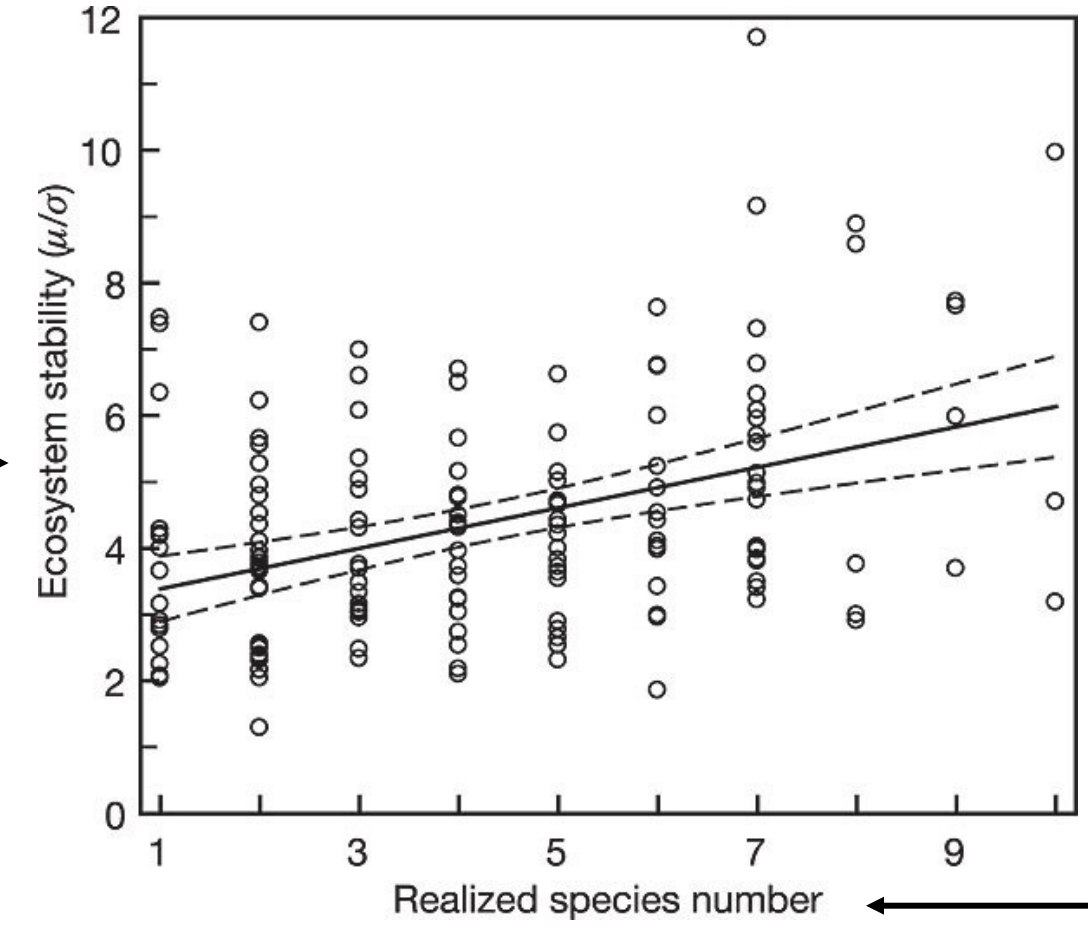


Cedar Creek experiment from the University of Minnesota

Tilman et al. 2006. *Nature.*

Why do we care about biodiversity?

mean plant biomass / standard deviation in plant biomass
(a proxy for primary productivity)



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number of species comprising 90% of aboveground biomass
(very rare species excluded)

