

# Fundamentals of Ecology

Week 9, Ecology Lecture 8

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February 29, 2024

# Let's recap a bit!

## Disease Ecology

- 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.
- We discussed a few examples of the transmission-virulence tradeoff: myxoma virus in rabbits, and a protozoan parasite of Monarch butterflies.
- We also discussed conditions in which this tradeoff is hard to observe or not supported, such as in cases of zoonotic virulence (where a pathogen optimizes on a non-target host), in cases where most disease is as immunopathology, or in cases where transmission and virulence are decoupled.
- We learned that virulence tends to be reduced when transmission is more local.
- And we learned that imperfect vaccines, especially those targeting pathogen growth rates, can also result in the evolution of higher virulence pathogens.

# Let's recap a bit!

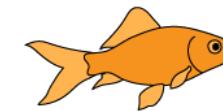
## Disease Ecology

- The “dilution effect” offers a hypothesis about the disease-buffering services of biodiversity, which is often supported by the case study of Lyme disease.
- Amplification vs. dilution effects are determined by biodiversity impacts on vector abundance, as well as the ratio of competent to non-competent hosts.

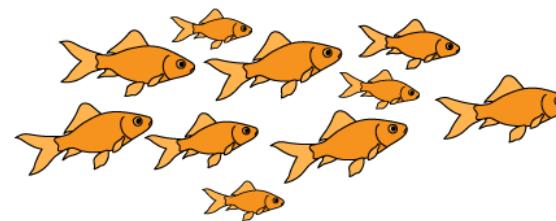
## Community Ecology

- Succession is the process of change in the species structure of ecological communities with time, from pioneer species dominated by r-selected species to climax communities dominated by K-selected species.
- Primary succession builds from bare substrate, while secondary succession builds on existing soil and nutrients.
- The intermediate disturbance hypothesis suggests that the highest biodiversity should occur in ecosystems with intermediate levels of disturbance where r- and K-selected species coexist.

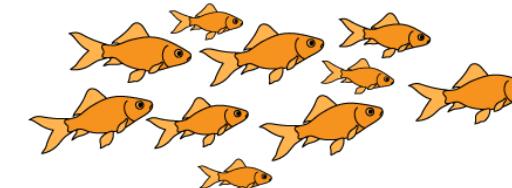
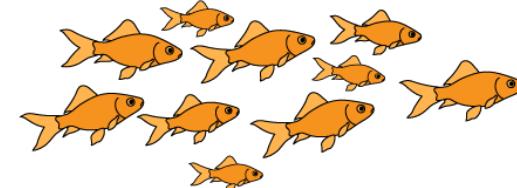
Ecology is the study of  
the **interactions** of  
**organisms** with each  
other and their  
**environment.**



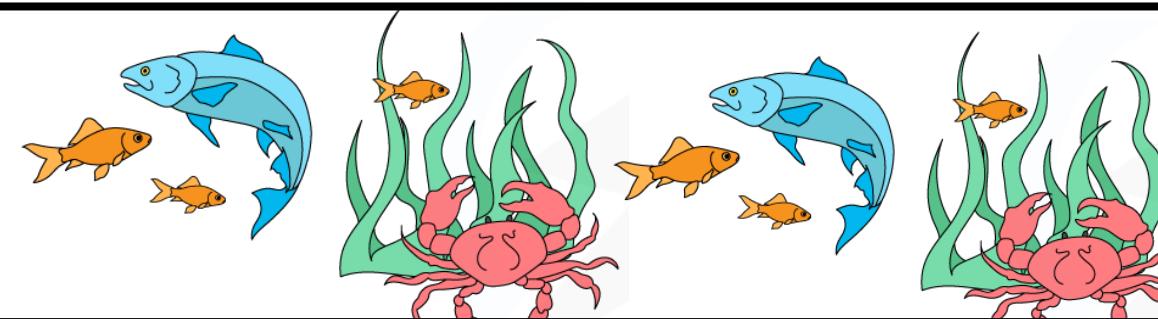
individual



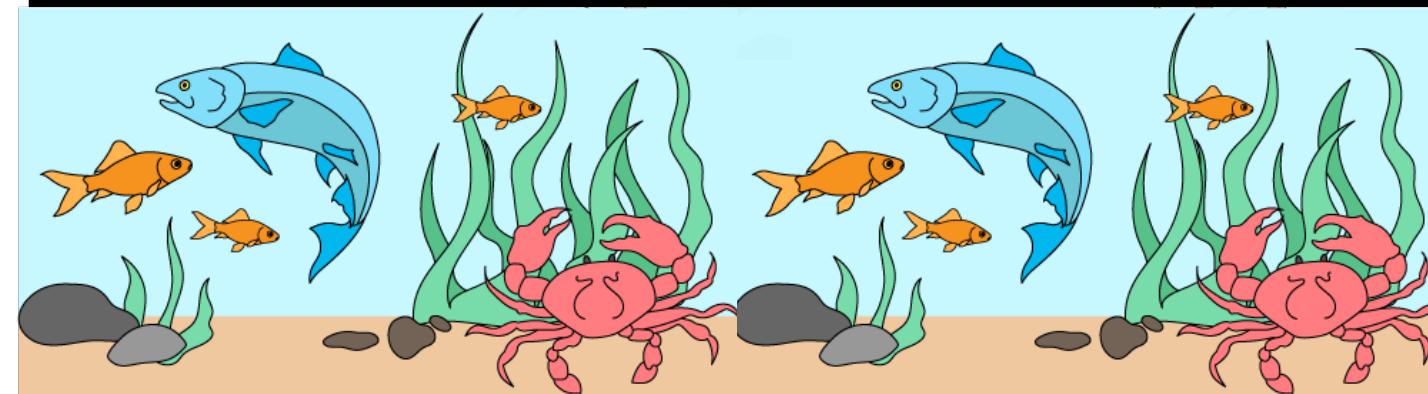
population



metapopulation

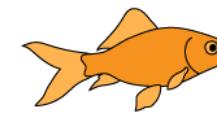


community



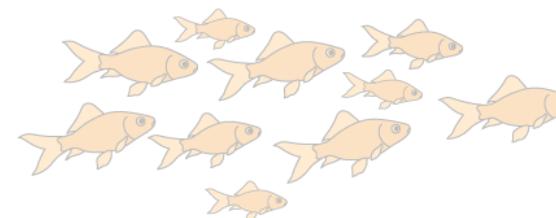
ecosystem

individual

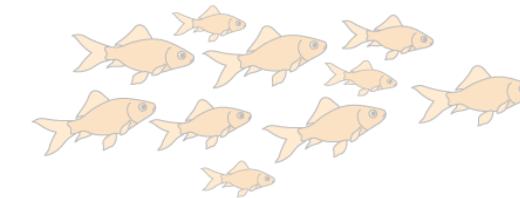
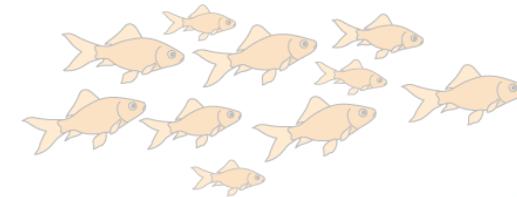


