Wk9-Lect9-Mar6

Visual settings

Edit

Are you sad this is the last poll?

not at all

0%

just a little

SEE MORE

0%

Fundamentals of Ecology

Week 9, Ecology Lecture 8

Cara Brook

March 6, 2025

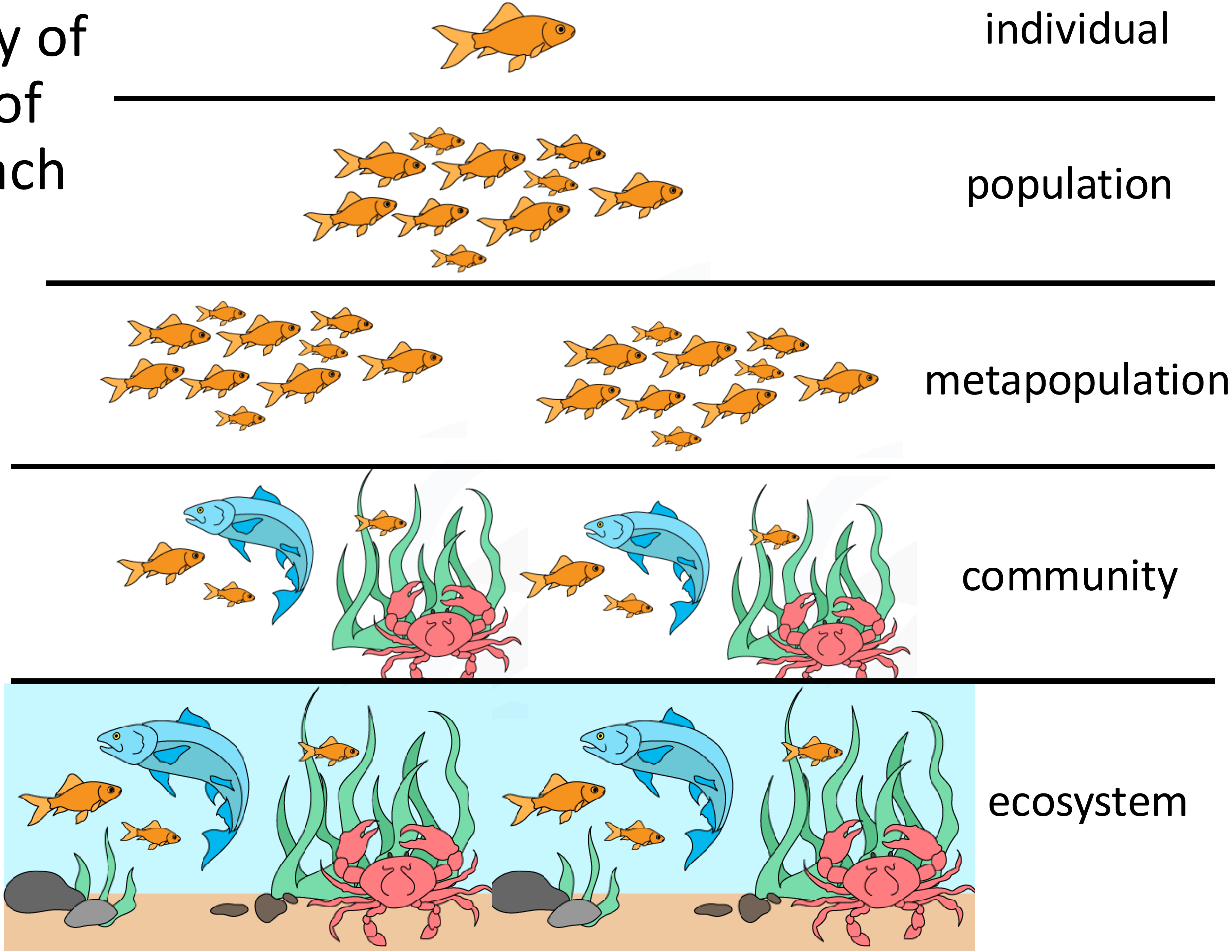
Office hours: On ZOOM
Thursday, March 6, 2025
4-5pm
See link in Canvas!

Learning objectives from Lecture 8

You should be able to:

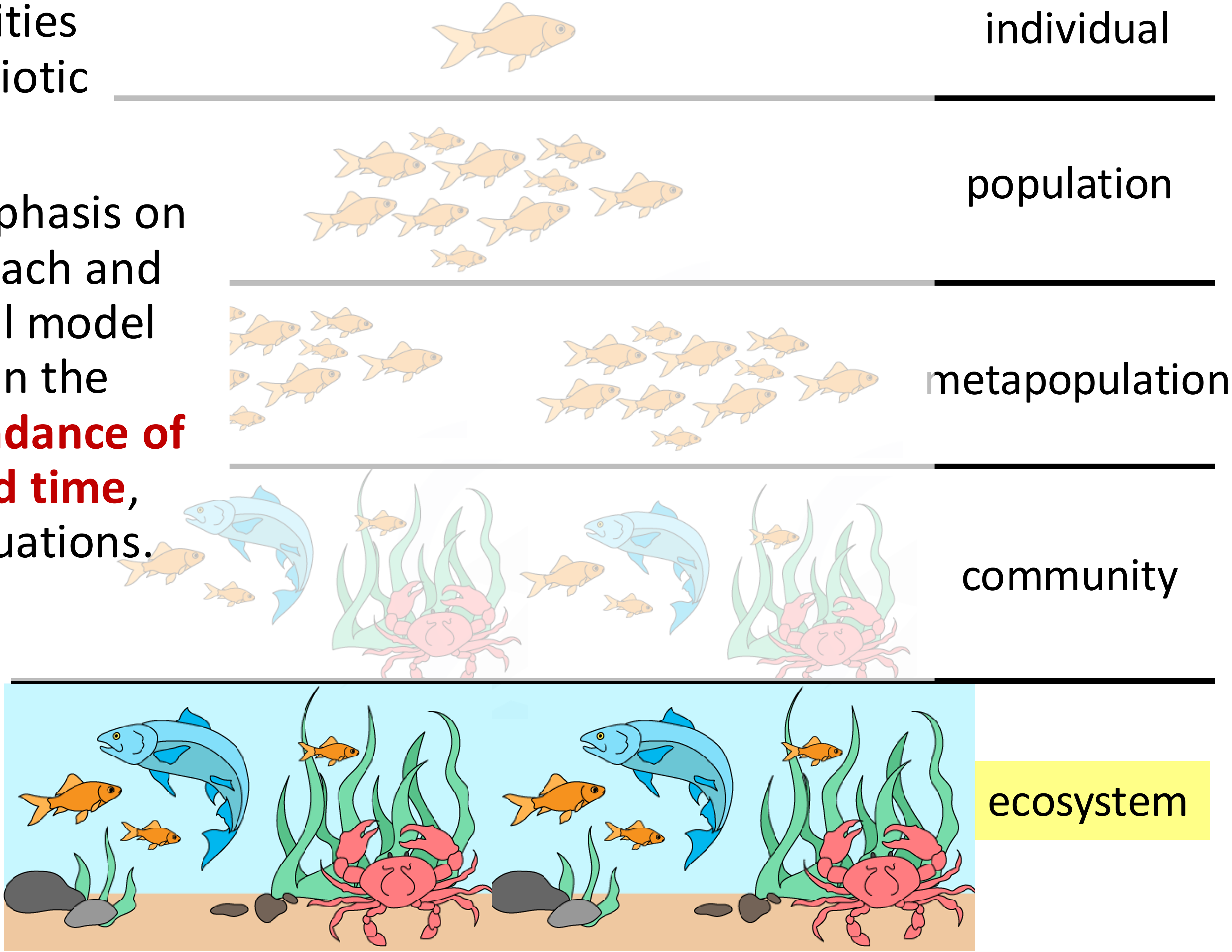
- Given a model diagram, recognize if the disease is transmitted directly or has a vector or animal reservoir
- Identify a reservoir, zoonosis, spillover, or spillback in a description or diagram
- Explain the virulence-transmission tradeoff
- Explain/recognize a dilution effect
- Understand zooprophyllaxis

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



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**, sometimes using equations.



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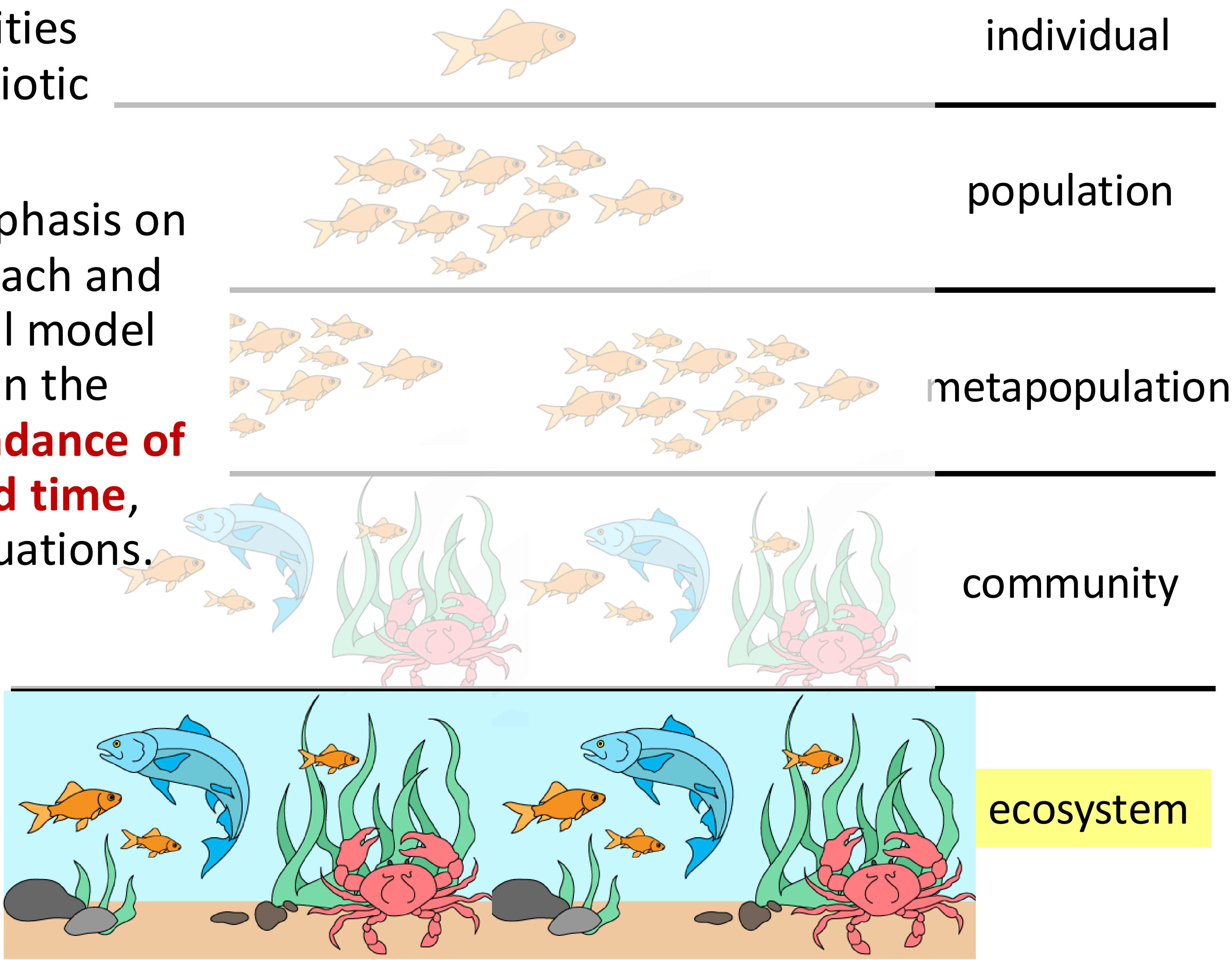
How do communities assemble?

Do a predictable number or type of species end up in a given environment?

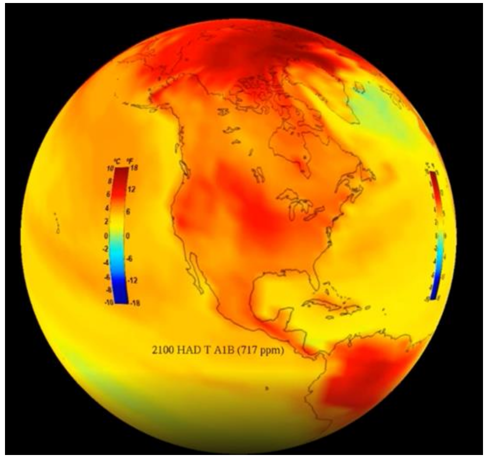


What is a model? an abstract representation of a phenomenon

Human

Solar System

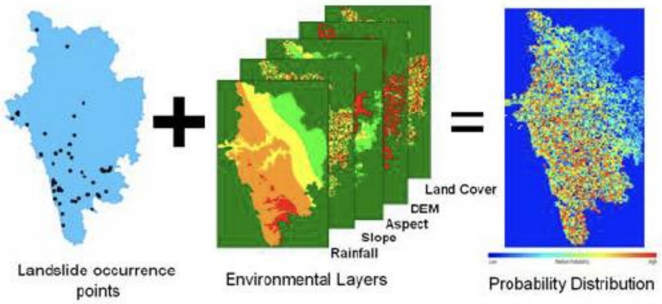
Climate



Human Genetics

Human Disease

Species Distribution



What is a model? an abstract representation of a phenomenon

Human

Solar System

Human Genetics

Human Disease

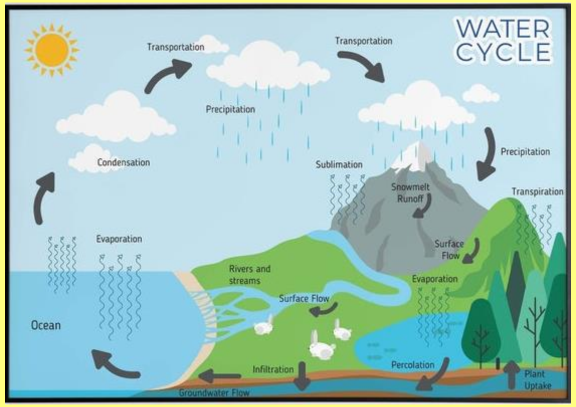
Mathematical

$$\frac{dS}{dt} = -\beta S I$$

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

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

Conceptual



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

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- Community begins with **pioneer species**, then develops with increasing complexity that self-reinforces to establish a **climax community**.

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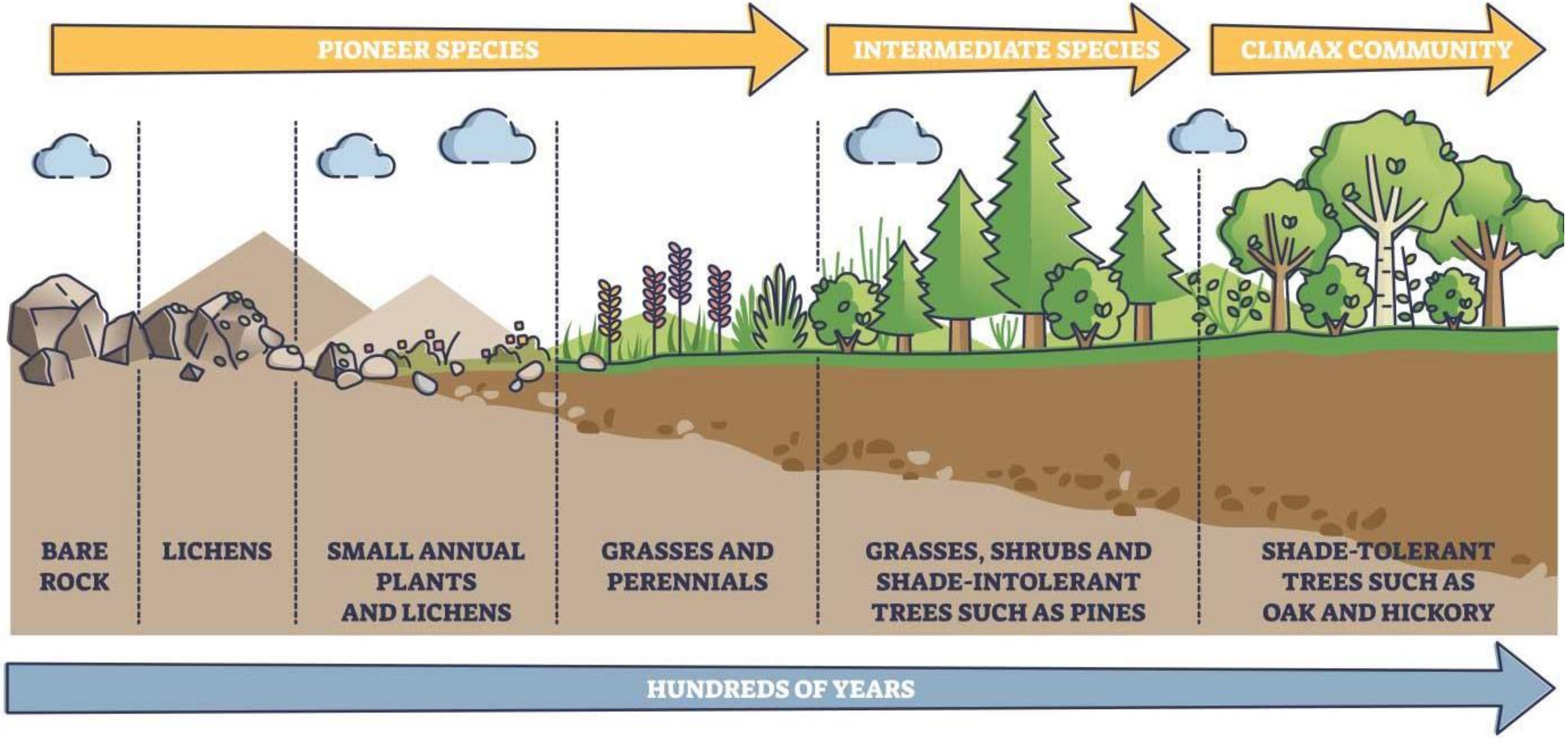
- Succession is the **process of change** in the **species structure** of ecological communities with time.
- Community begins with **pioneer species**, then develops with increasing complexity that self-reinforces to establish a **climax community**.
- Henry Chandler Cowles, a professor at the University 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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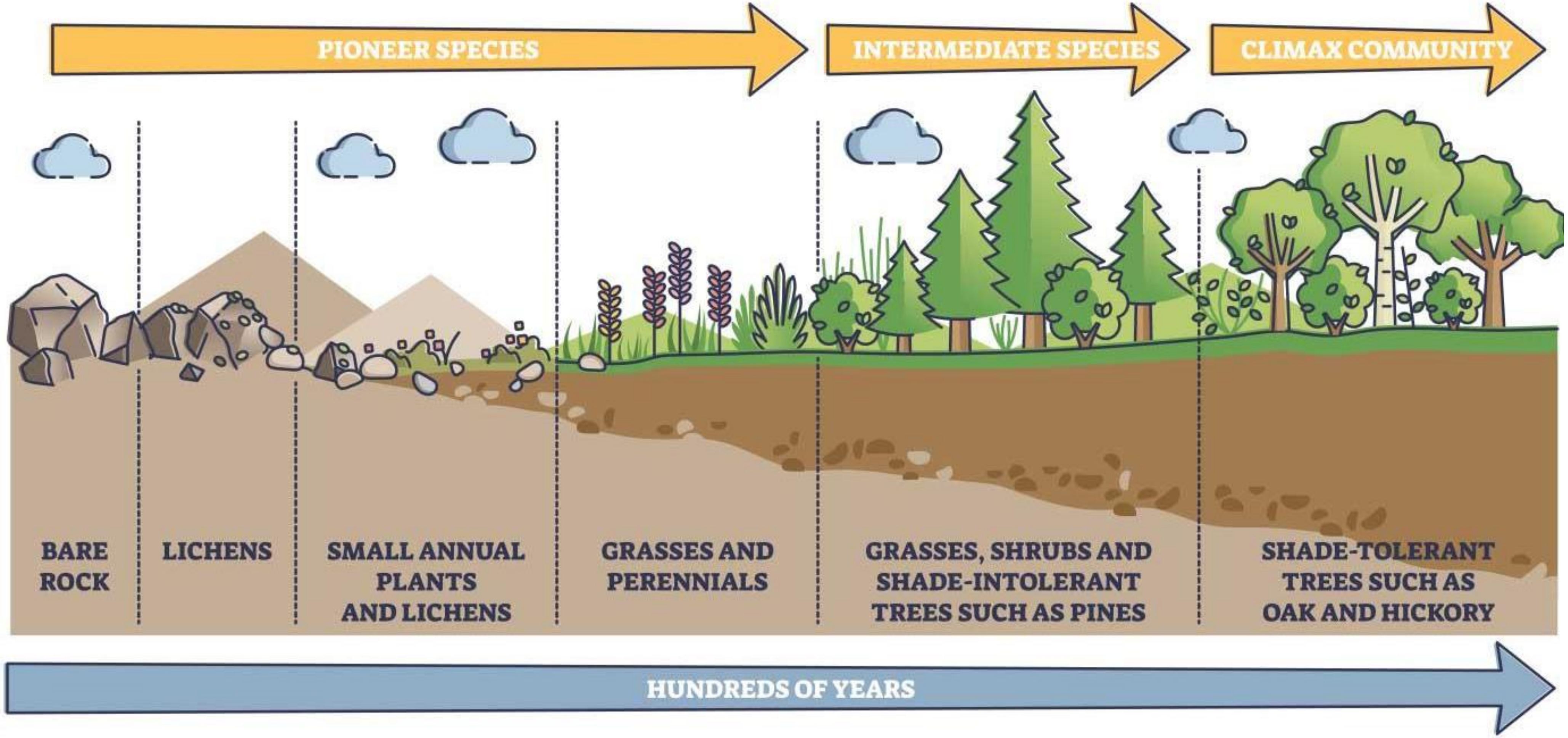
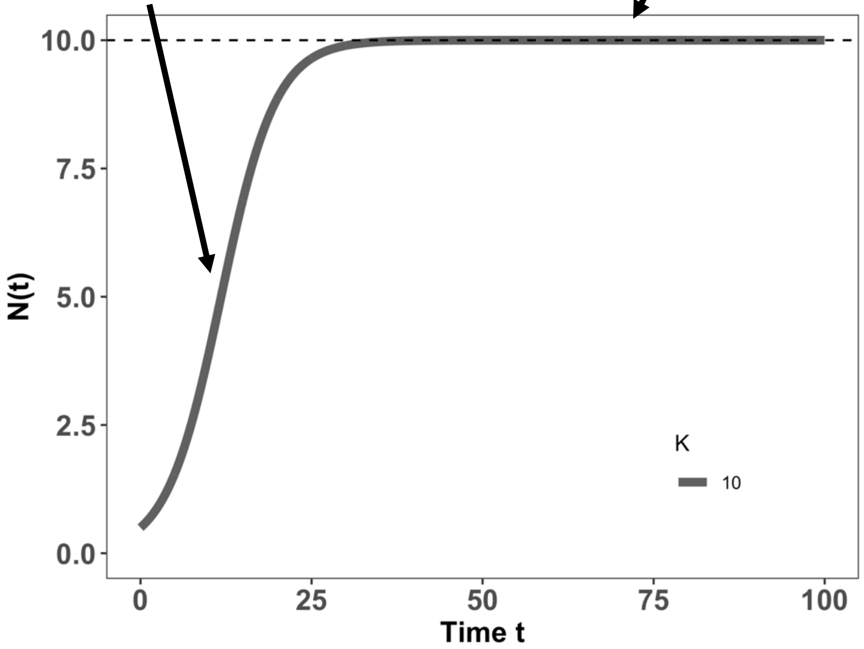


Continuum from "r-selected" → "K-selected" species.

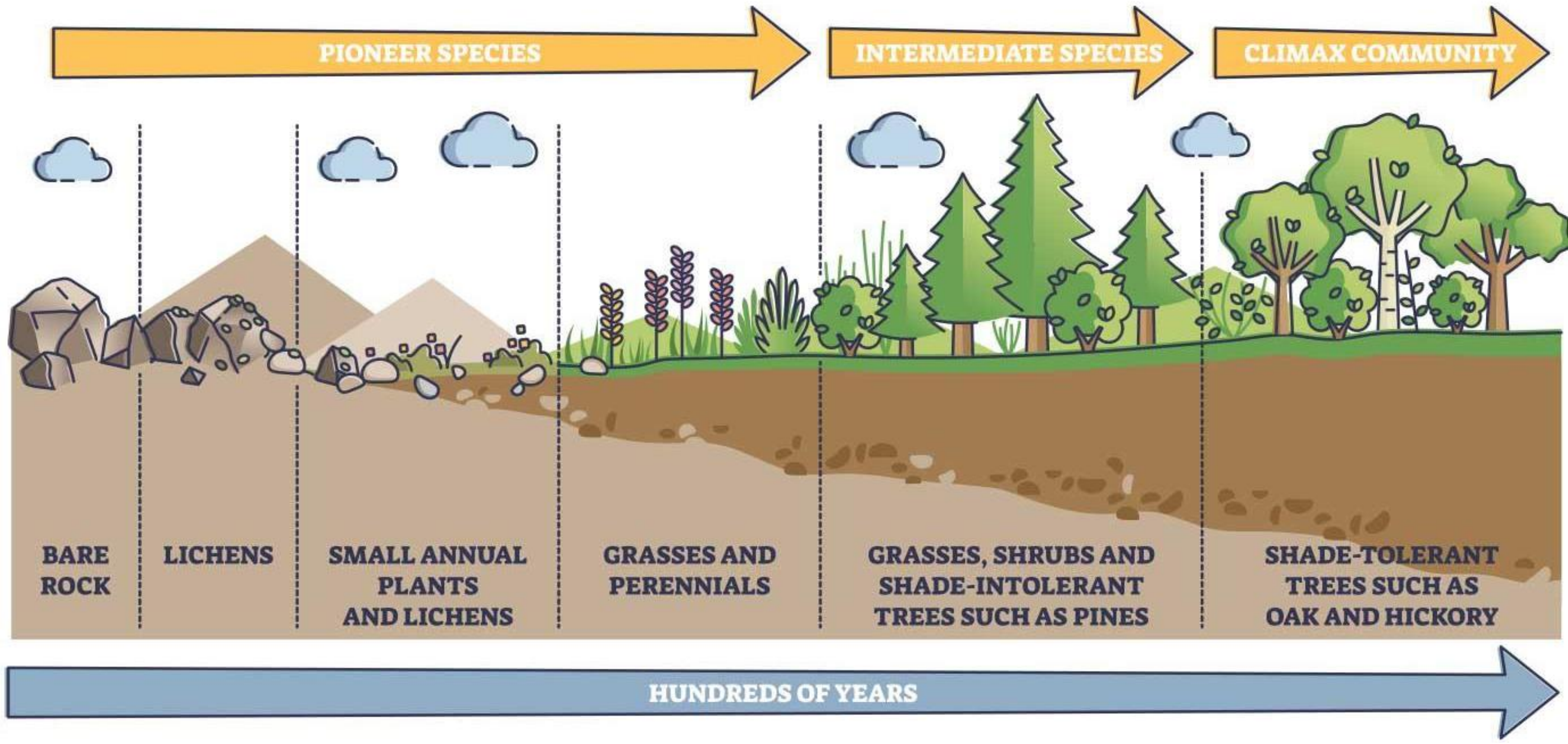
Primary succession occurs when species colonize a bare substrate.

K-selected species

r-selected species



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



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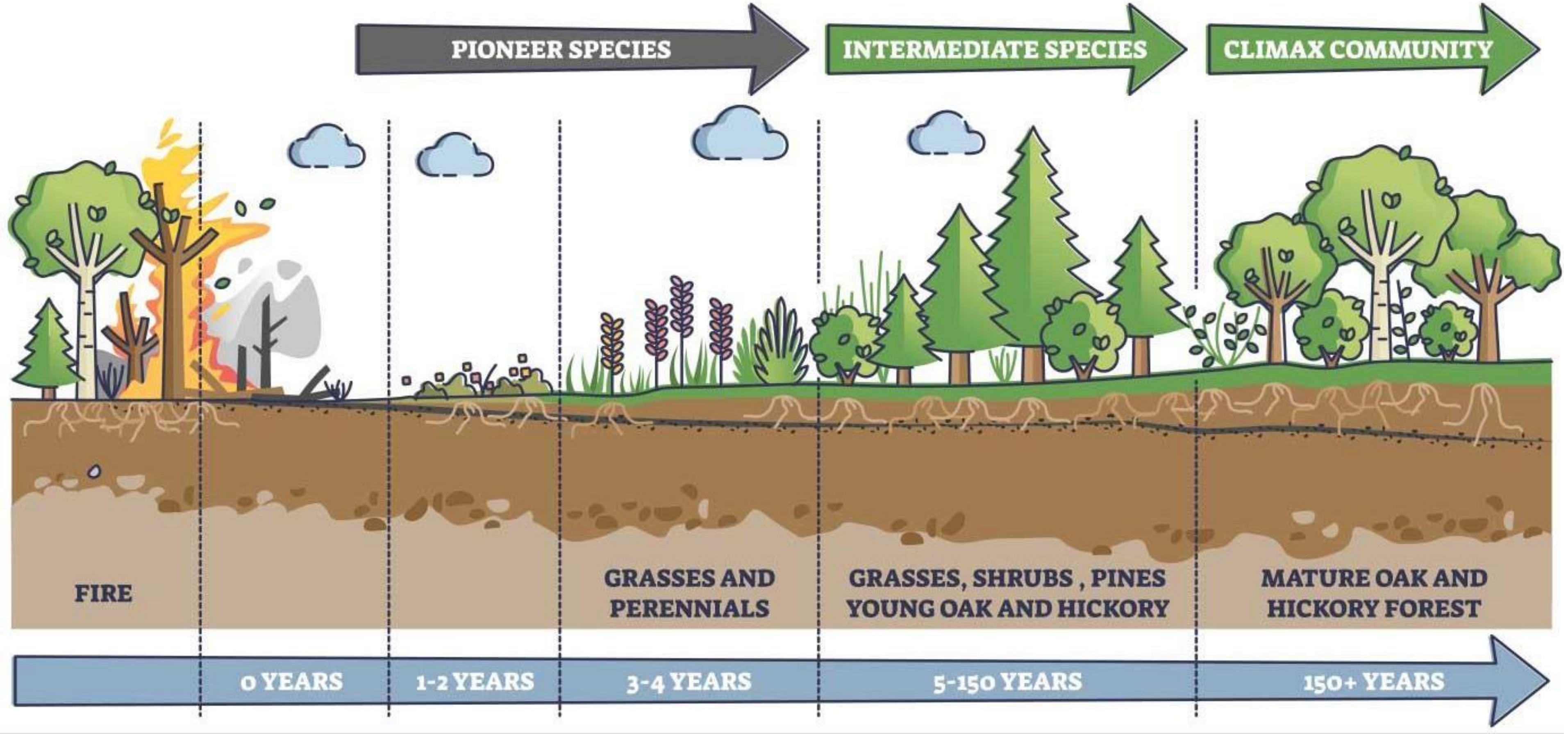
Secondary succession occurs when an environmental disturbance displaces a climax community, but soil and nutrients are still retained.



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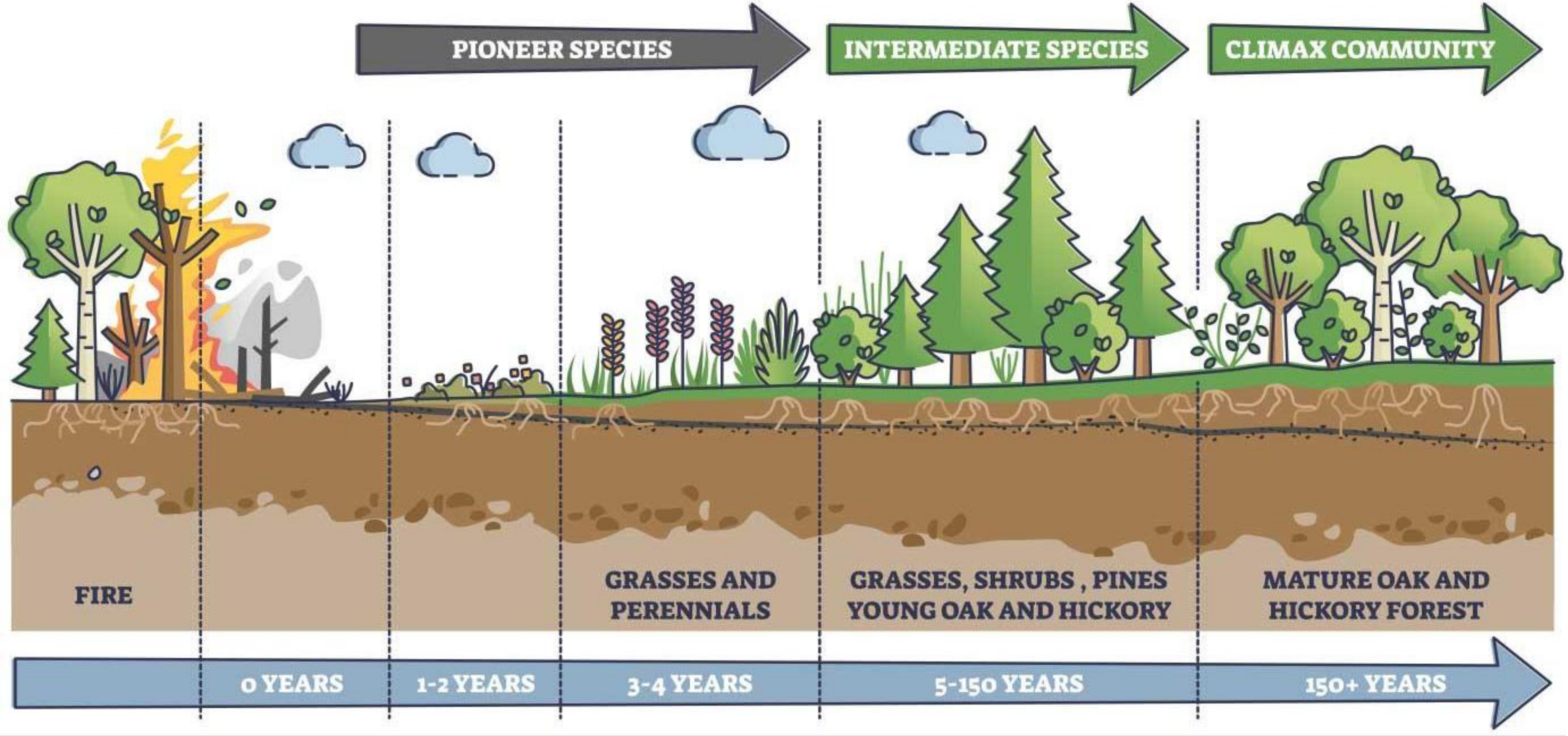
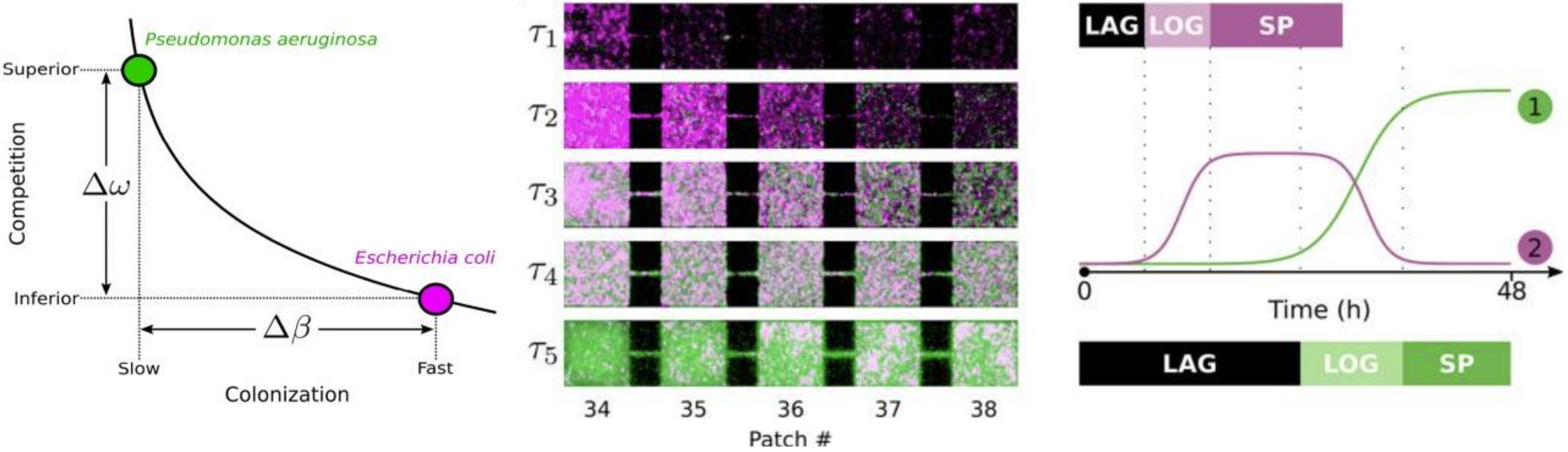


*Continuum from "**r-selected**" → "**K-selected**" species.*

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

- Frederic Clements (1916) argued that community succession was predictable and **deterministic**, much like ontogenetic development in individual organisms, moving always towards some superorganism.

Superorganisms vs. **Loose Collections** of Species

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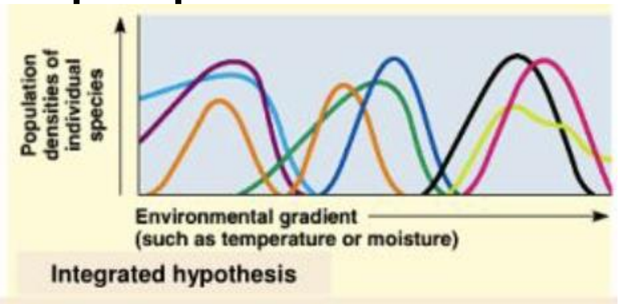
- **Priority effects**: inhibitory or facilitative priority effects occur when one species "prepares" the environment for the next species in succession



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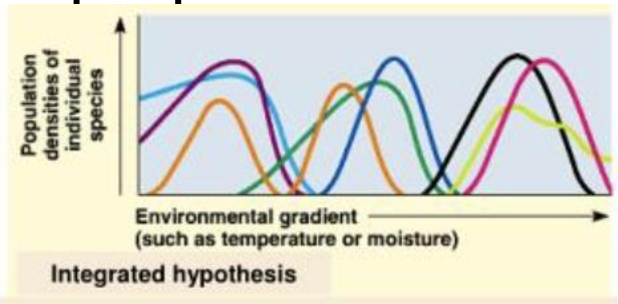
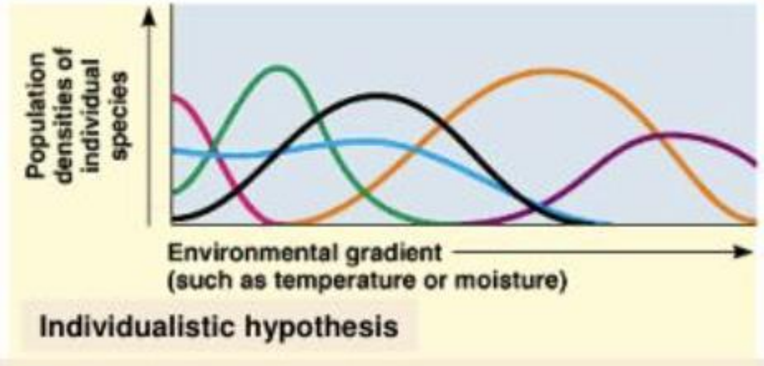


- Henry Gleason (1926) argued instead that chance favored the dispersal of nearby species into available habitat for succession, leading to **stochastic** assembly of communities
- Closer to Cowles’ original thinking



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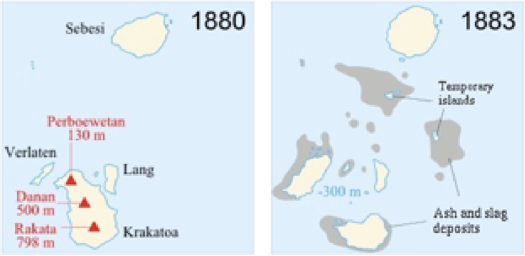
Volvanic eruptions on Krakatoa, Indonesia in 1883 led to the complete destruction of a large part of the land mass and buried the remnant regions in ash and slag. What type of succession best describes the return of vegetation to these islands?