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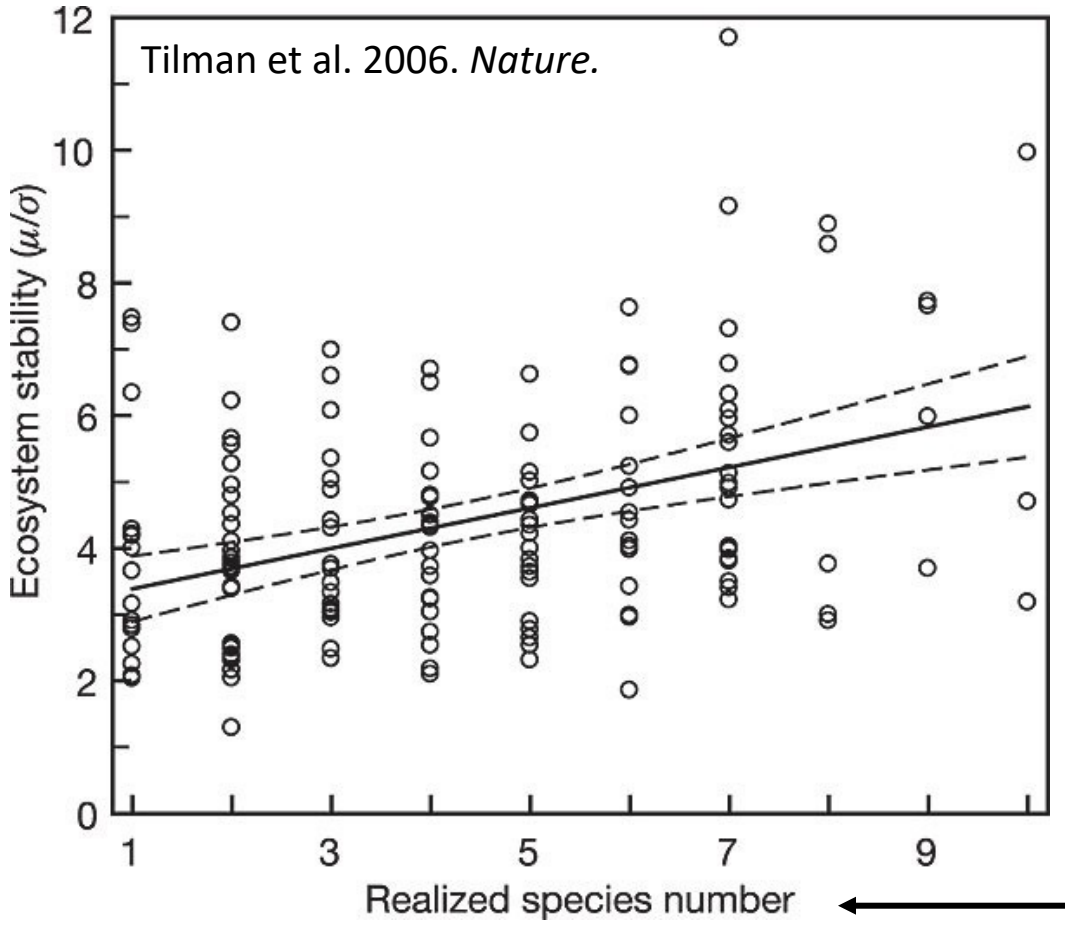


"Our results indicate that the reliable, efficient and sustainable supply of some foods, biofuels and ecosystem services can be enhanced by the use of biodiversity."

number of species comprising 90% of aboveground biomass *(very rare species excluded)*

Biodiversity promotes ecosystem "stability", meaning that **ecosystems are more likely to perform their essential functions when they are more diverse**!

Biodiversity performs important functions, including those which benefit humans, known as **ecosystem services**.

regulating services

- water and air purification
- carbon sequestration
- pollination
- pest (and sometimes disease) control

provisioning services

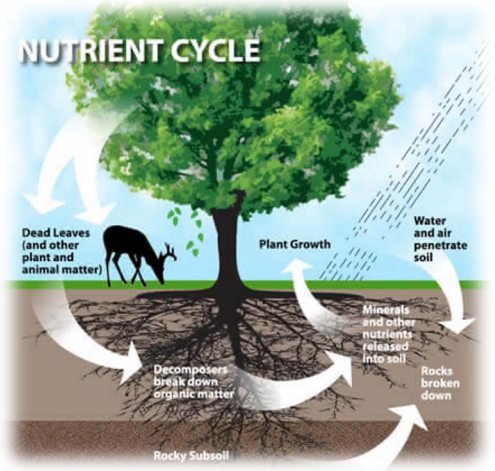
- food (fish, game)
- raw materials (lumber, skins, organic matter)
- medicinal resources
- ornamental resources

cultural services

- ecotourism
- therapeutic services
- historical and cultural values

supporting services

- nutrient cycling
- primary productivity
- habitat provisioning



The **Natural Capital Project** seeks to value the economic benefits of ecosystem services for humans.

natural capital PROJECT

Stanford Woods Institute for the Environment

The Nature Conservancy

Institute on the Environment
University of Minnesota
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WWF

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- The Catskill-Delaware watershed supplies 1.2 billion gallons of drinking water daily to 9 million residents of New York City.