**Individual:**  
metabolism, behavior,  
life history.

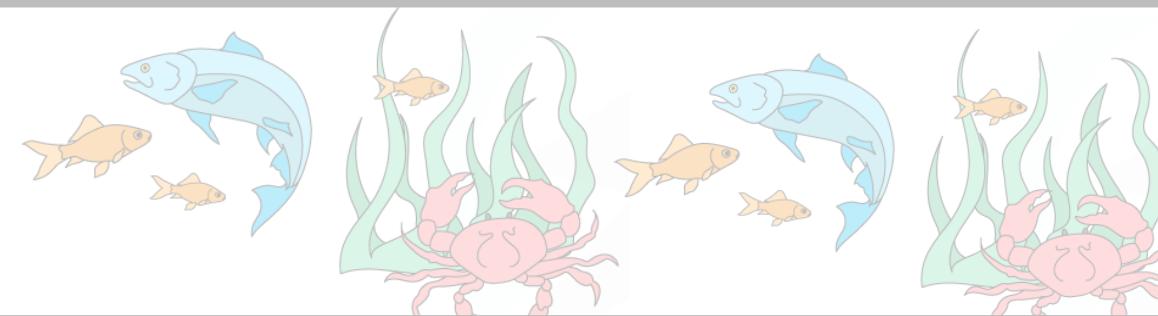
interactions of an  
individual with the  
environment



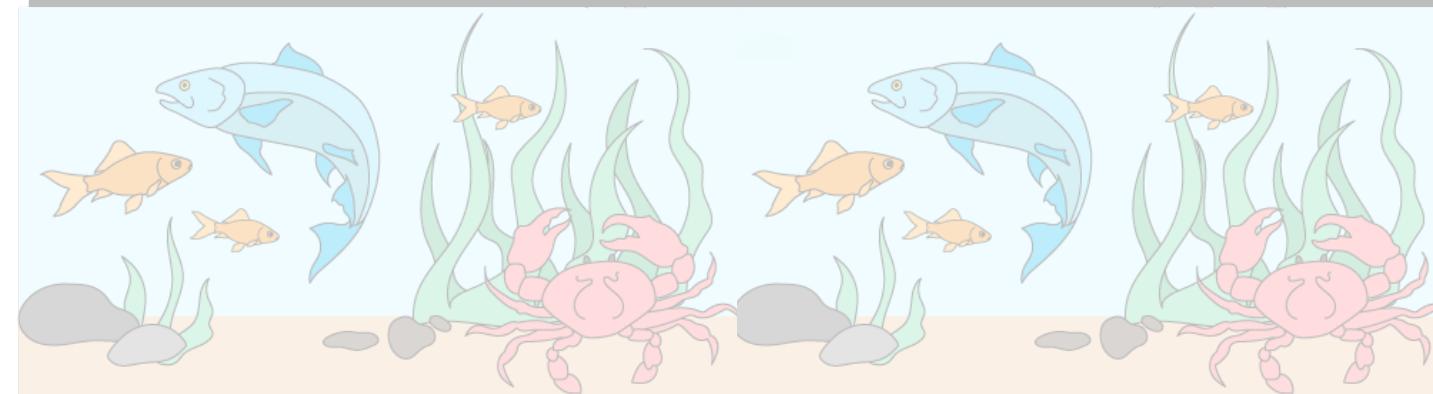
population



metapopulation

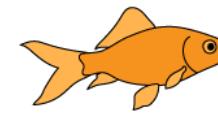


community



ecosystem

individual



**Individual:**  
metabolism,  
behavior, life history.

population

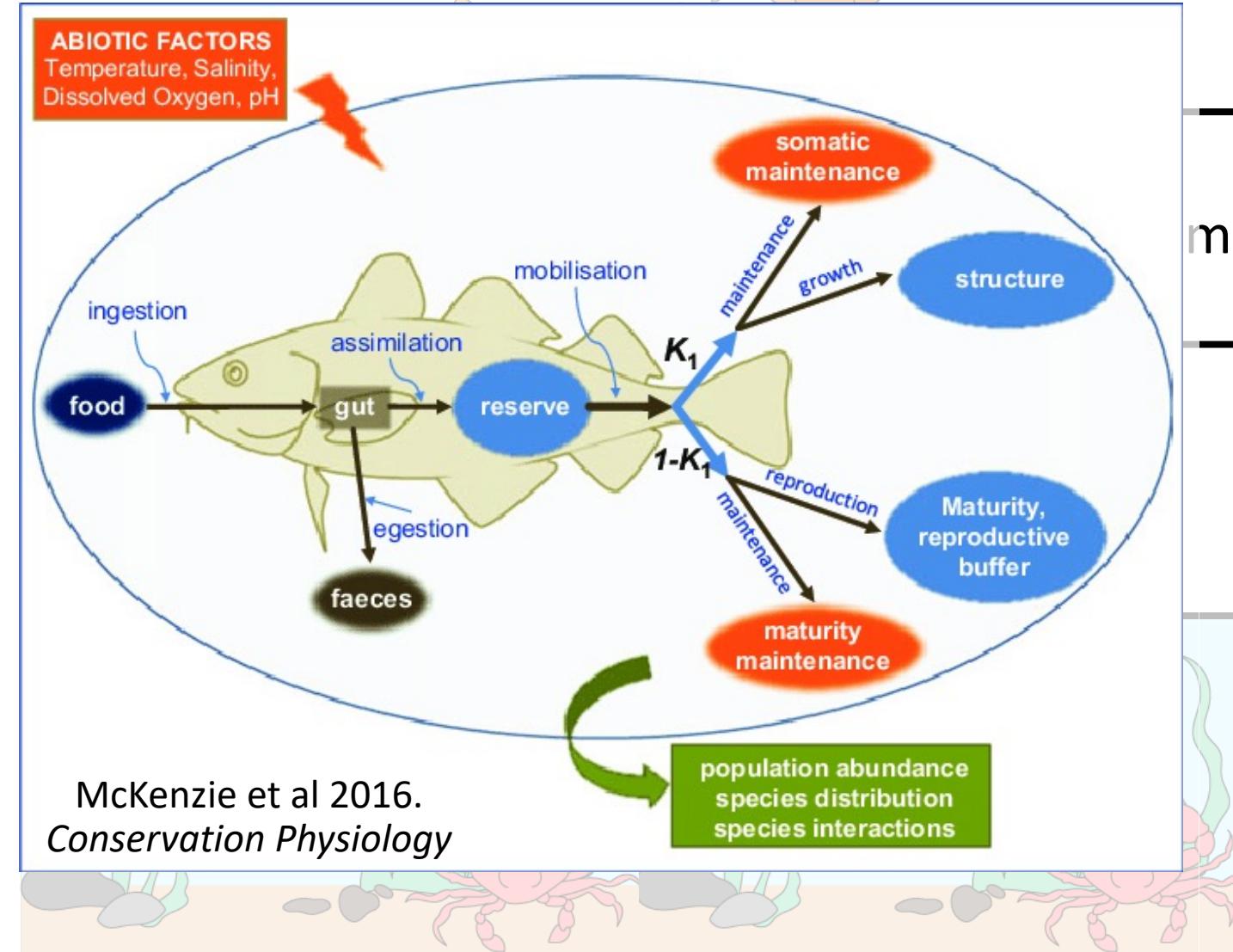
Dynamic Energy  
Budget (DEB) Model

metapopulation

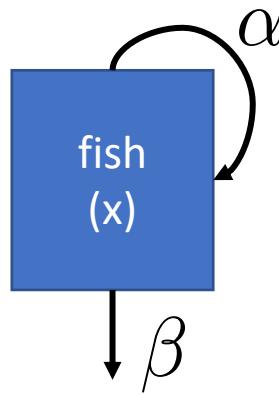
*How does a fish's  
metabolism **change**  
with temperature?*

community

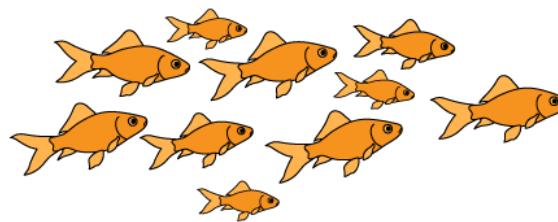
ecosystem



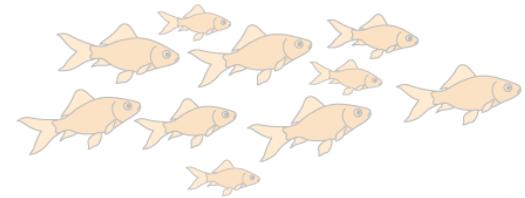
**Population** = multiple individuals of the same species (**conspecifics**) in the same habitat