A primary	0%
B secondary	0%
C tertiary	0%
D quarternary	0%

The field of **biogeography** studies the geographical distribution of plants and animals

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- Larger areas have more species!

$$S = cA^z$$

Preston 1964. *Ecology*

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number of species

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slope of relationship in log-log space

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habitat area

constant based on unit of area (standardizes to expected number of species per single unit area)

Preston 1964. *Ecology*

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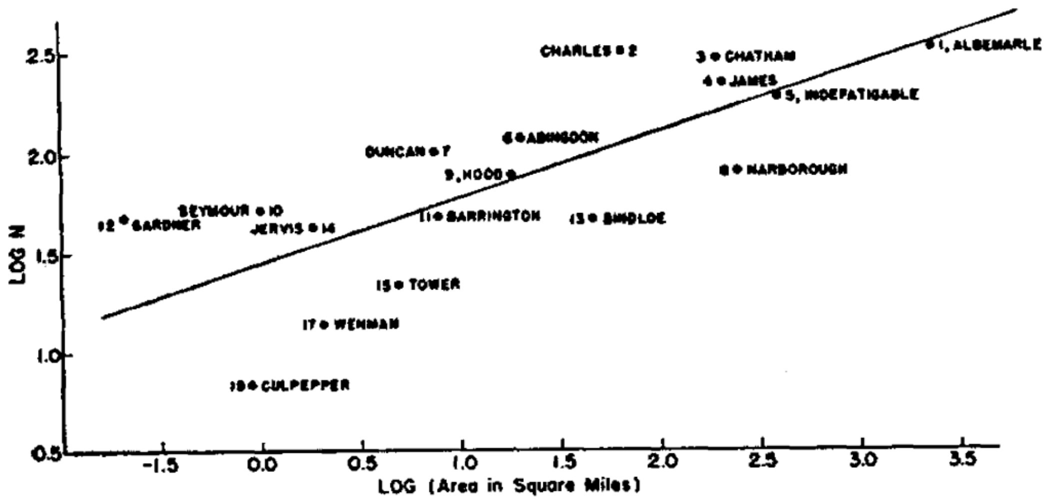
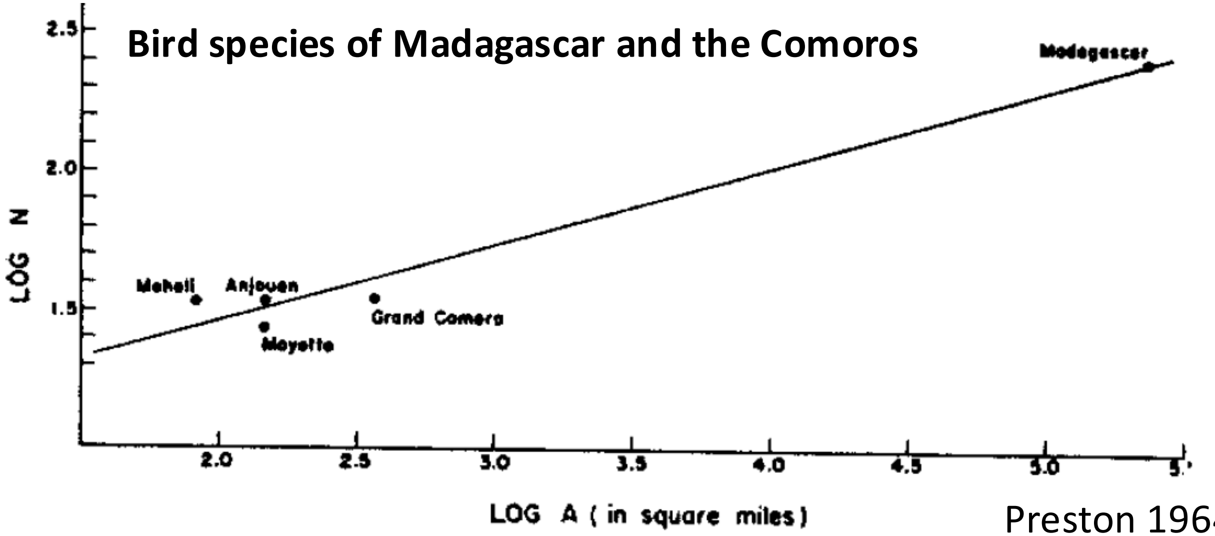
Plant species of the Galapagos islands



Bird species of Madagascar and the Comoros



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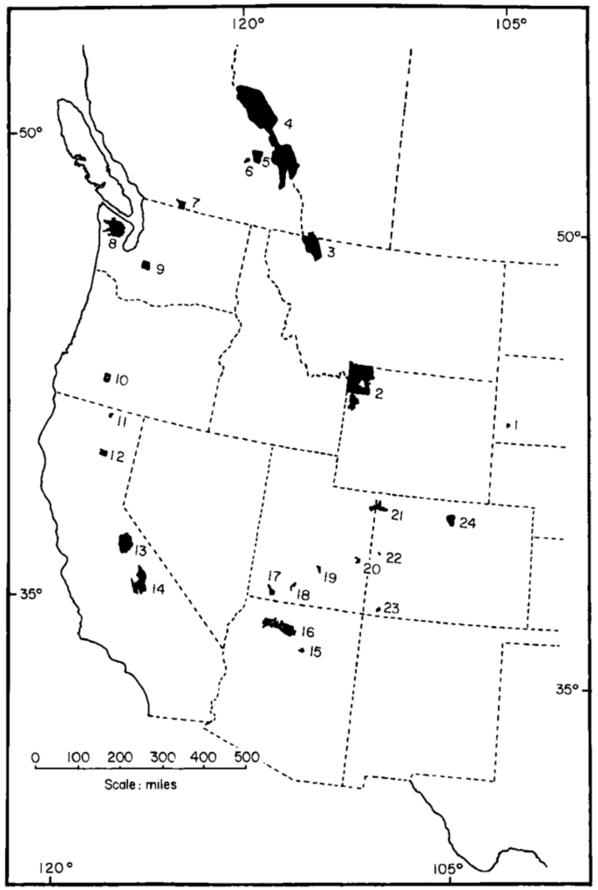
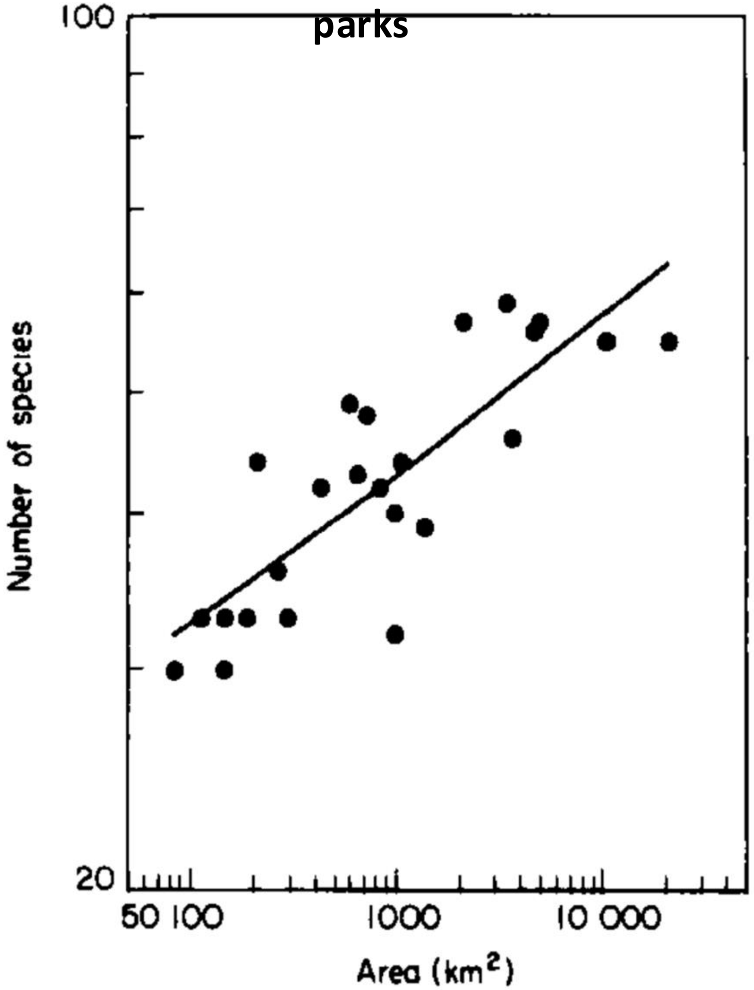
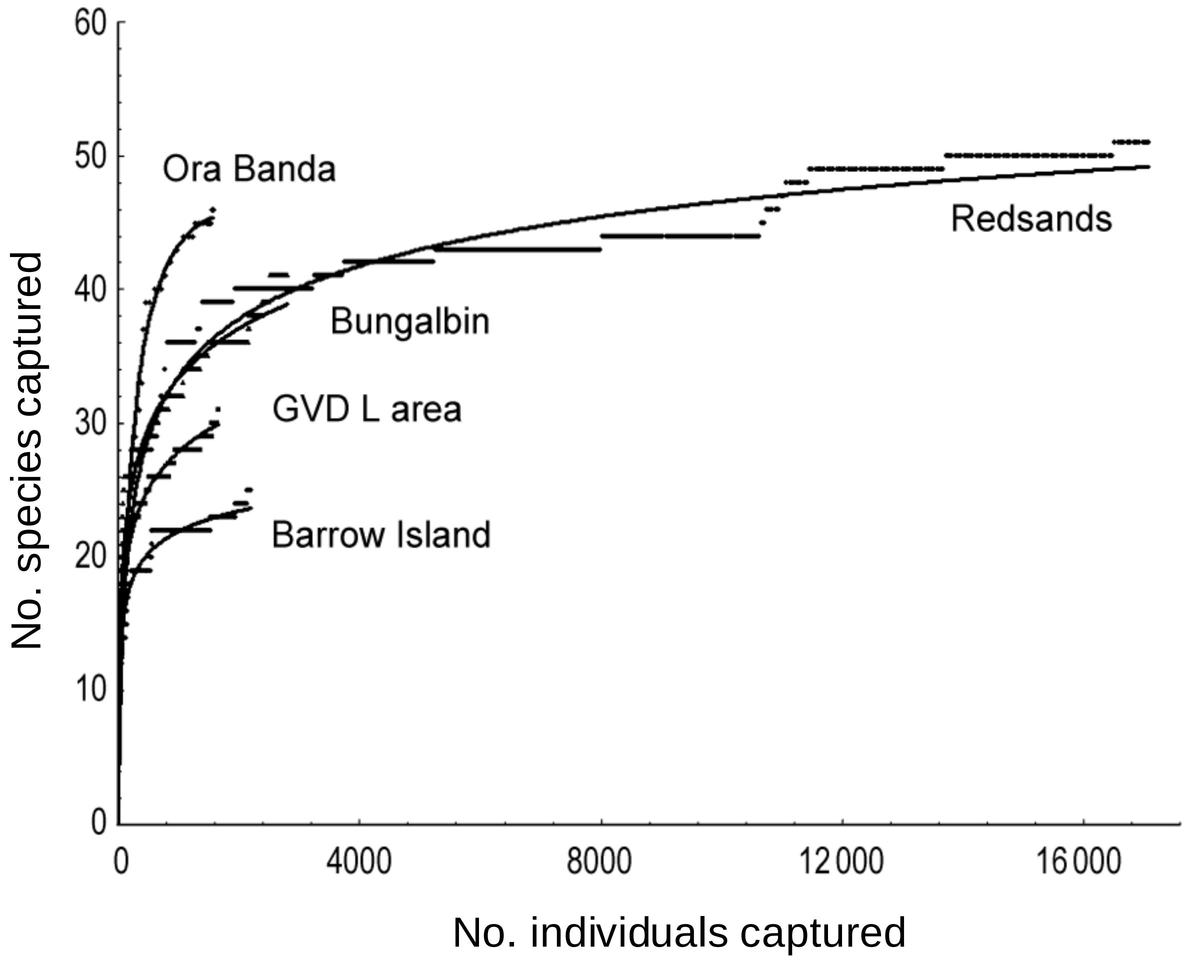
Mammal species of western US national parks





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.*

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Visual settings

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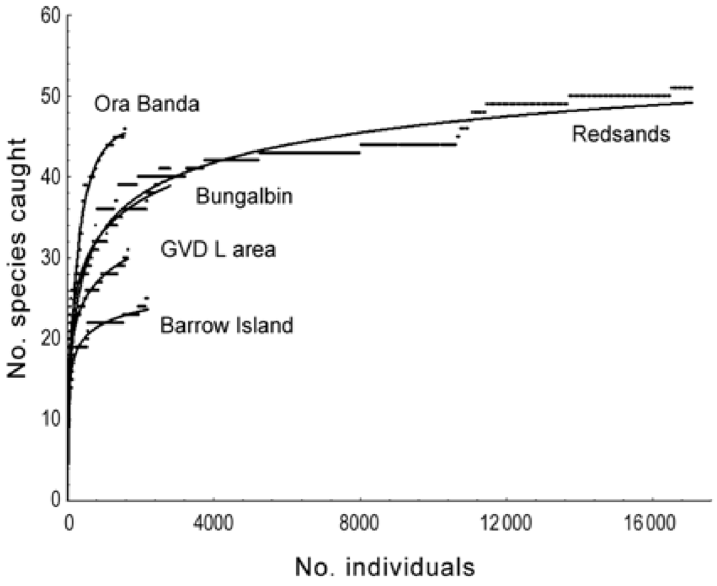
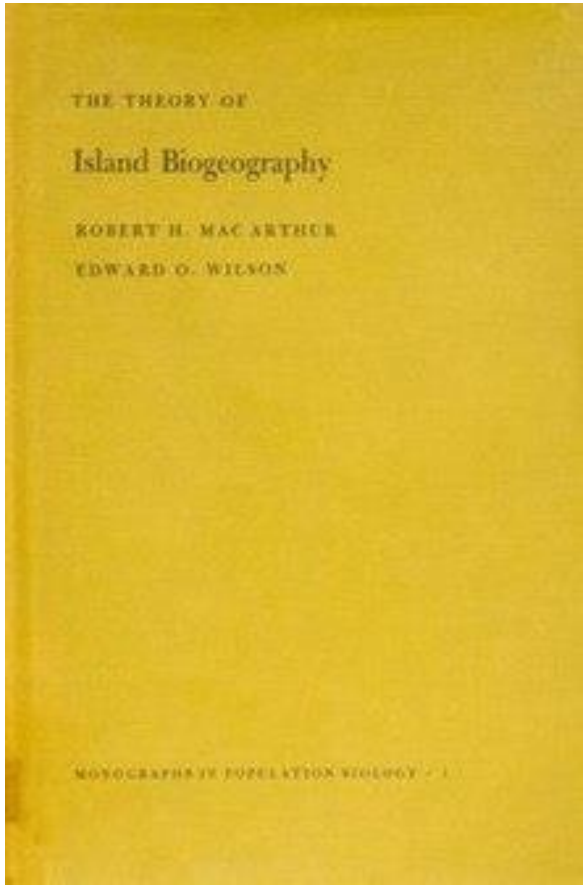
At which site has the majority of biodiversity likely been sampled?



A Ora Banda		0%
B Redsands		0%
C Bungalbin		0%
D GVD L area		0%
E Barrow Island		0%

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



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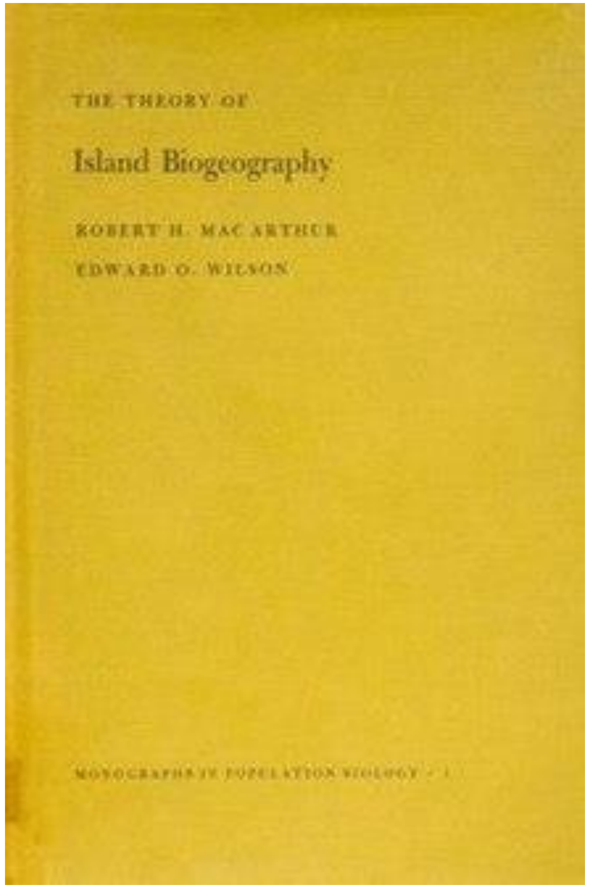
Building on the species-area relationship (SAR), MacArthur and Wilson proposed the **theory of island biogeography**.

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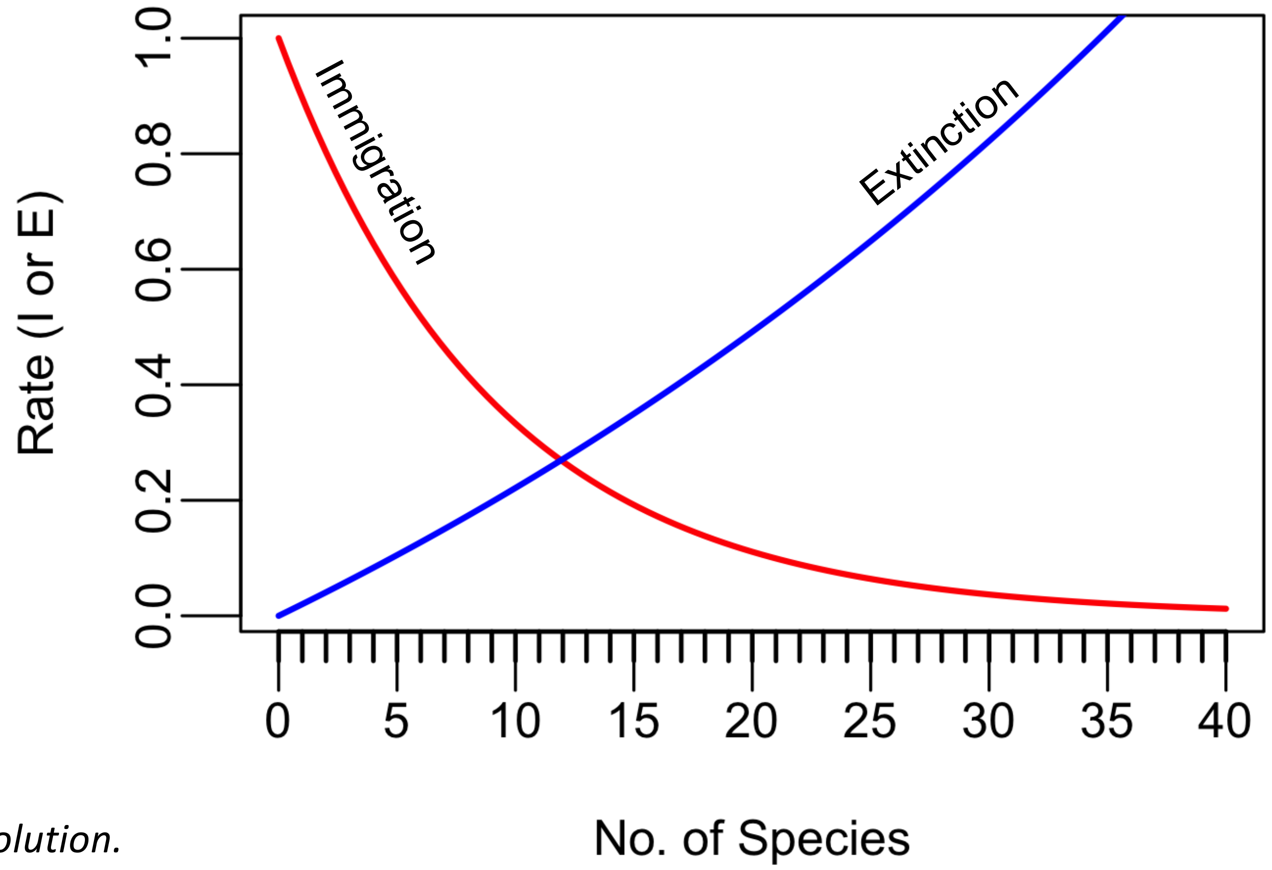
The equilibrium number of species in an "island" habitat is reached when:
the rate of immigration = the rate of extinction



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Immigration rates (species arriving) are **higher when the number of species is low**.

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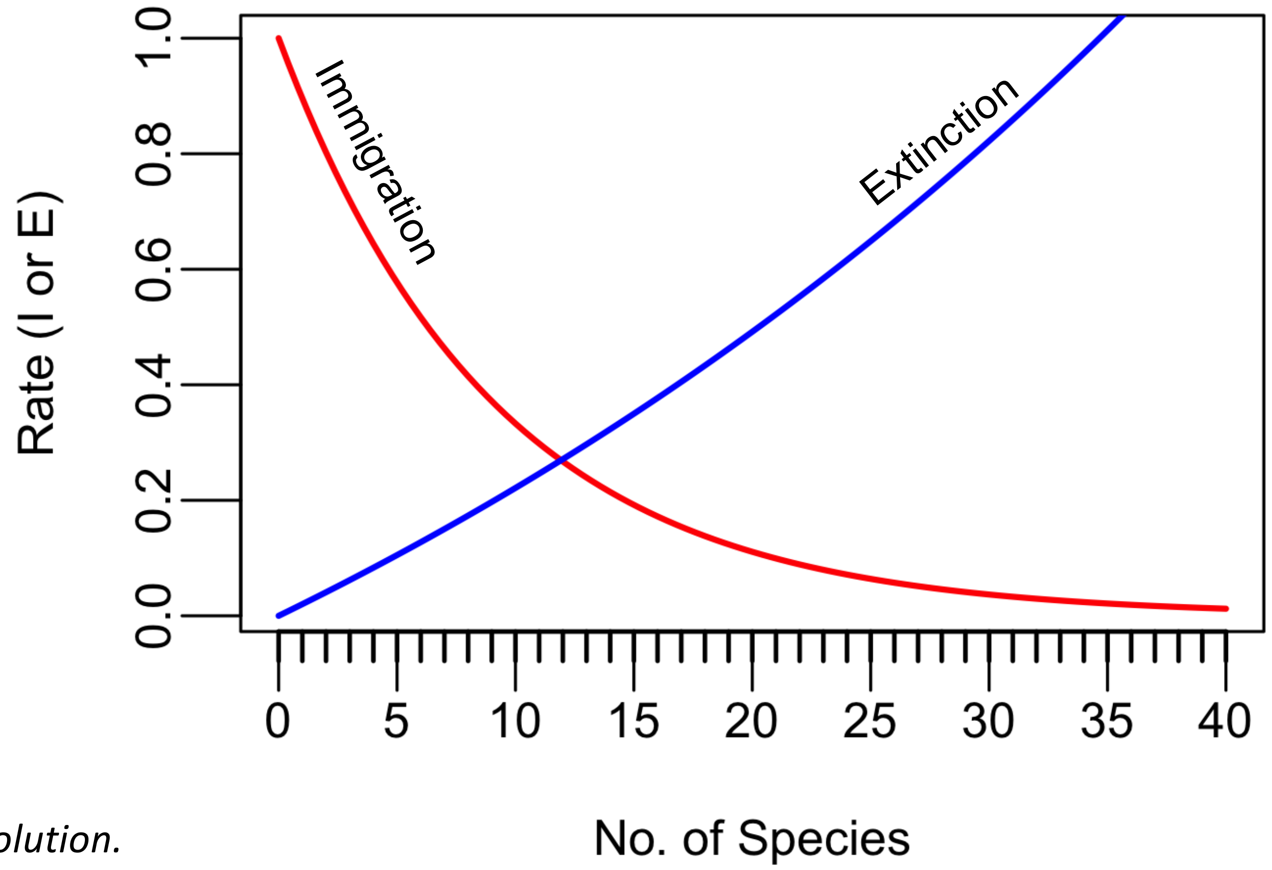

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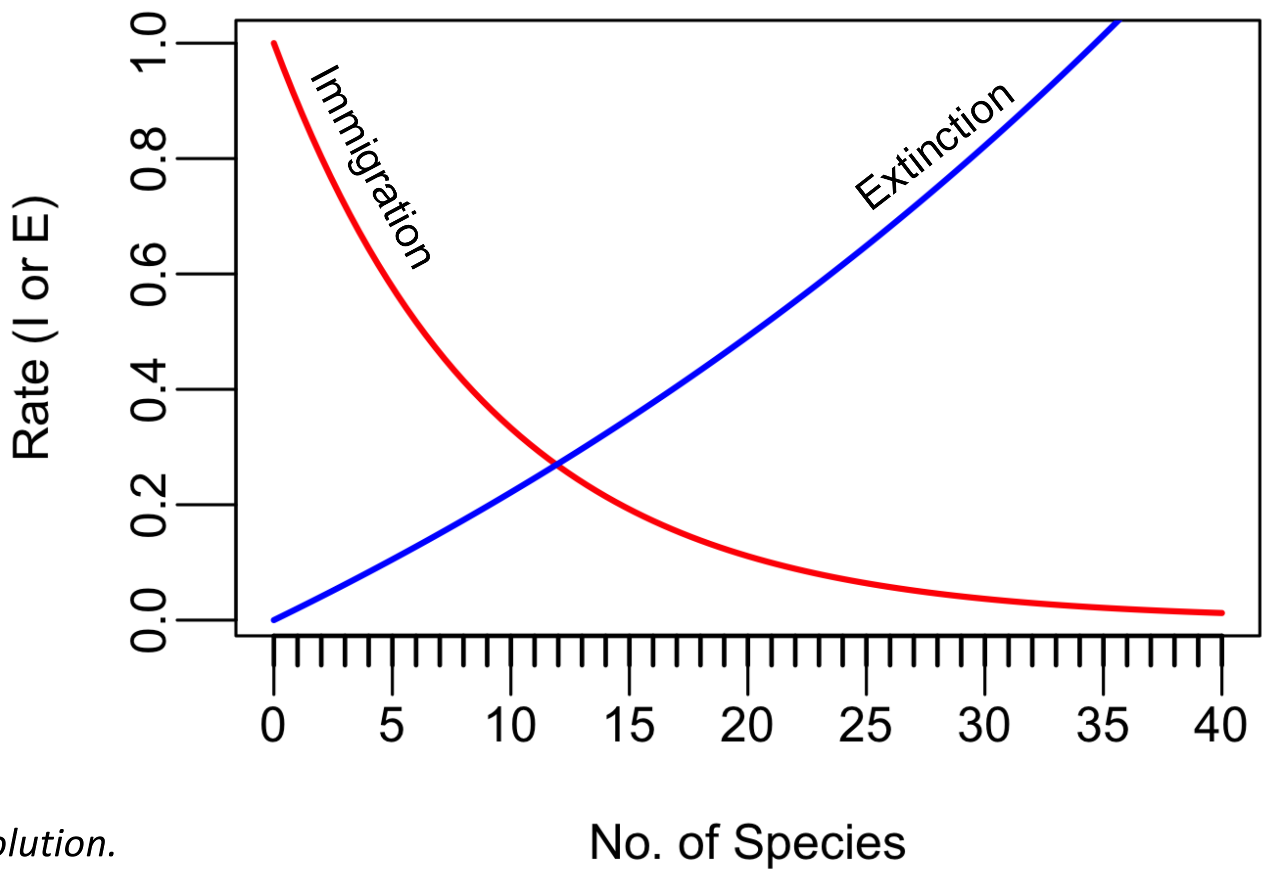
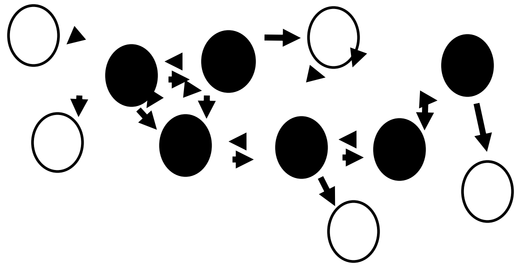


Conceptually similar to Levins' metapopulation model – and to density dependence in logistic growth!



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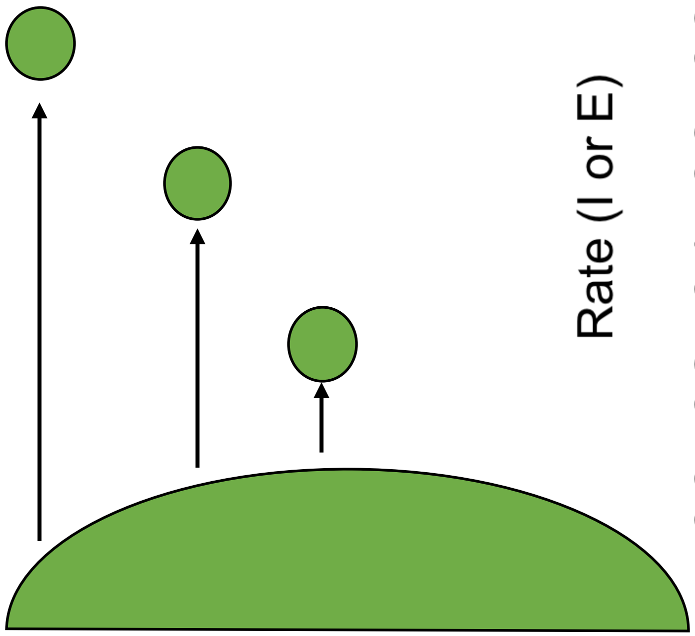
Distance effect: **Closer islands have higher immigration rates** because it's easier for organisms to disperse across short distances.



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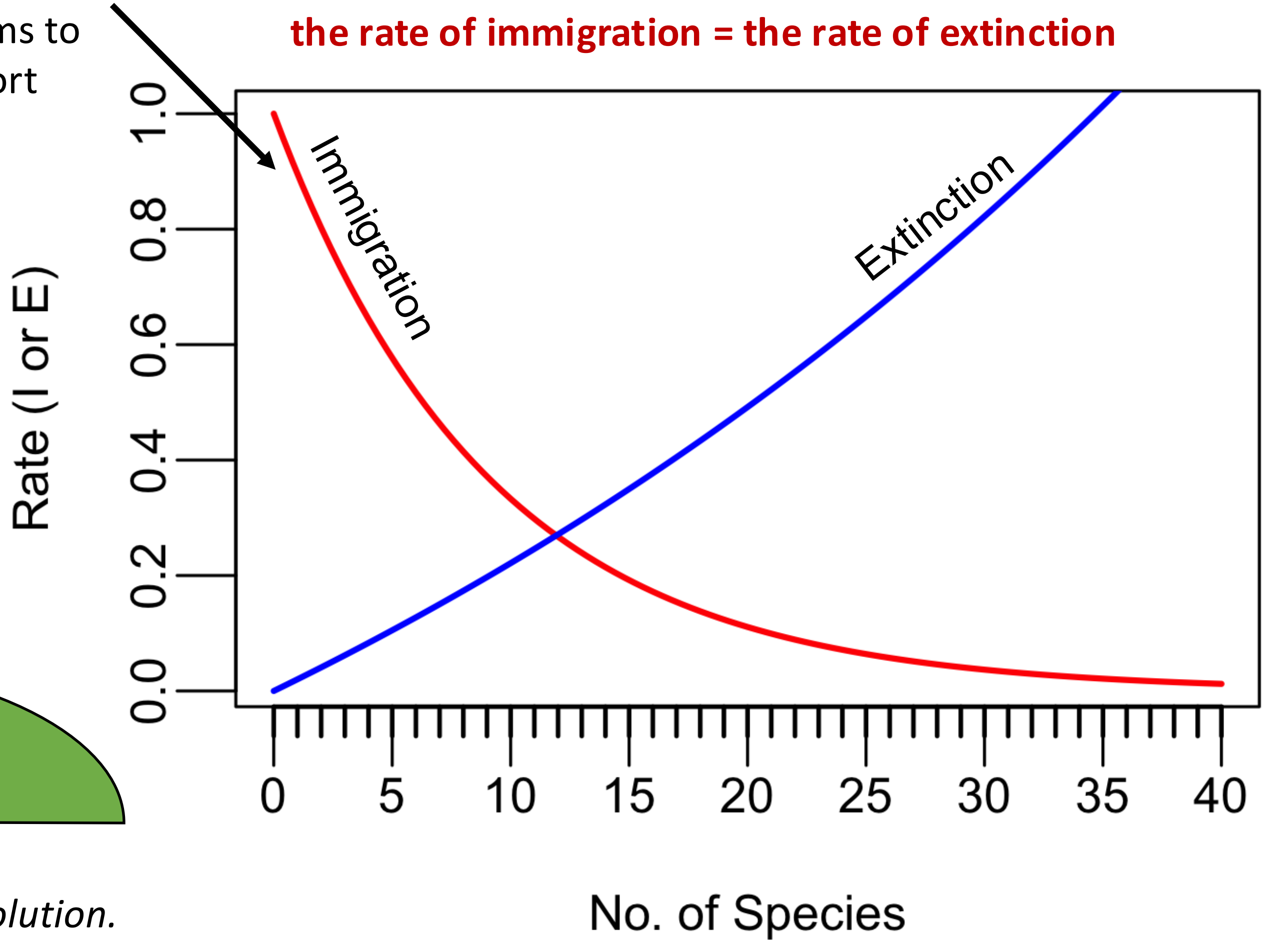

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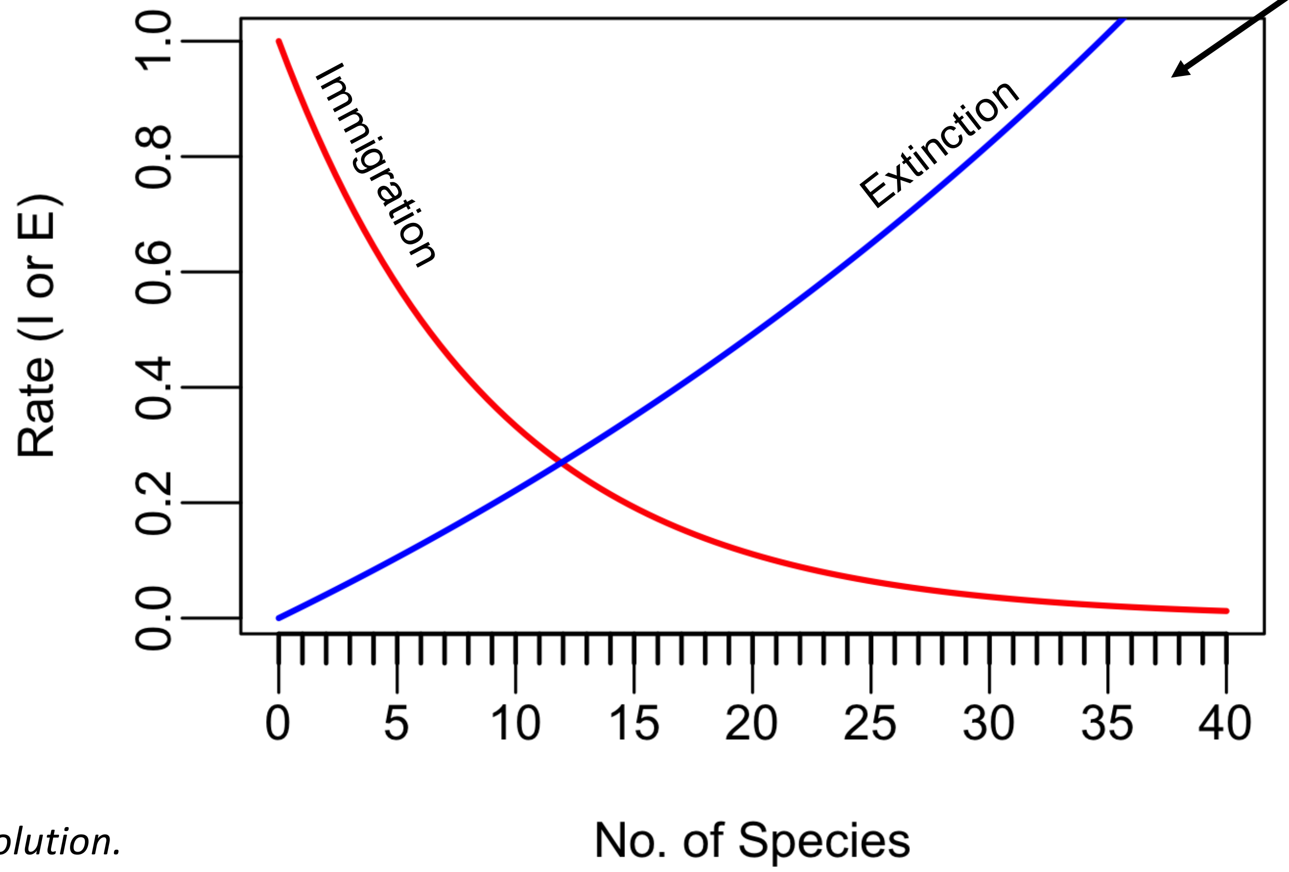
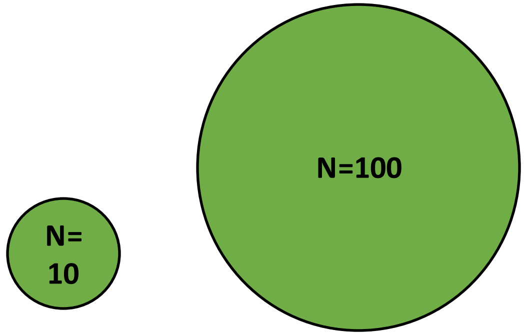


Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.



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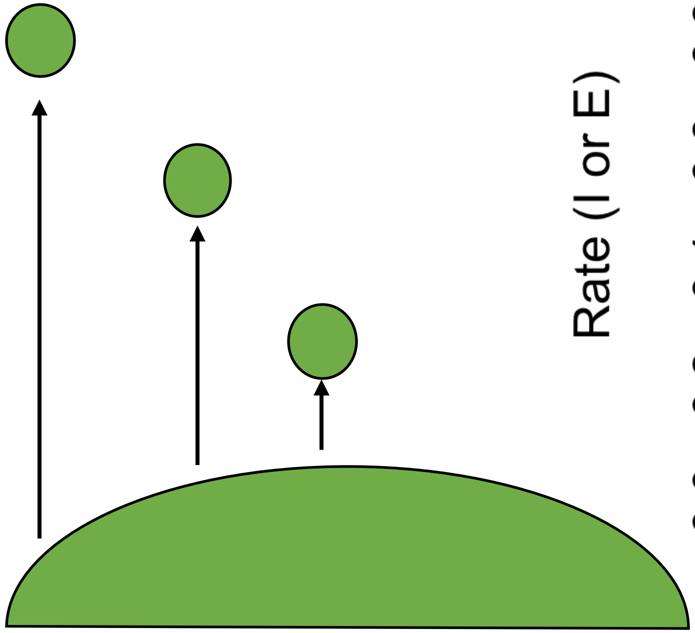

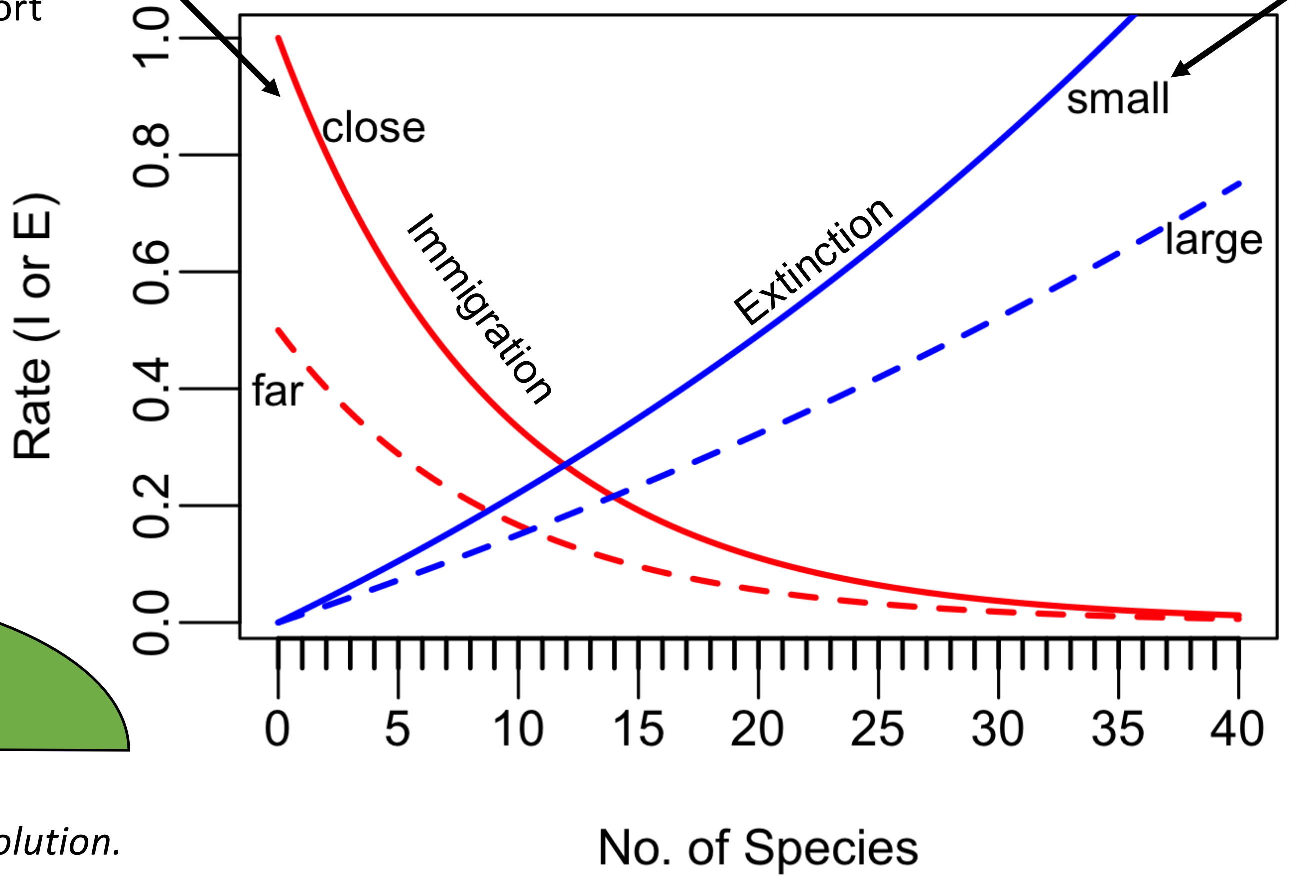

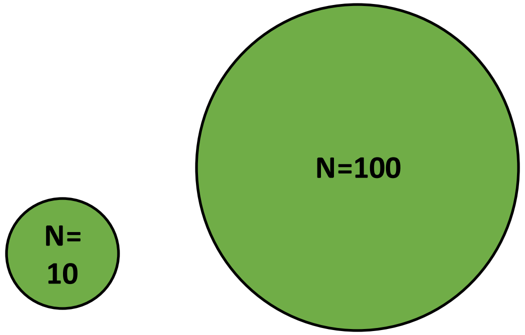

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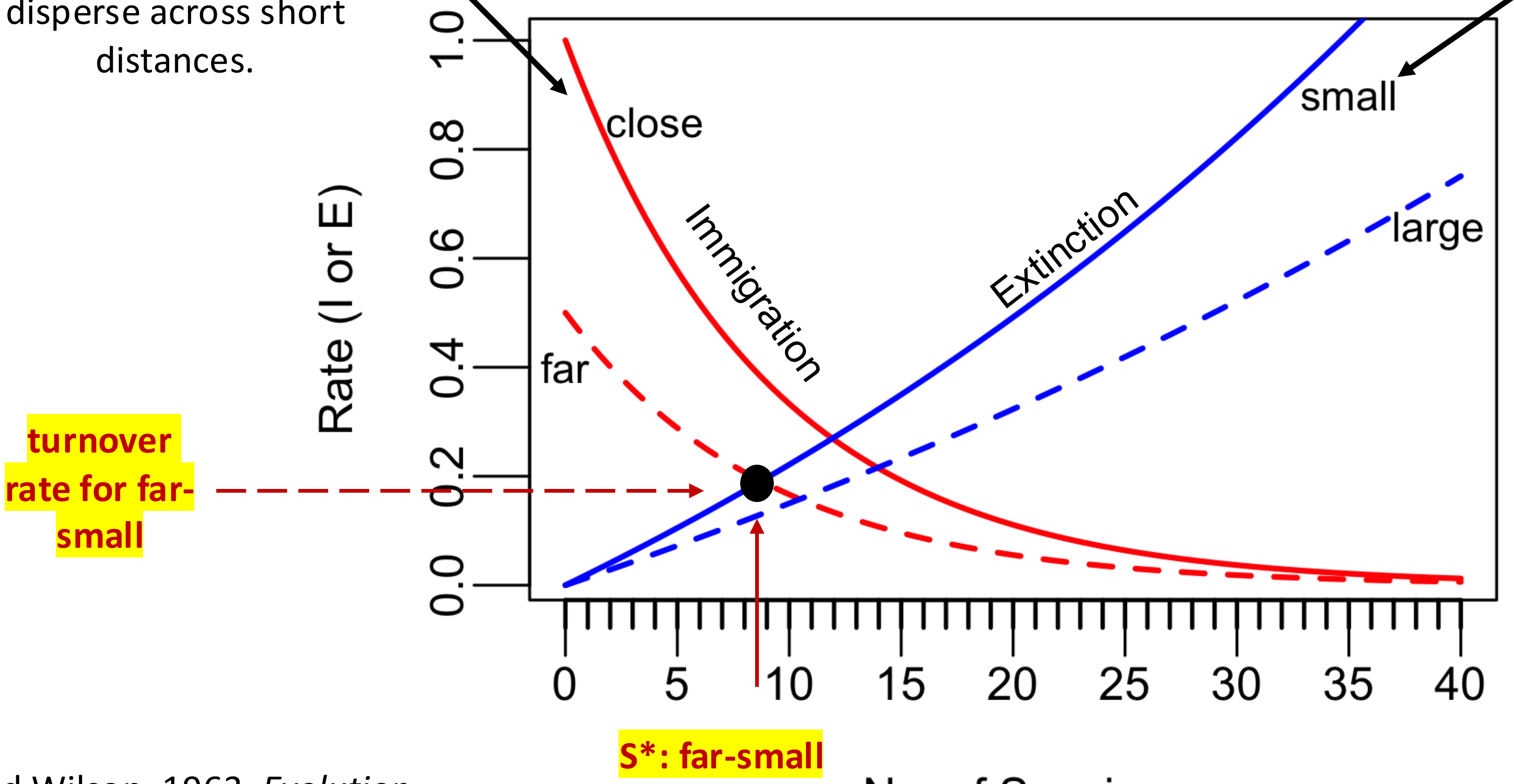