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- To this day, NYC's tap water remains clean and **unfiltered**.

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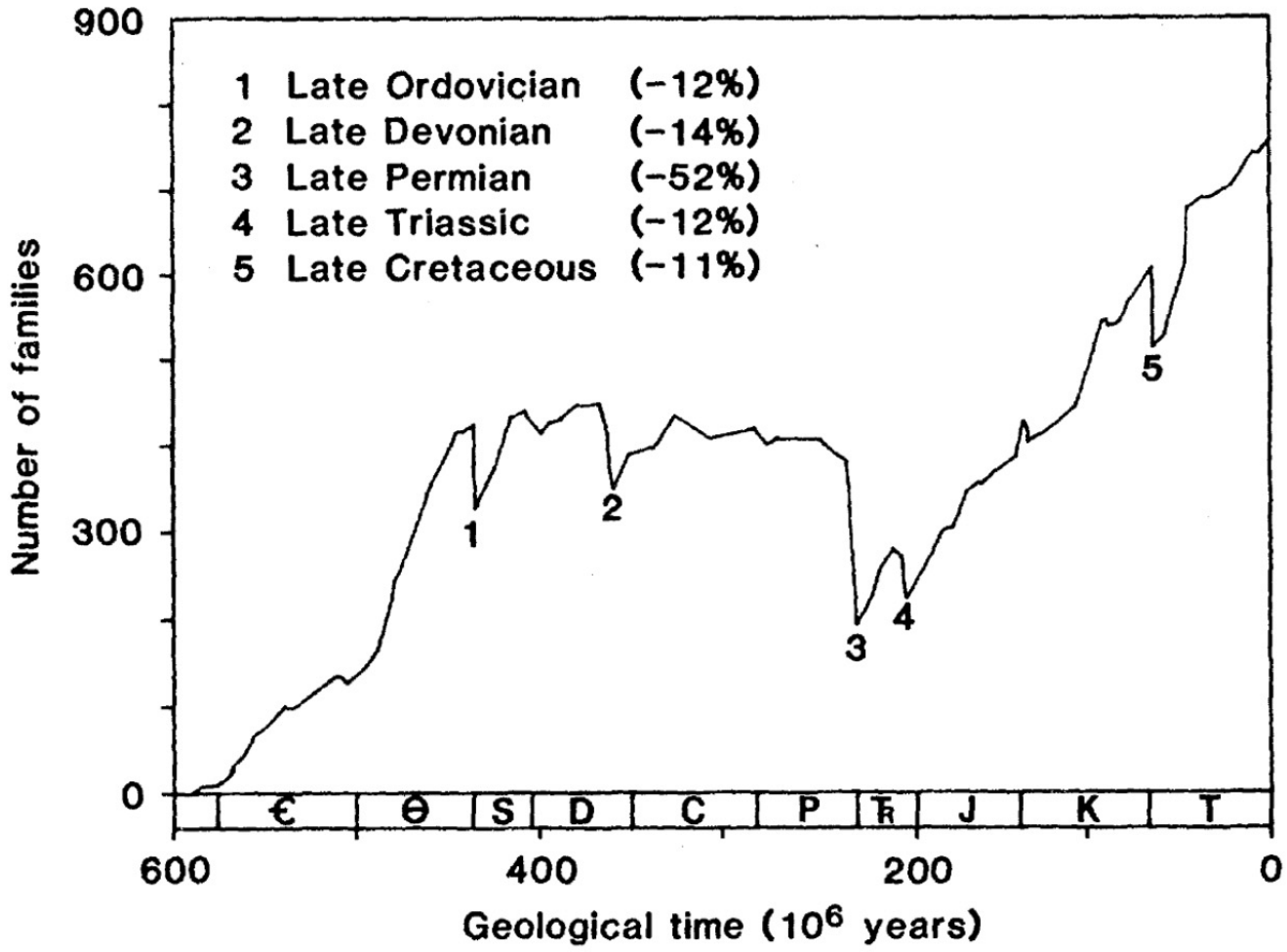
Five major **mass extinction events** are recognized in geologic time.