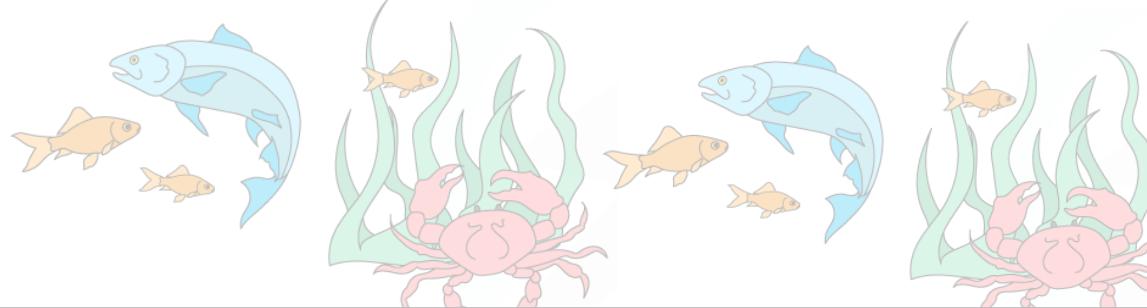
individual



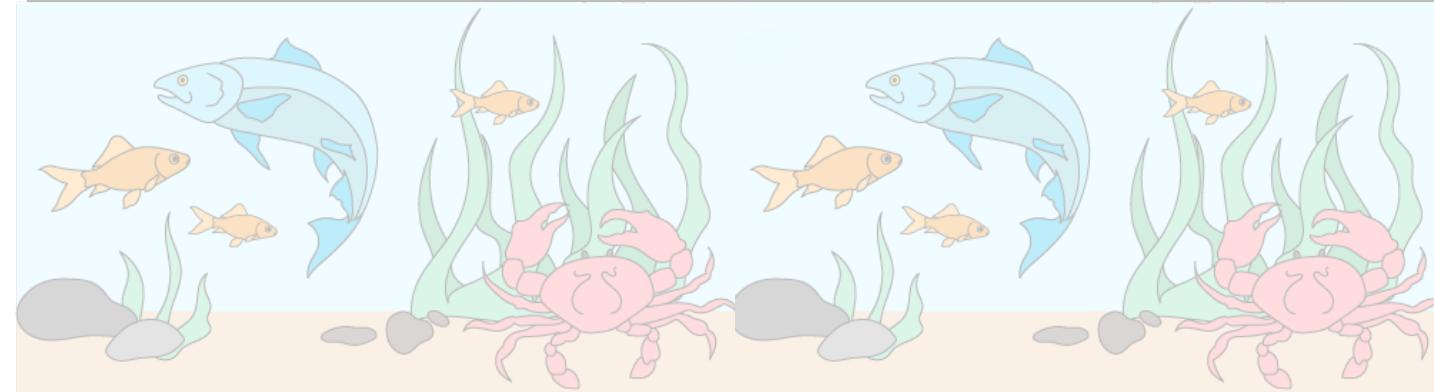
population



metapopulation



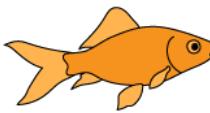
community



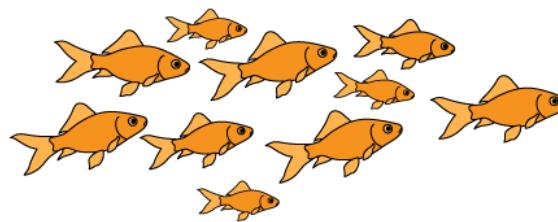
ecosystem

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

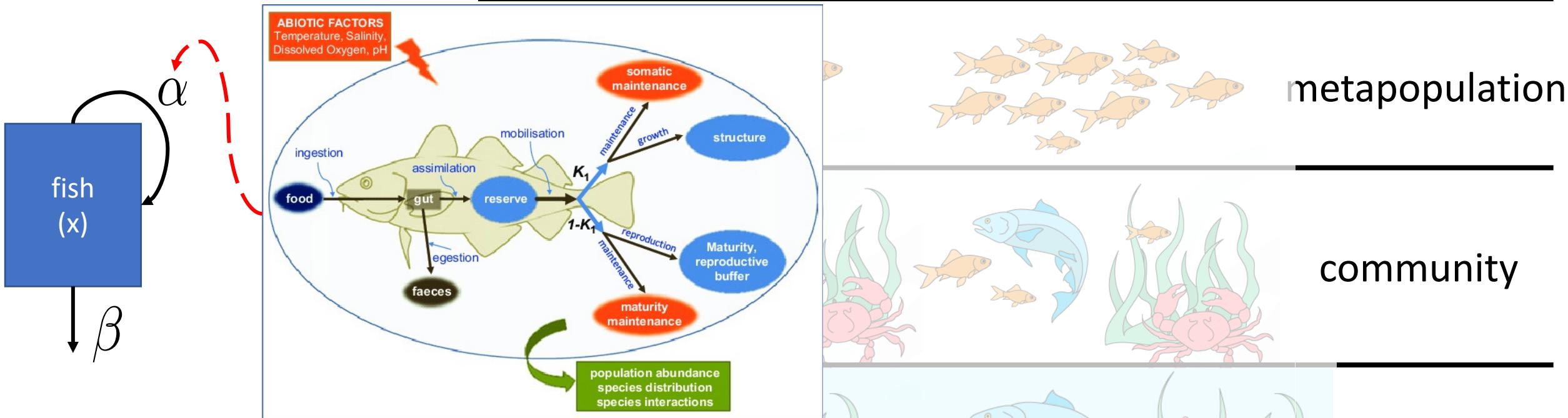
**Nested Models**, including a class of model known as **Integral Projection Models** (IPMs), link individual- and population-level processes