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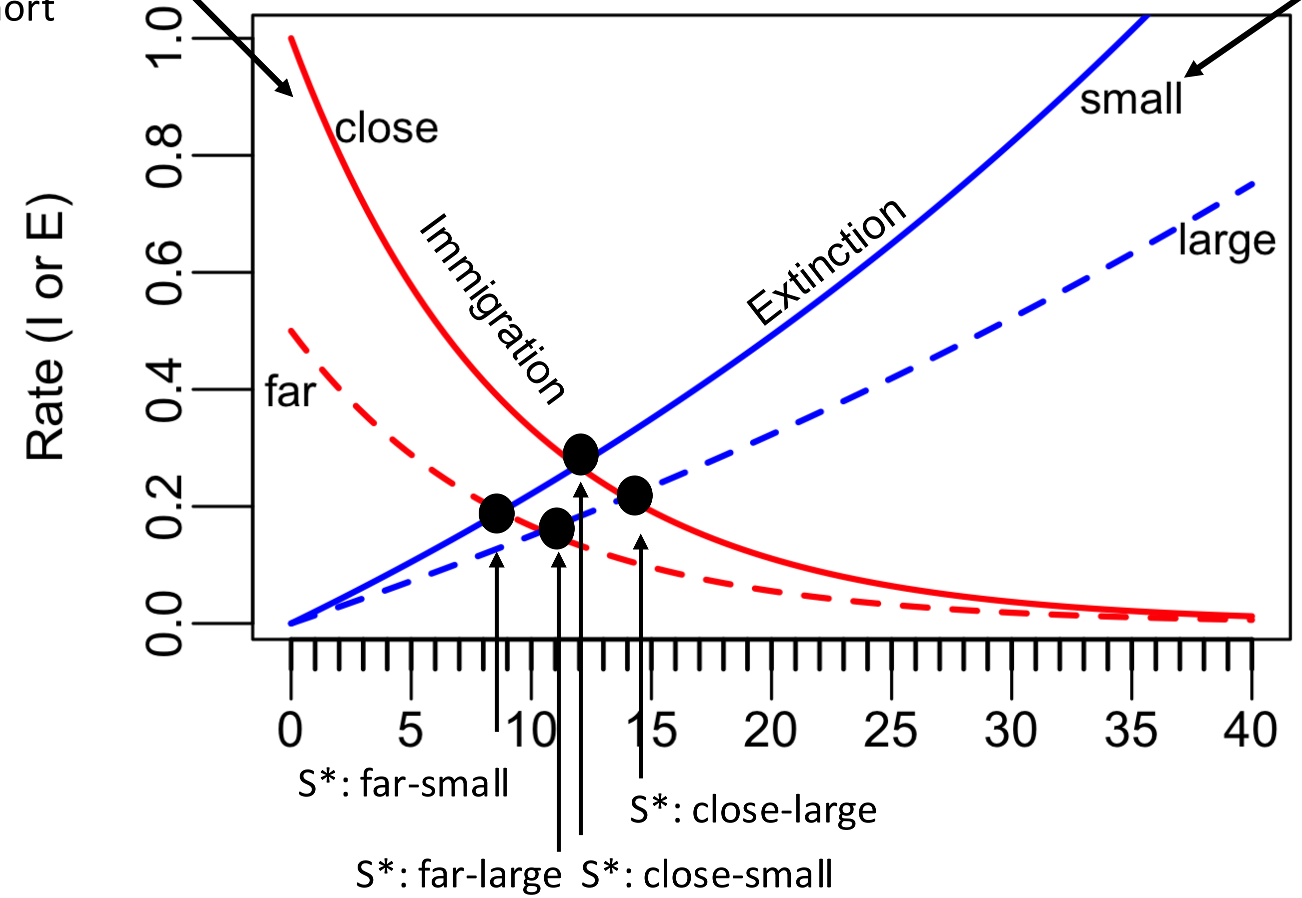

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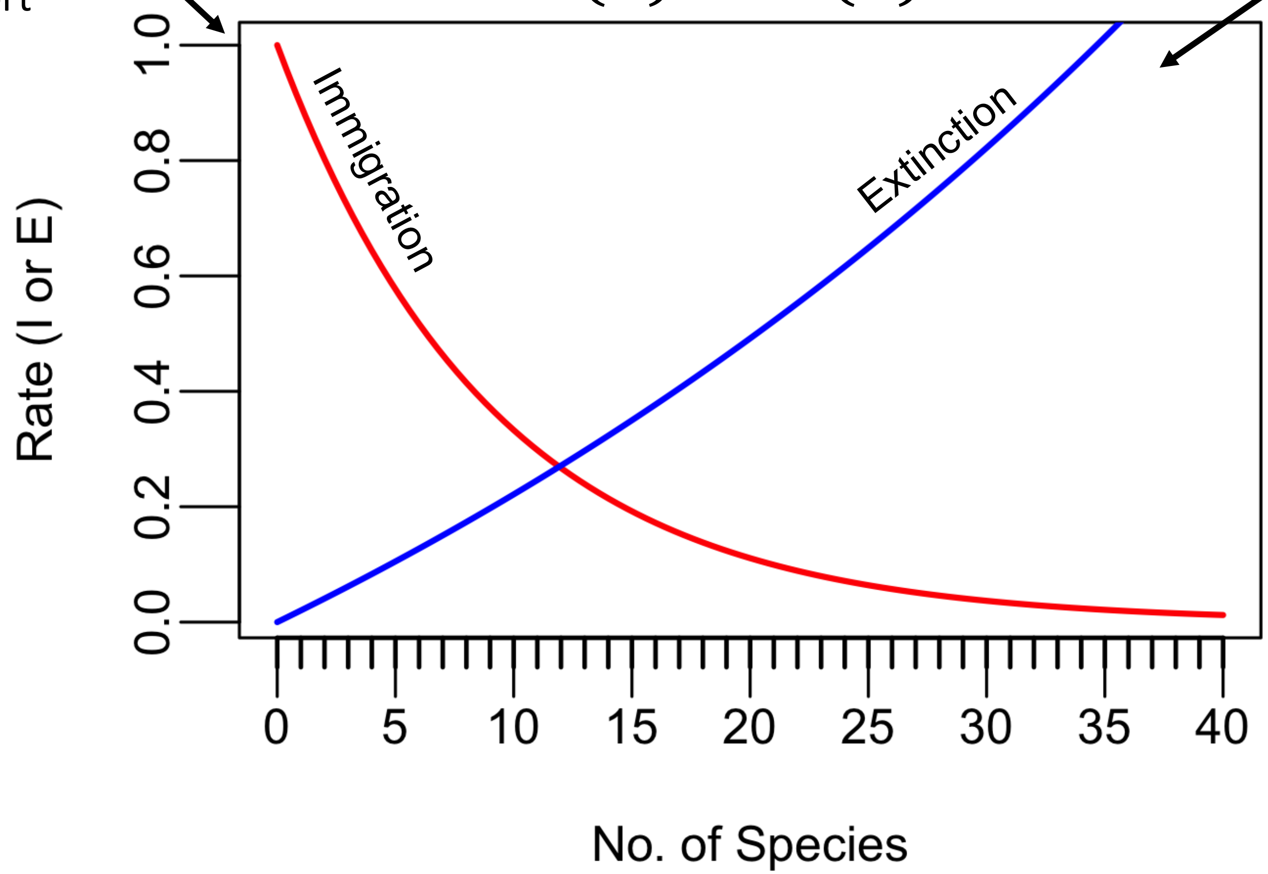

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$$I(S) = i(P - S)e^{-\phi d}$$

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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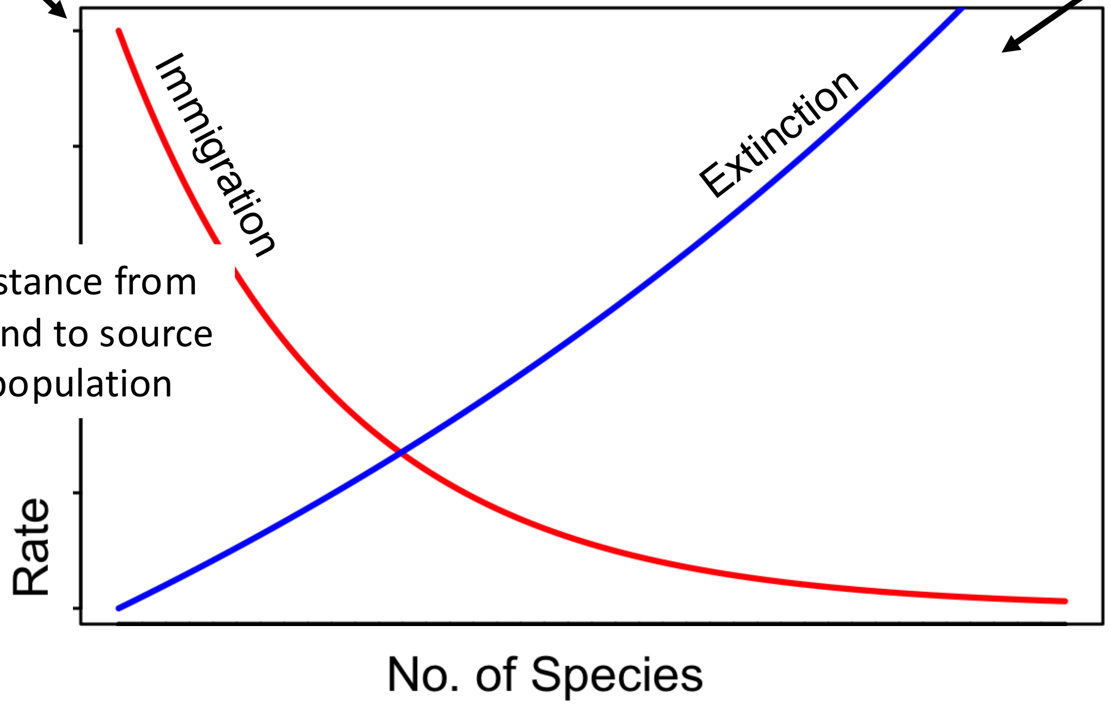

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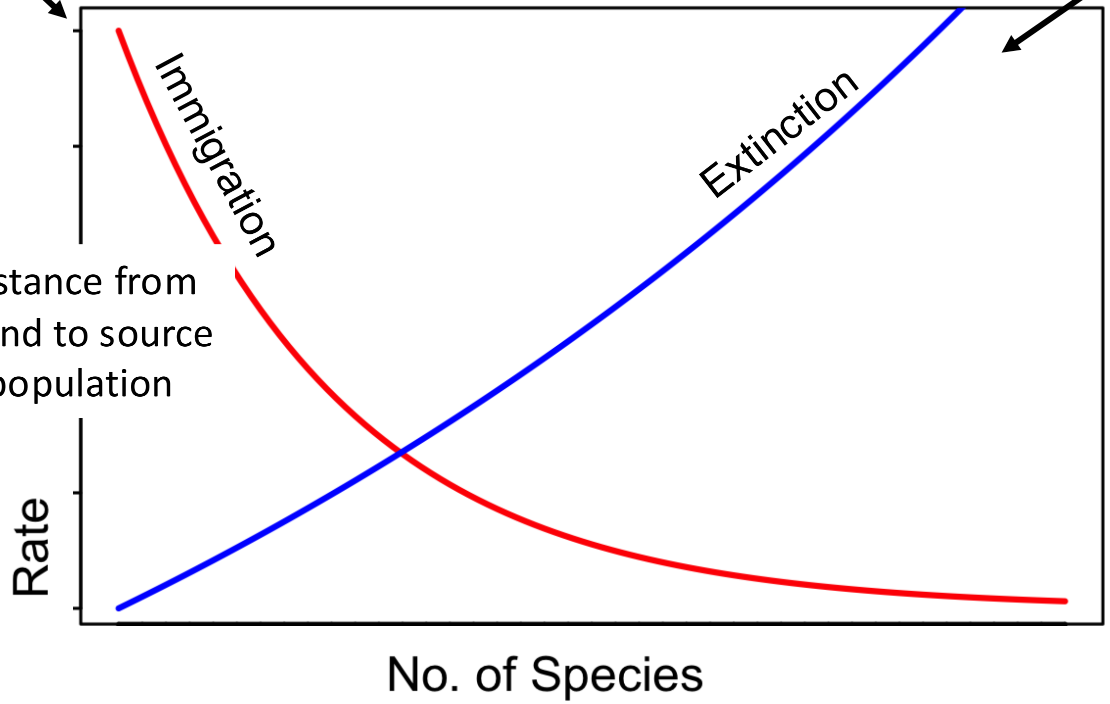


Immigration is highest when species number is lowest and distance is smallest!

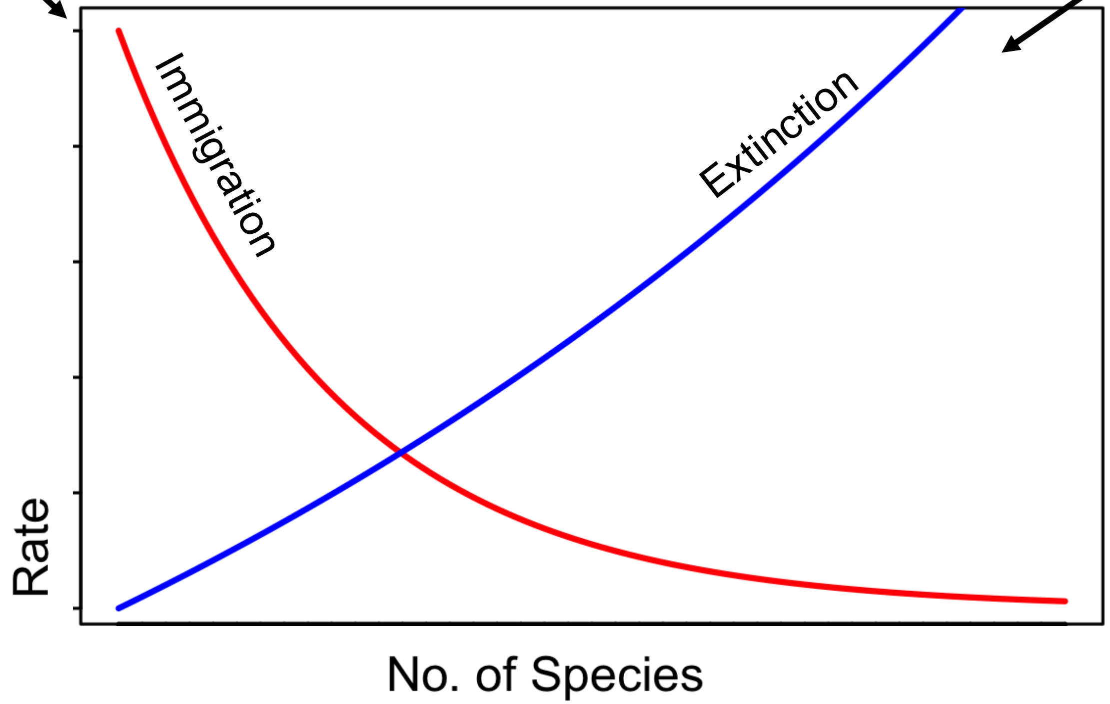
The **theory of island biogeography** offers a null model for the number of species found in a given habitat, predictable from both the **size** of the habitat and its **distance** from a source population.

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

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.

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

number of species on island

fit parameter scaling effect of area on extinction

area of habitat

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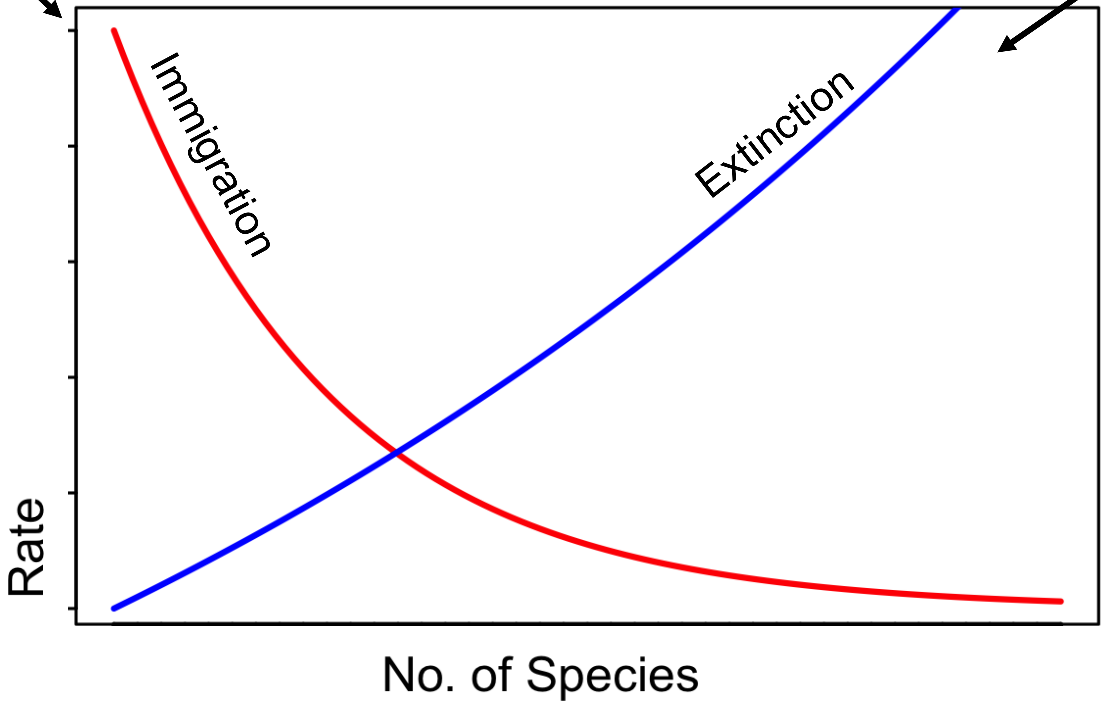

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Extinction is highest when species number is highest and area is smallest!

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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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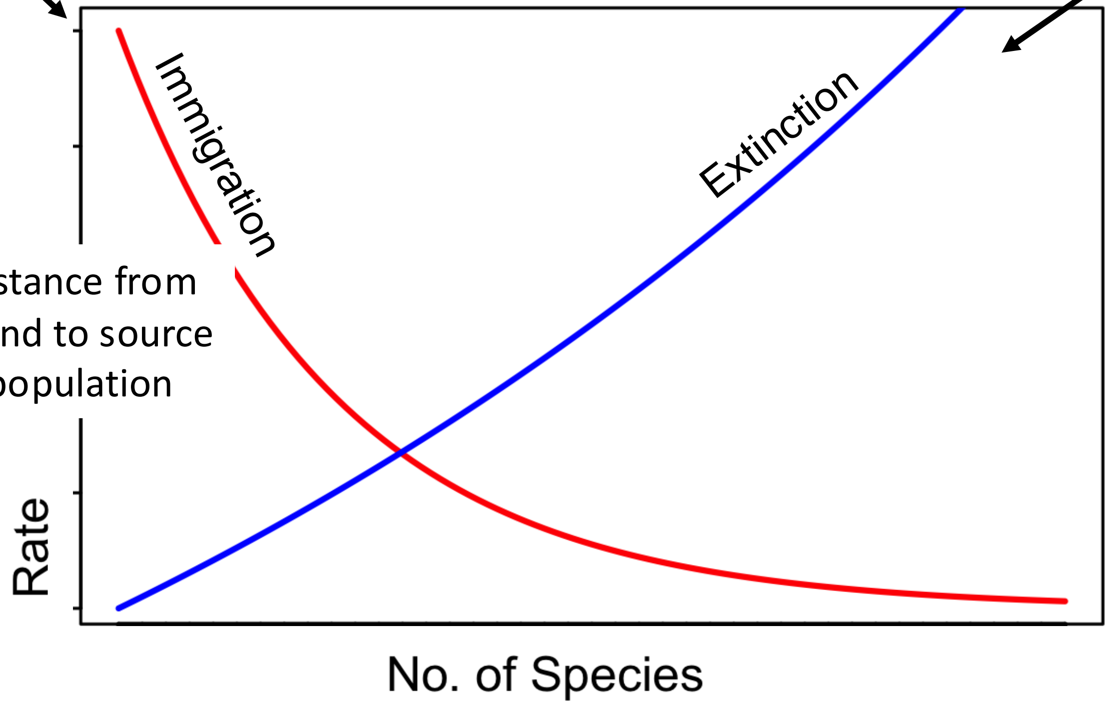

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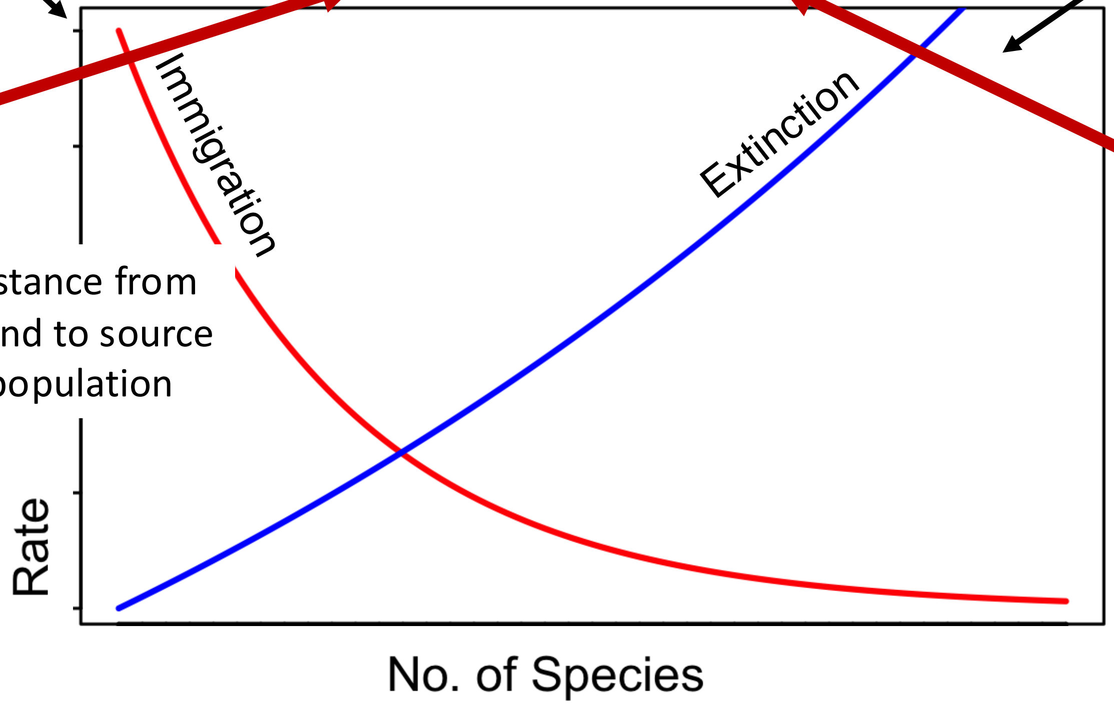

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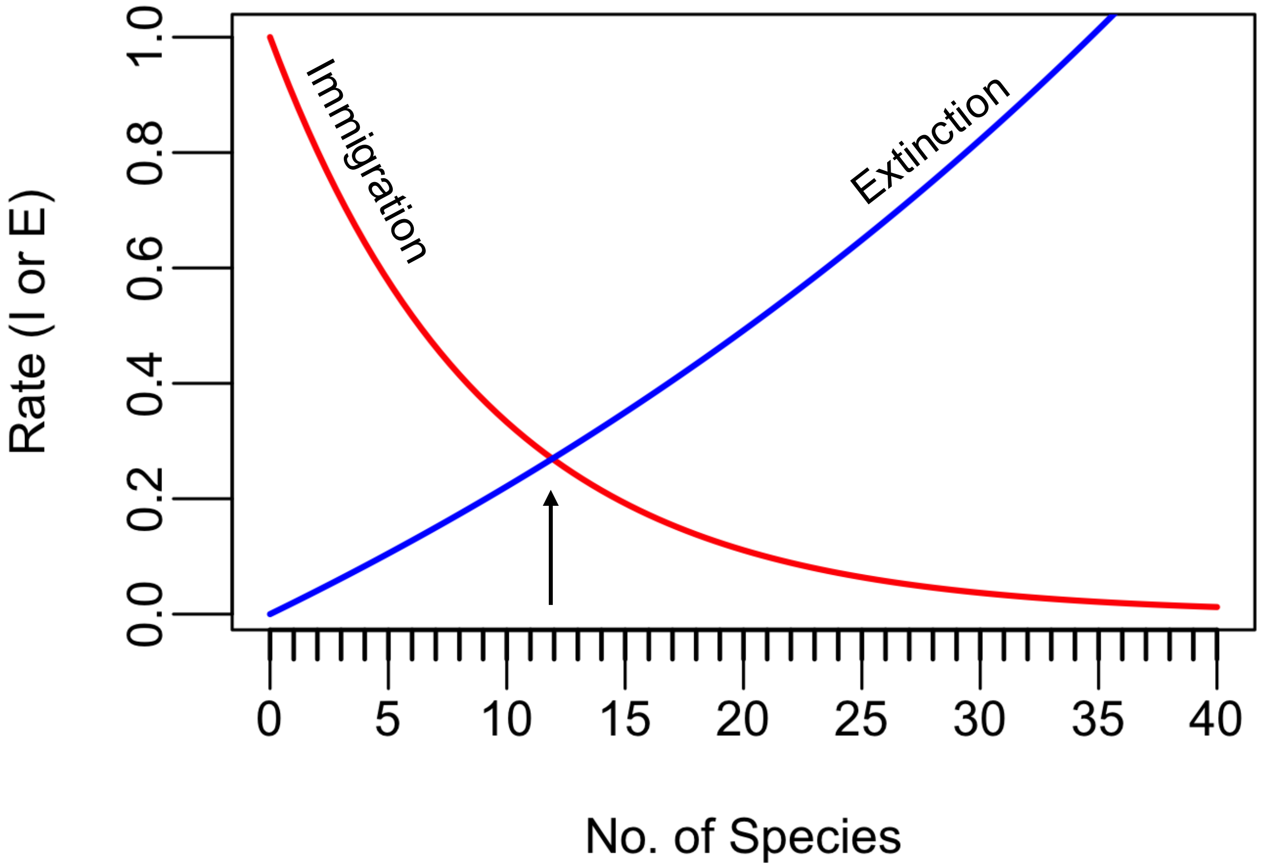
$$S^* = \frac{iPe^{\varepsilon A}}{ie^{\varepsilon A} + e^{\phi d}}$$



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

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The equilibrium number of species in an "island" habitat is reached when:

the rate of immigration = the rate of extinction

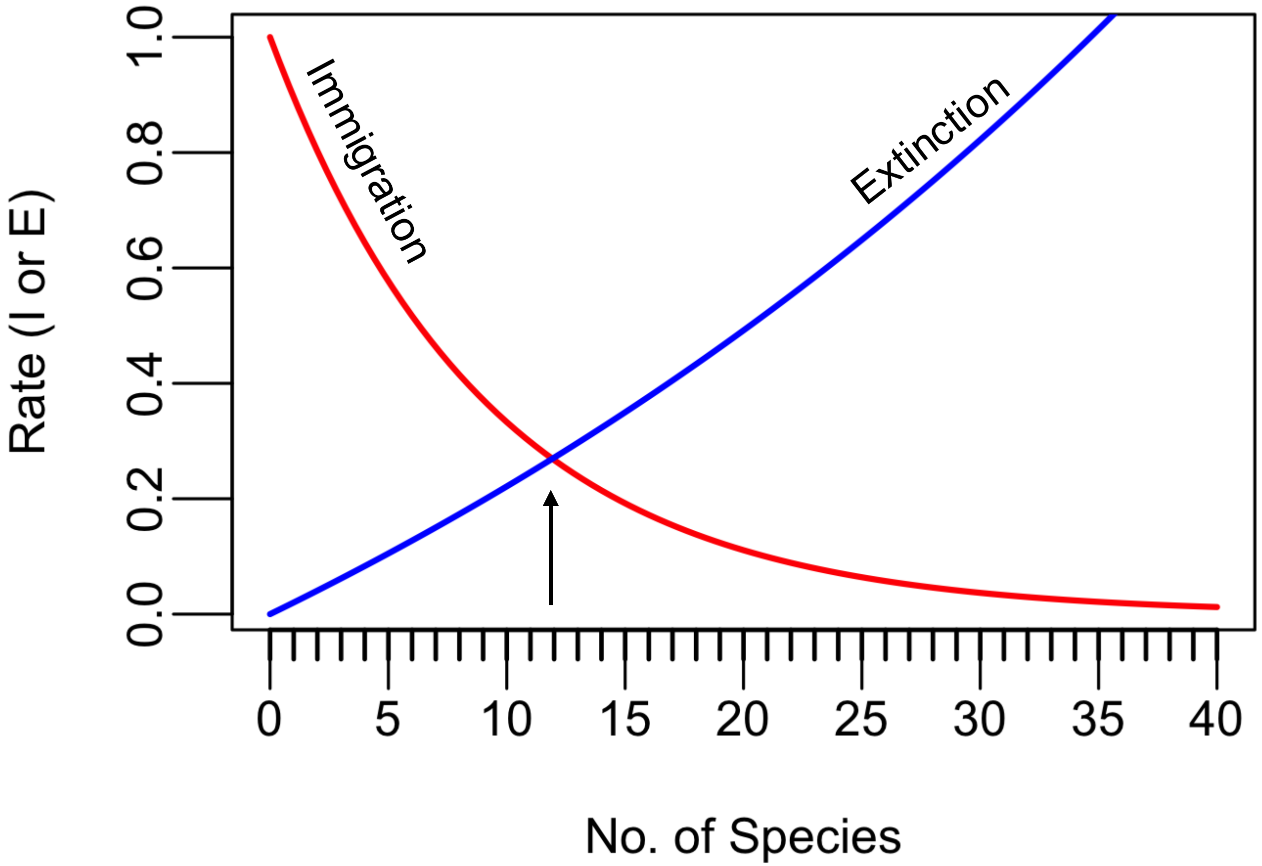
increases with number of species in source pool

increases with area of island

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

decreases with distance from with distance from mainland

equilibrium number of species



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

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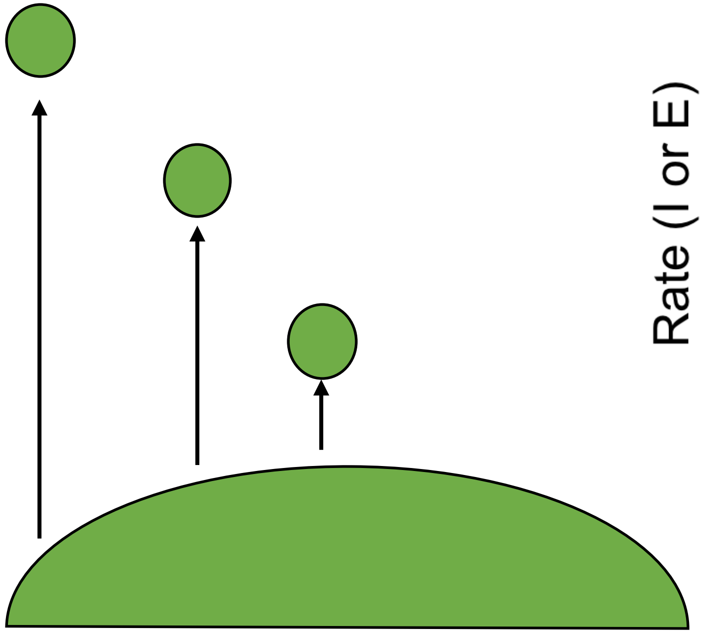
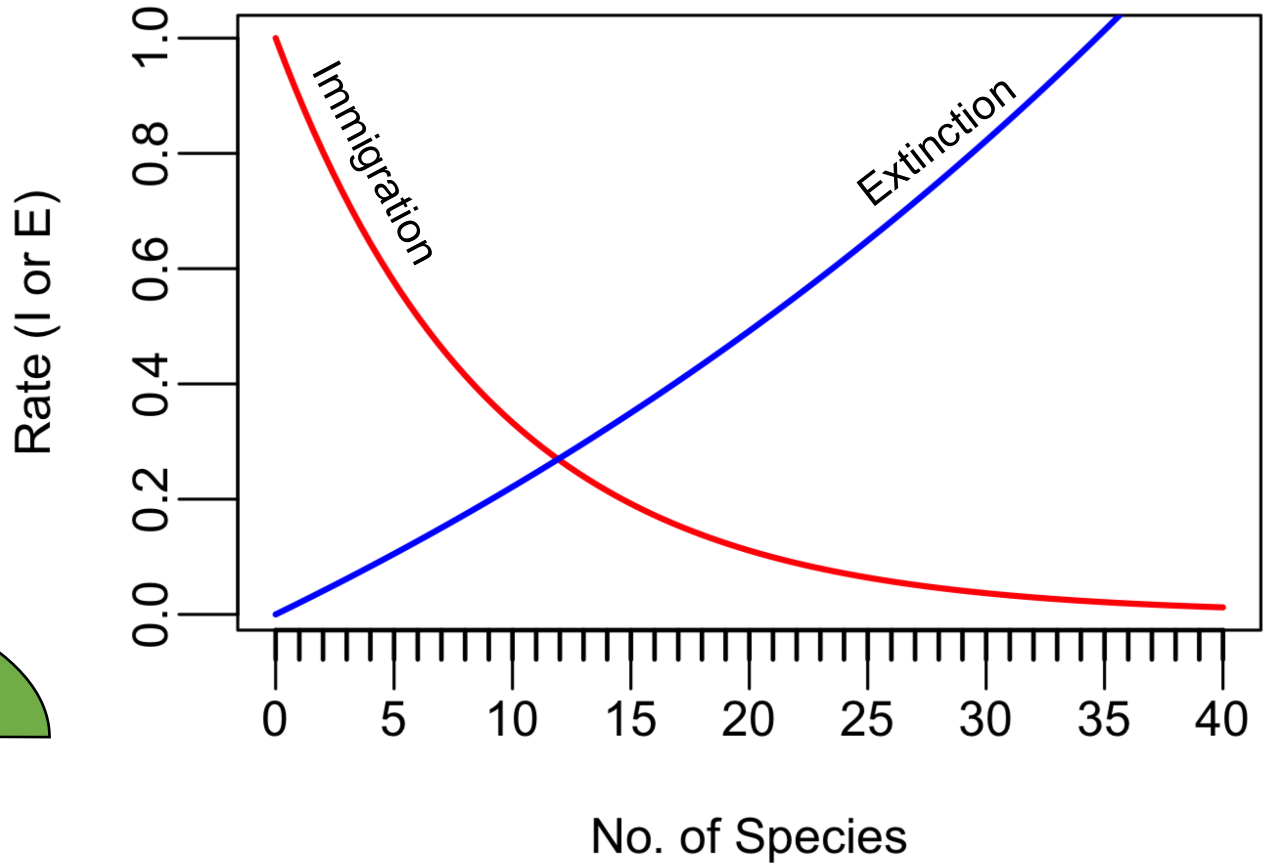
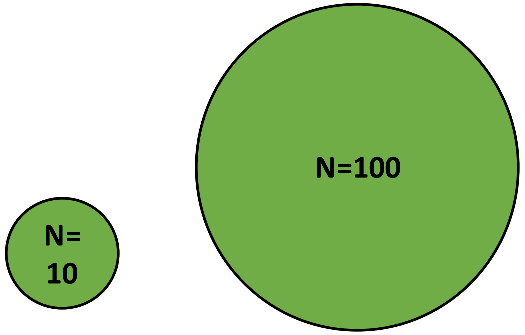


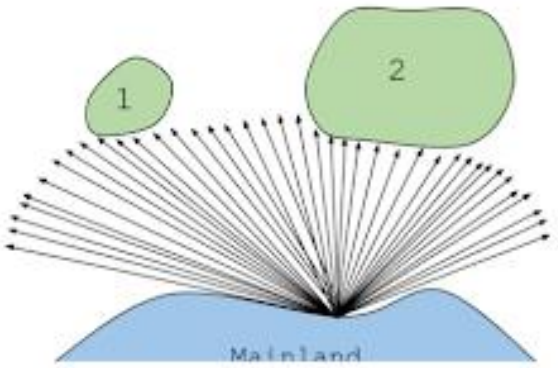




Extensions to the **theory of island biogeography**…

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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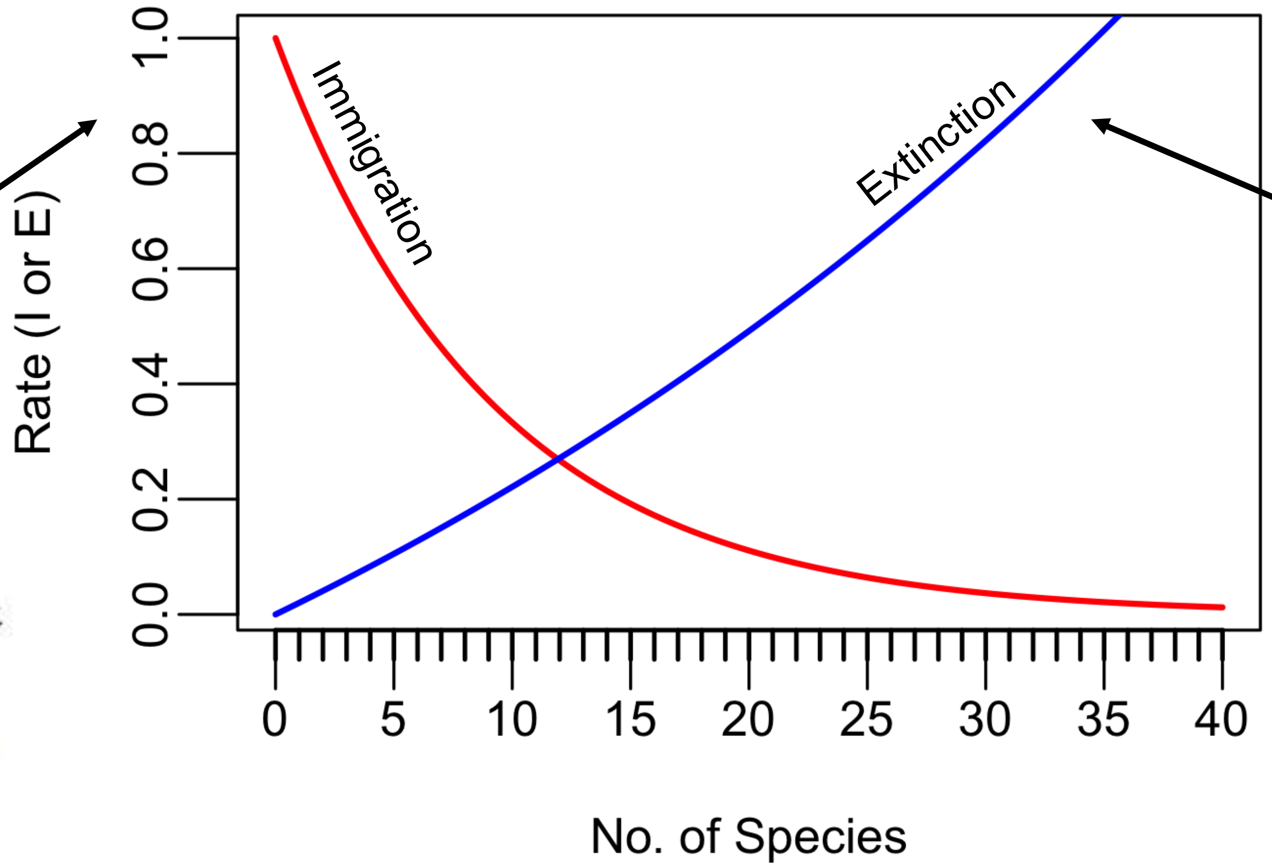
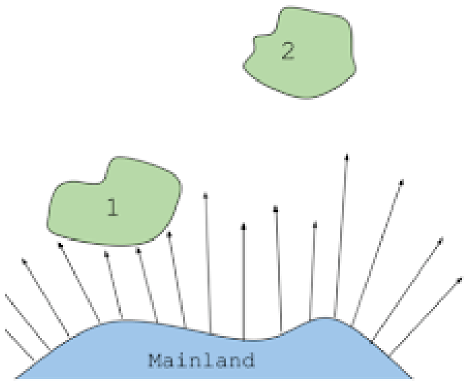


Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.

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

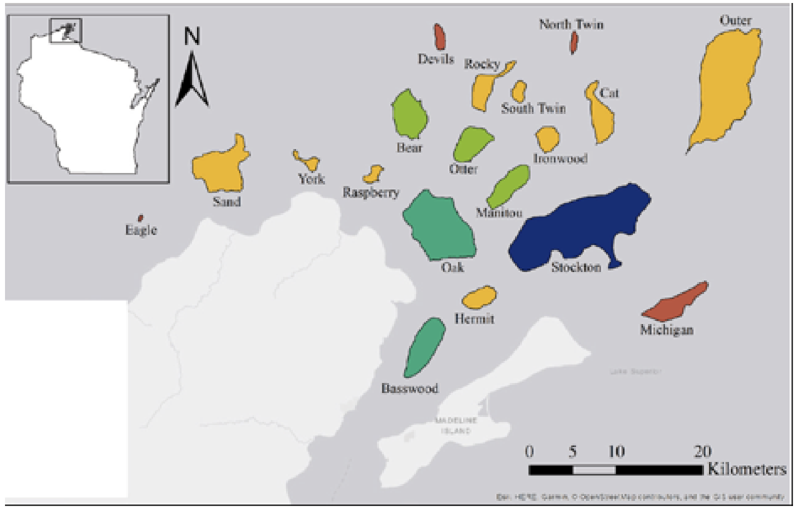


Wk9-Lect9-Mar6

Visual settings

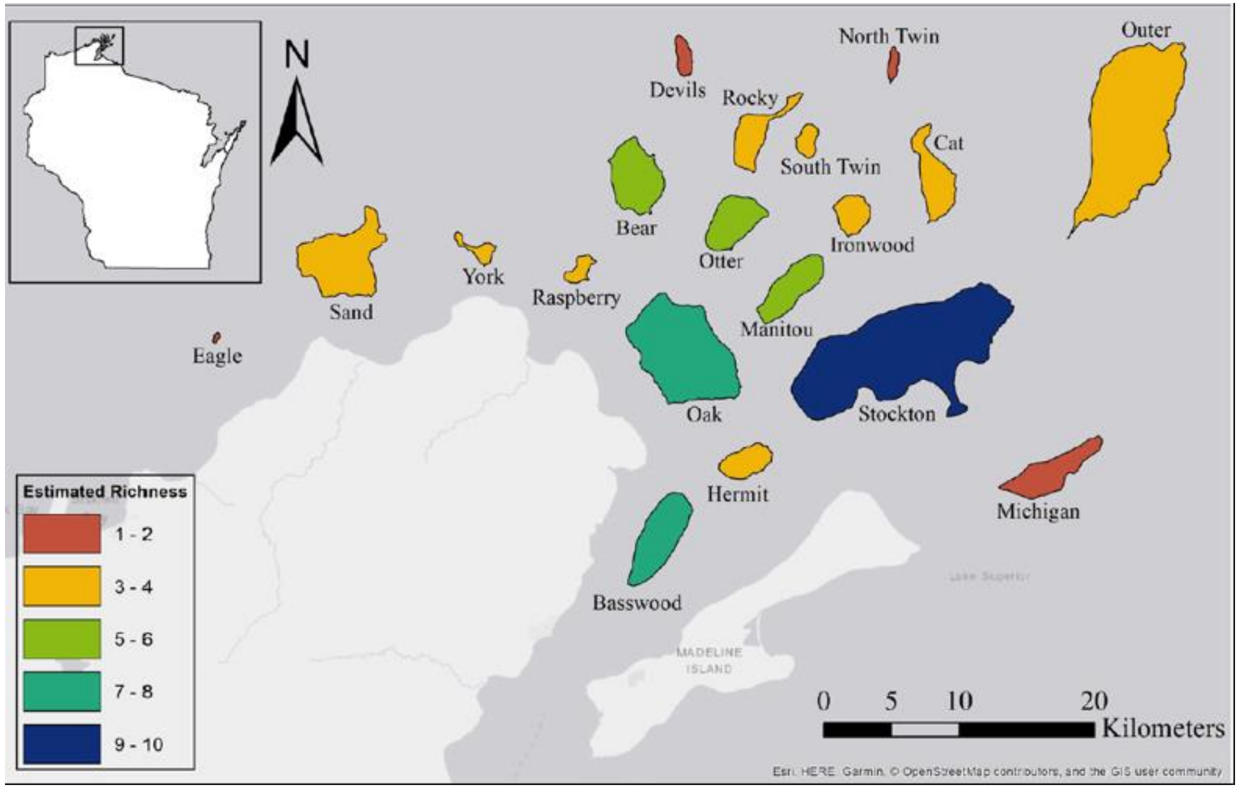
Edit

Each island is colored according to the number of carnivore species inhabiting the island. Which color likely corresponds to the highest number of species?