Mass extinctions are characterized by the loss of >75% of species within a geologically "short" timespan.

Raup and Sepkoski. 1982. *Science*

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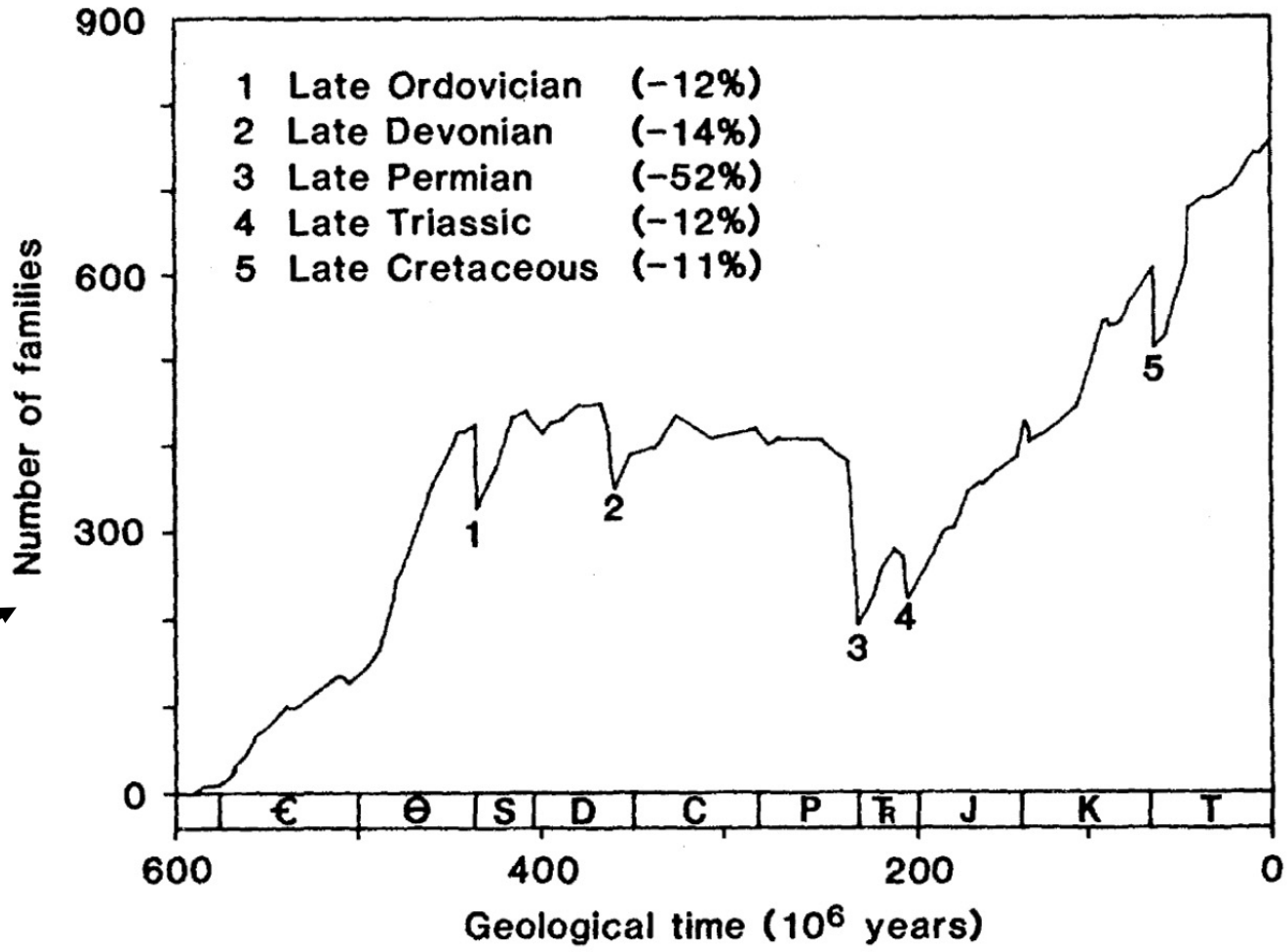