individual



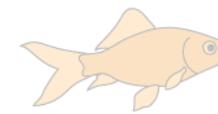
population



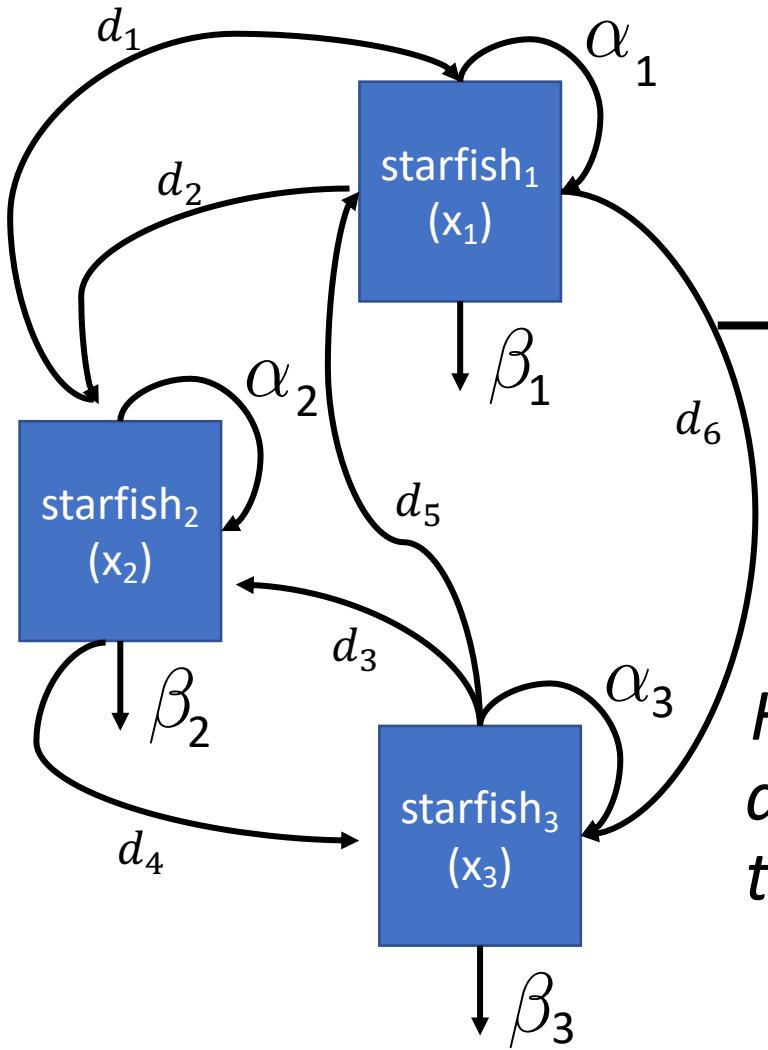
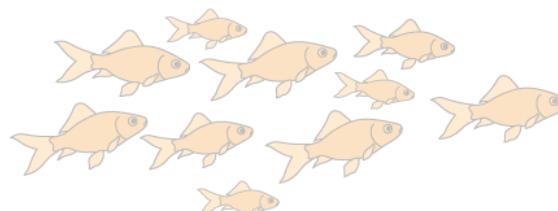
How does the abundance of fish **change** through time as temperature **changes** metabolism?