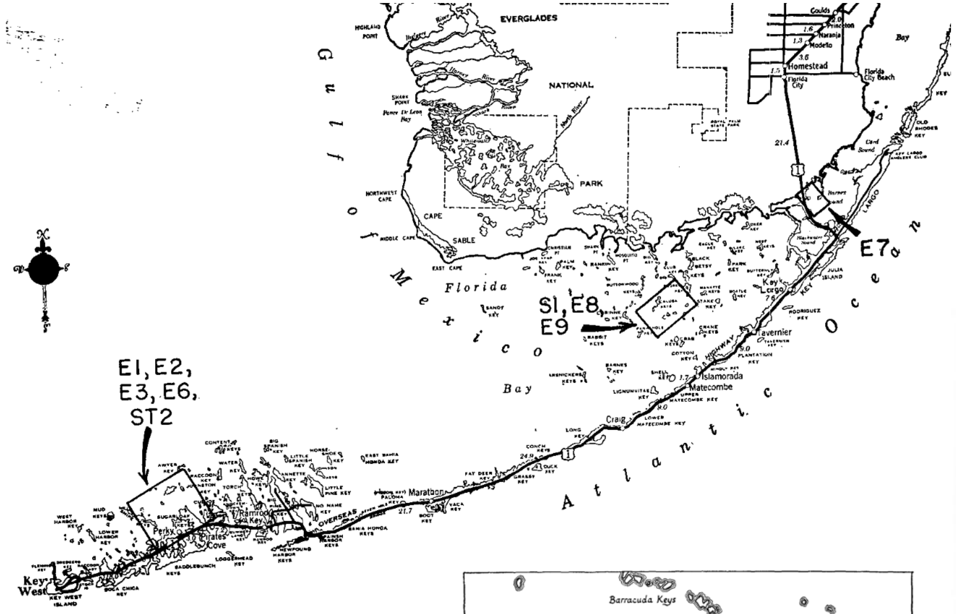
A yellow		0%
B lime green		0%
C red		0%
D navy blue		0%
E turquoise		0%

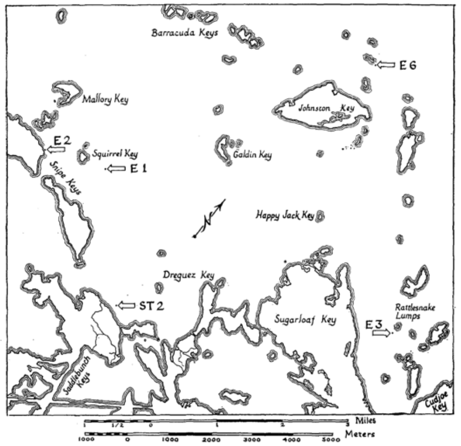
The importance of island size vs. distance varied for different species!

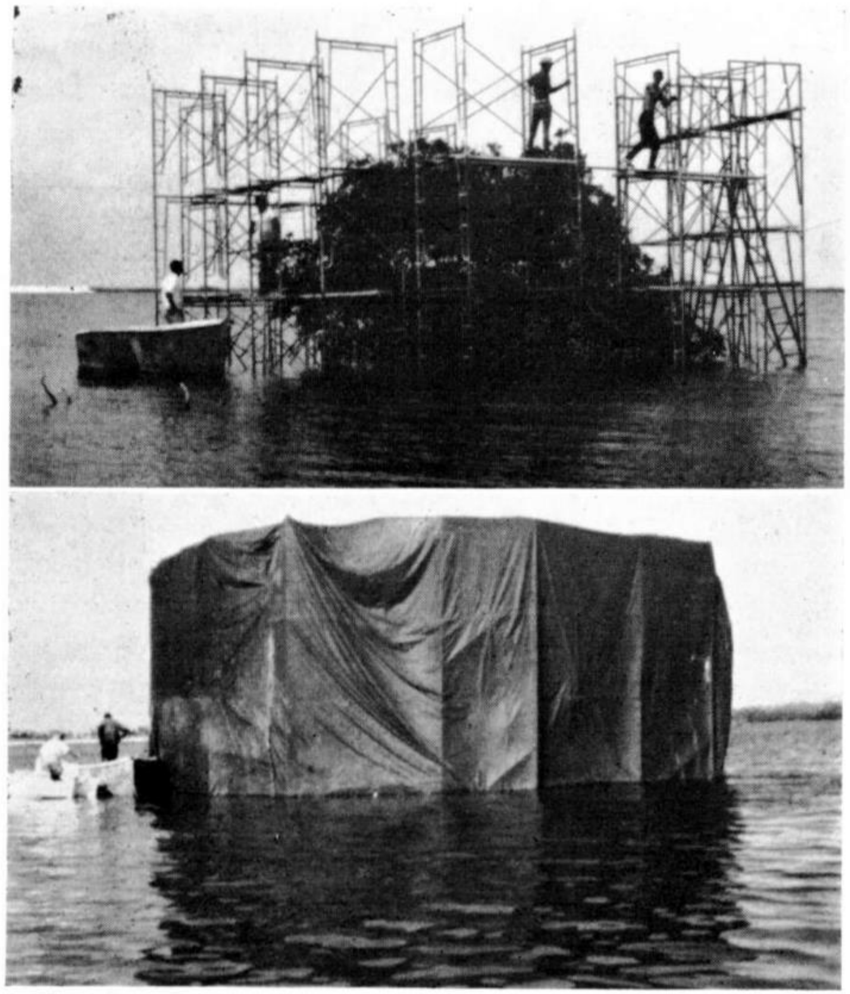


Allen et al. 2018. *Community Ecology.*

Wilson and Simberloff field-tested island biogeography 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).

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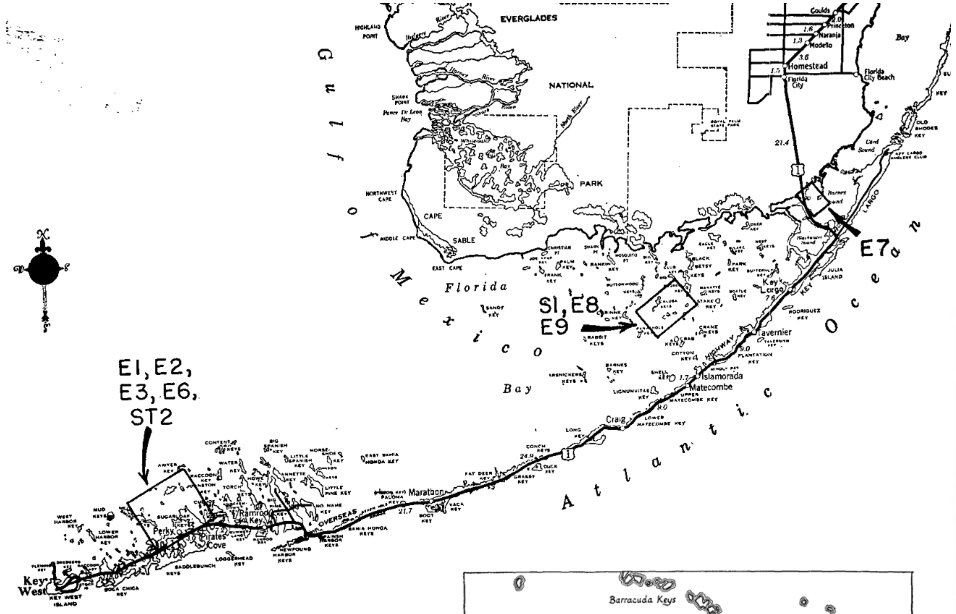

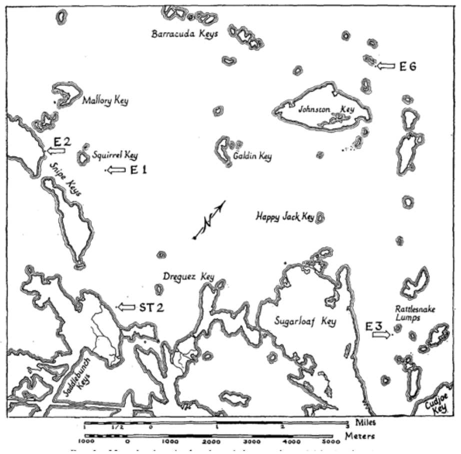

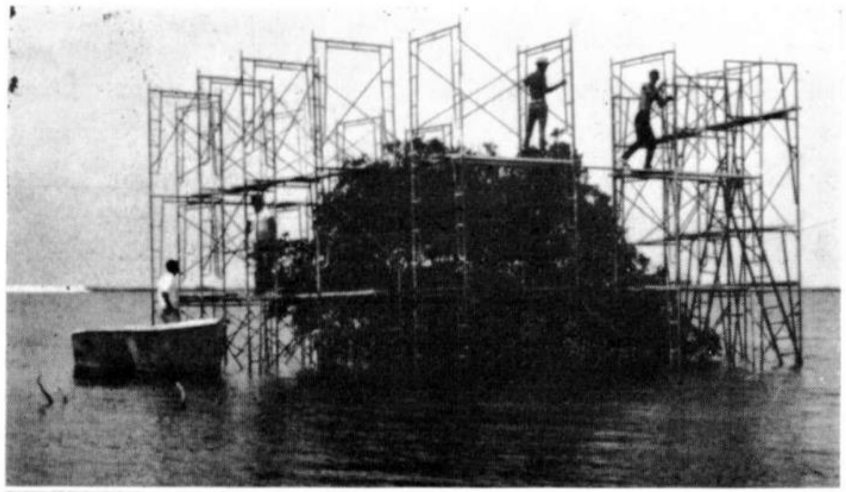

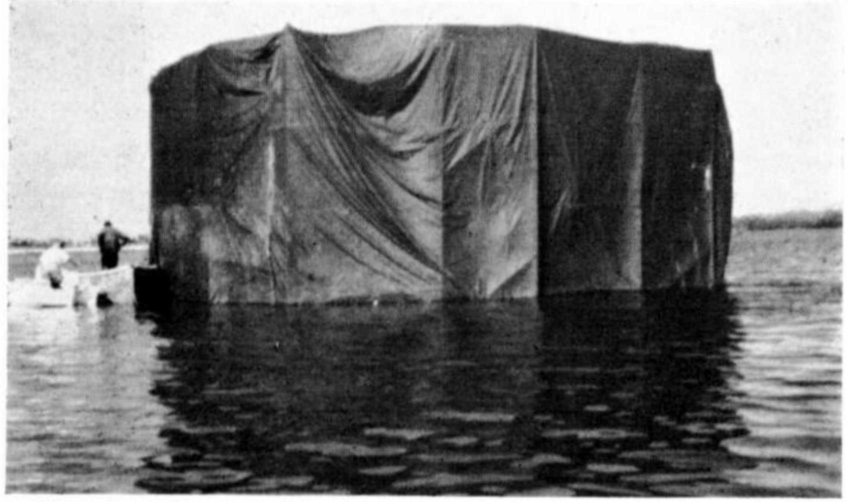

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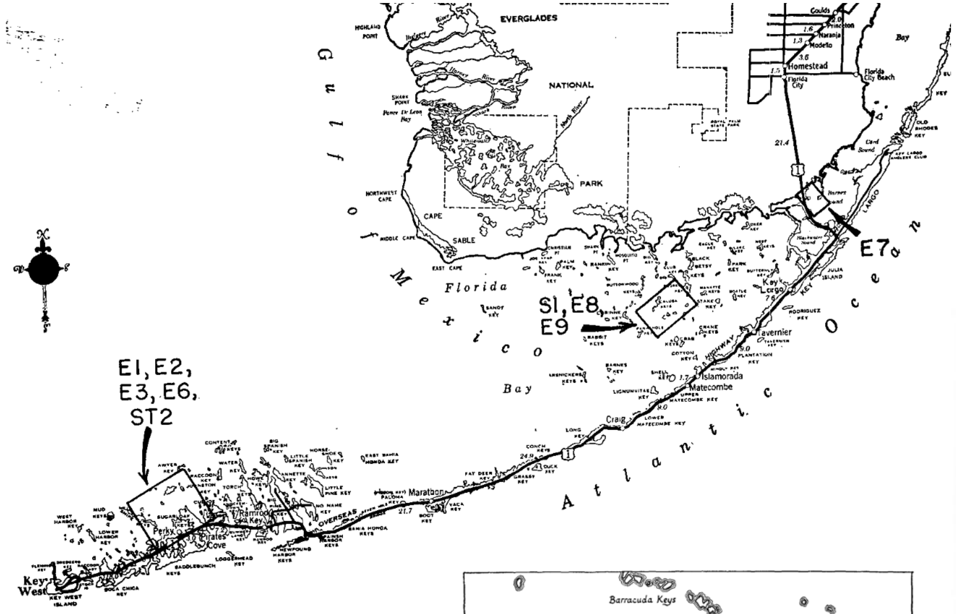

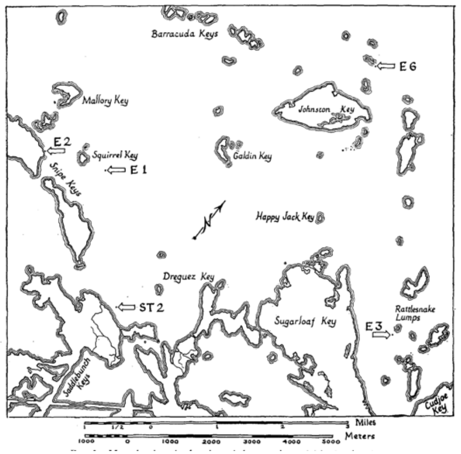

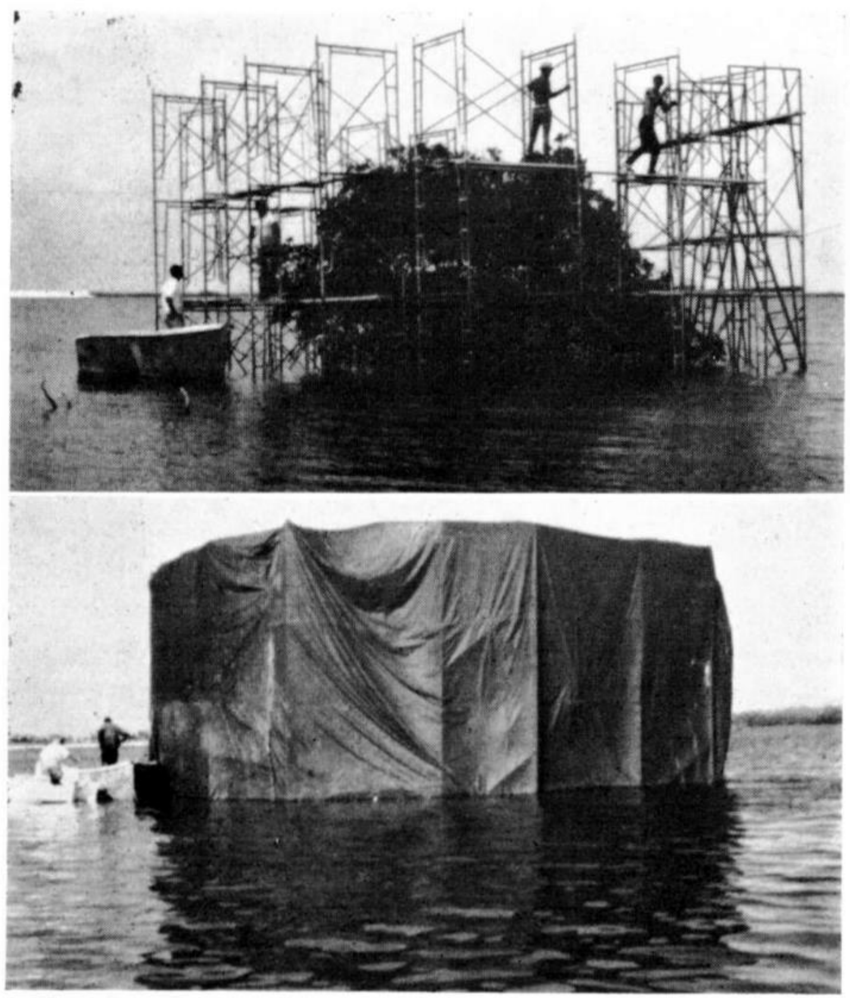

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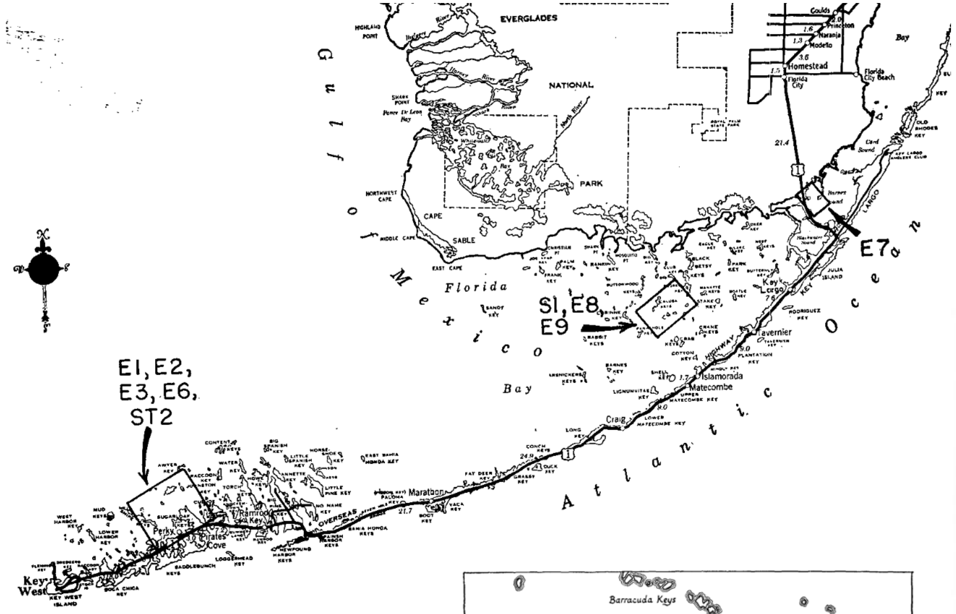

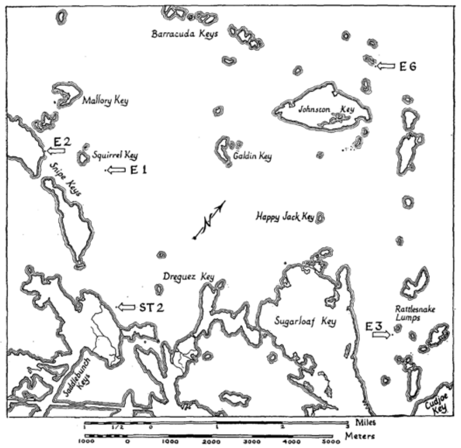

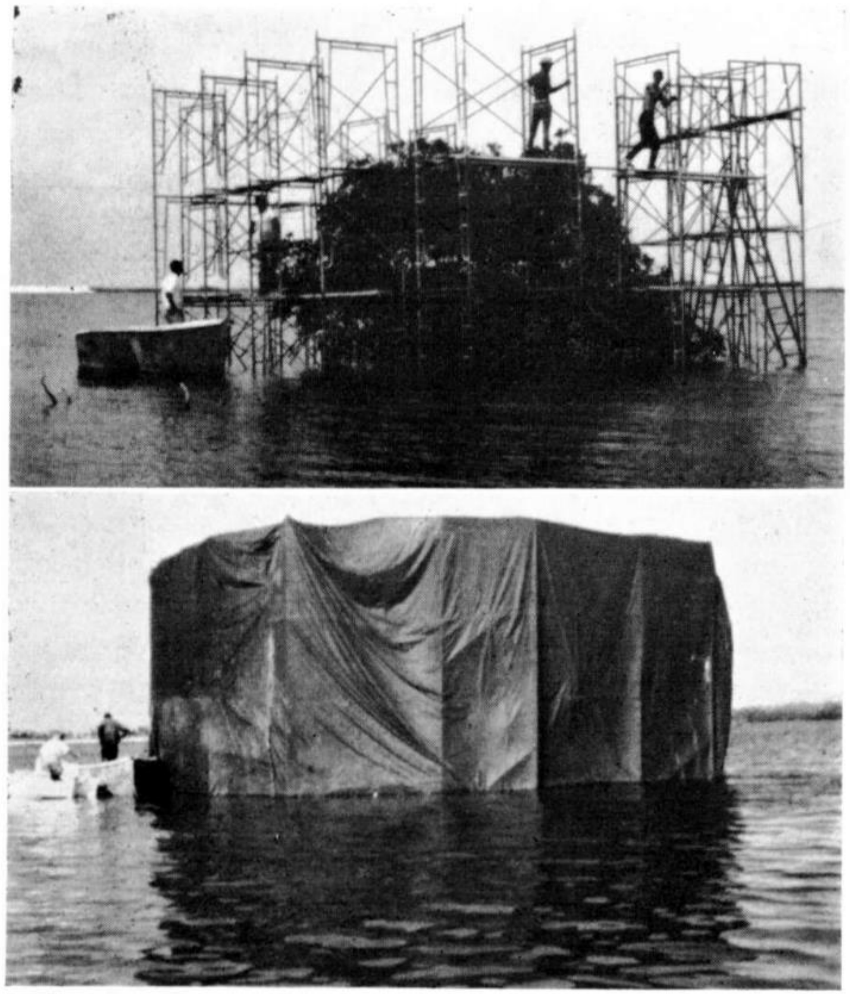

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- They catalogued their progressive recolonization after fumigation, tracking its predictability based on size and distance of these islands to the source pool.

Simberloff. 1969. *Ecology.*
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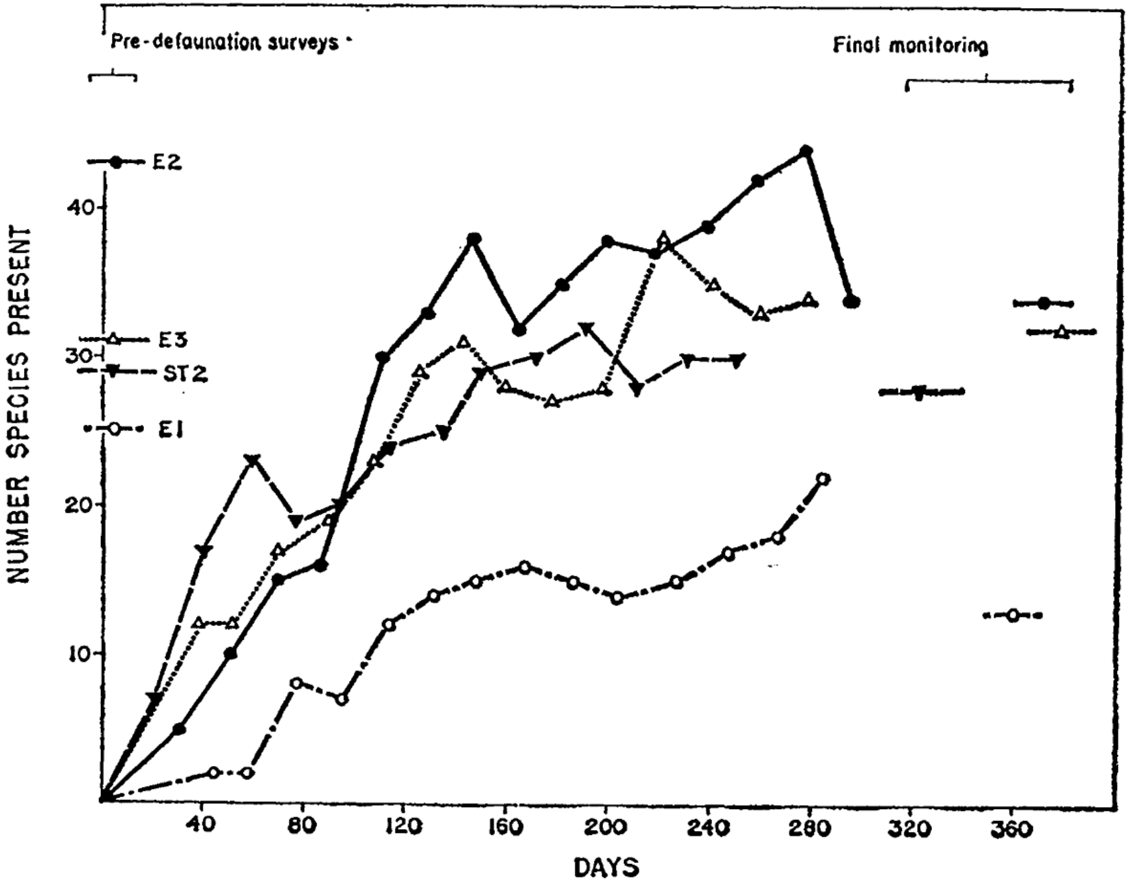

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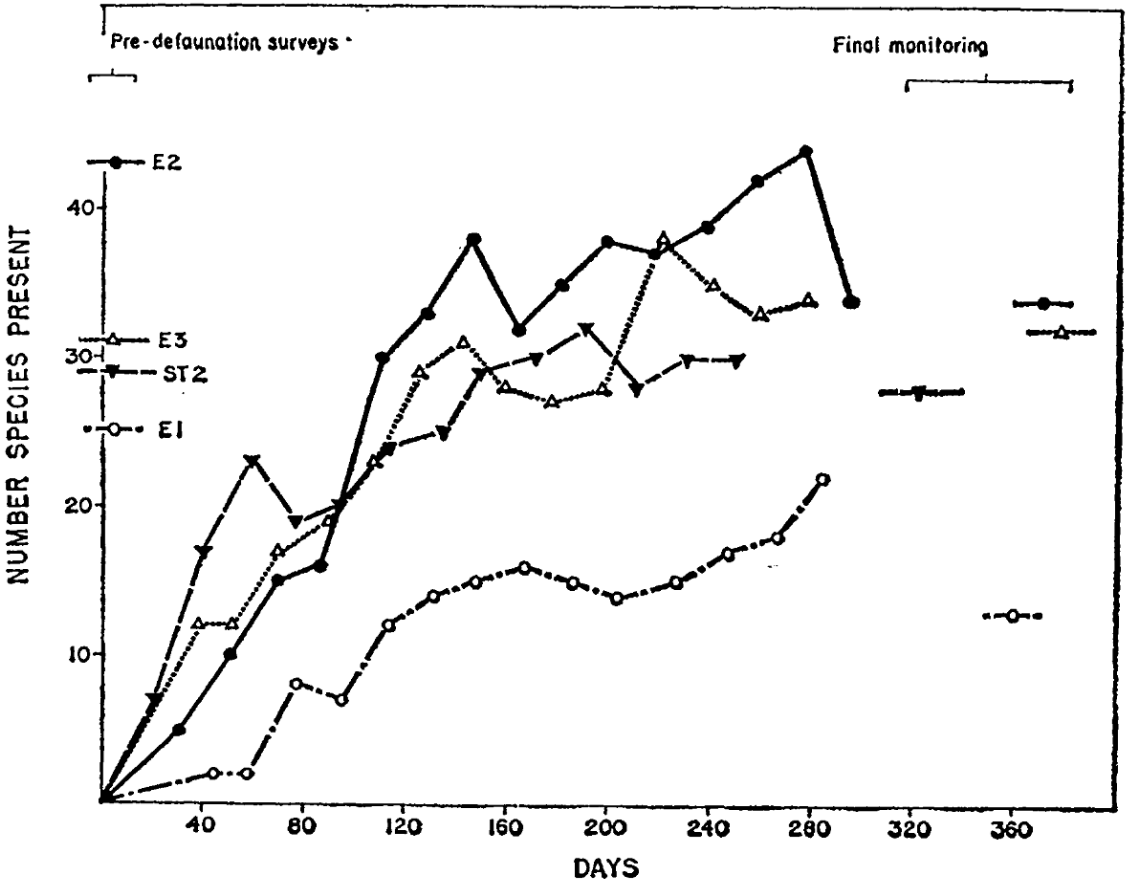

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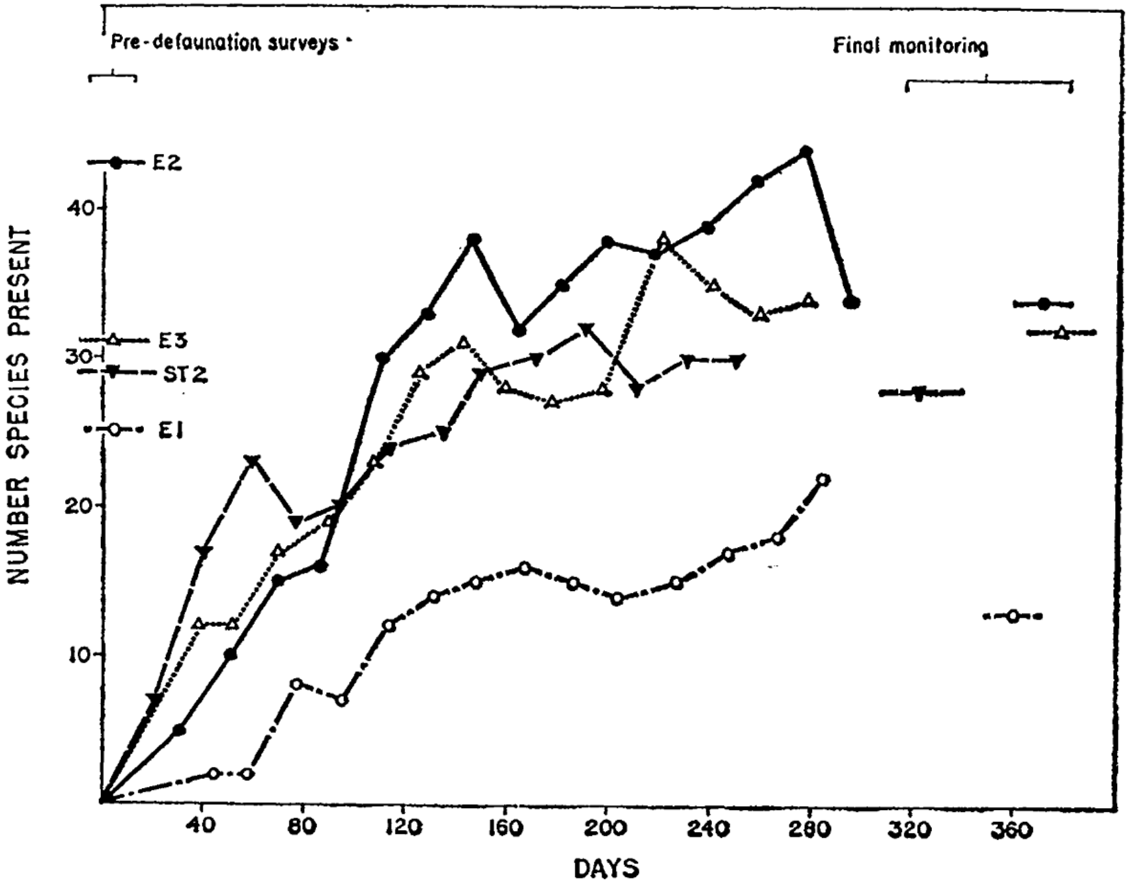

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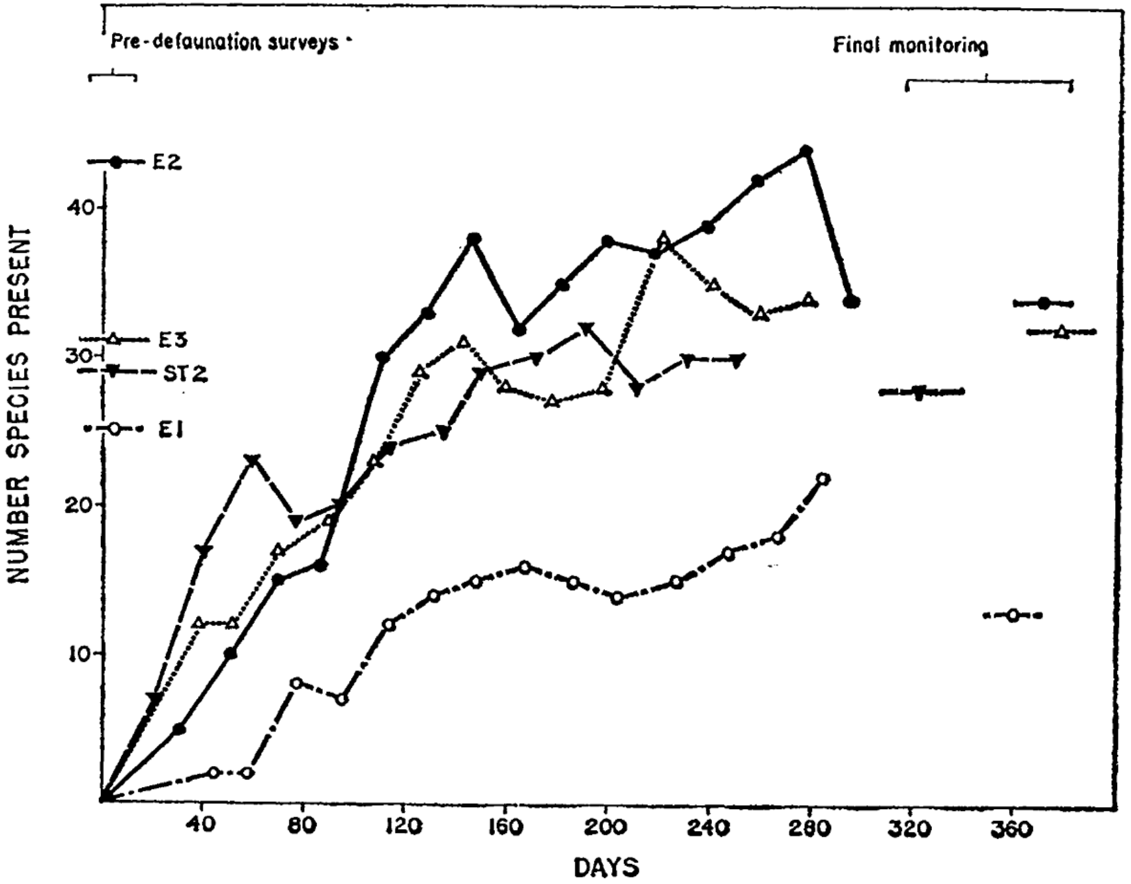

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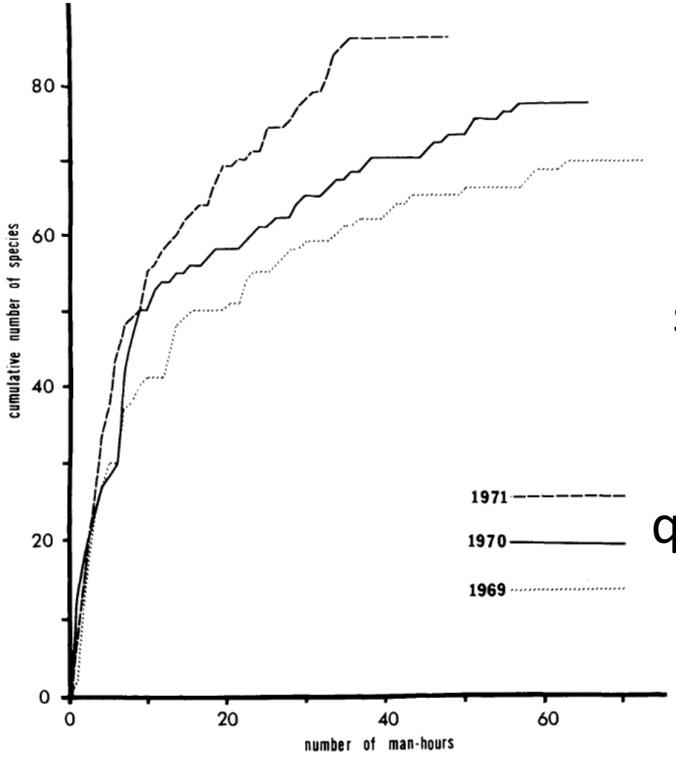
- Strong flyers recolonized first but were eventually replaced (outcompeted) by better competitors (typically ants) – in keeping with theories of faunal succession.
- The islands farthest from the mainland were the slowest to recolonize.

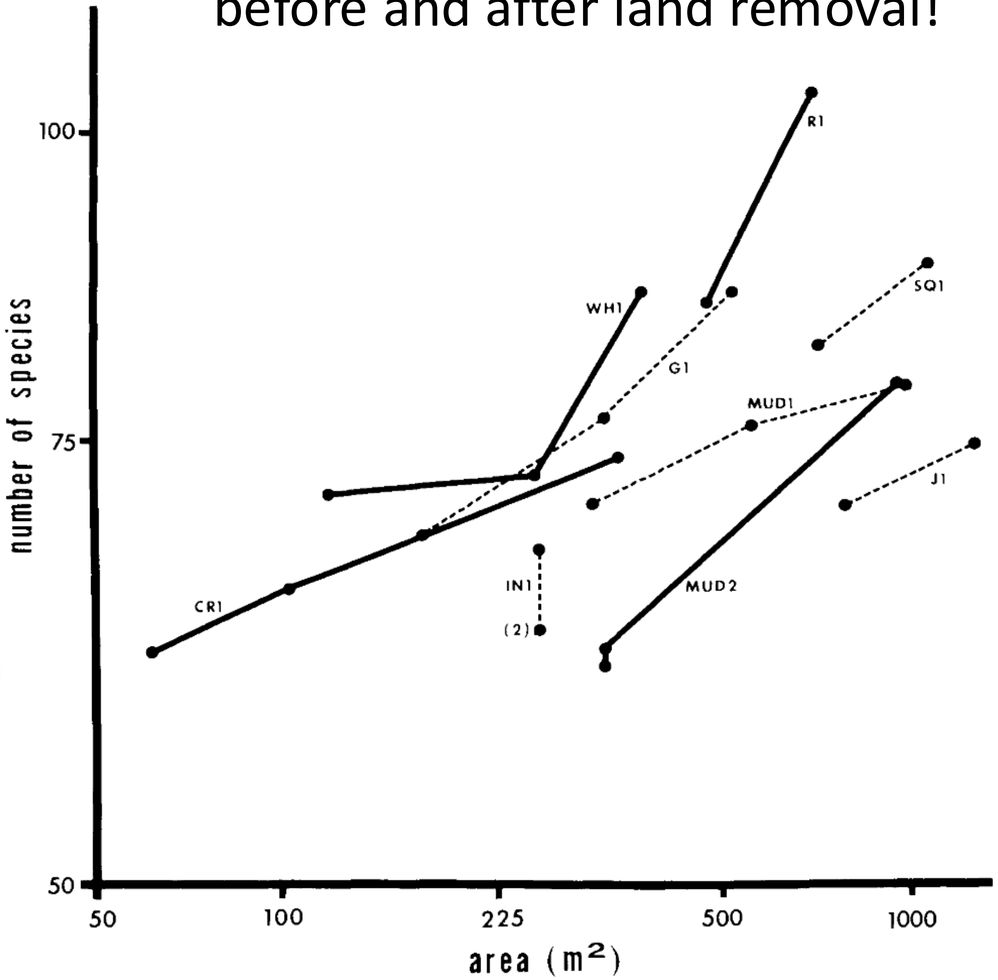
Simberloff. 1969. *Ecology.*
Wilson and Simberloff. 1969. *Ecology.*
Simberloff and Wilson. 1969. *Ecology.*

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.

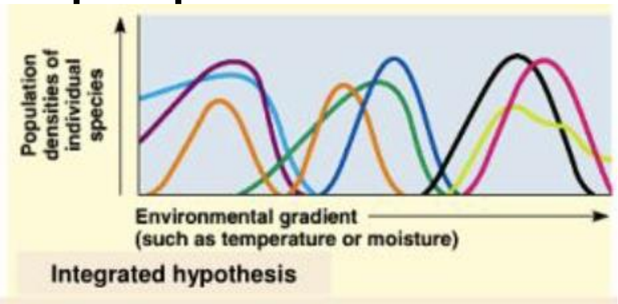
log-log plot of island area and species count before and after land removal!



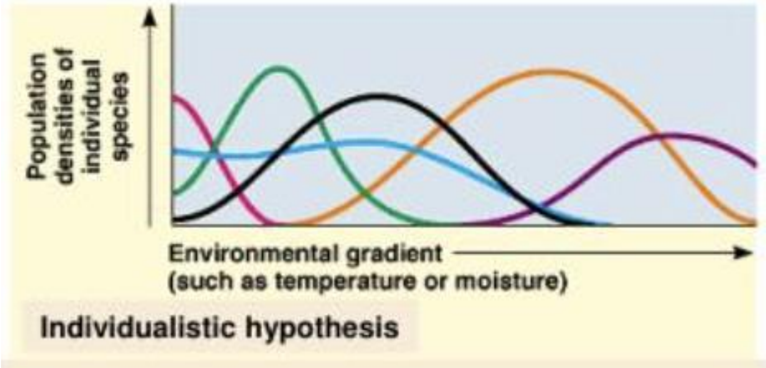
Simberloff. 1976. *Ecology.*

Superorganisms vs. Loose Collections of Species?

- Frederic Clements (1916) argued that community succession was predictable and **deterministic**, much like ontogenetic development in individual organisms, moving always towards some superorganism.
- **Priority effects**: inhibitory or facilitative priority effects occur when one species "prepares" the environment for the next species in succession



- 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



Niche-based assembly vs. **Neutral** theories of assembly?

- **Niche**: match of a species to specific environmental conditions
- Assembly will be **deterministic**
- Joseph Grinnell (1917) – coined the term for the CA thrasher and its chapparal habitat. Includes physical match and behavioral adaptations

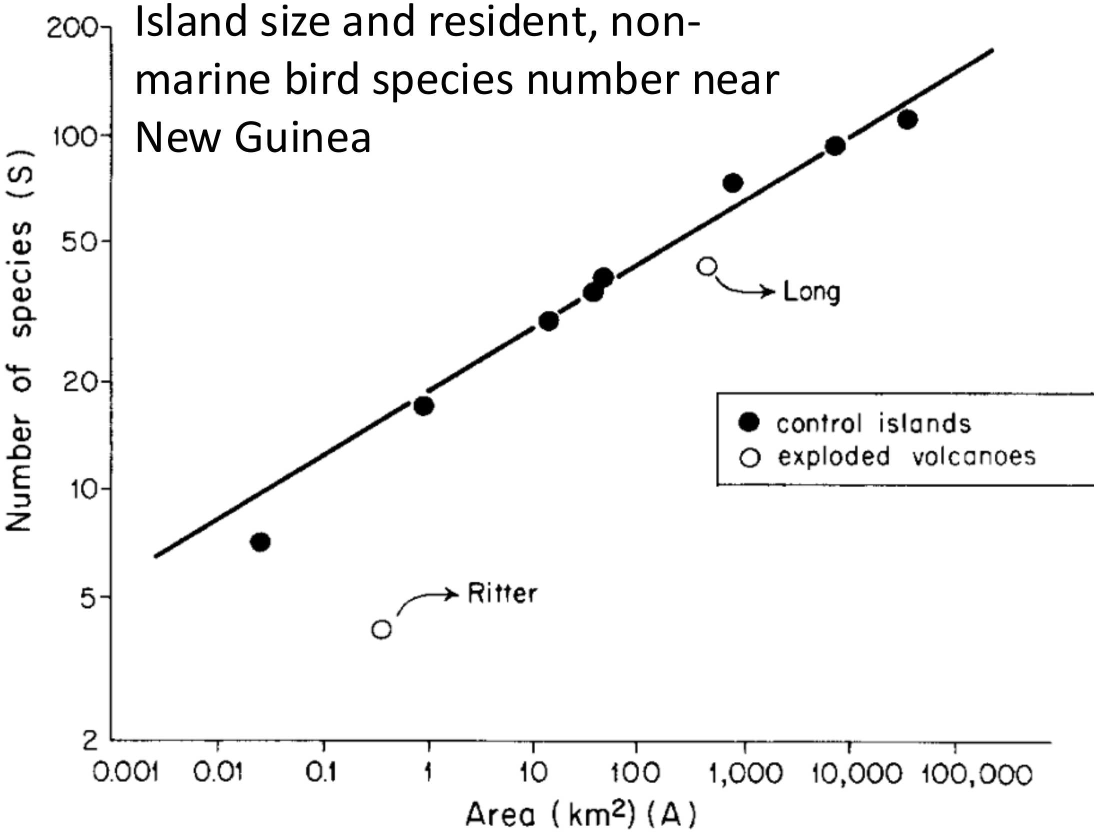
THE NICHE-RELATIONSHIPS OF THE CALIFORNIA THRASHER.[1]

BY JOSEPH GRINNELL.