Number marine vertebrate and invertebrate families preserved in the fossil record

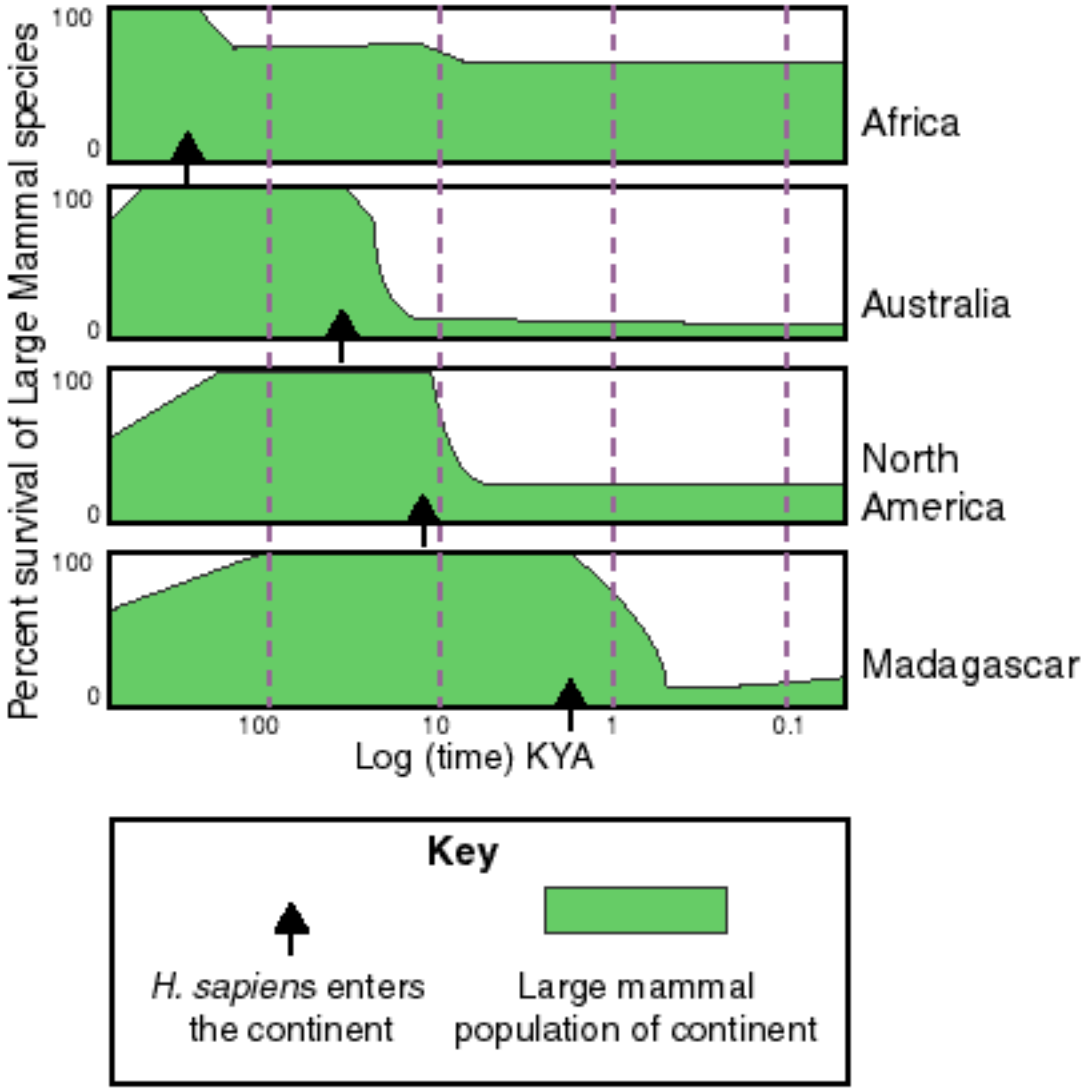
Mass extinctions are characterized by the loss of >75% of species within a geologically "short" timespan.