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

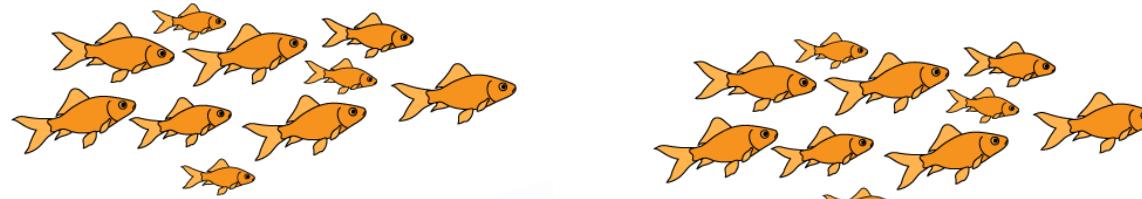
individual



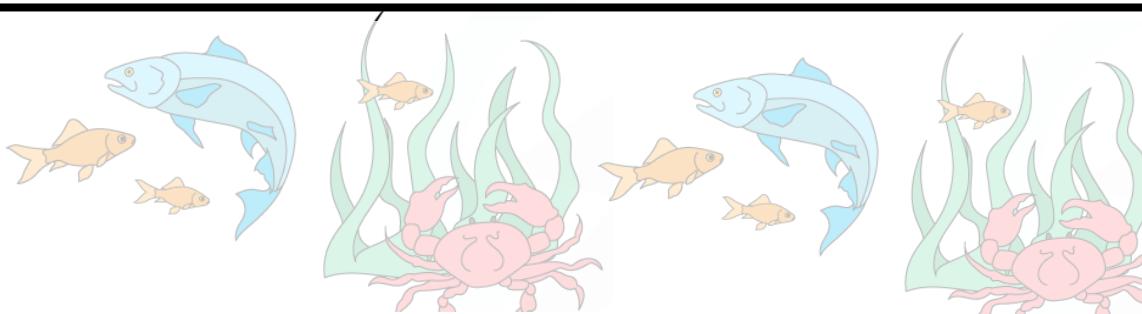
population



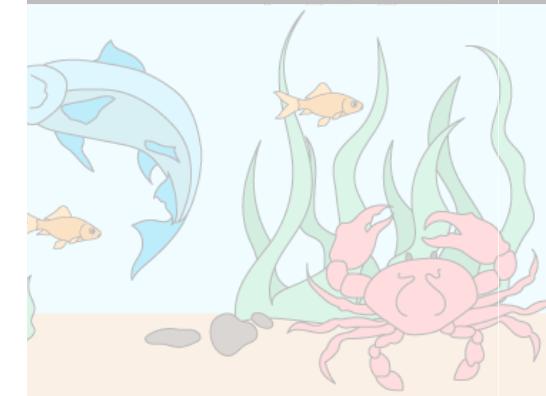
metapopulation



community

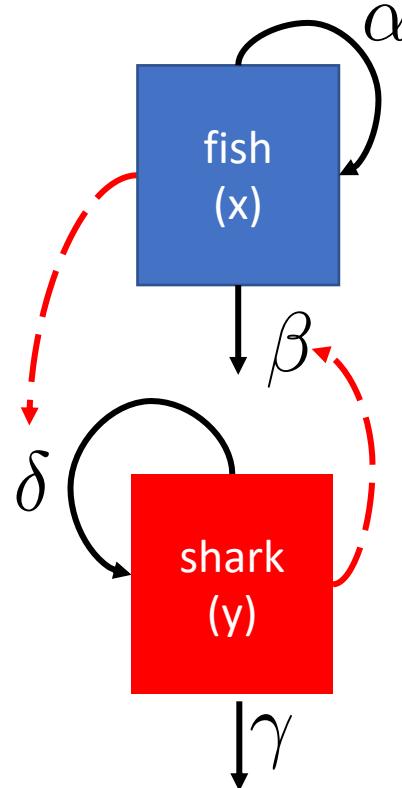


ecosystem

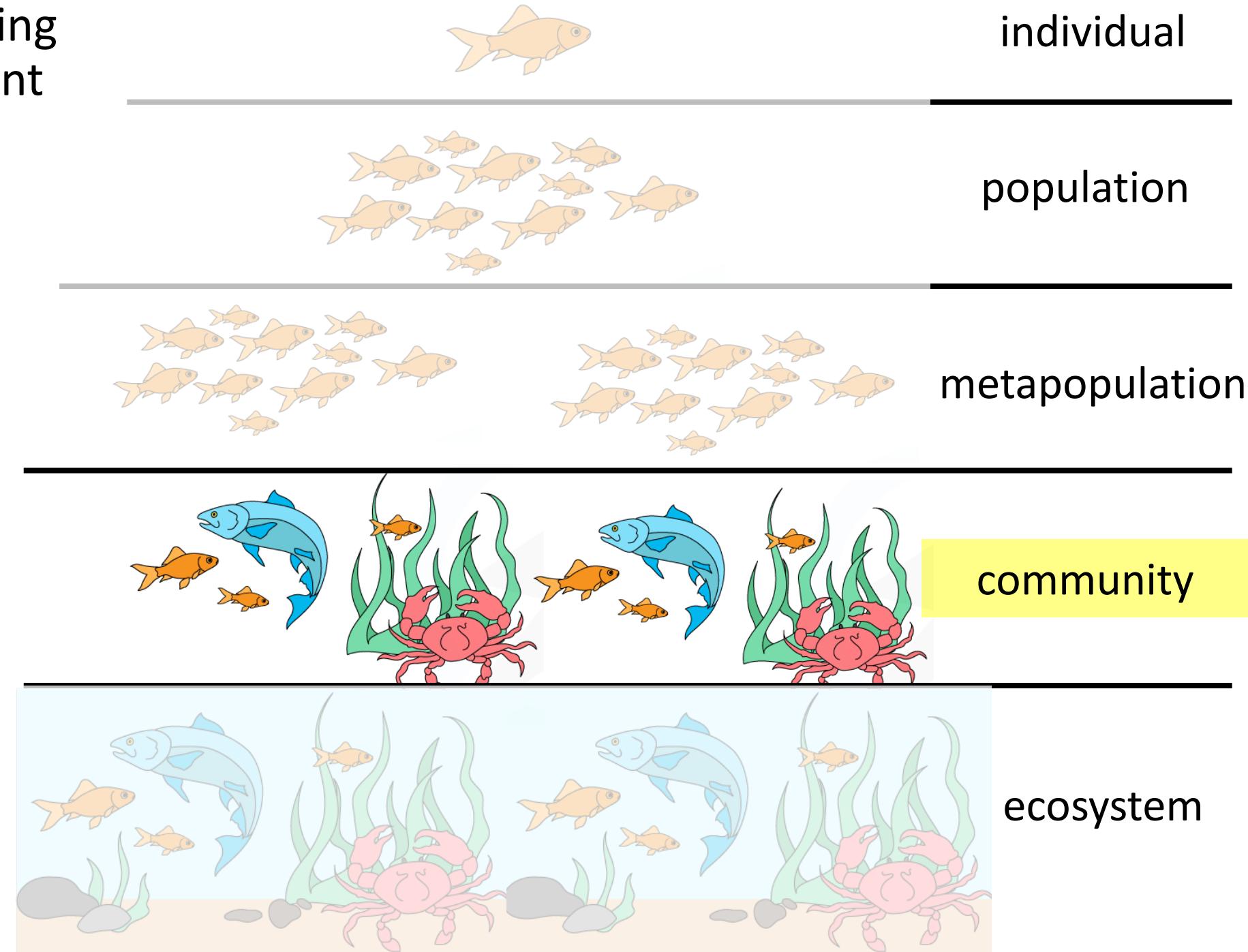


*How do the abundances of different subpopulations of the same fish **vary** in space [and time]?*

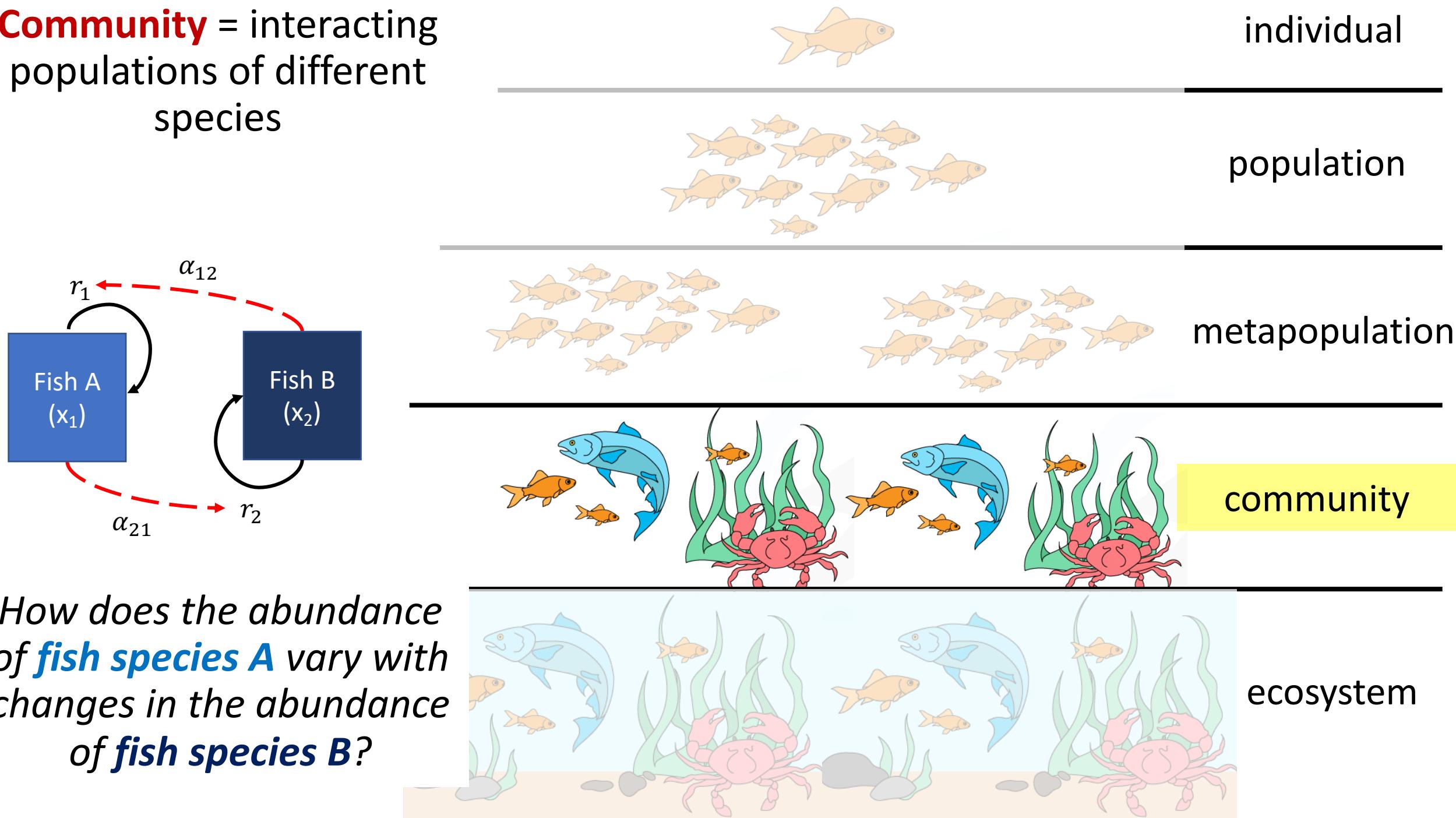
**Community** = interacting populations of different species



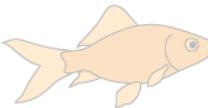
How does fish abundance **vary** with changes in shark abundance?



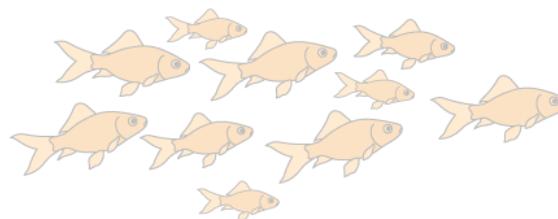
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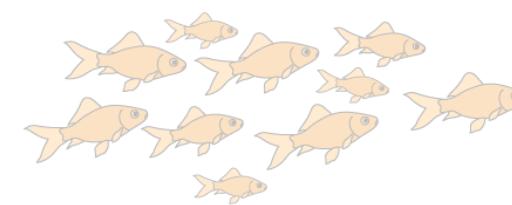
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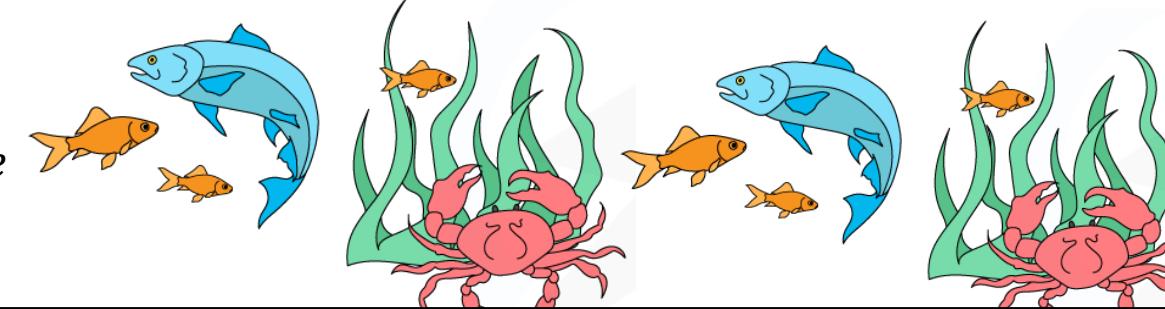
individual