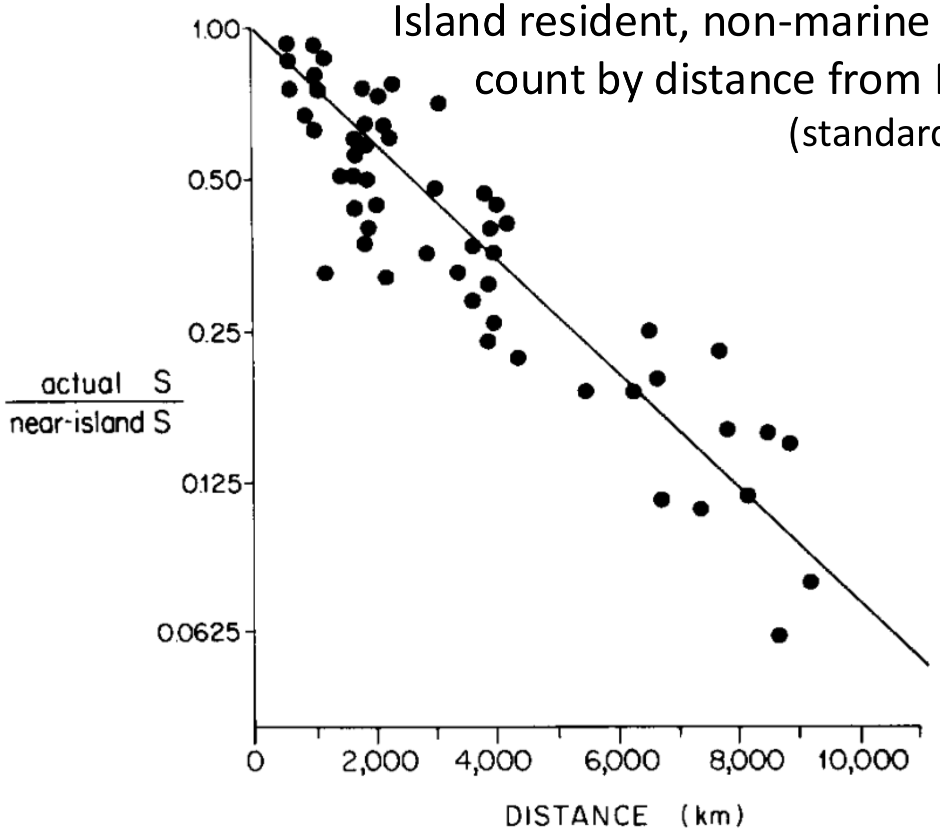
- **Neutral**: species-specific differences within a trophic level will be irrelevant to their success
- Assembly will be **stochastic**
- MacArthur and Wilson 1967
- Hubbell (2001) - Unified neutral theory of biodiversity and biogeography **(UNTB)**

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



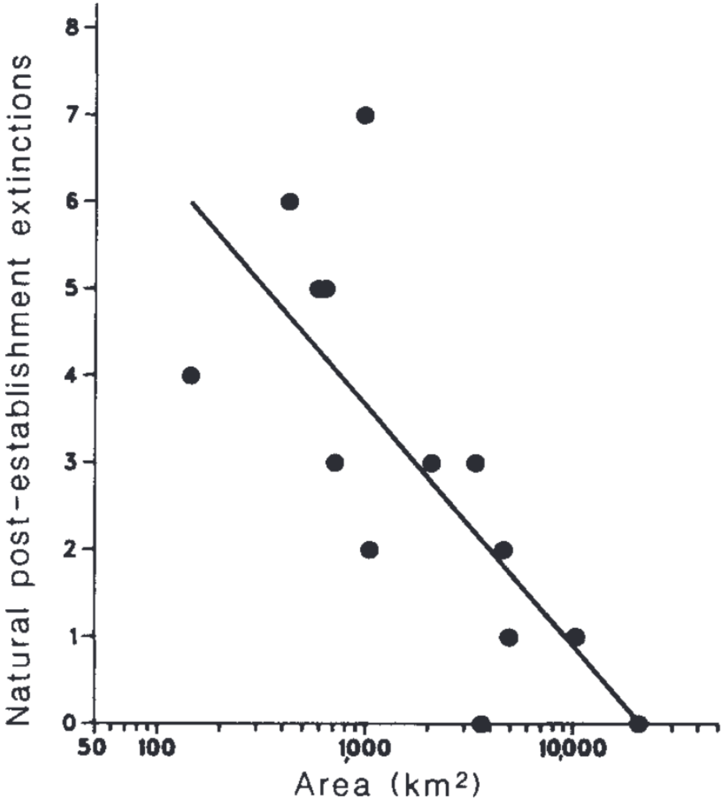
Distance effect:
Island resident, non-marine bird species count by distance from New Guinea
(standardized by area)

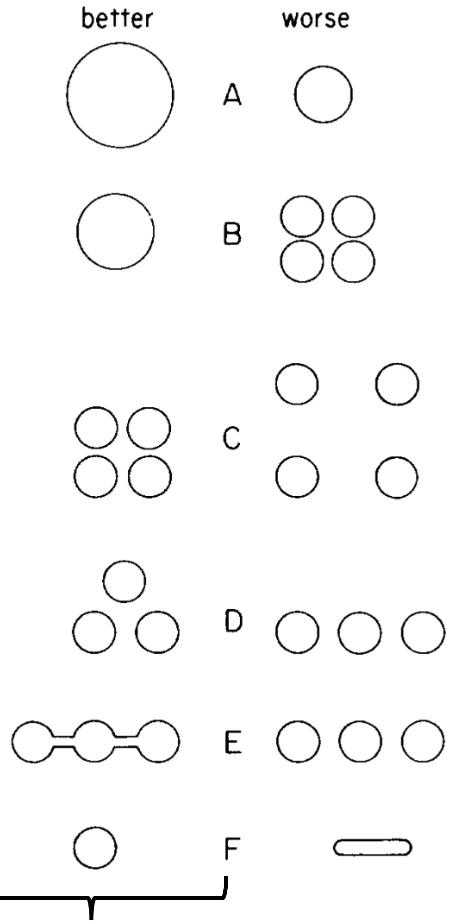


Diamond. 1975. *Biological Conservation.*

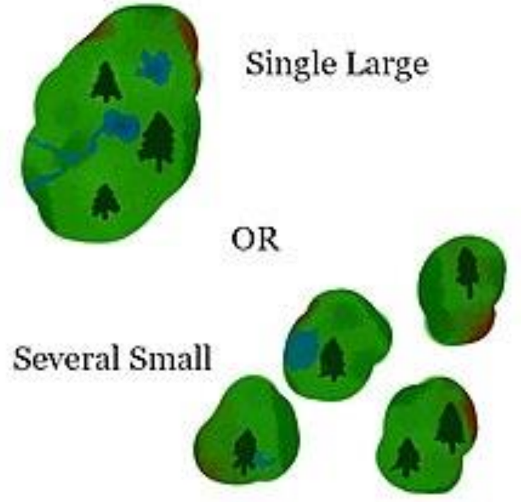
Island biogeography has greatly influenced the design of **protected area reserves**

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





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



"**SLOSS**" debate

(1970s-1980s)

Newmark. 1987. *Nature.*

Diamond. 1975. *Biological Conservation.*

Population Biology

Conservation Biology	Disease Ecology
• **Goal:**	• **Goal:**
• protect **populations** from **extinction**	• protect **populations** from disease via pathogen **extinction**

Population Biology

Conservation Biology	Disease Ecology

Conservation Biology

- **Goal:**
  - protect **populations** from **extinction**
- **Concept:**
  - **Minimum Viable Population** size (MVP)

MVP = the minimum number of individuals in a population needed to sustain the population 1000 years into the future

Disease Ecology

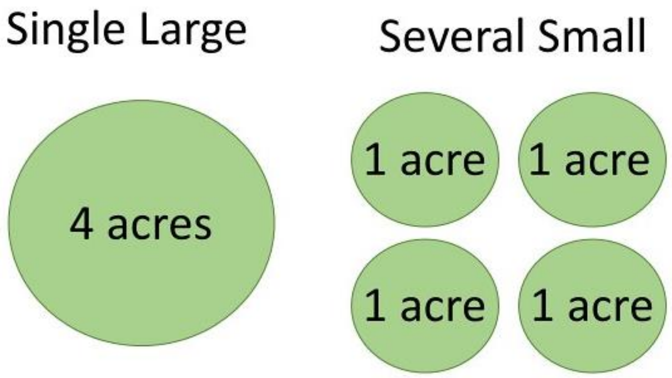
- **Goal:**
  - protect **populations** from disease via pathogen **extinction**
- **Concept:**
  - **Critical Community Size** (CCS)

CCS = the minimum number of hosts needed to sustain endemic transmission of a pathogen indefinitely into the future

Population Biology

Conservation Biology

- **Goal:**
  - protect **populations** from **extinction**
- **Concept:**
  - **Minimum Viable Population** size (MVP)
- **Approach:**
  - protected area **reserves**



Disease Ecology

- **Goal:**
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- **Concept:**
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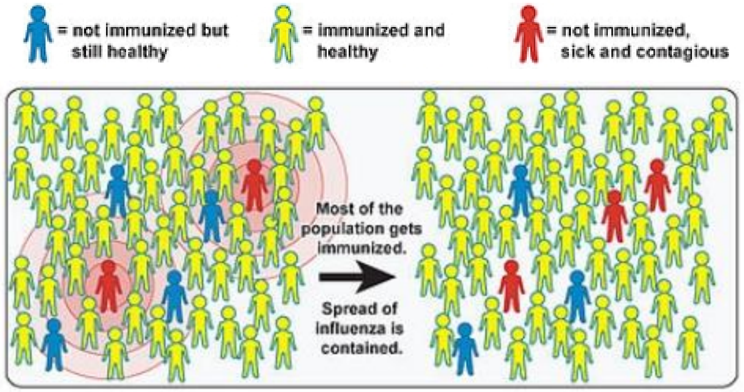
- **Approach:**
  - sanitation
  - **vaccination**



Biodiversity can be measured in several ways!

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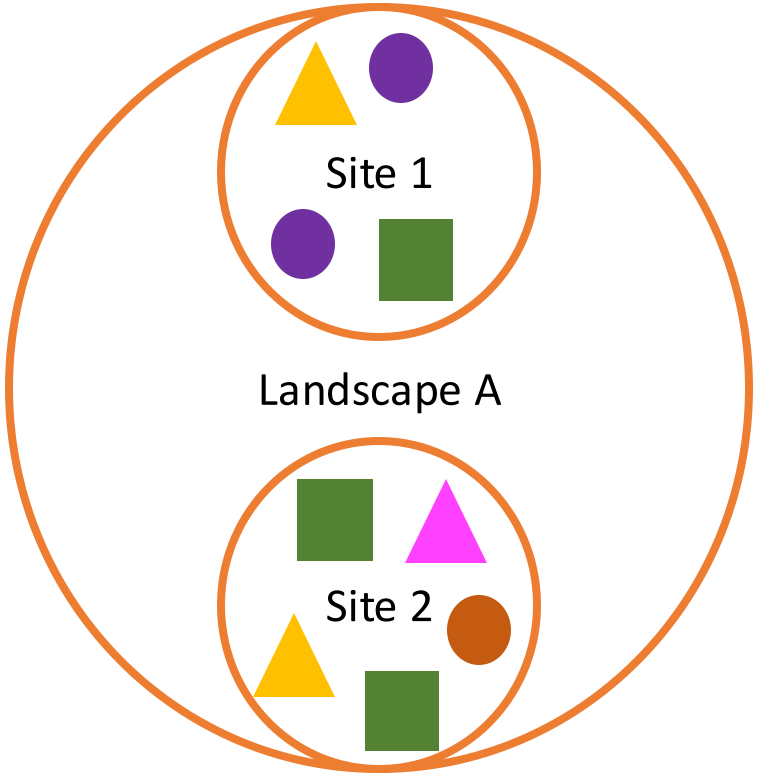

Whittaker. 1960. *Ecological Monographs*.

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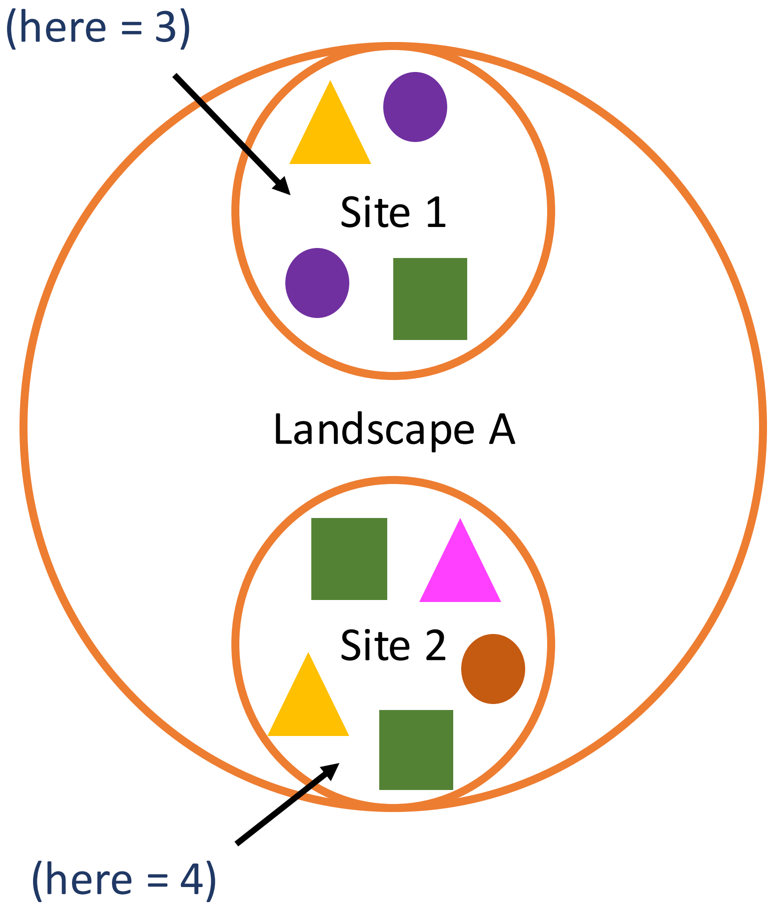

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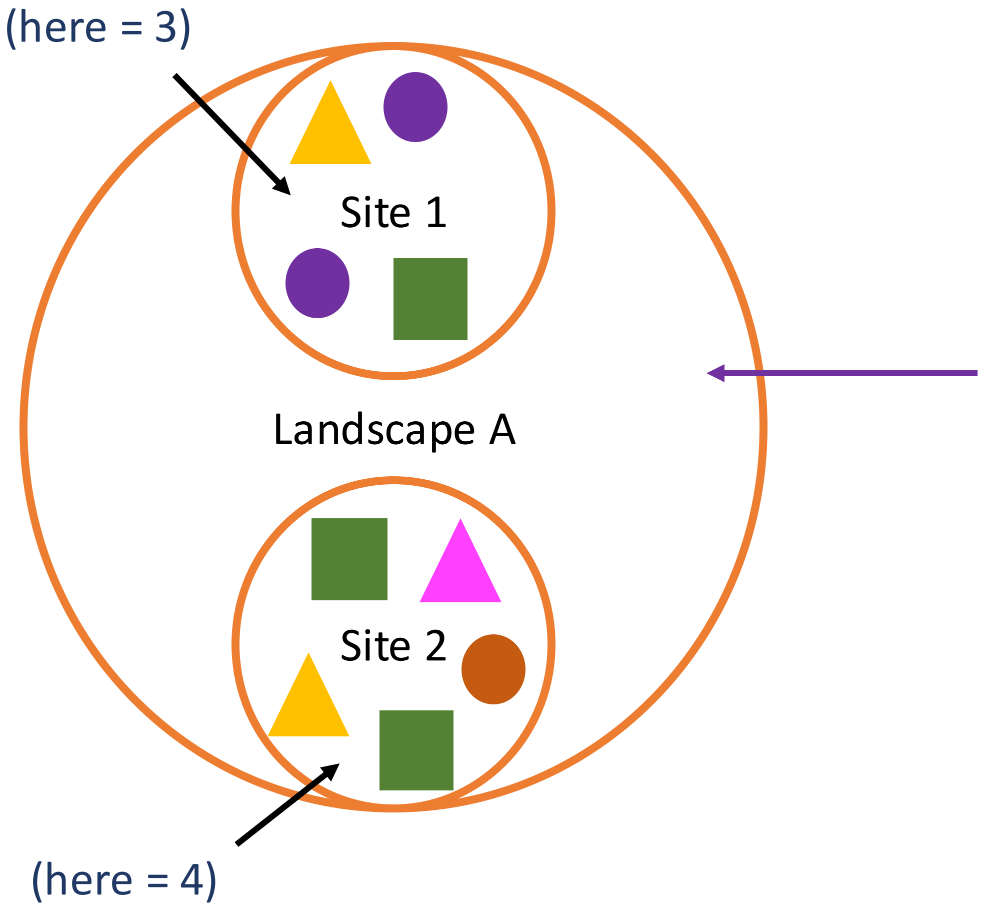

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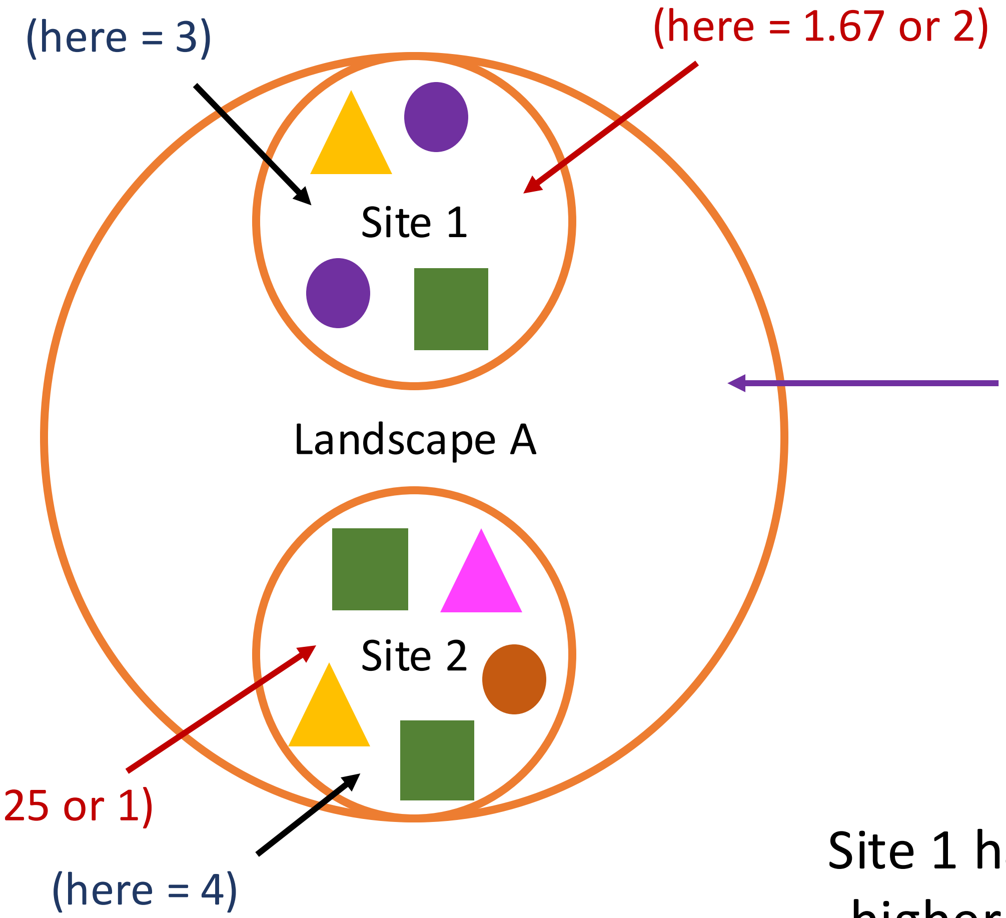


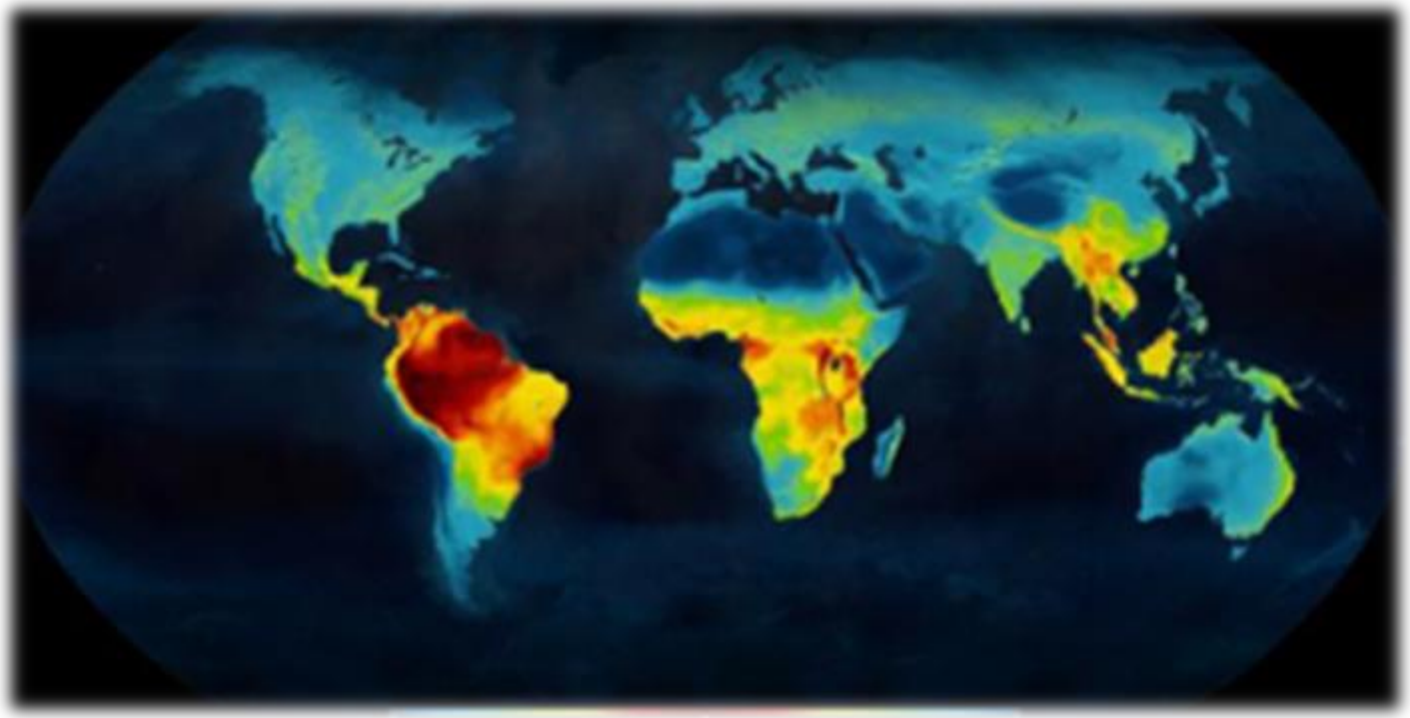
γ – diversity = total species diversity in the landscape (here = 5)

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

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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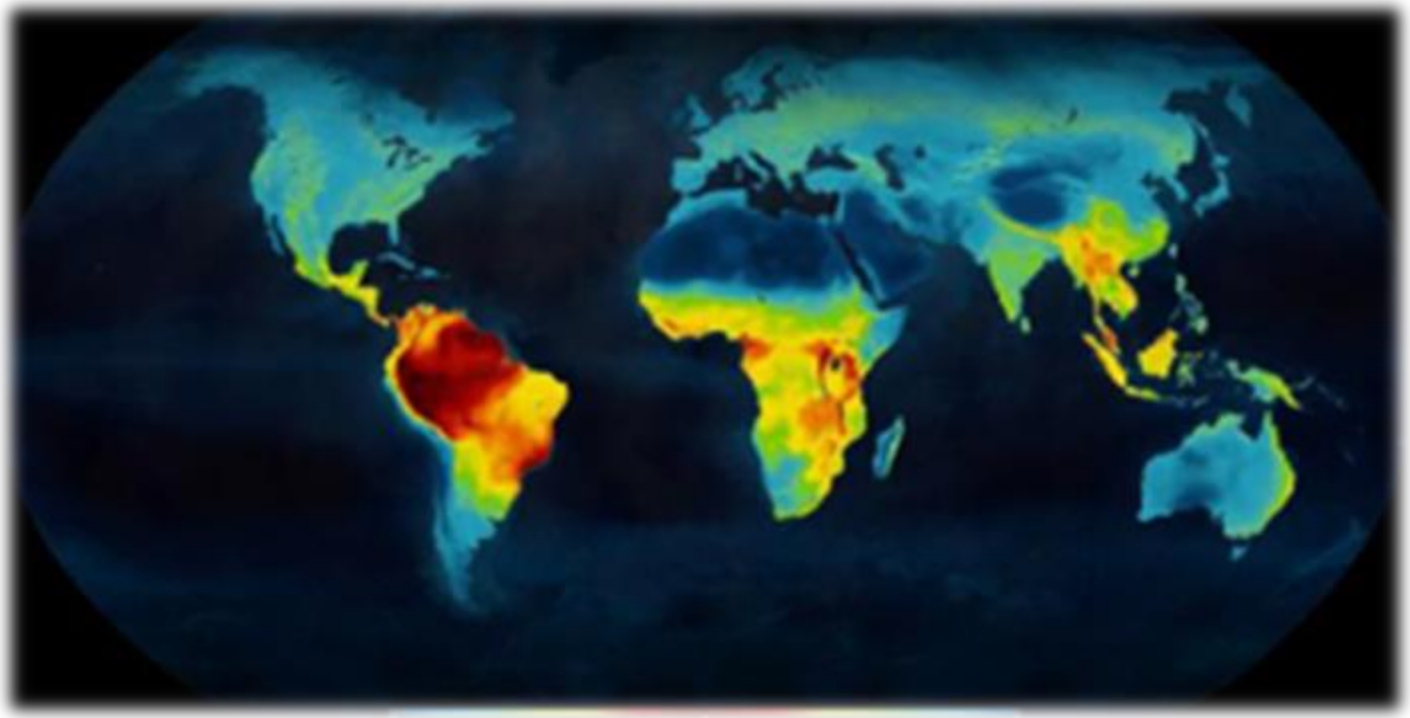

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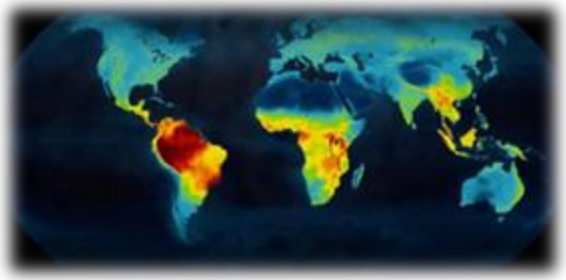

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Some candidate hypotheses:

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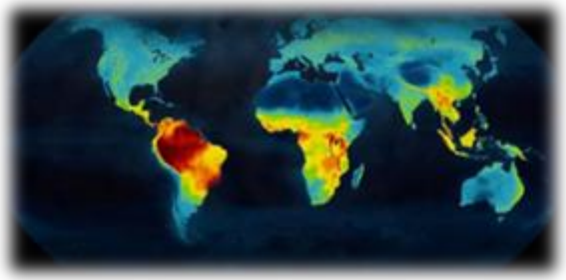

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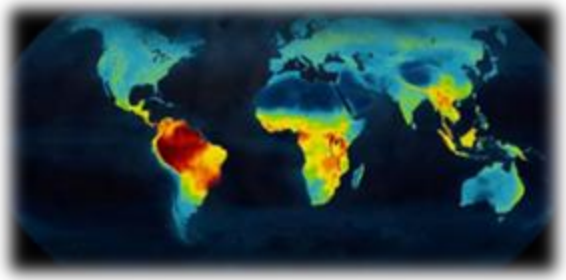

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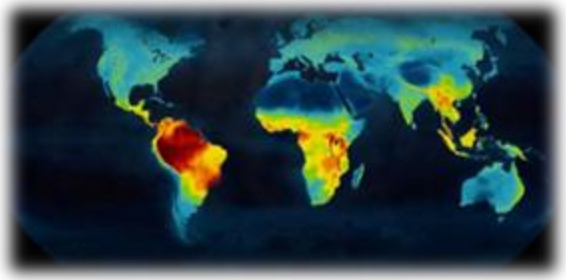

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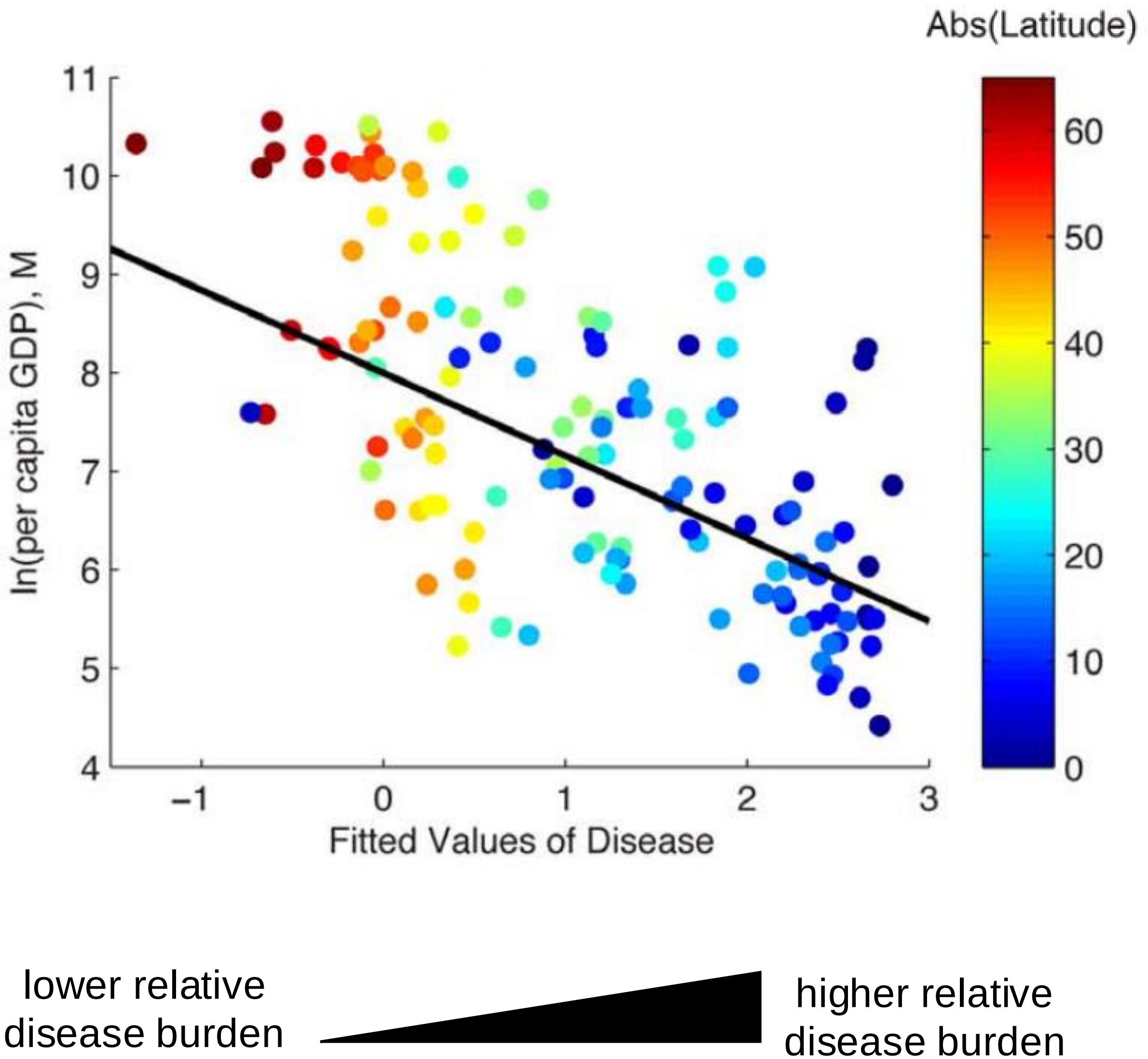
4. **Biotic interactions hypothesis.** More species yield more species as processes of competition, predation, etc. are intensified in the tropics… *but cannot provide the basal cause for the accumulation of more species to begin with!*

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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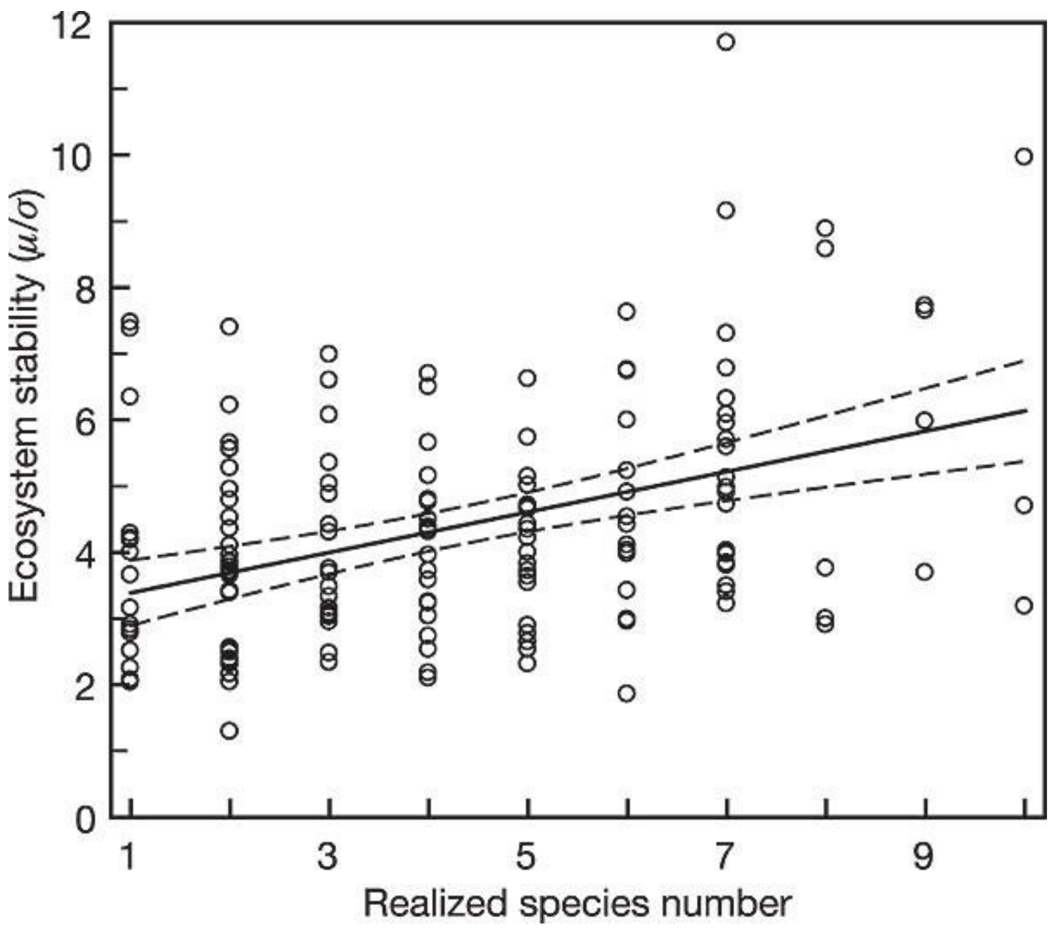
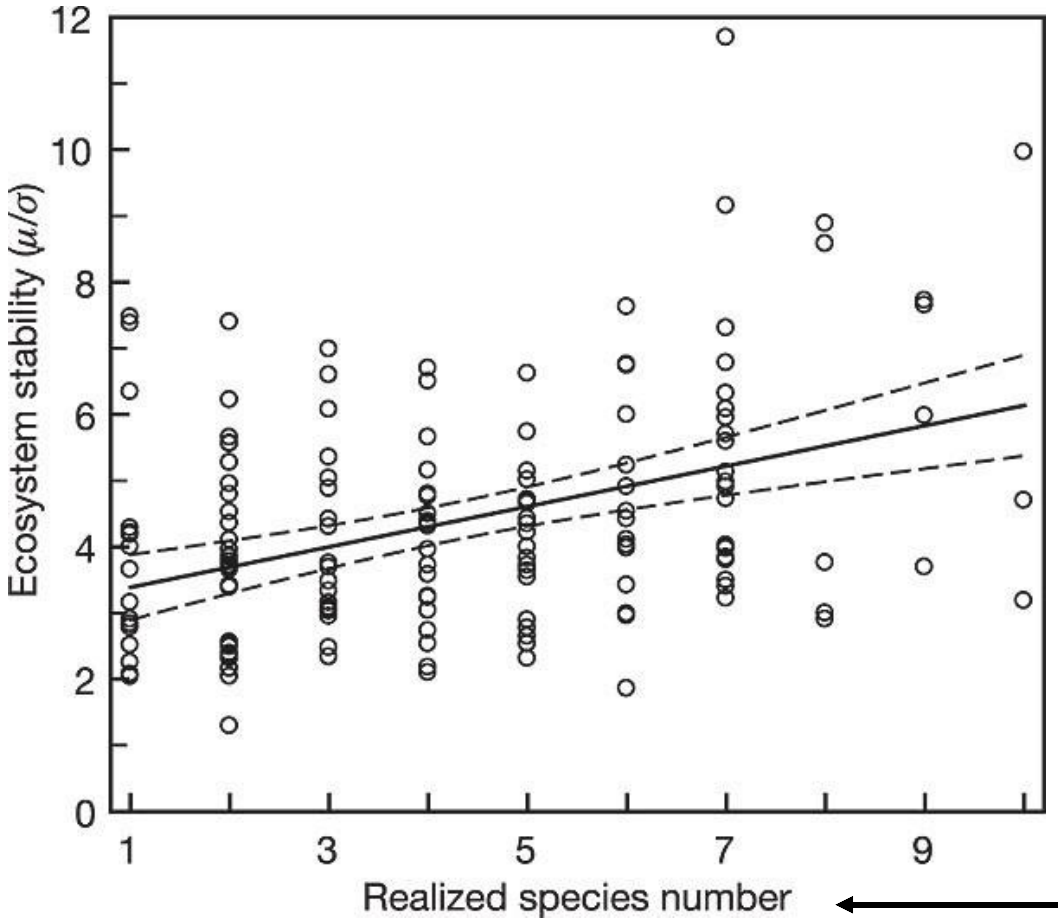


Cedar Creek experiment from the University of Minnesota

Tilman et al. 2006. *Nature.*

Why do we care about biodiversity?

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



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

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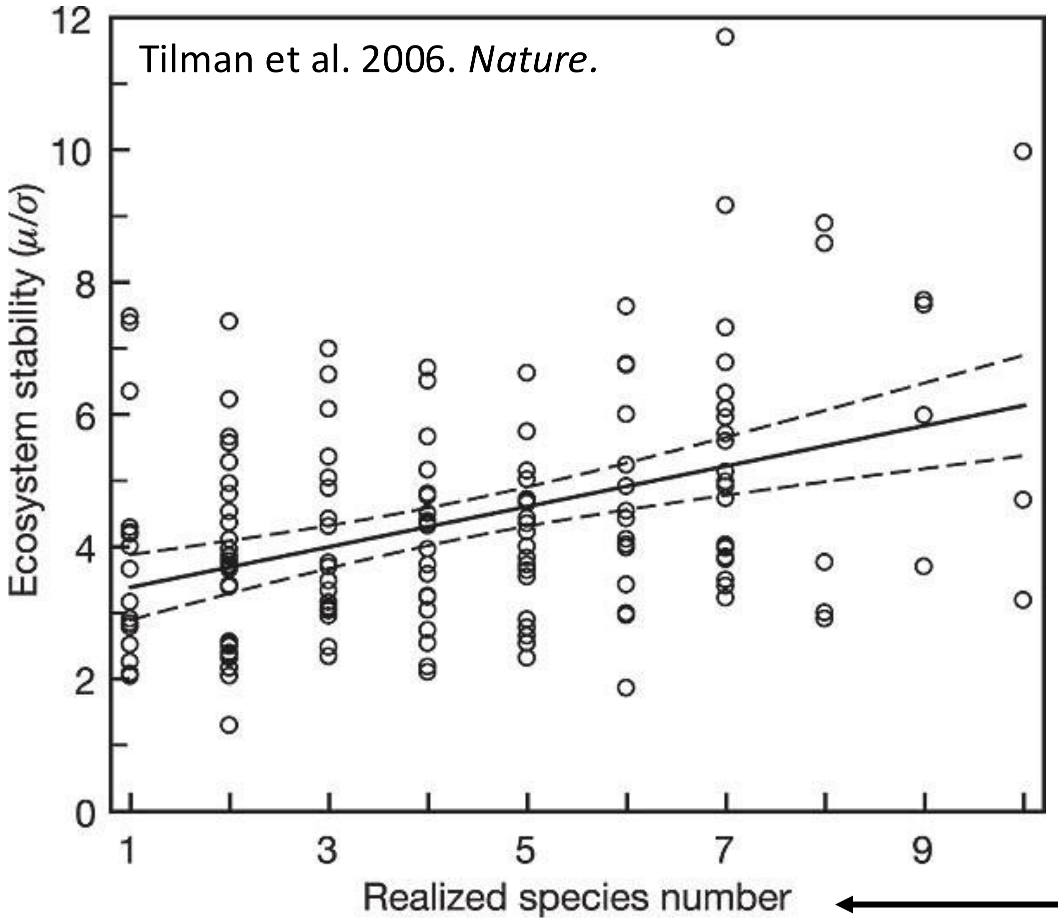

number of species comprising 90% of aboveground biomass
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"Our results indicate that the reliable, efficient and sustainable supply of some foods, biofuels and ecosystem services can be enhanced by the use of biodiversity."

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**.