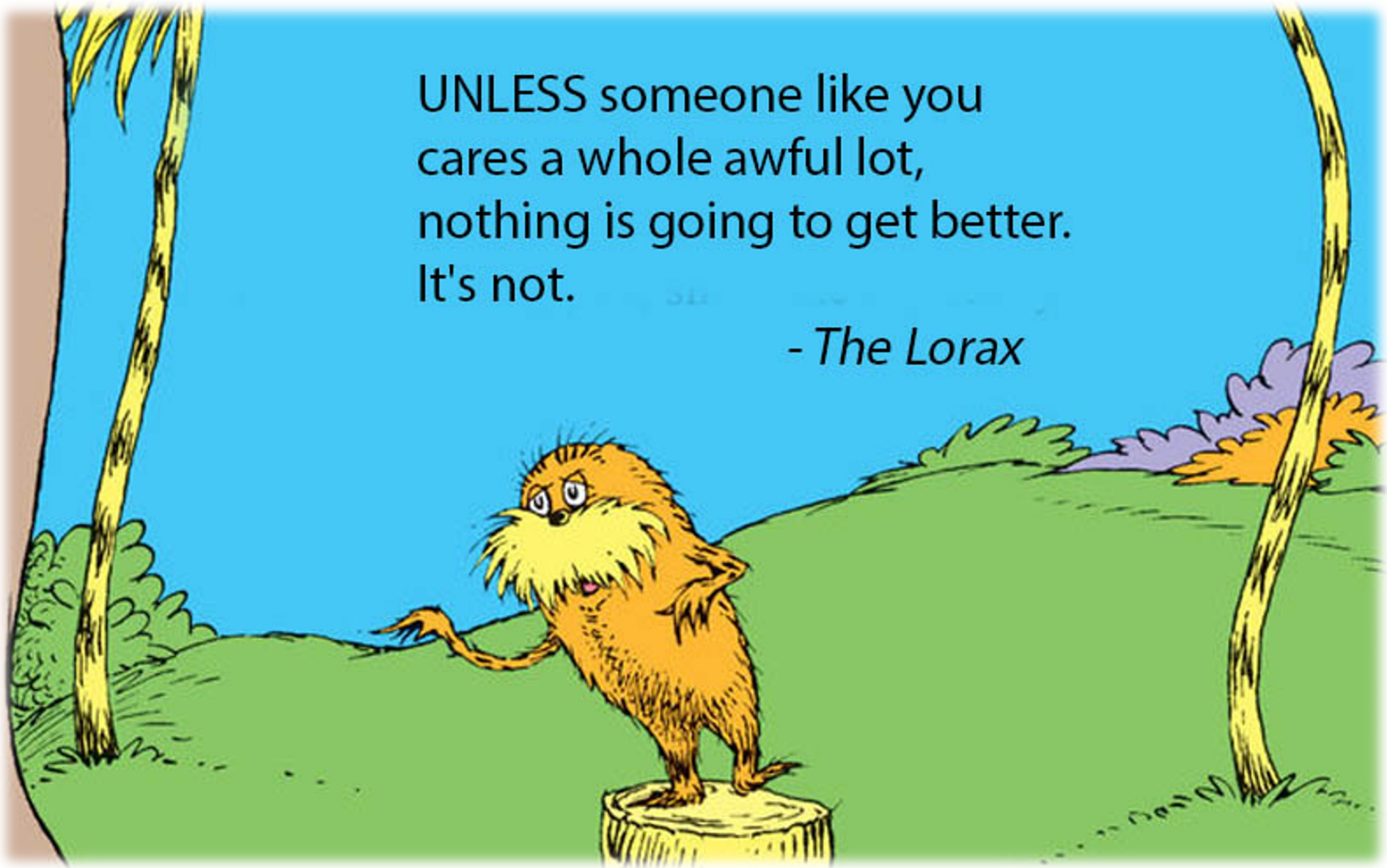
present day

Raup and Sepkoski. 1982. *Science*

We are living through the sixth mass extinction: the **Holocene**, or **Anthropocene extinction**

- Mass megafaunal extinctions followed human arrival to each continent, in North America timed around the end of the Pleistocene (~10-14,000 years ago).
- Today, the contemporary rate of extinction is estimated at 100 to 1000 times higher than background (e.g. historically typical) and 10 to 100 times higher than previously witness during the 5 previous mass extinction events in earth history.
- The current extinct rate is considered to be anthropogenic in origin.




UNLESS someone like you
cares a whole awful lot,
nothing is going to get better.
It's not.
- The Lorax

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