population

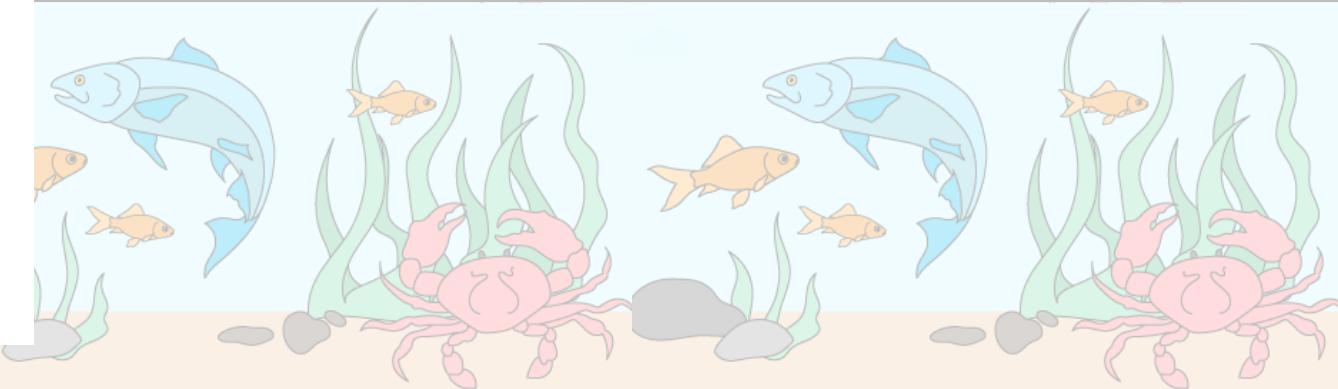


metapopulation



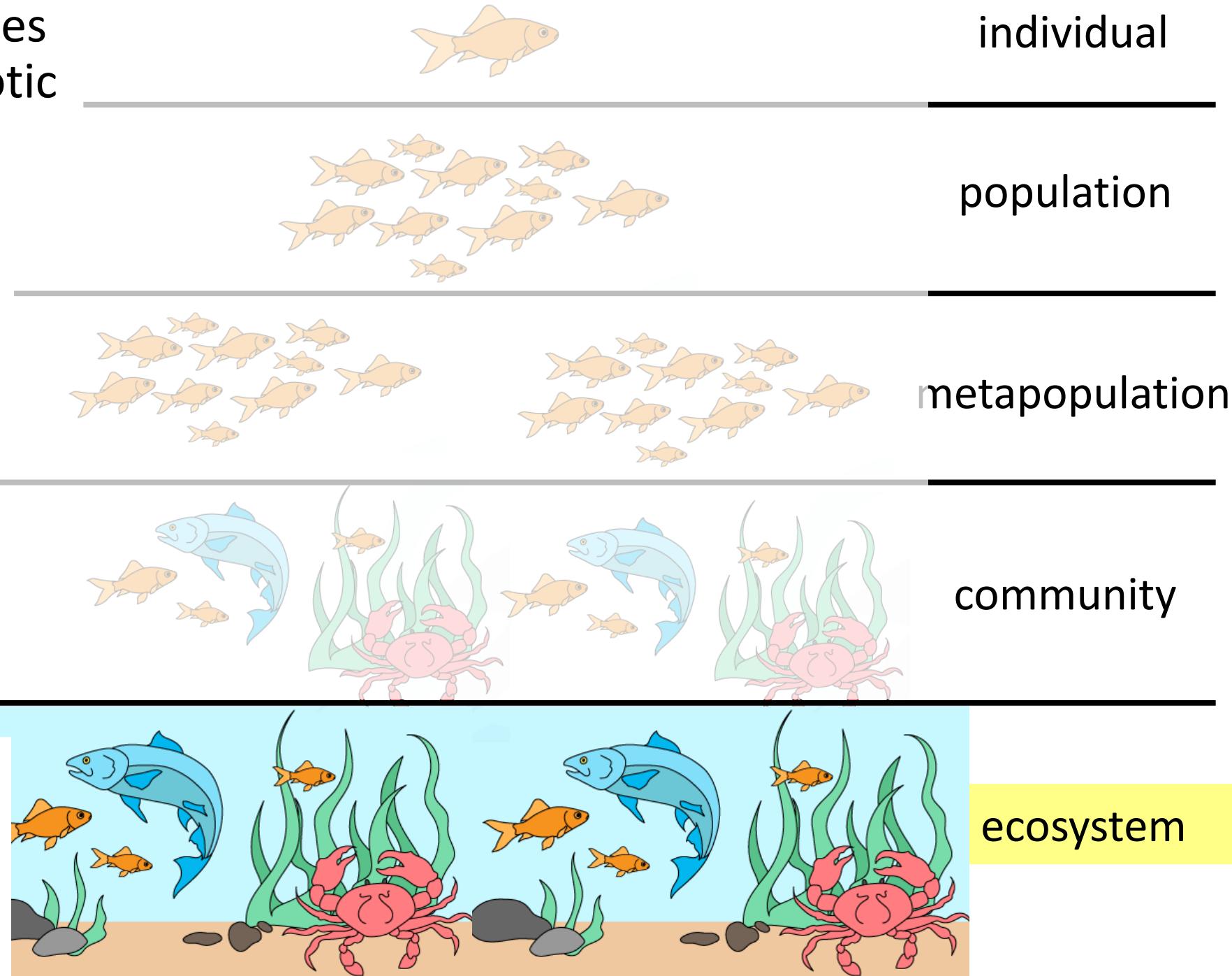
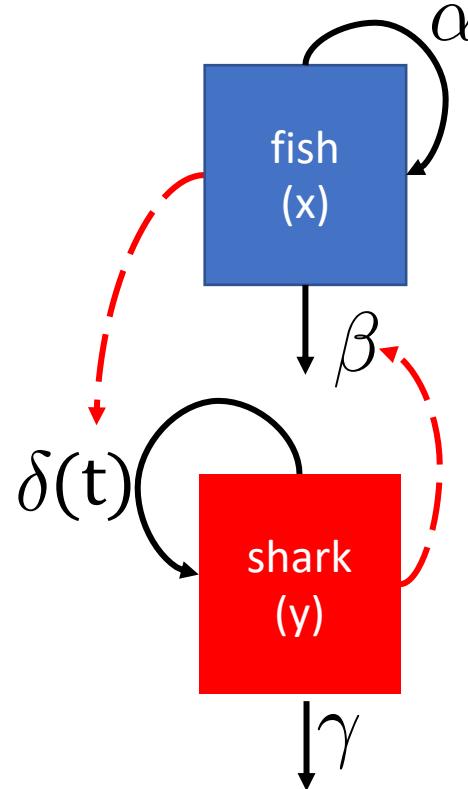
community

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



ecosystem

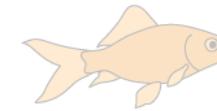
**Ecosystem** = communities interacting with the abiotic environment



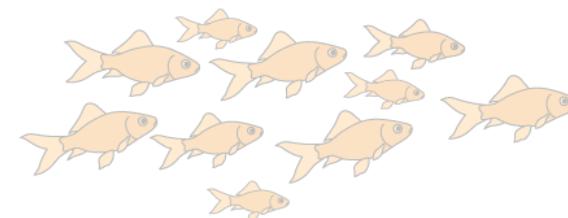
How does fish abundance **vary** with changes in shark birth rates with **temperature**?