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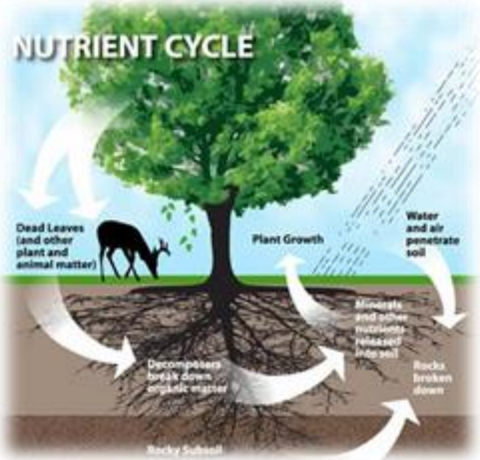
regulating services

provisioning services

cultural services

supporting services



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regulating services

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

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cultural services

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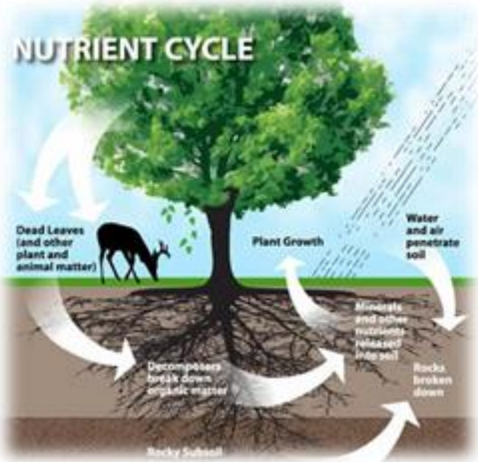

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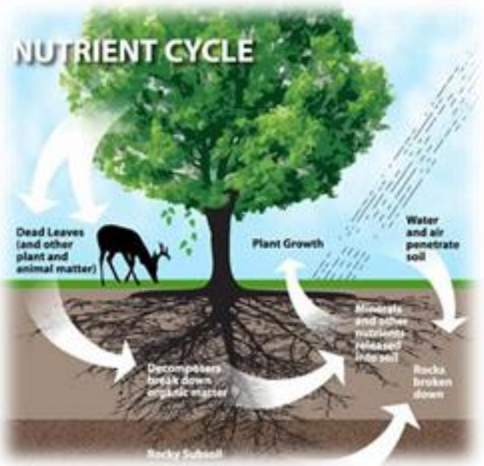
- raw materials (lumber, skins, organic matter)
- medicinal resources
- ornamental resources

cultural services

supporting services



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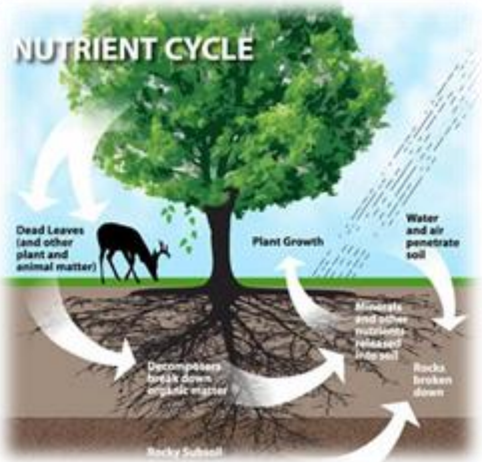
cultural services

- ecotourism
- therapeutic services
- historical and cultural values

supporting services



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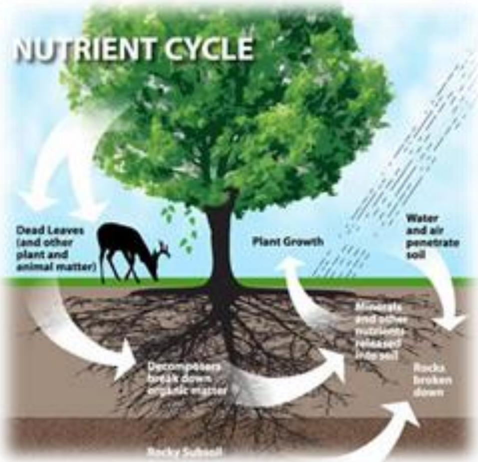
supporting services

- 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
Driven to Discover

WWF

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- Instead, in 1997, the city embarked on a $1.5 billion plant to preserve the Catskills watershed, buying thousands of upstate acres, shielding reservoirs from pollution, and subsidizing environmentally-sound economic development.
- To this day, NYC's tap water remains clean and **unfiltered**.

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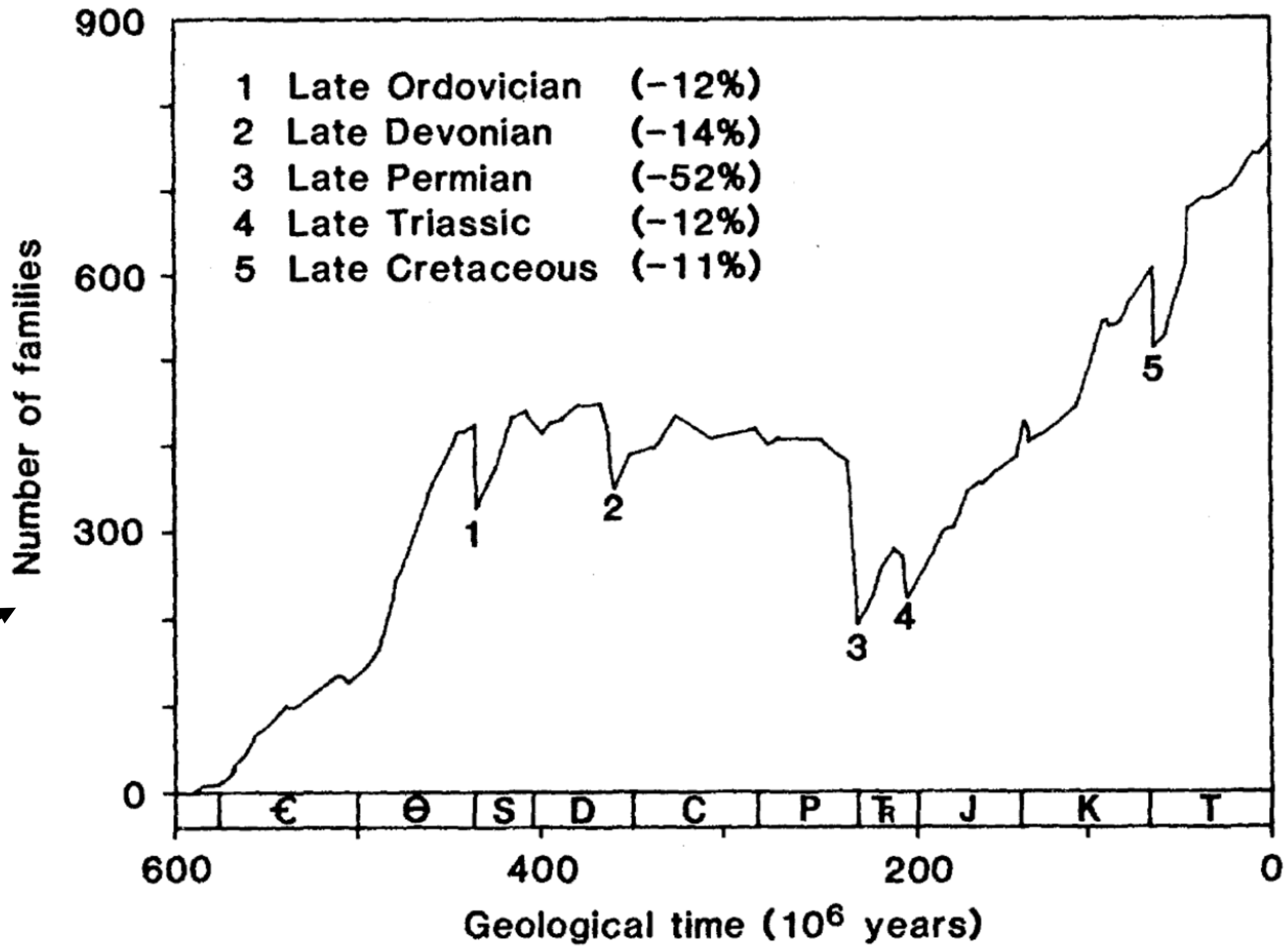
Visual settings

Edit

What are the four categories of ecosystem services?

A regulating, stabilizing, provisioning, cultural	0%
B spiritual, provisioning, regulating, theoretical	0%
C provisioning, regulating, supporting, cultural	0%
D improving, provisioning, regulating, cultural	0%

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



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*

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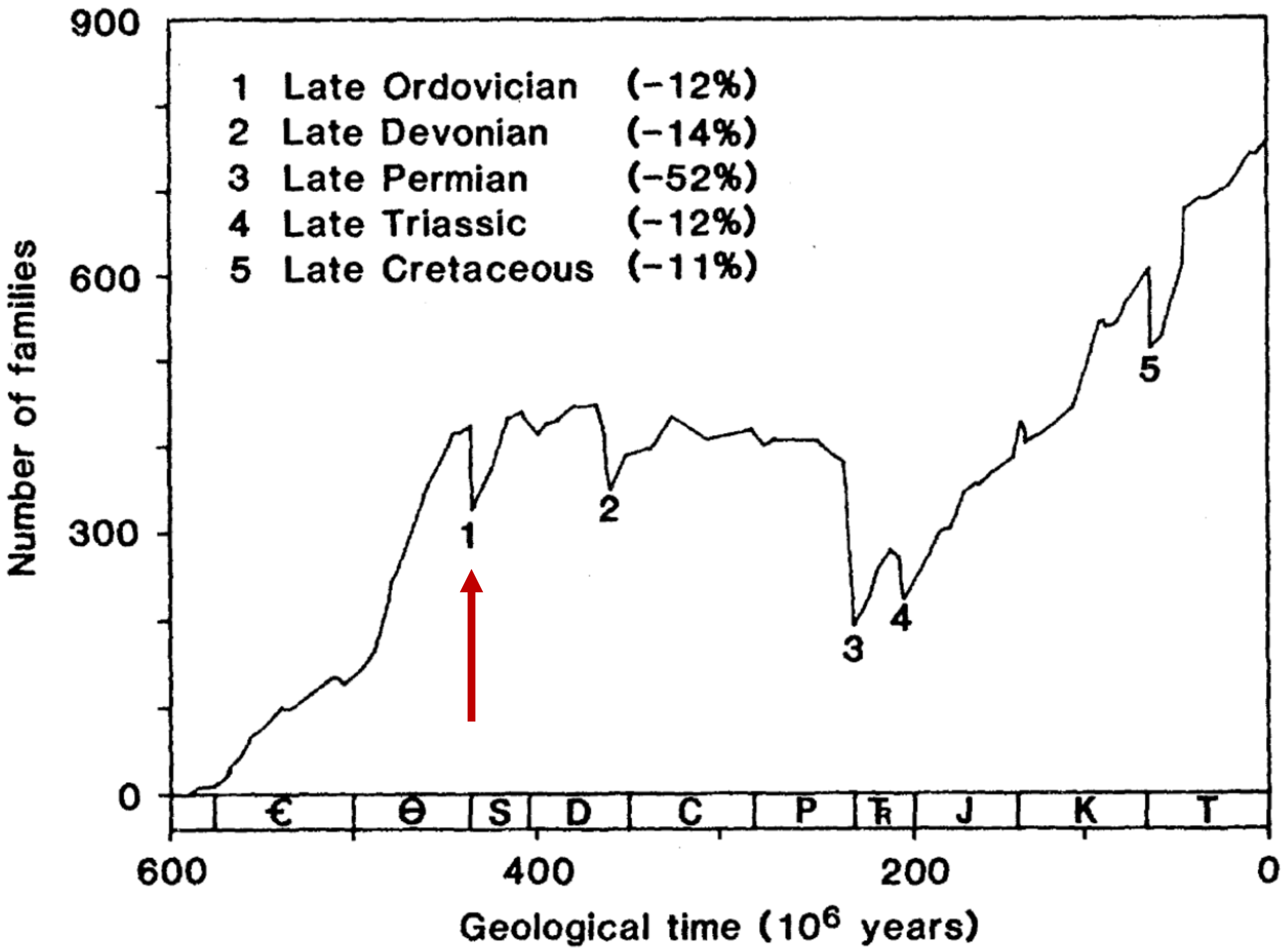

1. **Late Ordovician-Silurian** – 445-444 MYA – second largest extinction in history.

Estimated 85% of the planet's species went extinct.

Proposed causes: global warming, volcanism, anoxia.

Raup and Sepkoski. 1982. *Science*

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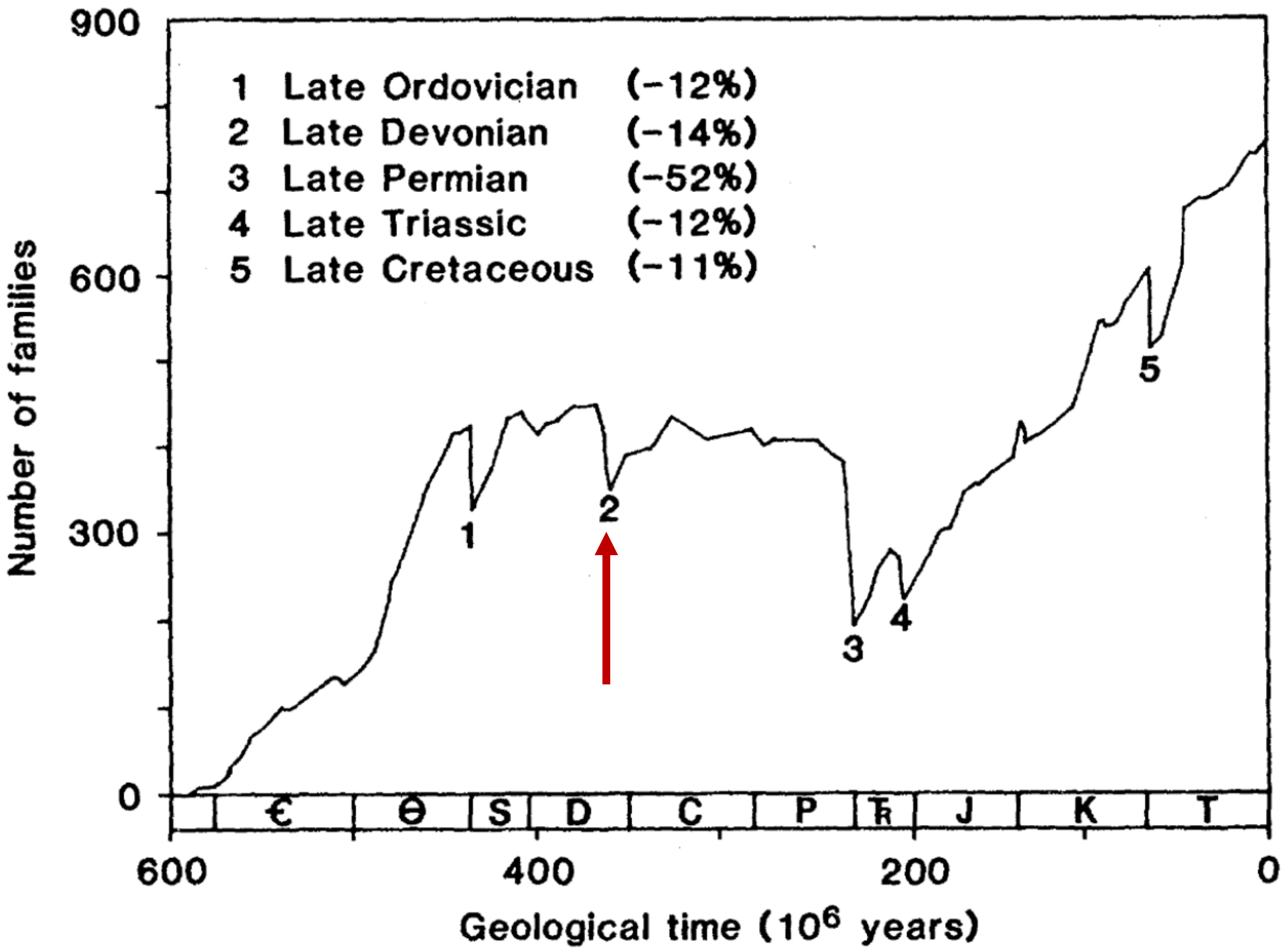

2. **Late Devonian** – 372-359 MYA – two subsequent extinction events.

Annihilation of coral reefs and numerous benthic animals. Estimated 70% of the planet's species went extinct.

Proposed causes: global cooling, anoxia, meteor impacts.

Raup and Sepkoski. 1982. *Science*

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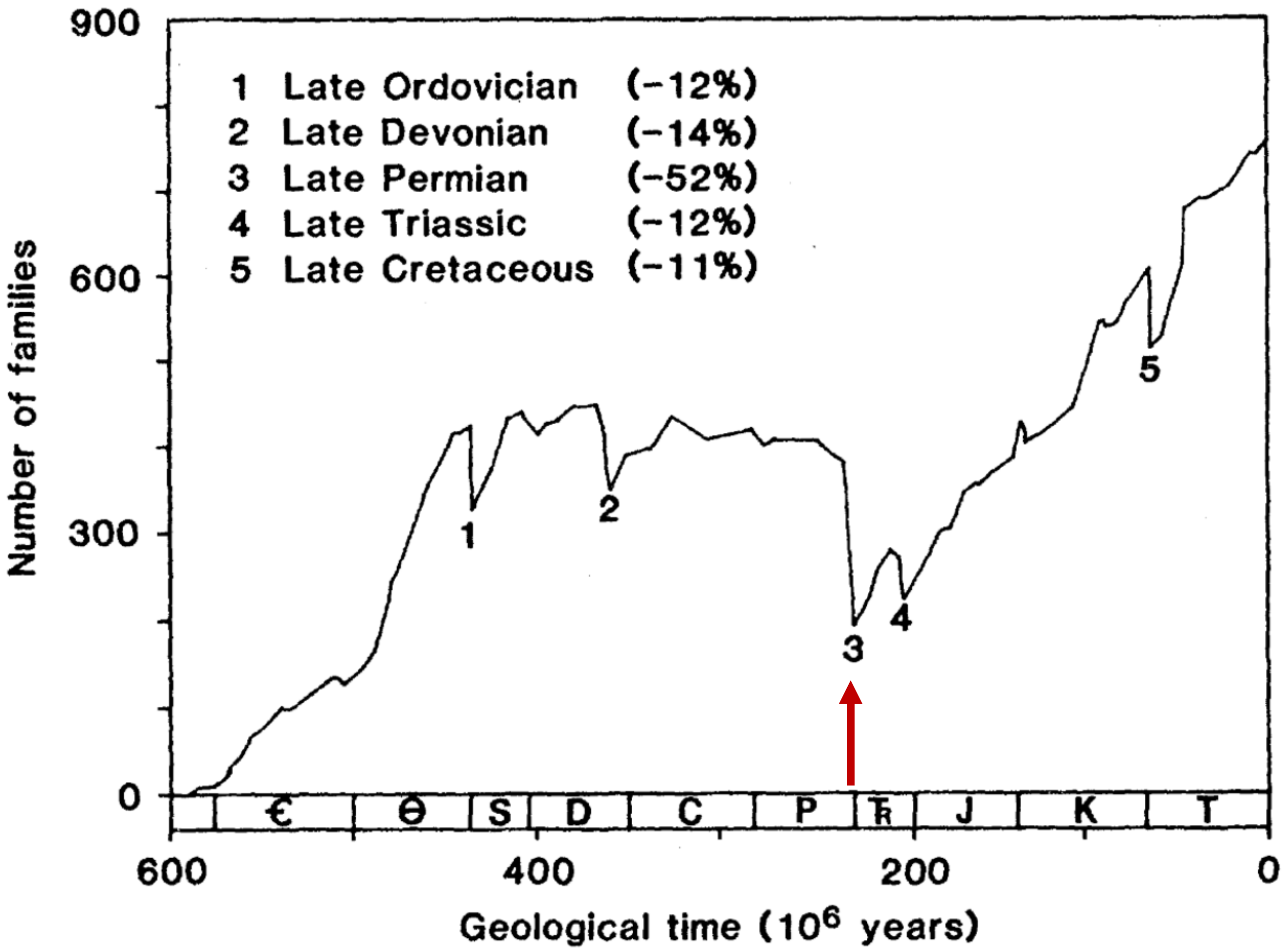

3. **Permian – Triassic** – 252 MYA – largest extinction in history – known as the 'Great Dying'.

Trilobite went extinct, along with early synapsids and estimated 90-96% of the planet's species.

Proposed causes: methane hydrate explosions, volcanism, anoxia, aridification, ocean acidification, asteroid impact.

Raup and Sepkoski. 1982. *Science*

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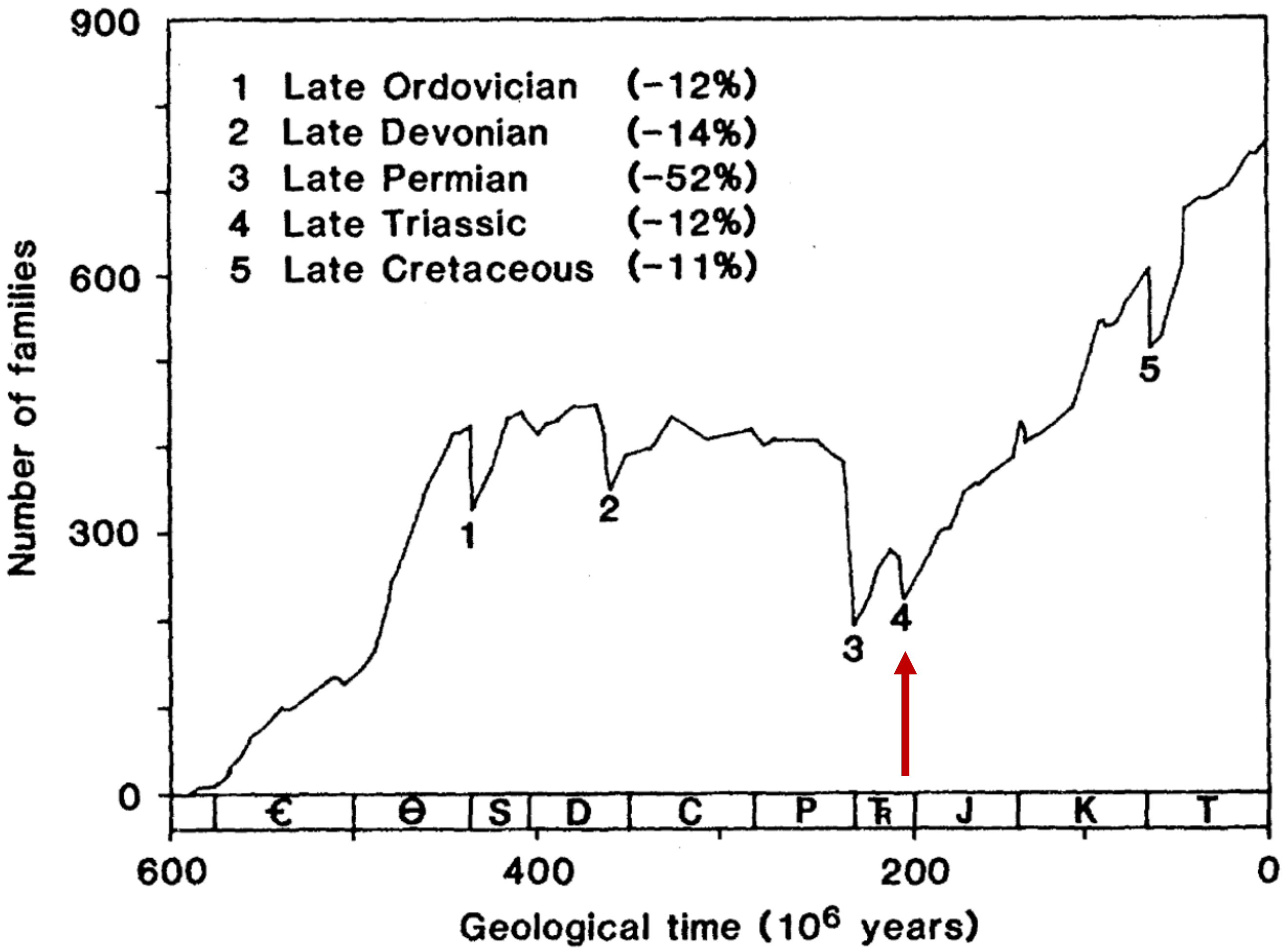


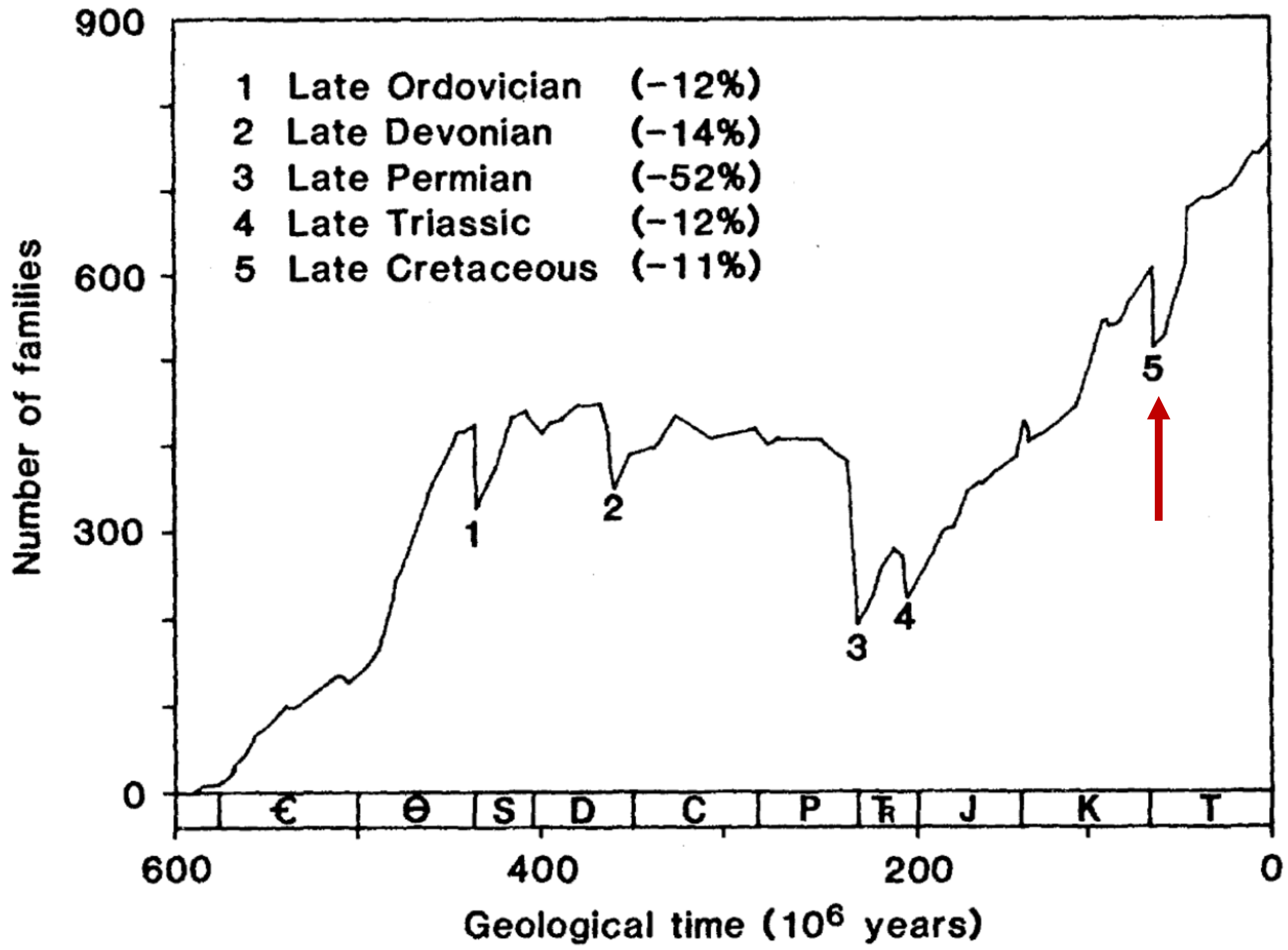
4. **Triassic - Jurassic** – 201 MYA .

Most non-dinosaurs went extinct, leaving dinosaurs with little terrestrial competition.

Proposed causes: global warming, CO2 accumulation, ocean acidification

Raup and Sepkoski. 1982. *Science*

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



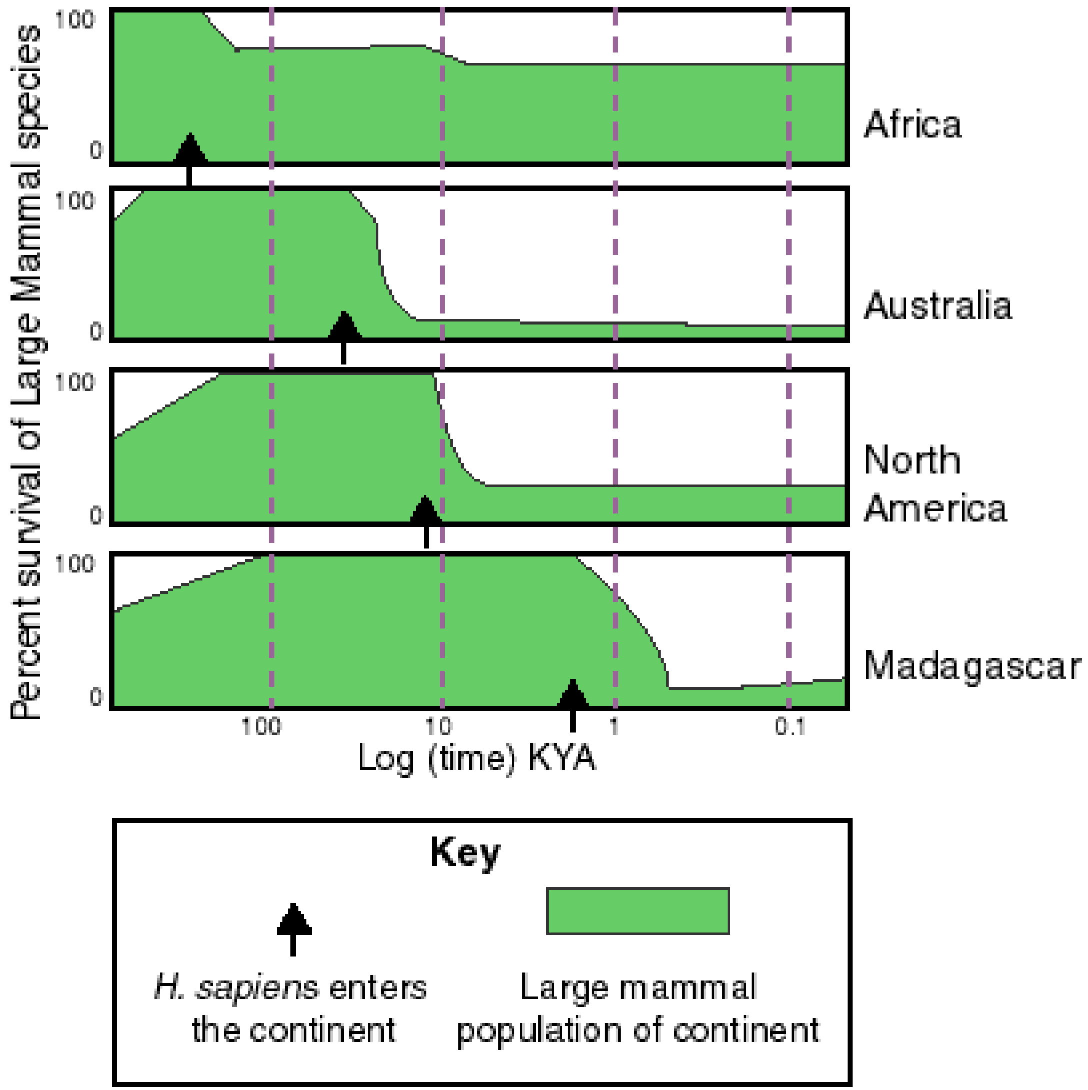
5. **Cretaceous - Paleogene (KT)**– 66 MYA .

Extinction of all non-avian dinosaurs and 75% of all the planet's species. Gave way to the age of mammals

Proposed causes: Chicxulub asteroid impact in present-day Yucatan

Raup and Sepkoski. 1982. *Science*

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



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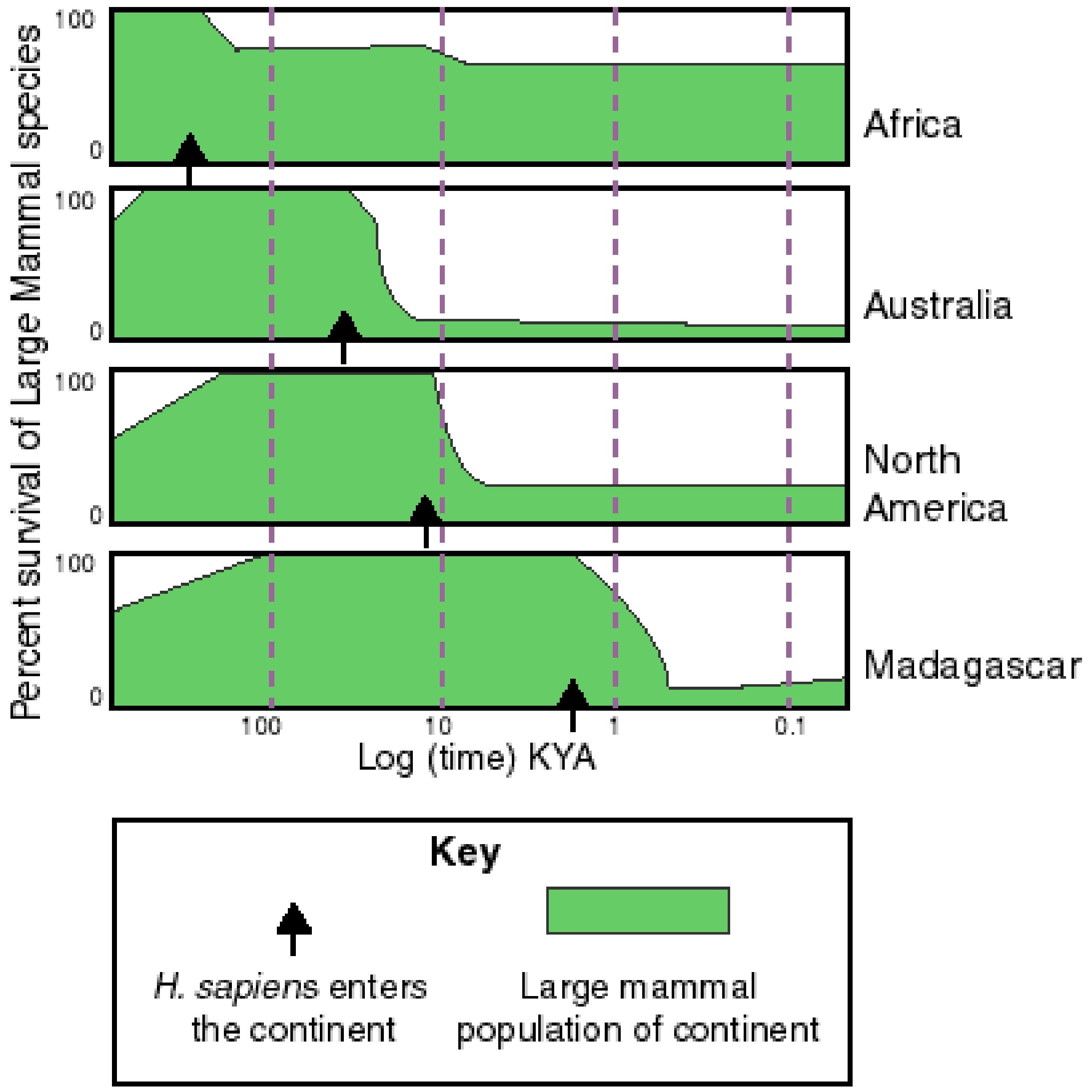

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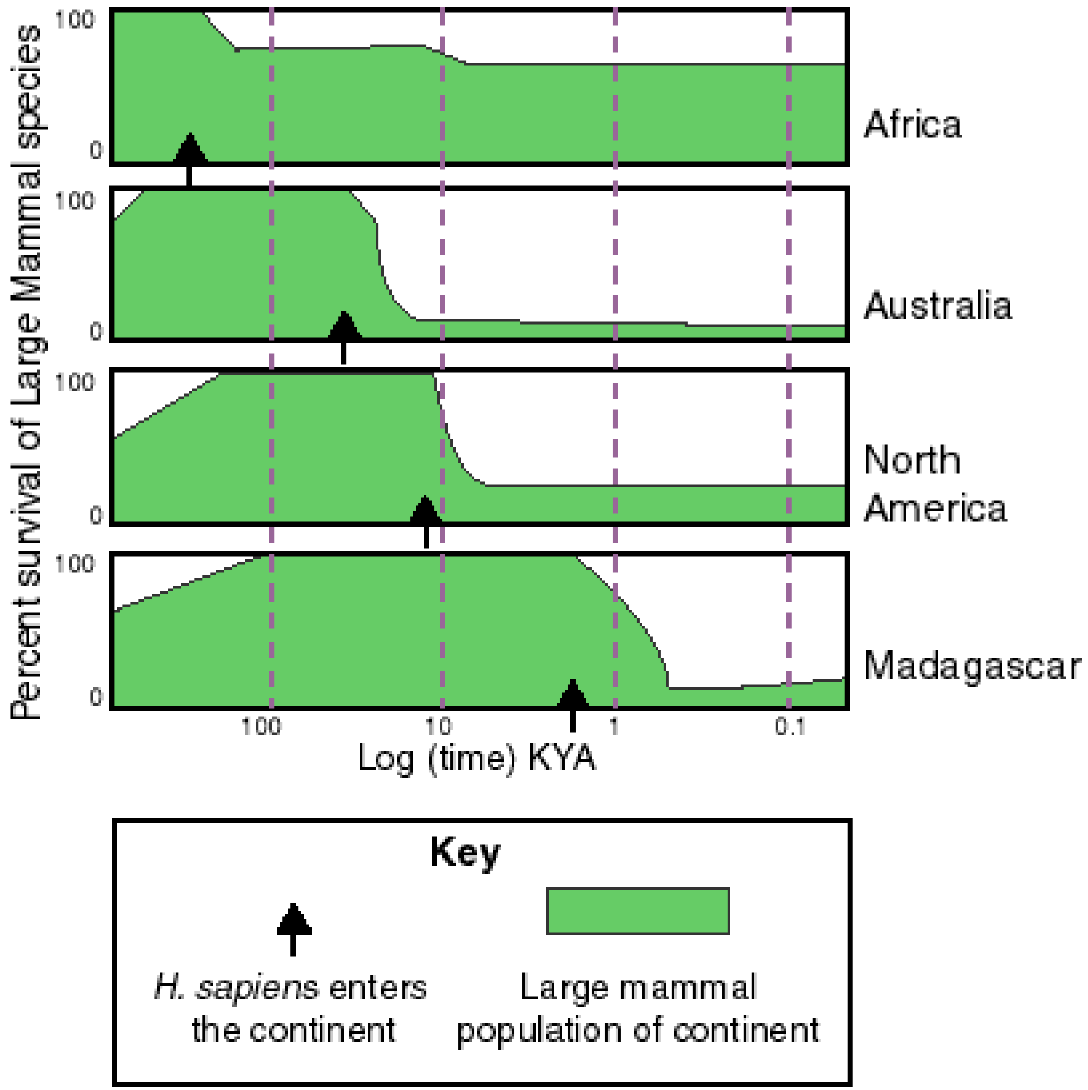

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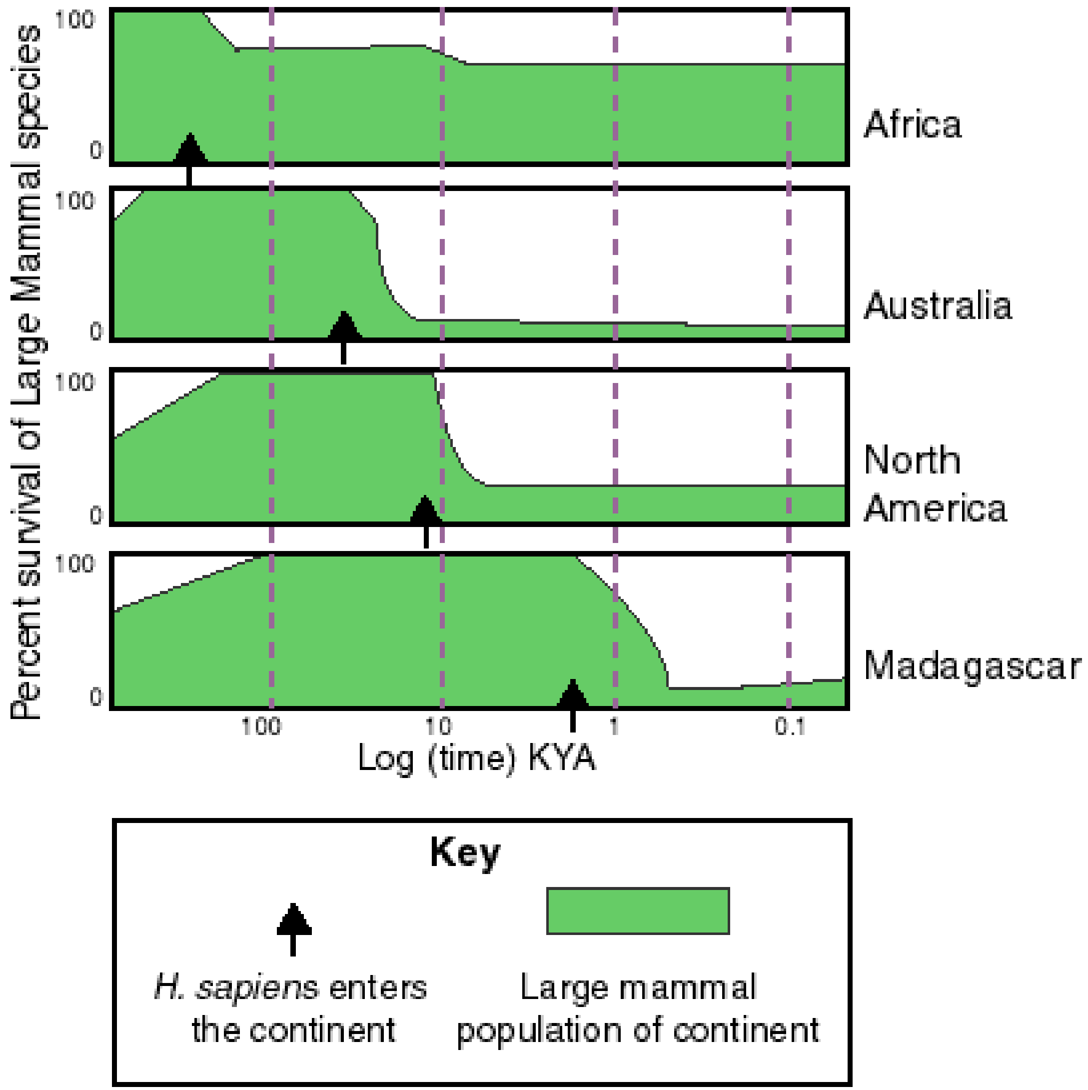
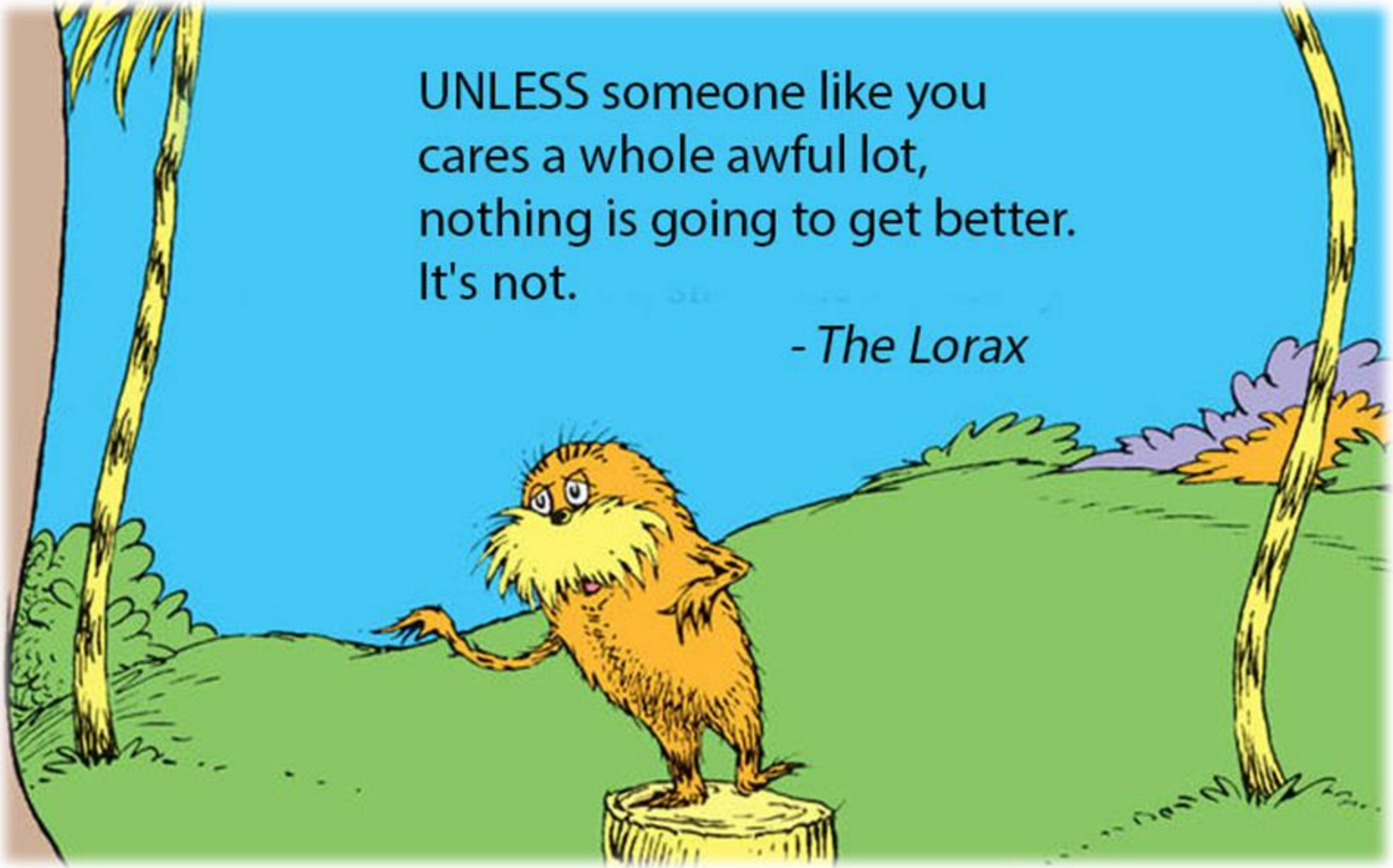
- Today, the contemporary rate of extinction is estimated at 100 to 1000 times higher than background (e.g. historically typical) and 10 to 100 times higher than previously witnessed during the 5 previous mass extinction events in earth history.
- The current extinct rate is considered to be anthropogenic in origin.




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

Want more ecology?

- BIOS 23232. Ecology and Evolution in the Southwest.
    - Instructor: Eric Larsen. Term: Spring
- BIOS 23249. Animal Behavior.
    - Instructor: Jill Mateo. Term: Winter
- BIOS 23254. Mammalian Ecology.
    - Instructor: Eric Larsen. Term: Spring
- BIOS 23289. Marine Ecology.
    - Instructor: Tim Wootton. Term: Winter
- BIOS 23409. The Ecology and Evolution of Infectious Diseases.
    - Instructor: Greg Dwyer. Term: Spring
- BIOS 23410. Complex Interactions: Coevolution, Parasites, Mutualists, and Cheaters.
    - Instructor: Thorsten Lumbsch. Term: Spring

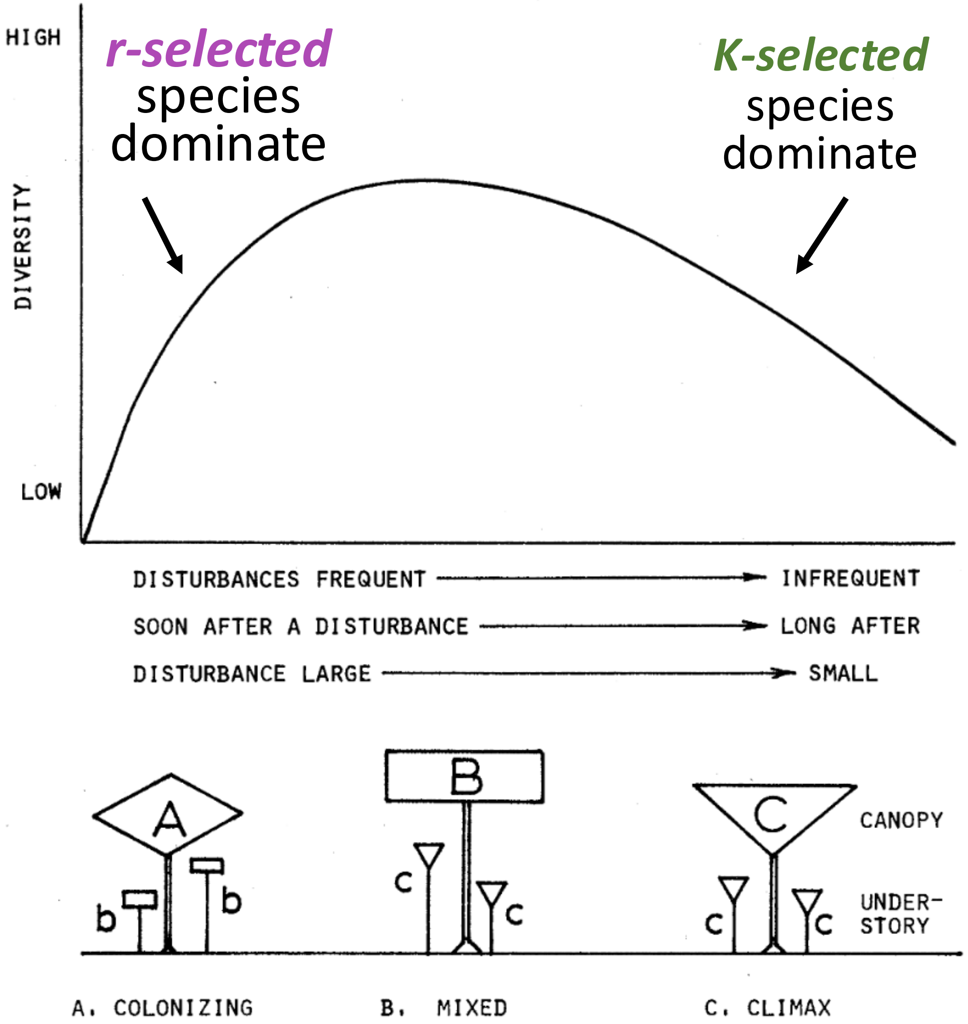
Learning objectives from Lecture 9

You should be able to:

- Describe the different types of succession
- Predict how species number will change with area from the SAR
- Understand island biogeography theory: recognize and interpret curves and equations, predict equilibrium number of species and turnover rate conceptually, and explain why immigration curve varies with distance and extinction curve with size
- Know Simberloff's experiments and be able to identify near/far or small/ large islands from the data
- Know some of the hypotheses of why diversity varies with latitude
- Know some of the benefits of biodiversity

Extra

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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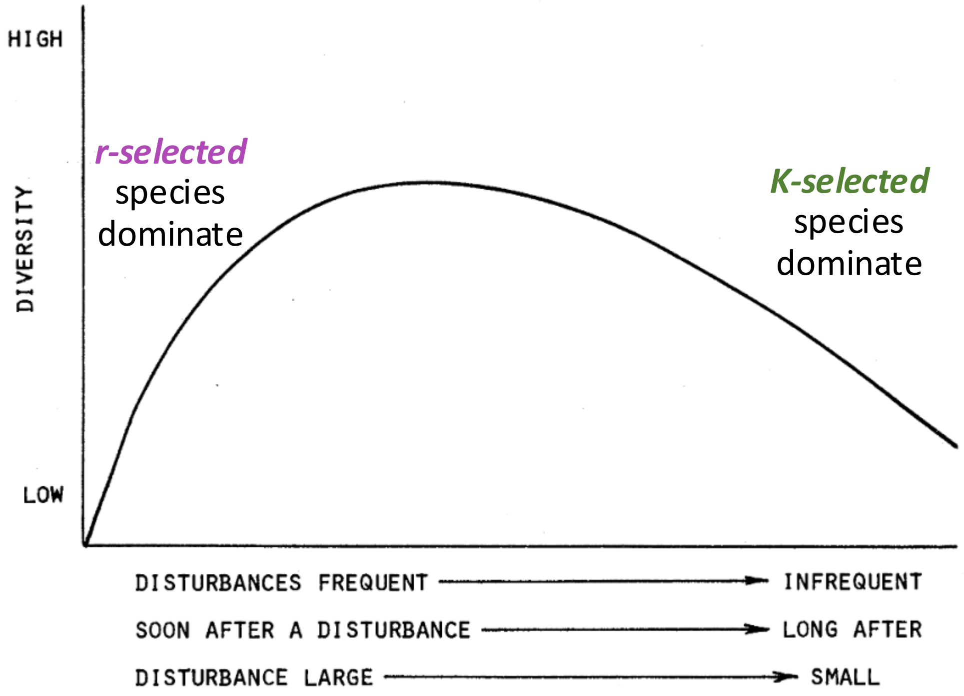

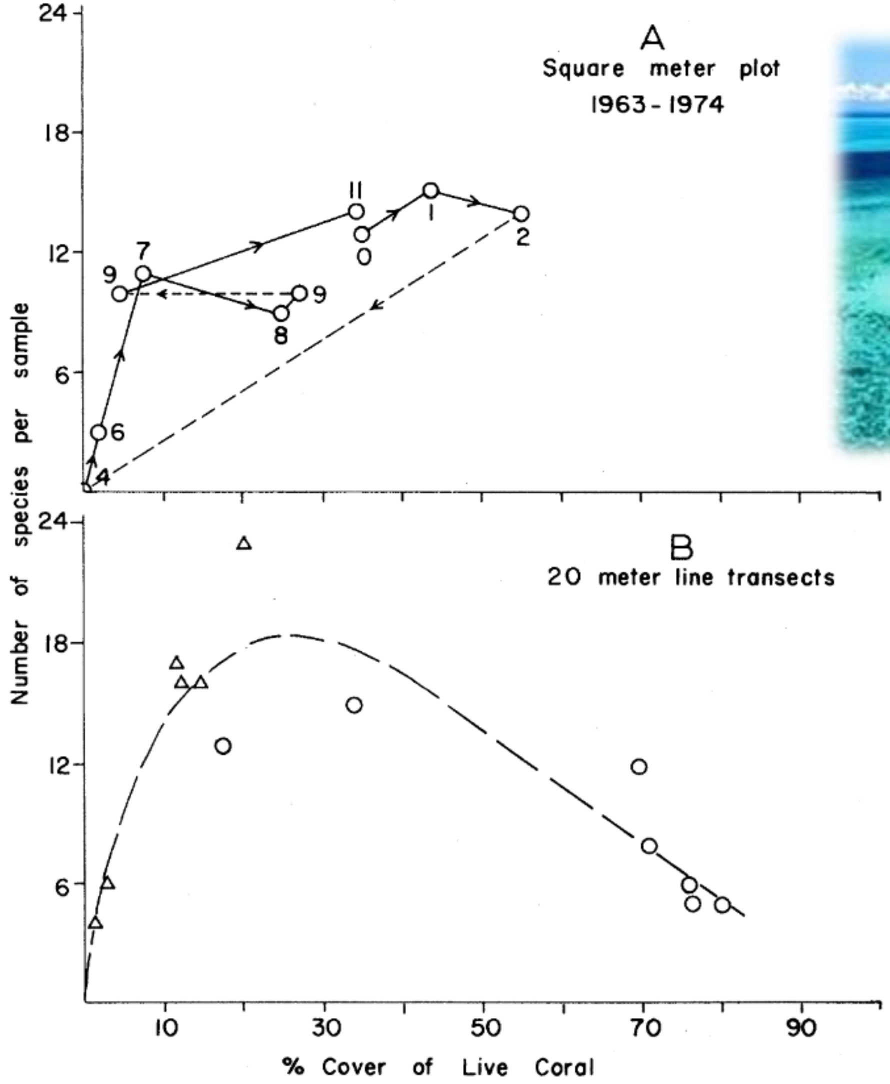

Heron Island, Australia

Sometimes it seems to be correct!

Connell 1978. *Science.*

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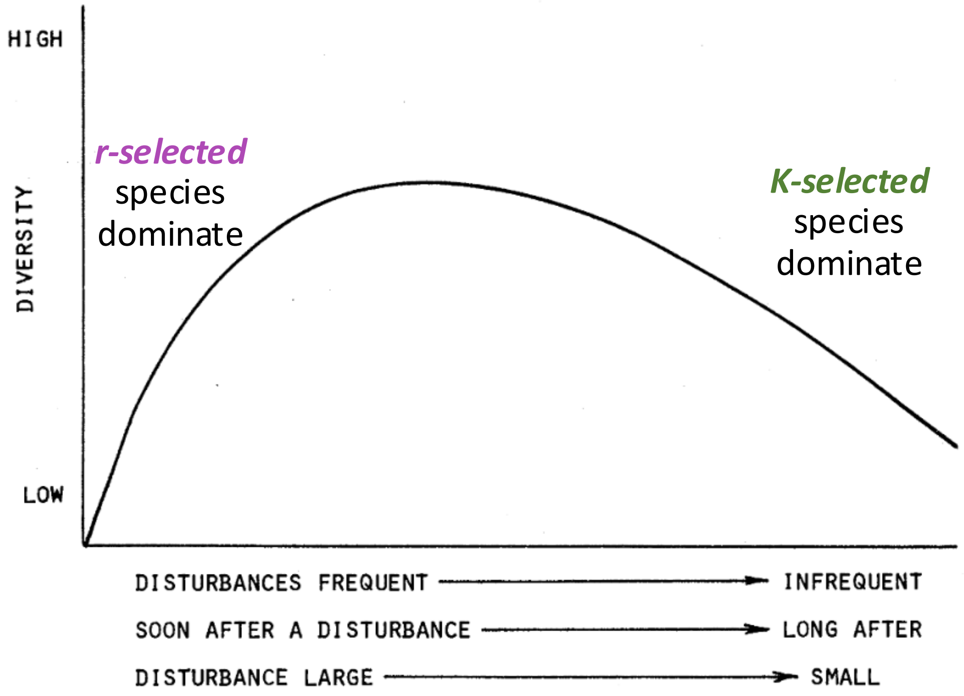
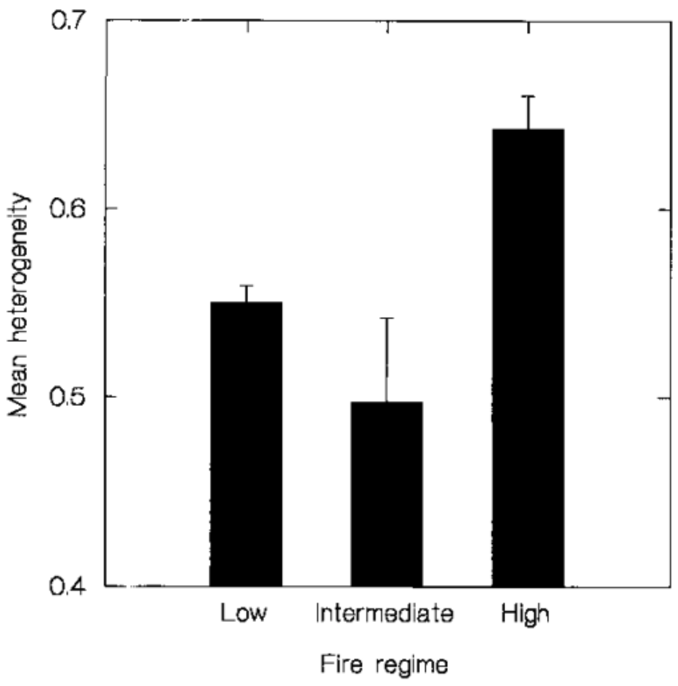
Sometimes it is not so well-supported empirically!



South African Fynbos



Schwilk et al. 1997. *Plant Ecology*

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

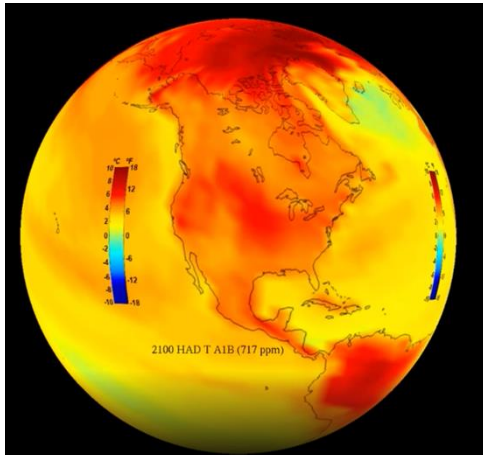
What is a model?

an abstract representation of a phenomenon

Human

Solar System

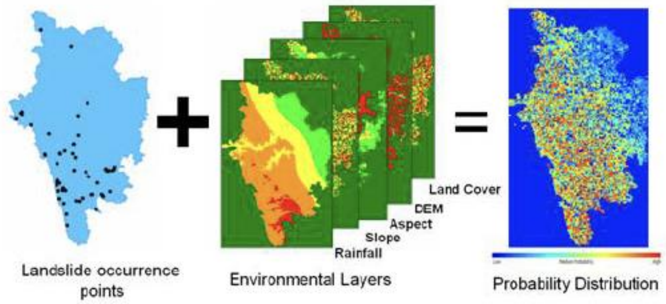
Climate



Human Genetics

Human Disease

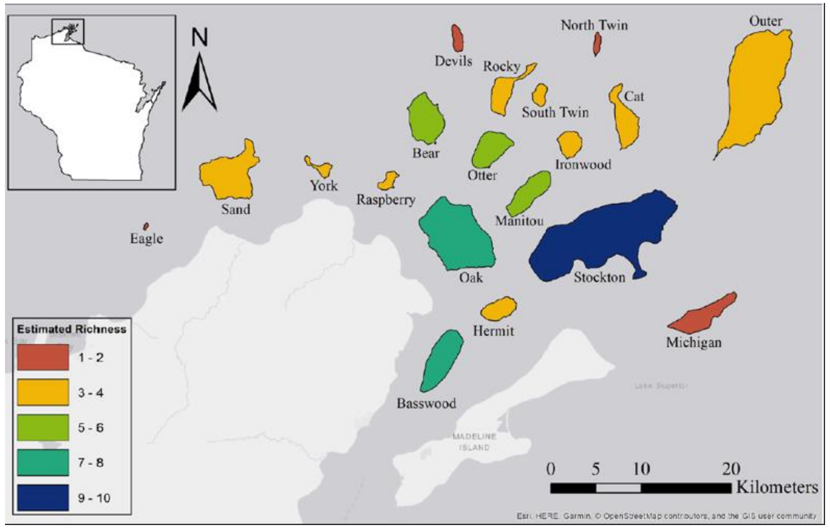
Species Distribution



The importance of island size vs. distance varied for different species!

Island	Island size (km^2)	Distance to mainland (km)	Distance to nearest island (km)	Maximum elevation (m)	Mean elevation (m)
Eagle	0.08	3.54	5.13	8	5.4
North Twin	0.65	20.76	2.73	13	8.4
York	1.10	1.48	3.47	12	6.3
Raspberry	1.16	2.69	2.91	30	15.4
Devils	1.25	14.33	3.36	21	10.6
South Twin	1.36	15.06	1.05	15	8.3
Ironwood	2.69	14.44	1.66	27	15.3
Hermit	3.17	3.67	2.20	56	21.7
Rocky	4.24	12.41	1.05	31	14.4
Otter	5.35	8.43	1.29	44	24.4
Manitou	5.36	8.43	1.66	43	19.7
Cat	5.41	18.03	2.74	25	13.3
Michigan	6.18	17.86	4.09	29	15.0
Bear	7.34	7.23	2.84	72	26.9
Basswood	7.74	1.87	2.20	58	32.3
Sand	11.58	2.04	3.47	19	9.6
Oak	20.32	2.12	2.22	147	66.8
Outer	21.78	23.83	4.28	83	31.7
Stockton	40.00	7.84	2.15	61	25.7

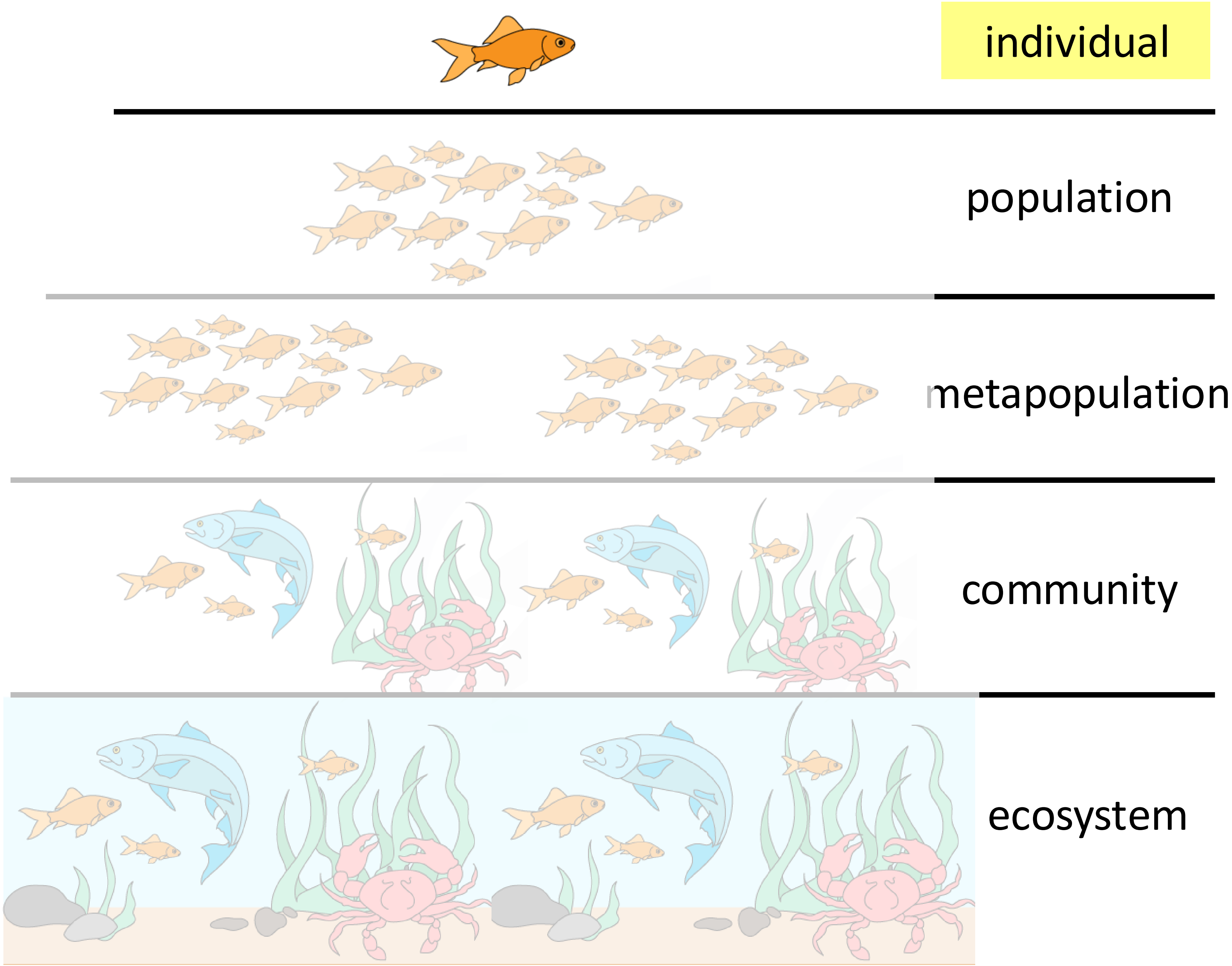
- **Coyotes** – density predicted by (1) island size, (2) distance from mainland, (3) inter-island distances
- **Black bears** – predicted by (1) island size and (3) inter-island distances only
- **Weasels** – not predicted by any of these variables



Allen et al. 2018. *Community Ecology.*

Individual:
metabolism, behavior, life history.

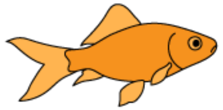
interactions of an individual with the environment



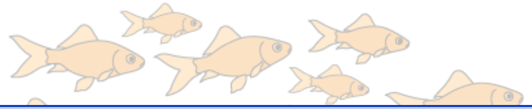
Individual:
metabolism,
behavior, life history.

Dynamic Energy Budget (DEB) Model

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



individual

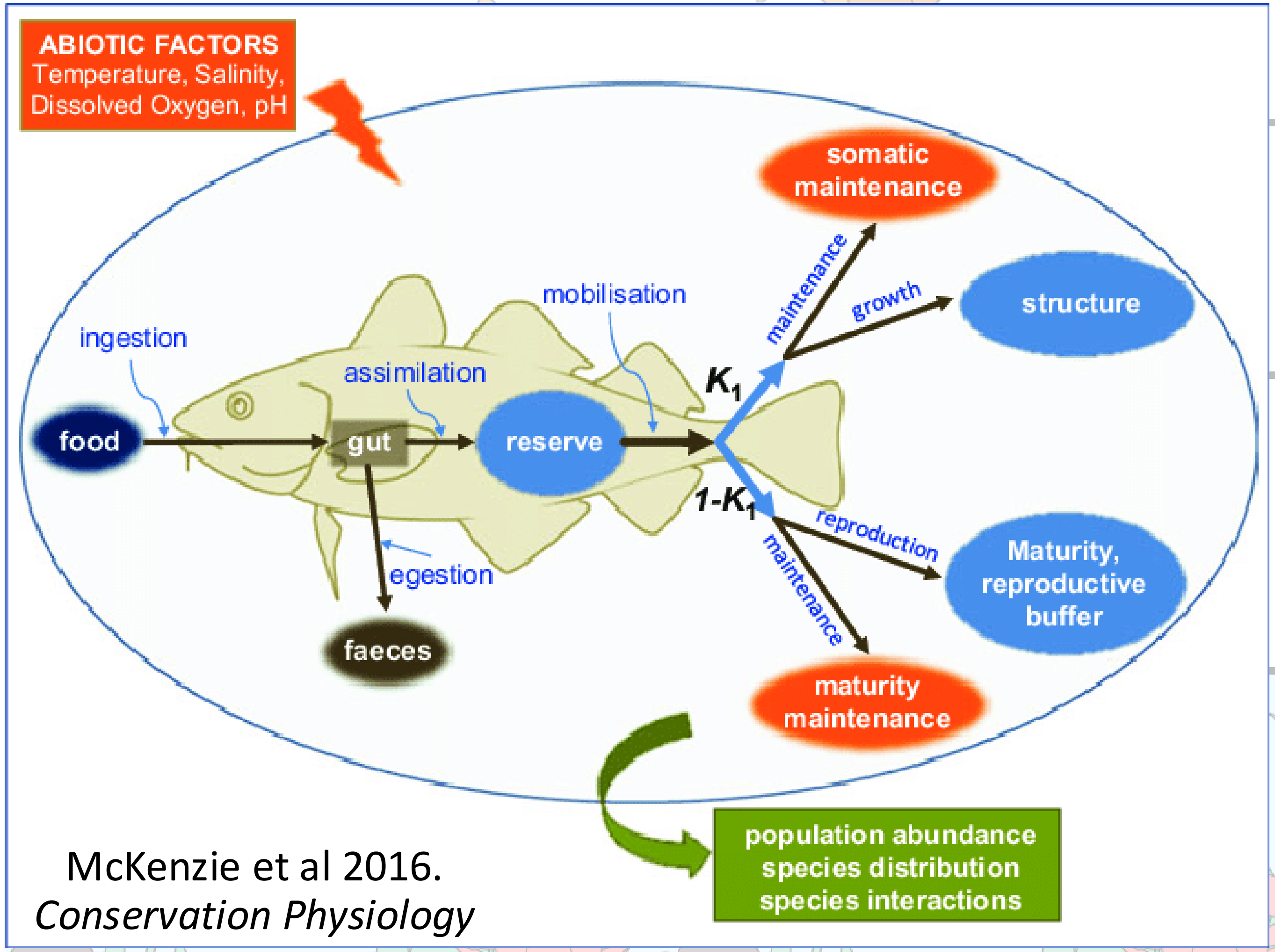


population

metapopulation

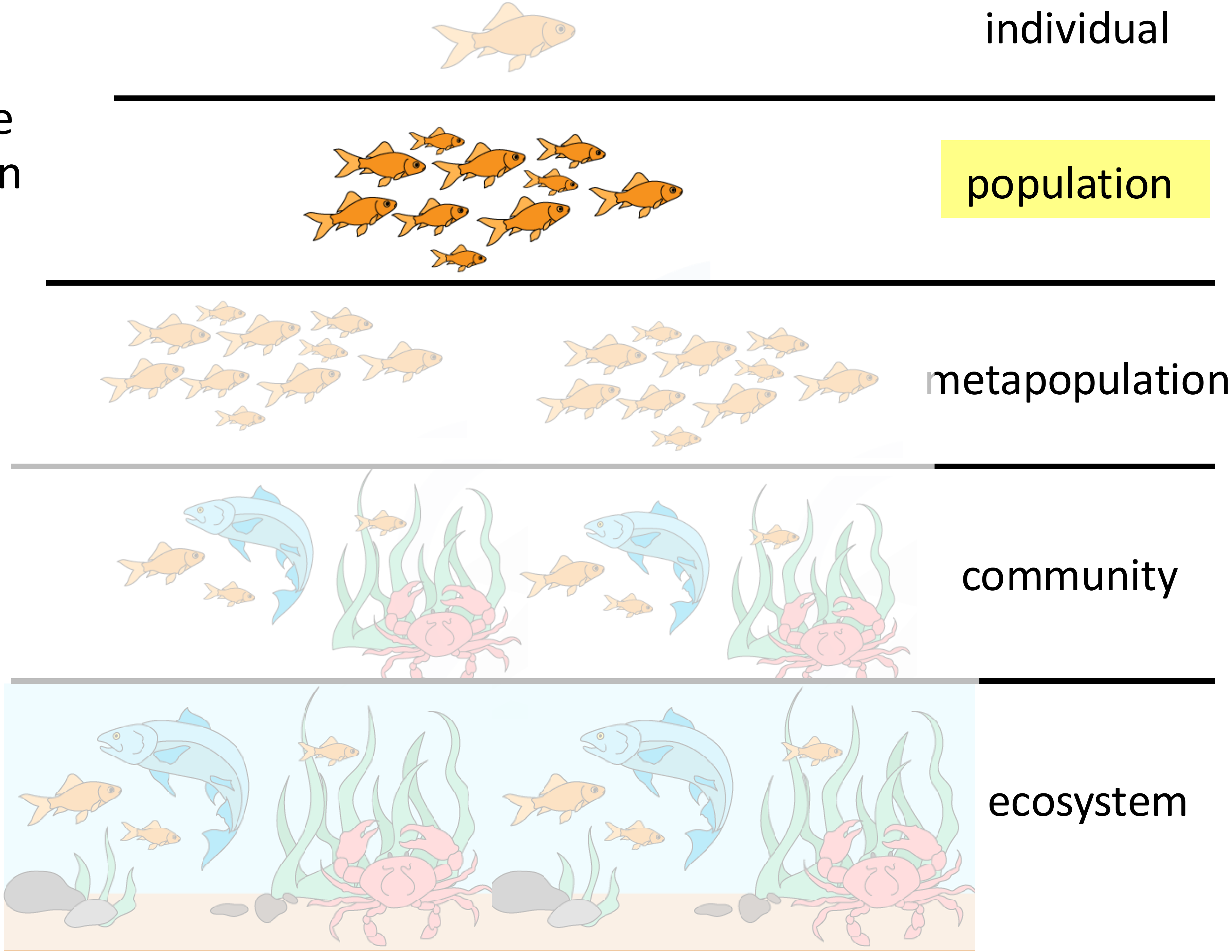
community

ecosystem

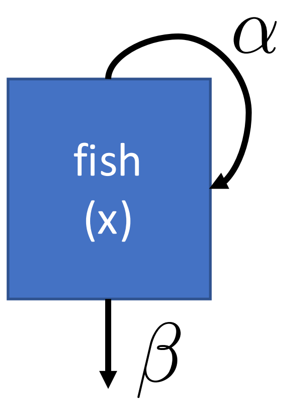


McKenzie et al 2016. *Conservation Physiology*

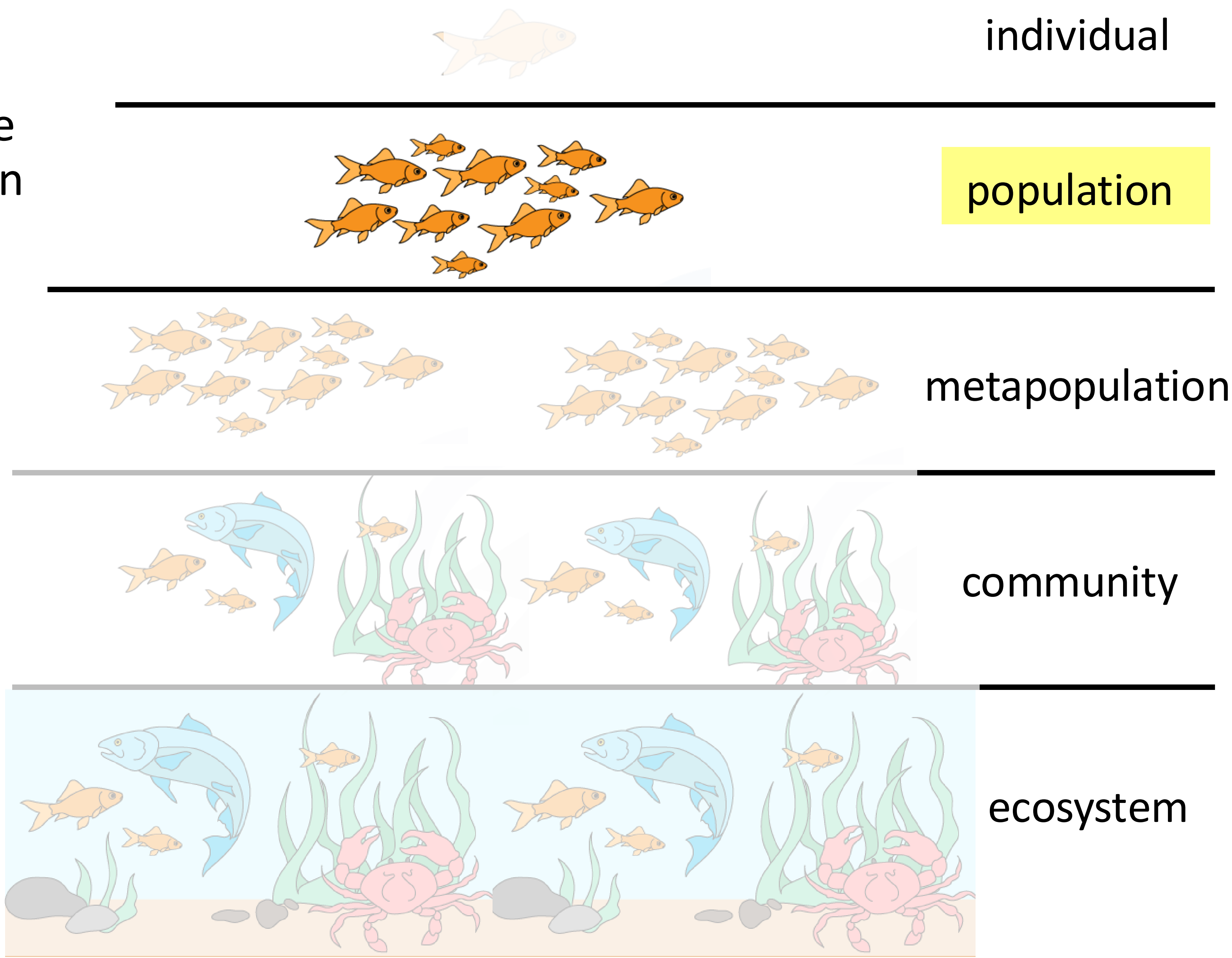
Population = multiple individuals of the same species (**conspecifics**) in the same habitat



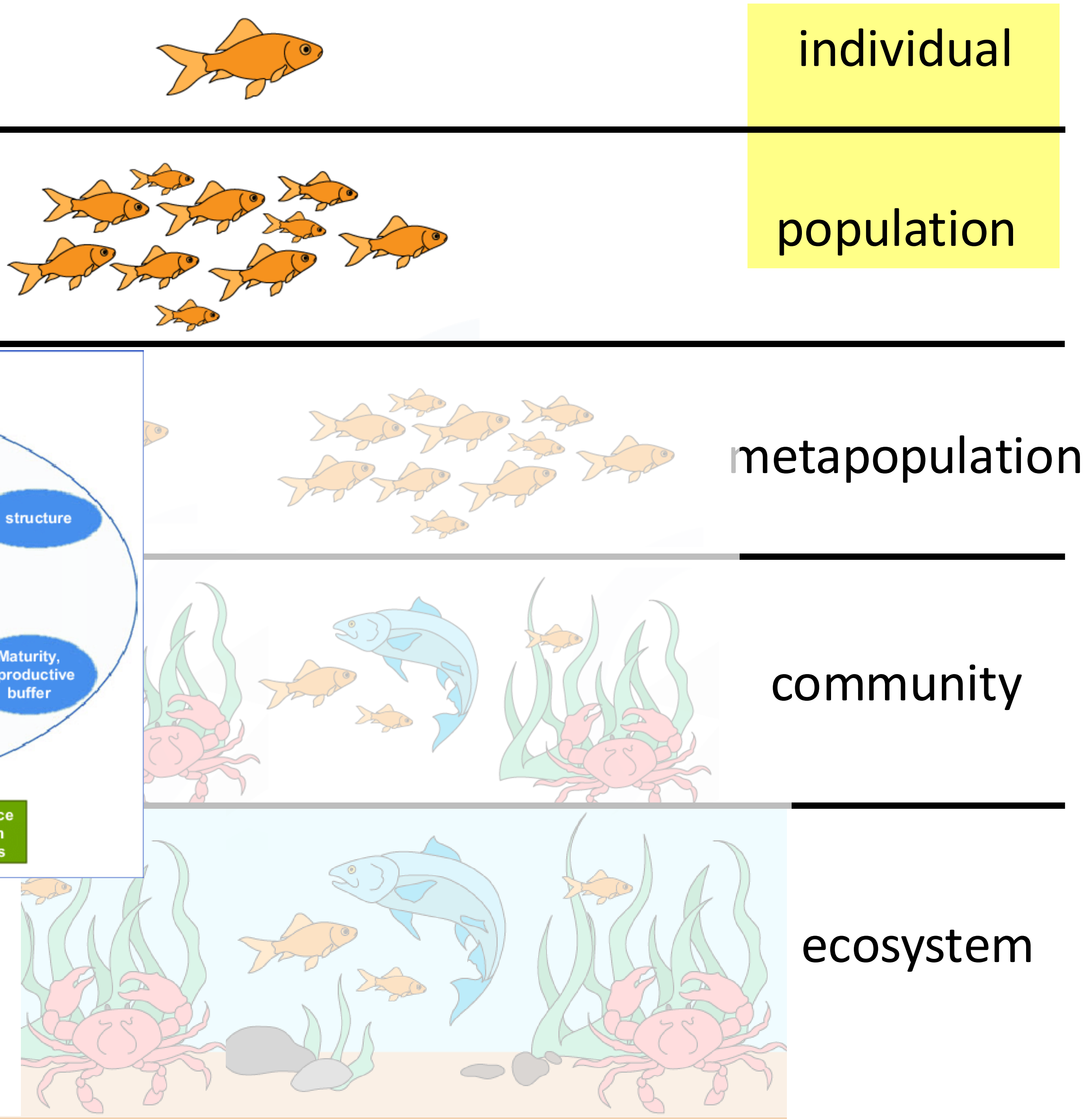
Population = multiple individuals of the same species (**conspecifics**) in the same habitat

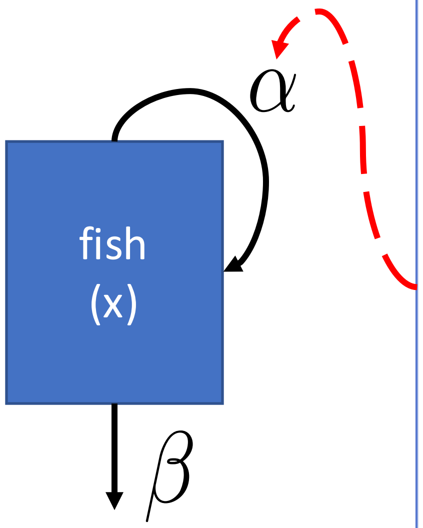


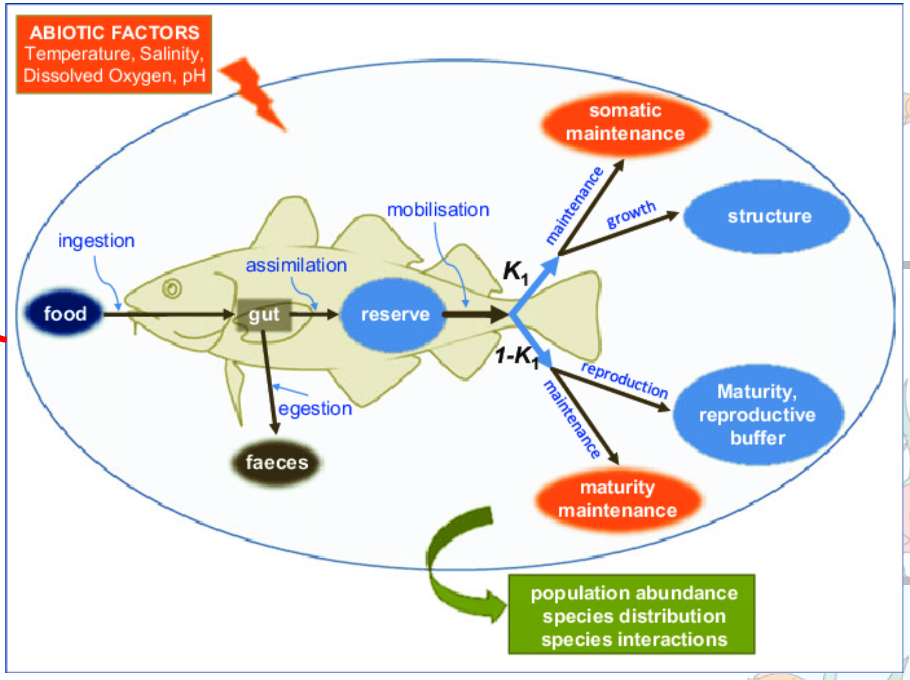
*How does the abundance of fish **change** through time?*