**Ecosystem** = communities interacting with the abiotic environment

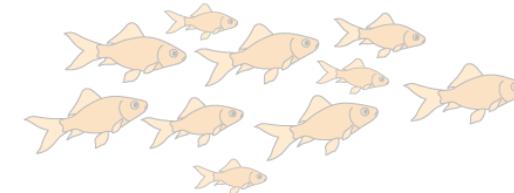
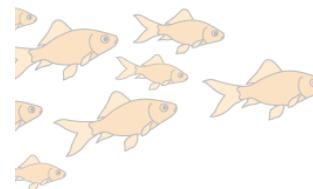
There is often less emphasis on the box model approach and more of a conceptual model approach to explain the **distribution and abundance of species in space and time**



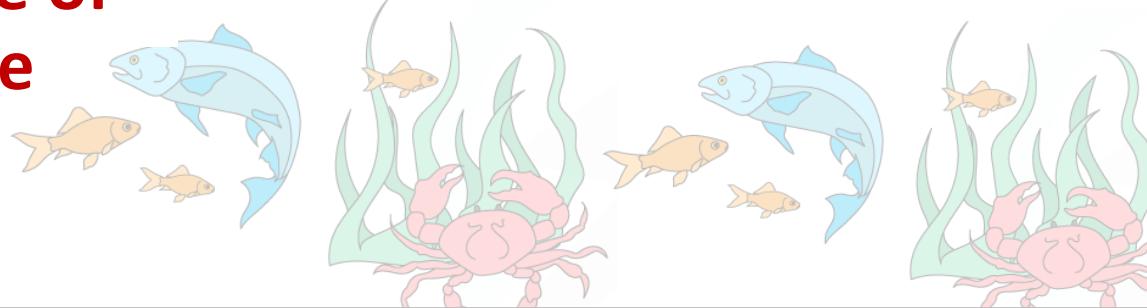
individual



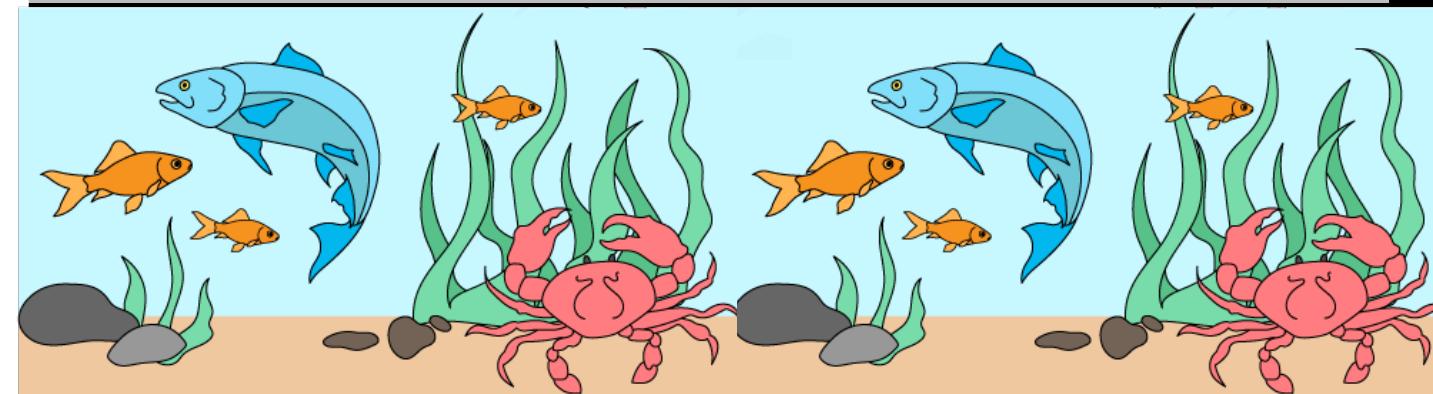
population



metapopulation



community



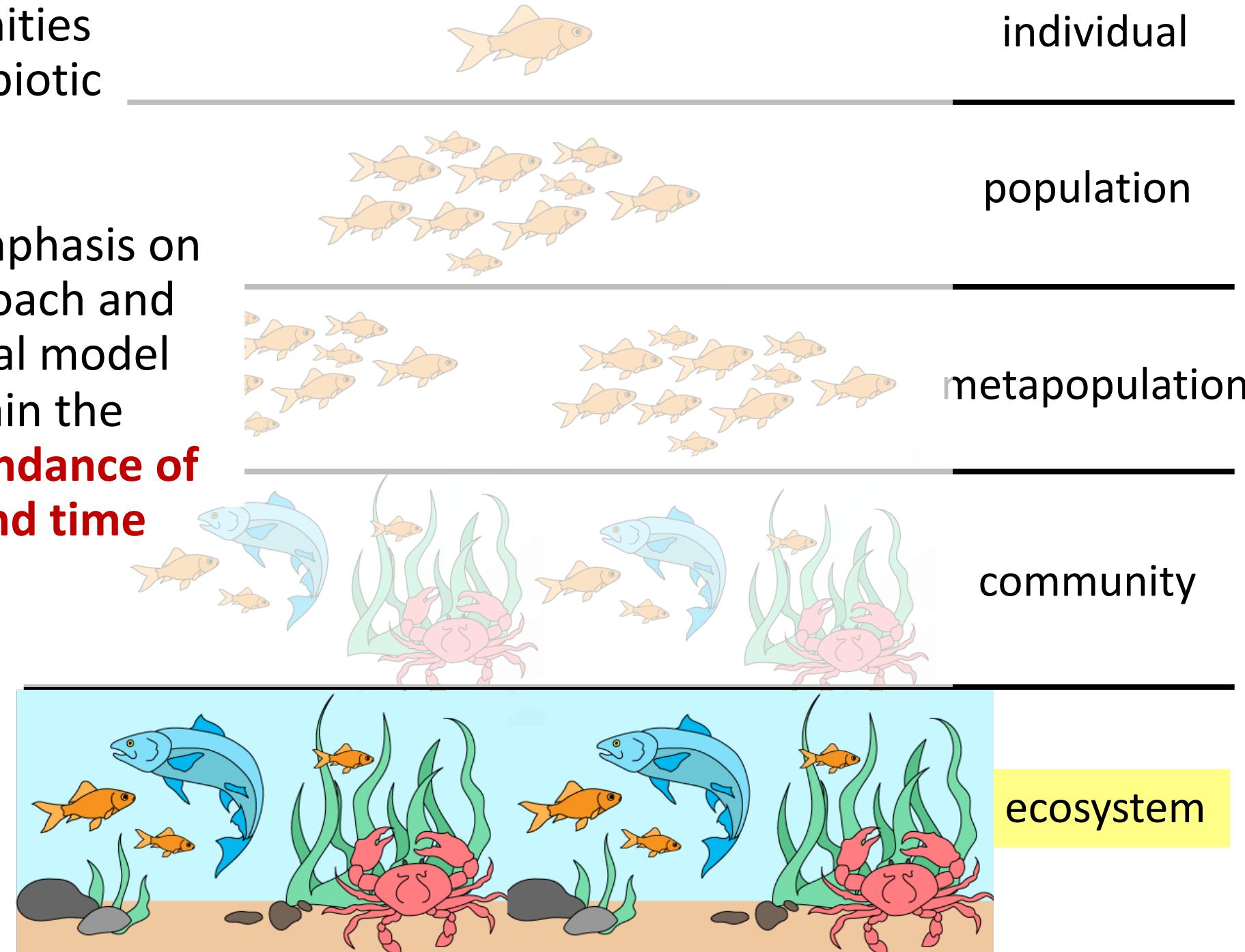
ecosystem

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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**

*How do communities assemble?*

*Do they end up the same in different environments?*



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

- Larger areas have more species!

$$S = cA^z$$

↑           ↑           ← slope of  
number of      habitat      relationship  
species      area      in log-log  
                                 space