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

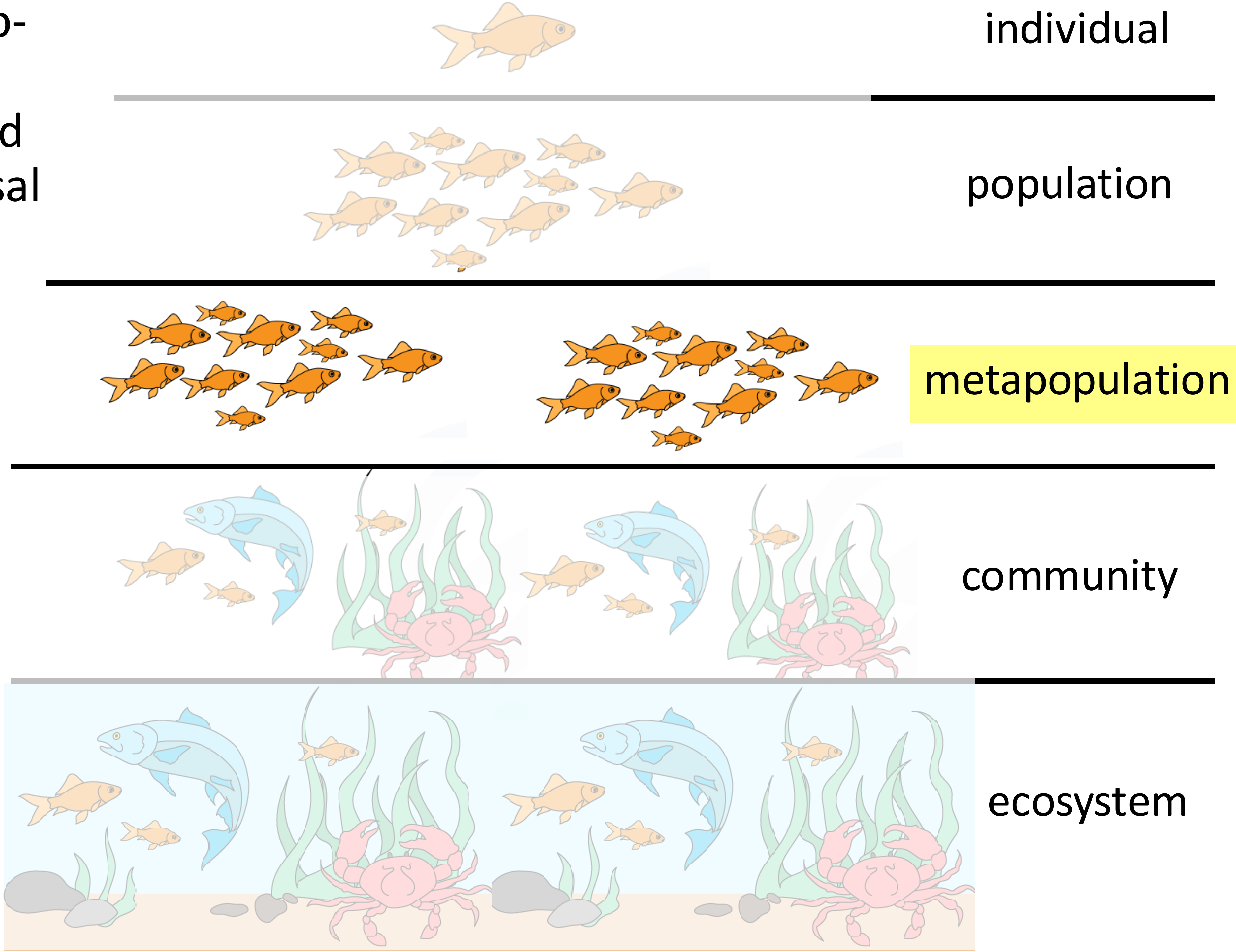




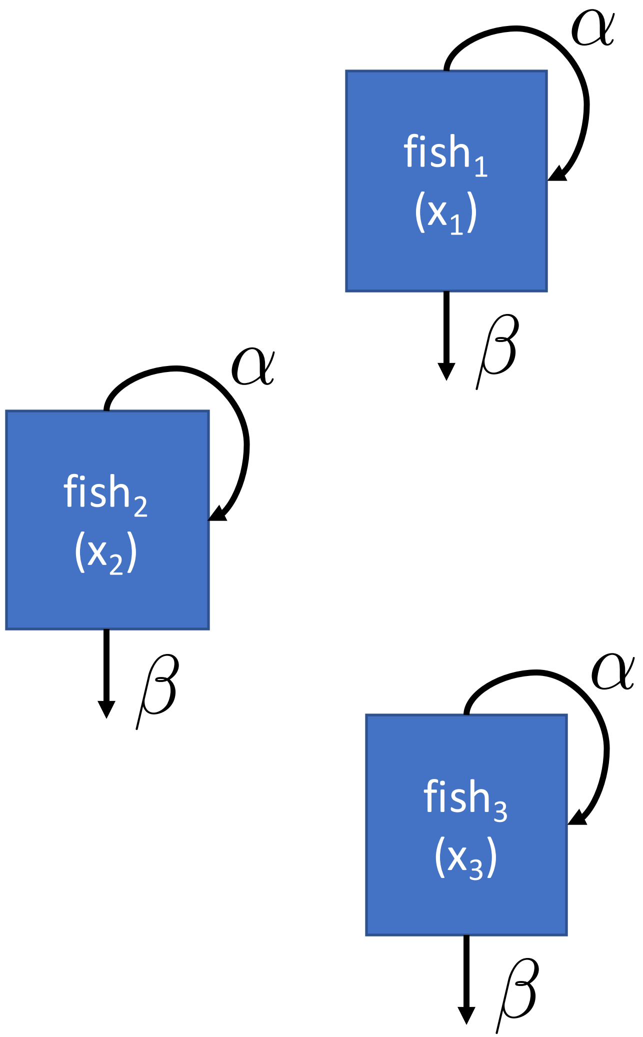


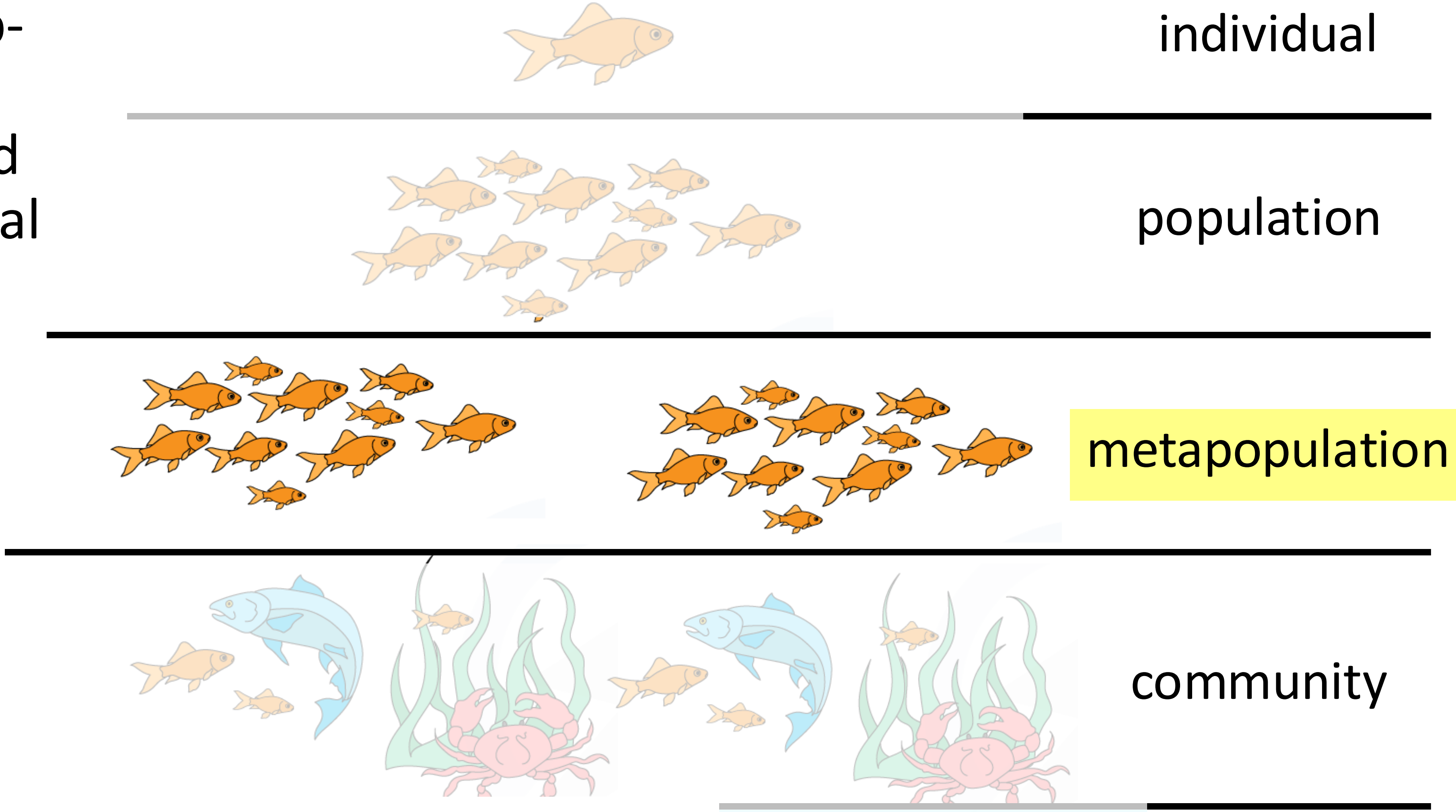
How does the abundance of fish ***change*** *through time as temperature* ***changes*** *metabolism?*

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



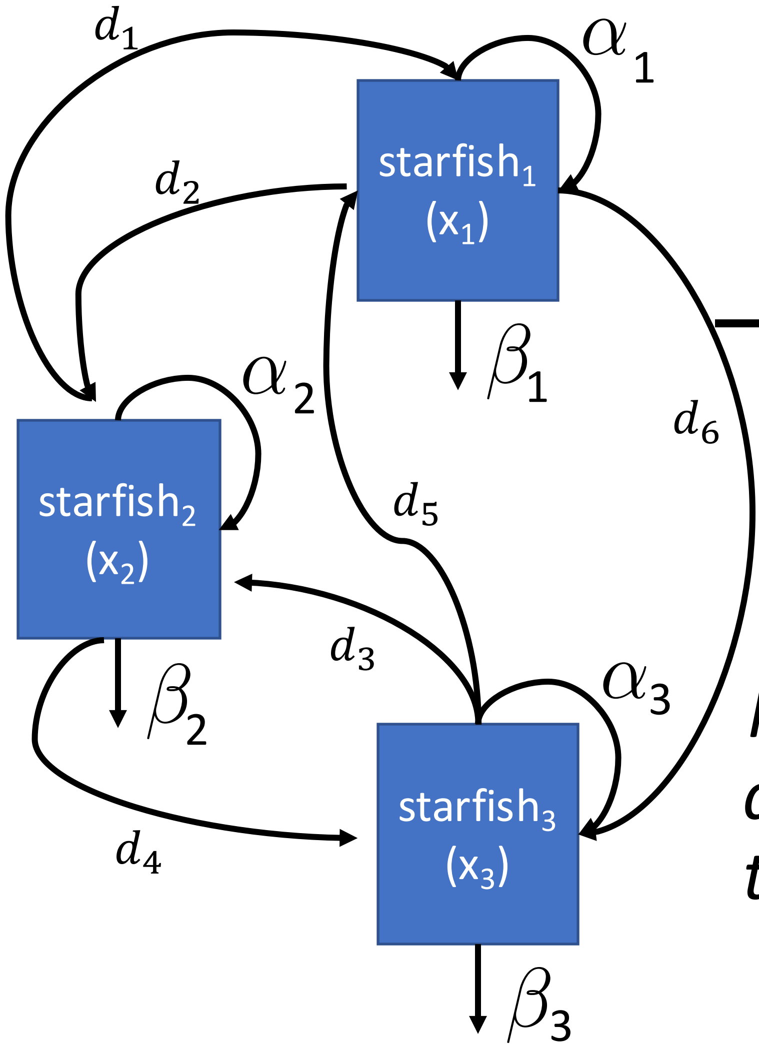
Metapopulation = sub-populations of conspecifics connected by migration or dispersal

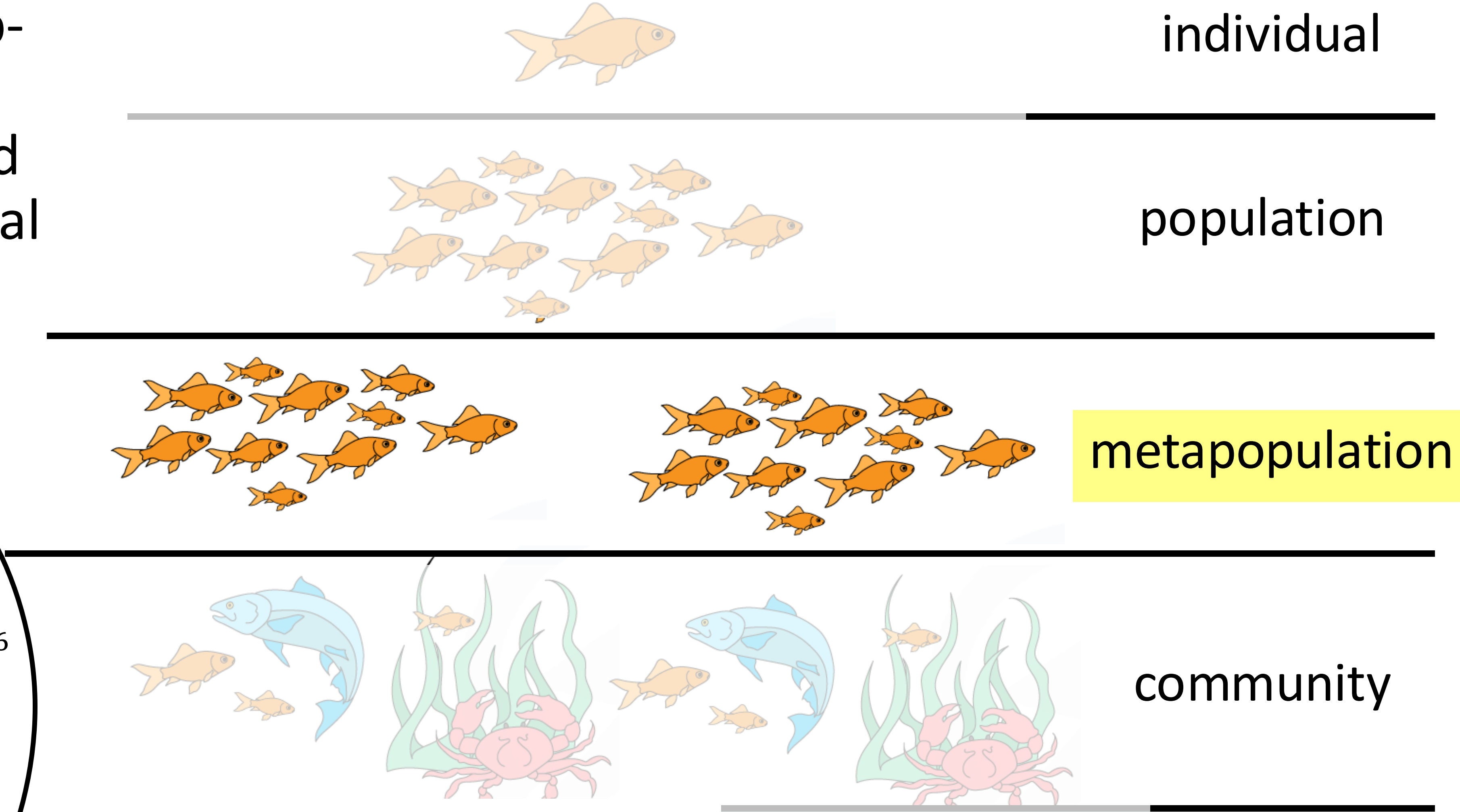




*How do the abundances of different subpopulations of the same fish **vary** in space [and time]?*

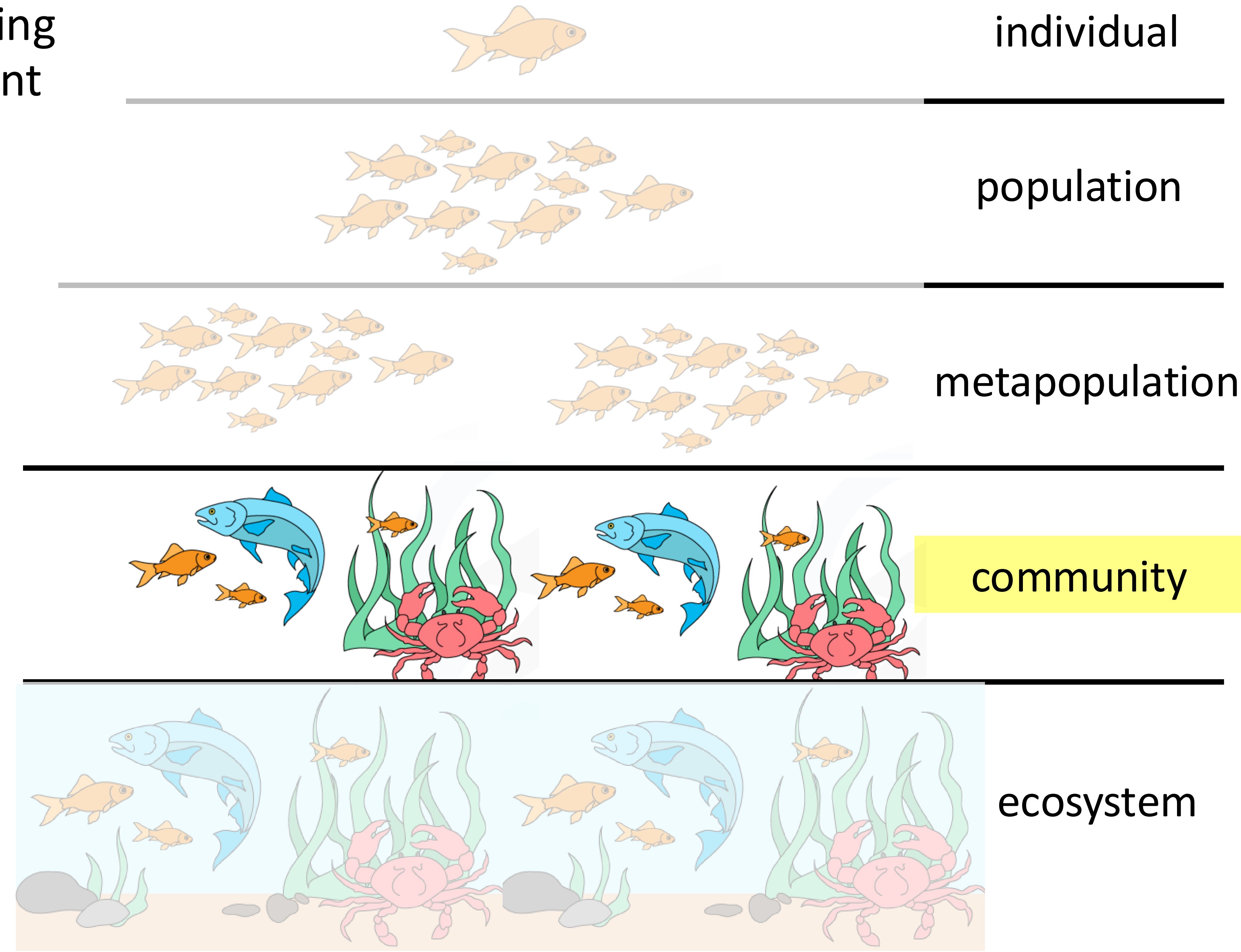
Metapopulation = sub-populations of conspecifics connected by migration or dispersal



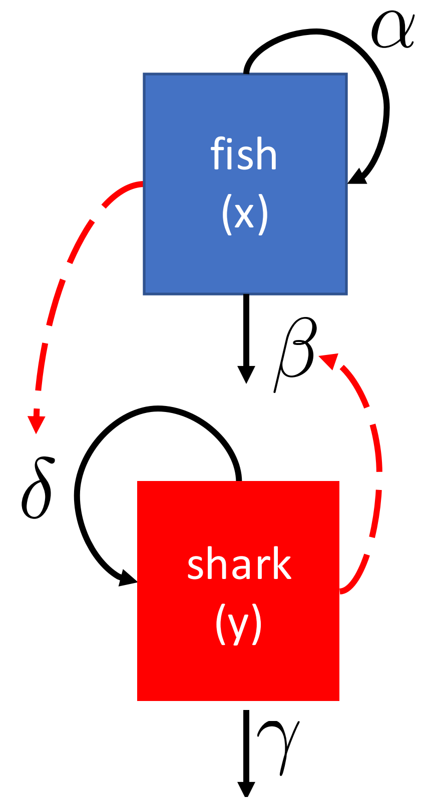


*How do the abundances of different subpopulations of the same fish **vary** in space [and time]?*

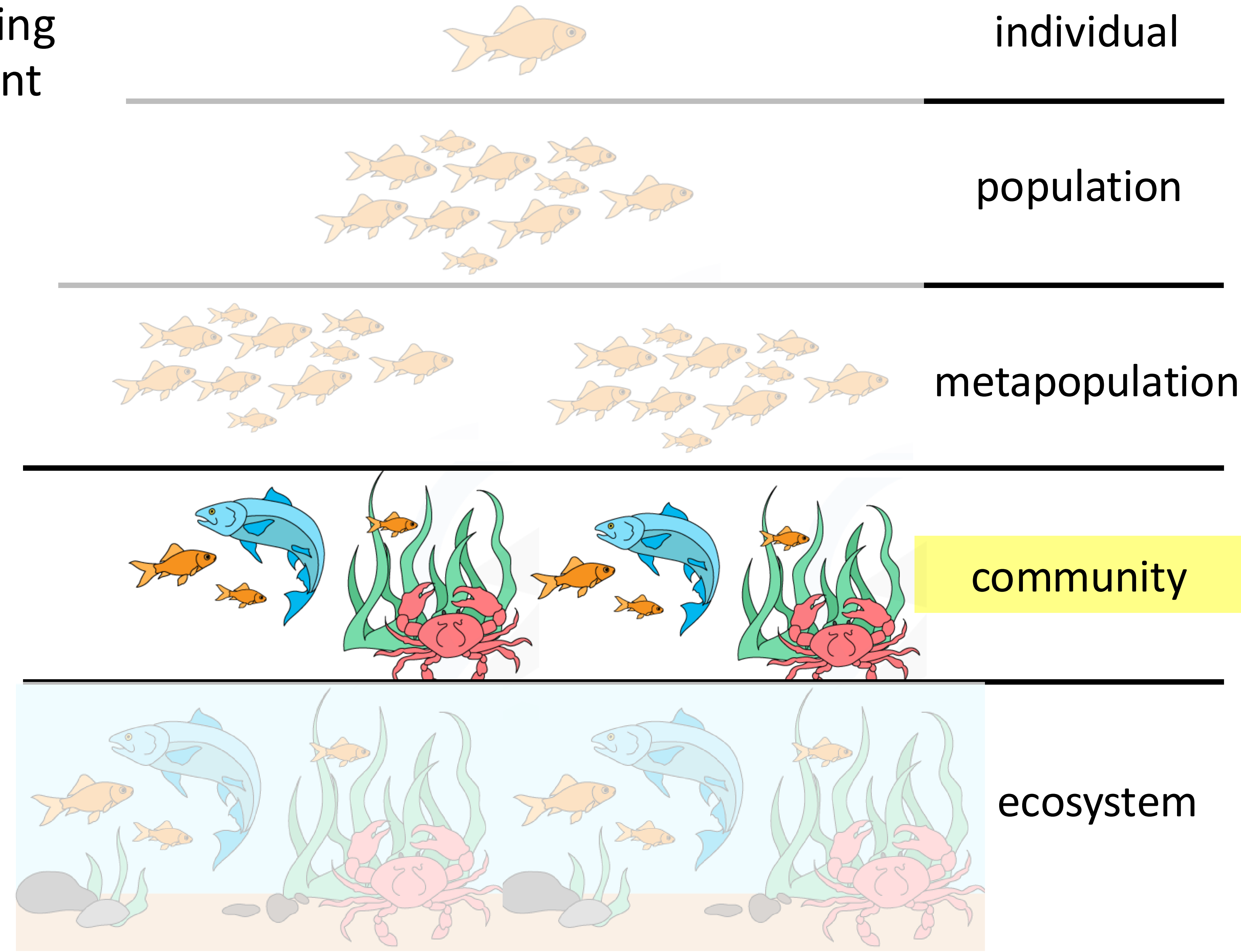
Community = interacting populations of different species



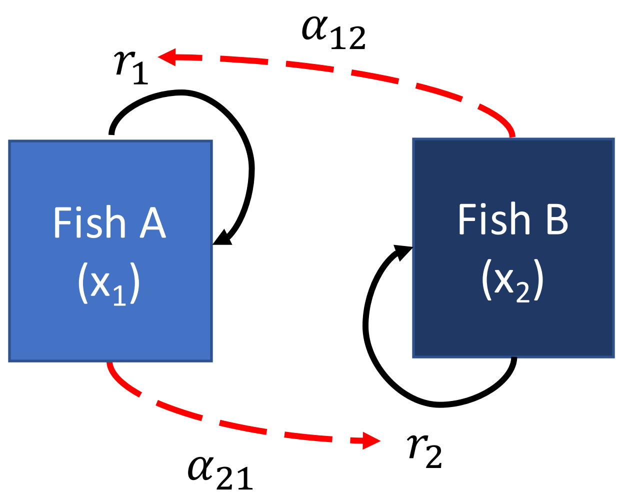
Community = interacting populations of different species



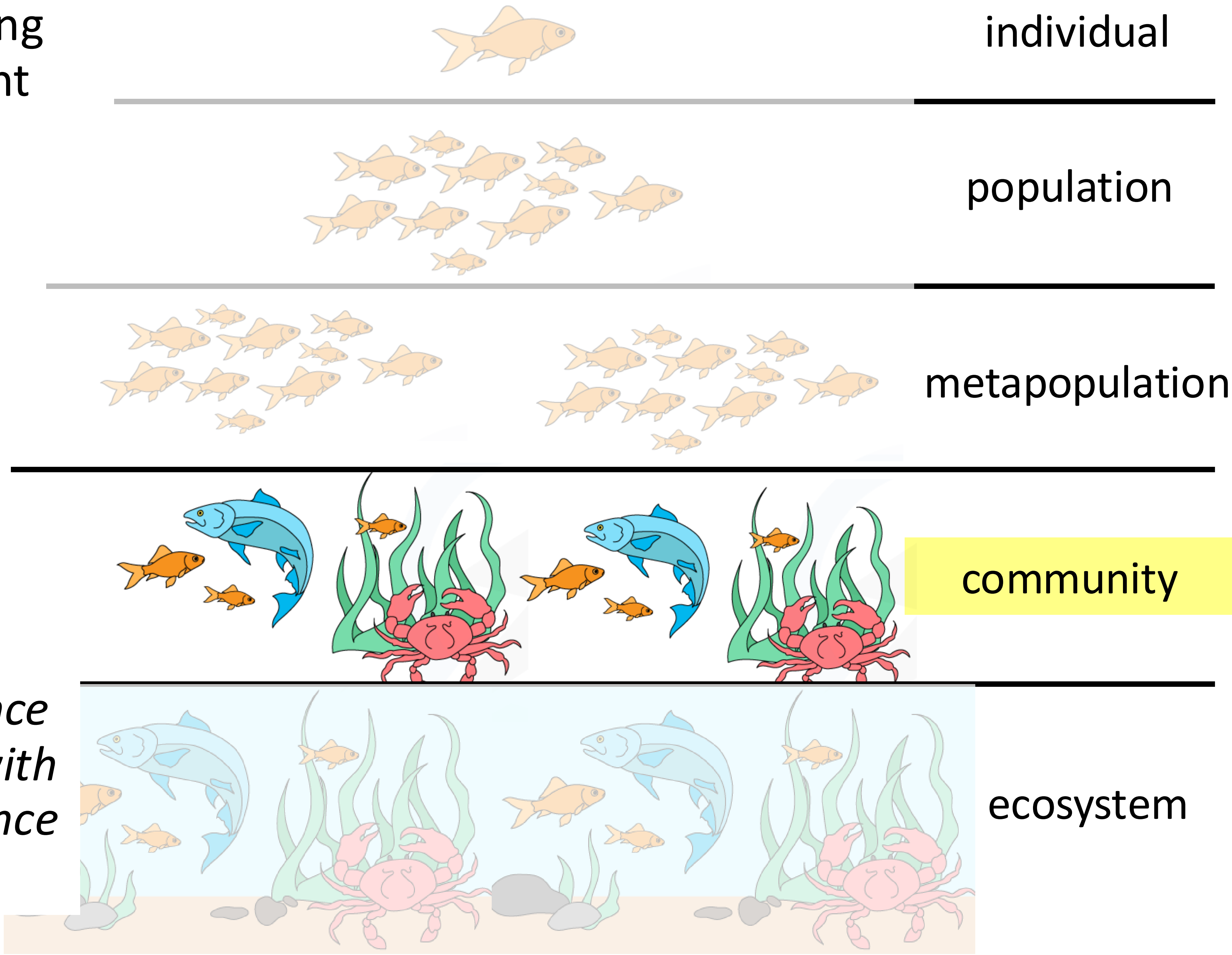
How does fish abundance ***vary*** *with* ***changes*** *in shark abundance?*



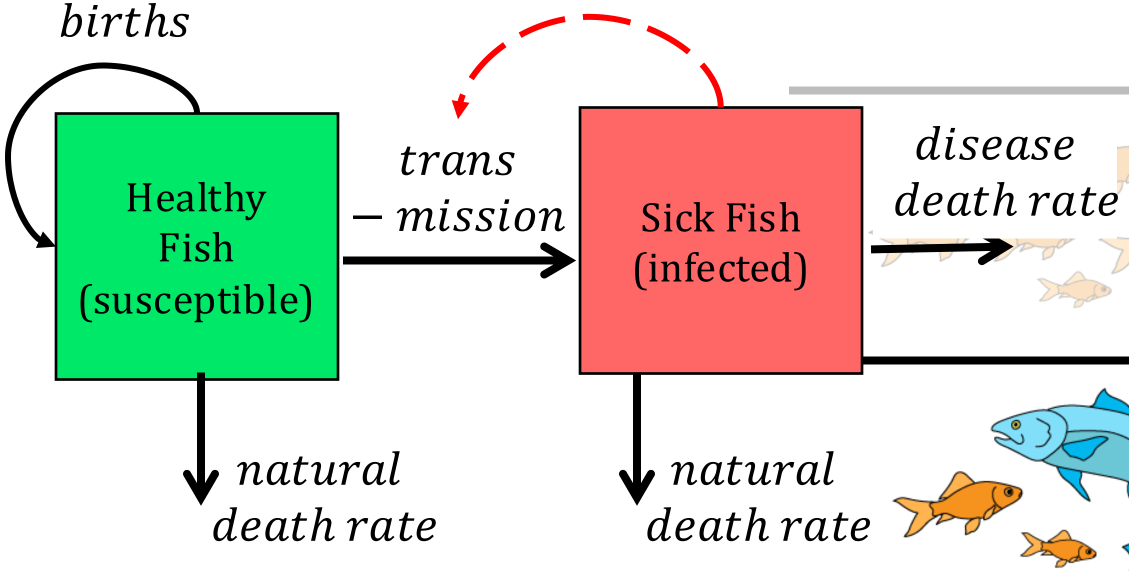
Community = interacting populations of different species

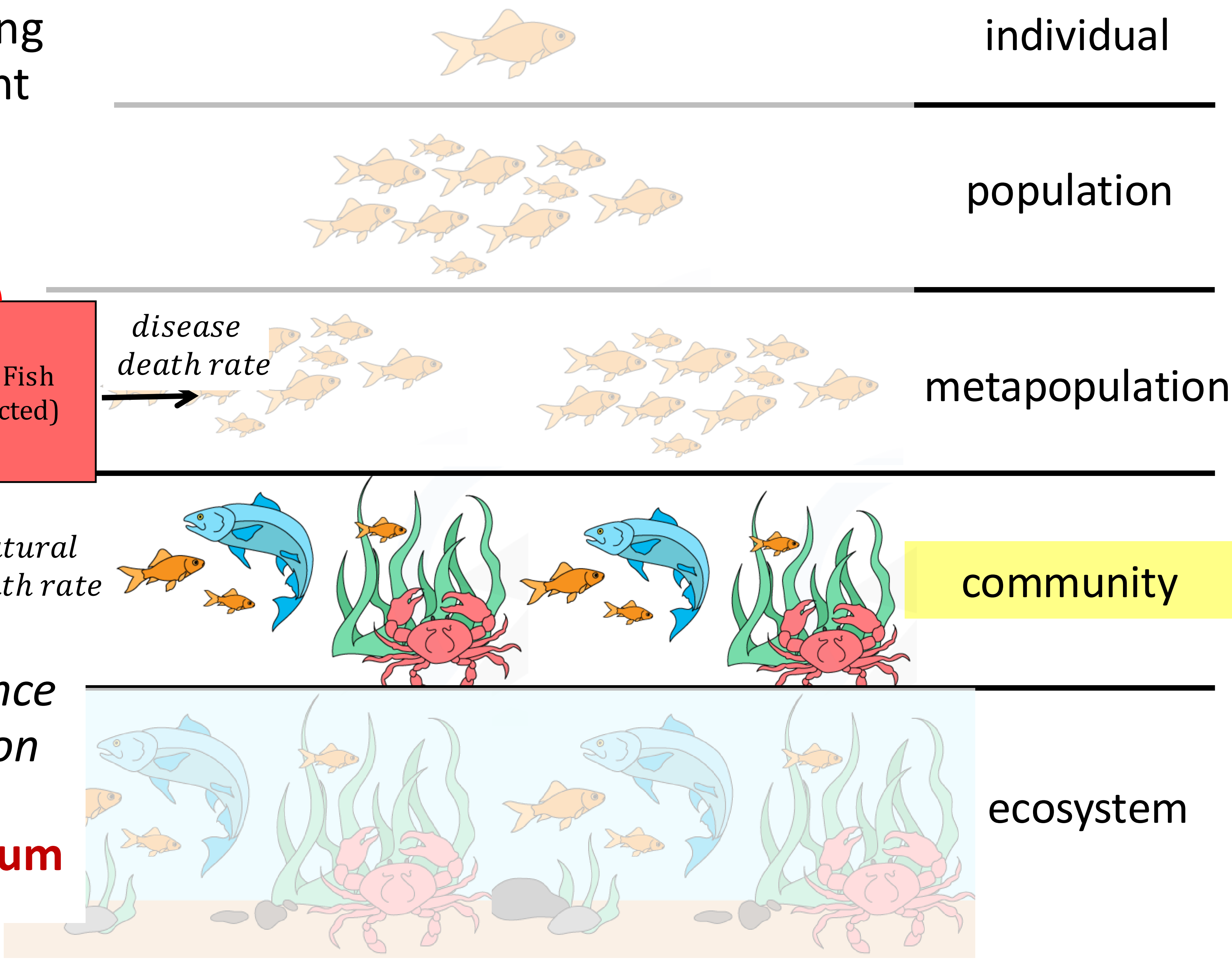


*How does the abundance of **fish species A** vary with changes in the abundance of **fish species B**?*



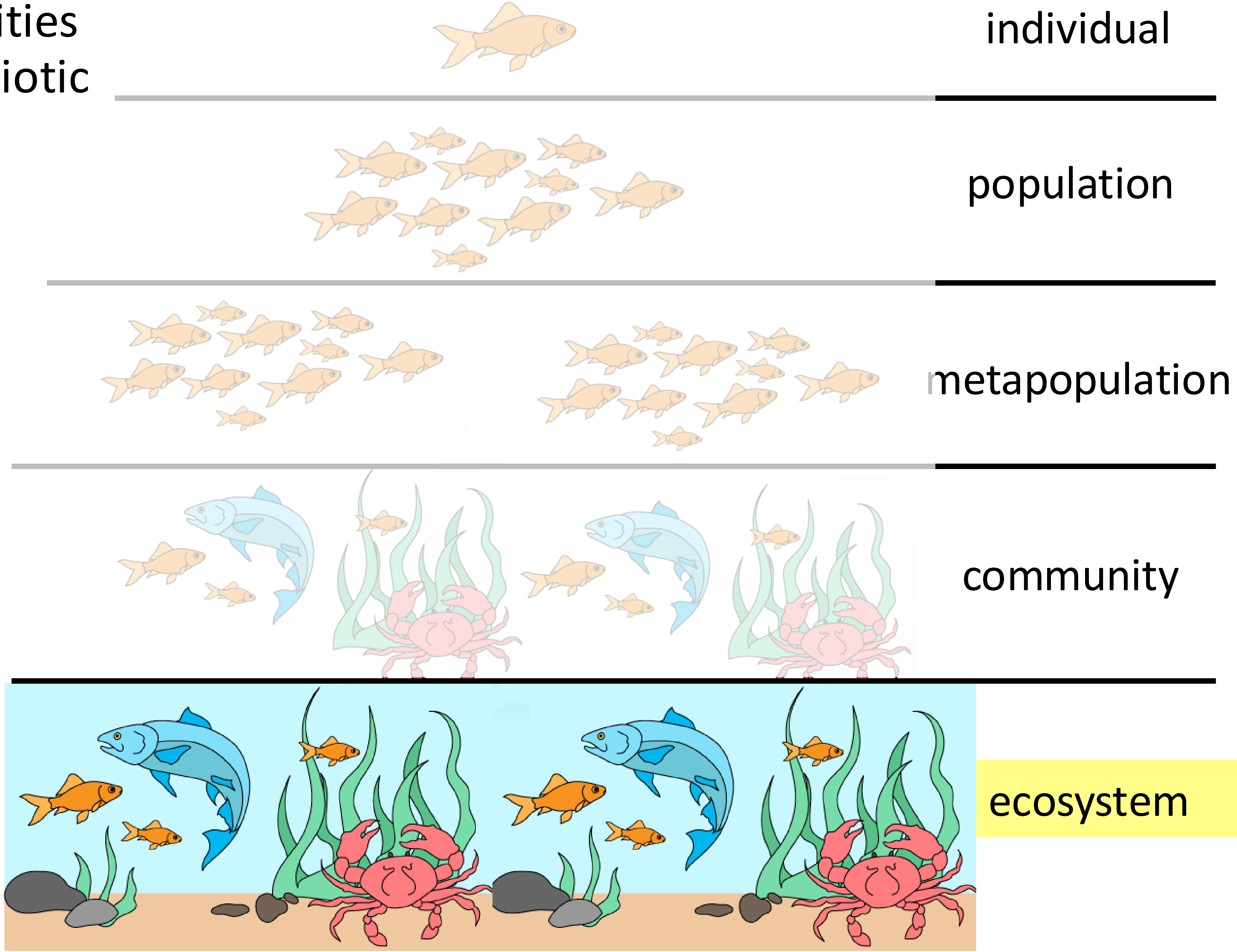
Community = interacting populations of different species



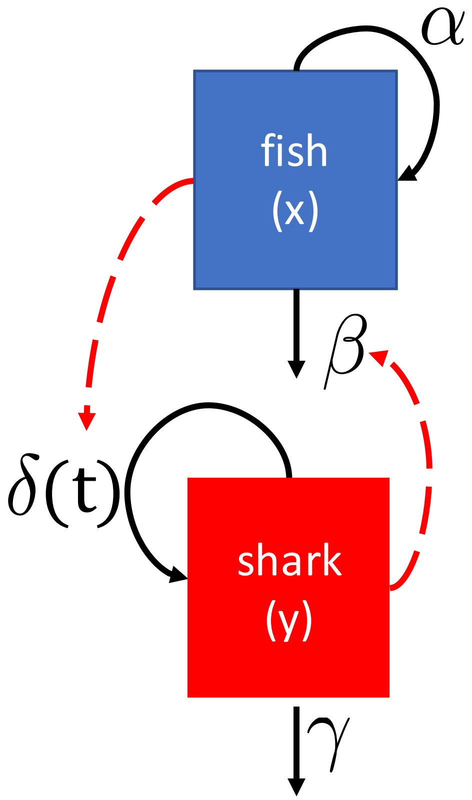


How does the abundance of ***fish*** *change based on* ***infection with***
Mycobacterium marinum
(wasting disease)?

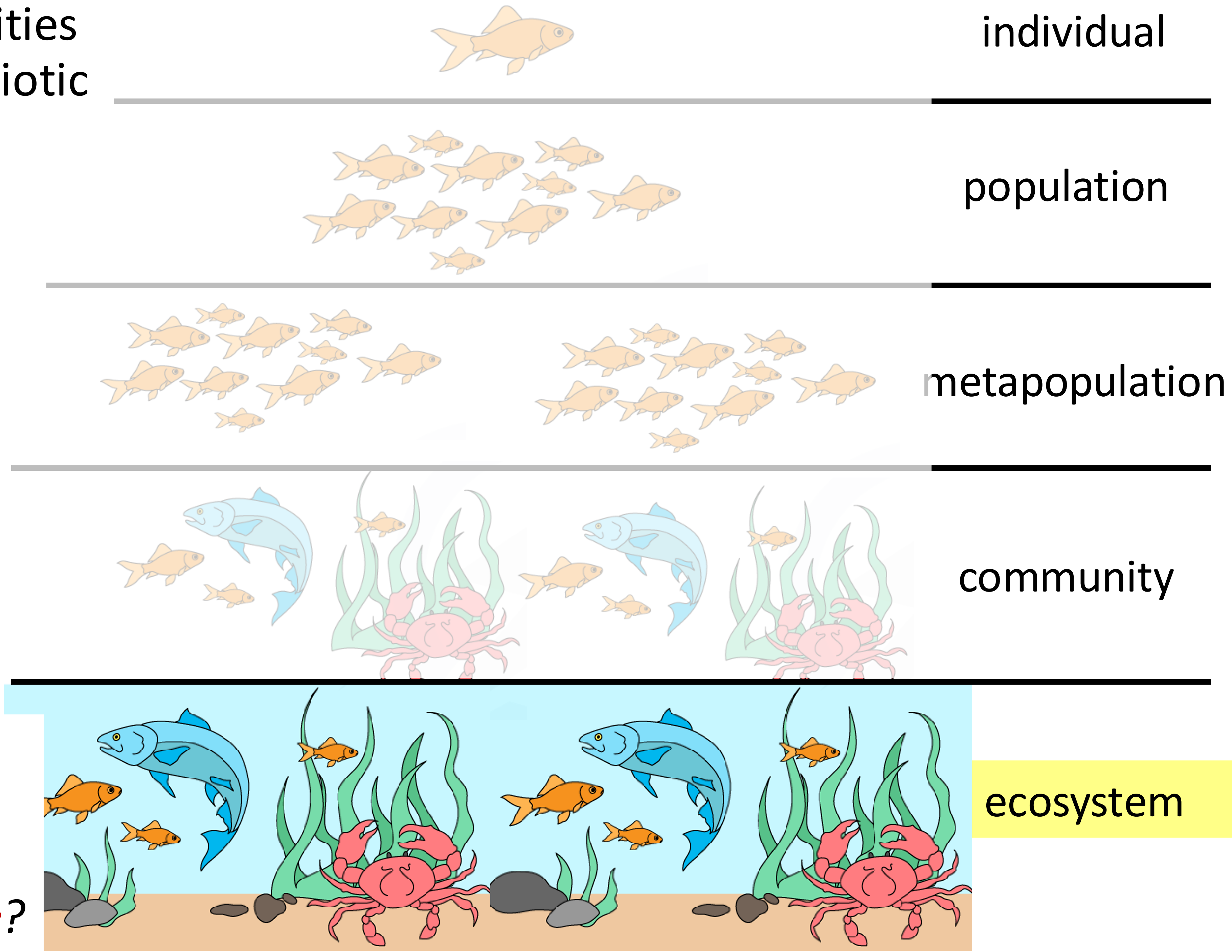
Ecosystem = communities interacting with the abiotic environment



Ecosystem = communities interacting with the abiotic environment



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



Visual settings

Edit

Imagine a forest with endemic Lyme disease and a high population of deer. What outcome would you expect if the deer were experimentally removed, but the increase in grass availability leads to an explosion in the population of white-footed mice?

A. Lyme risk to humans …	0%
B. Lyme risk to humans …	0%
C. Lyme risk will not change	0%
D. We'll need to build a mo…	0%