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

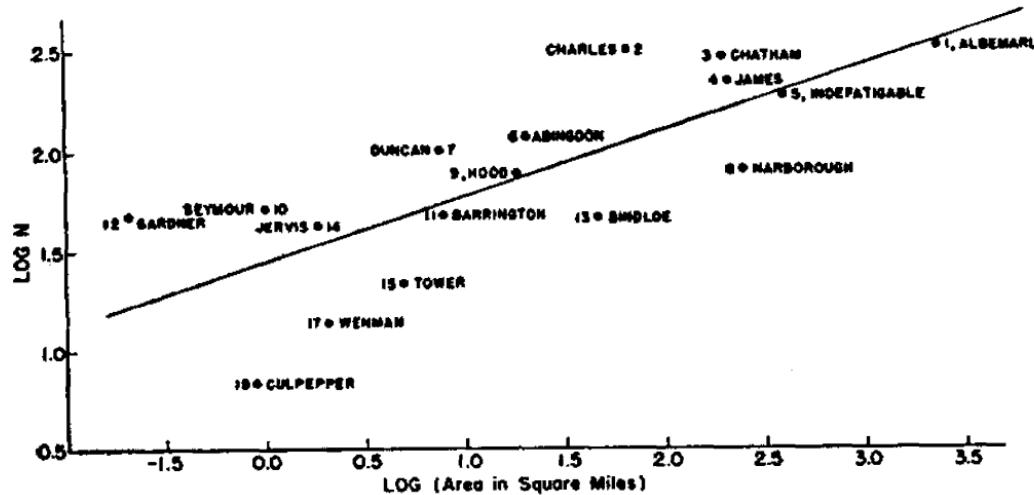
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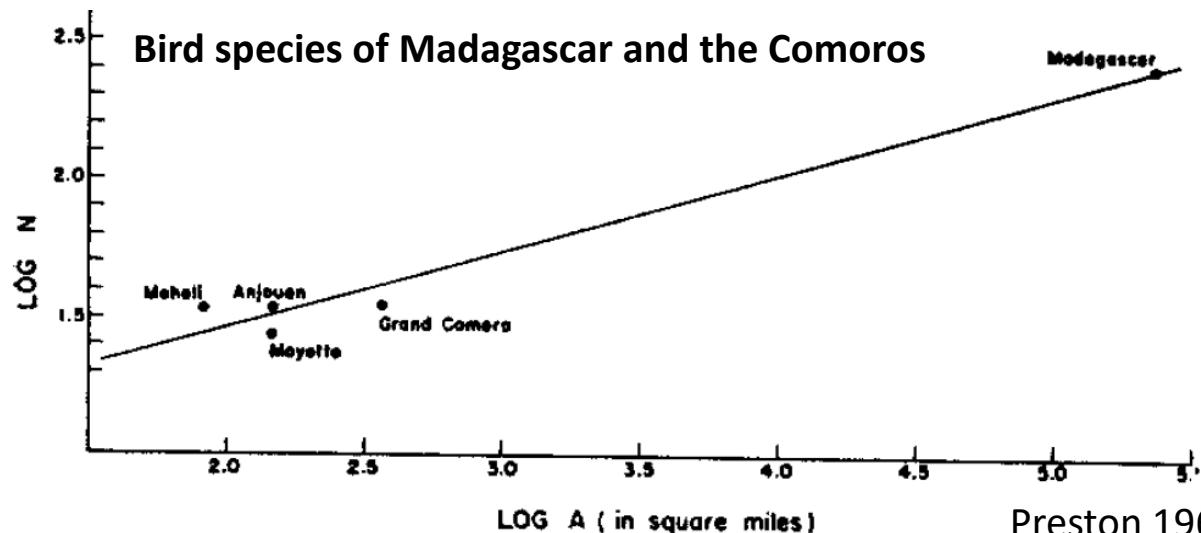
$$S = cA^z$$

- The slope of the log-log relationship ( $z$ ) will differ across diverse communities and ecosystems.

Plant species of the Galapagos islands



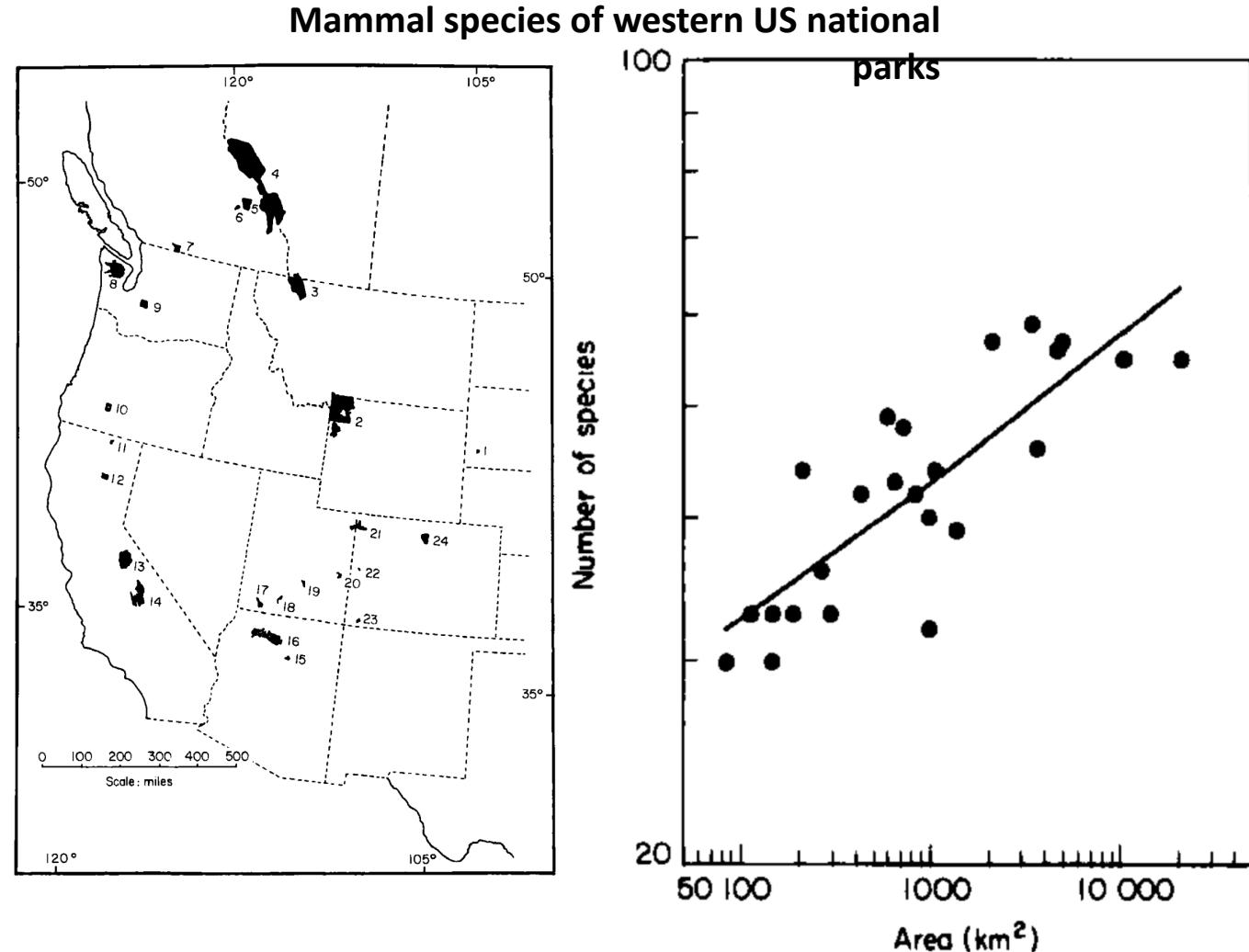
Bird species of Madagascar and the Comoros



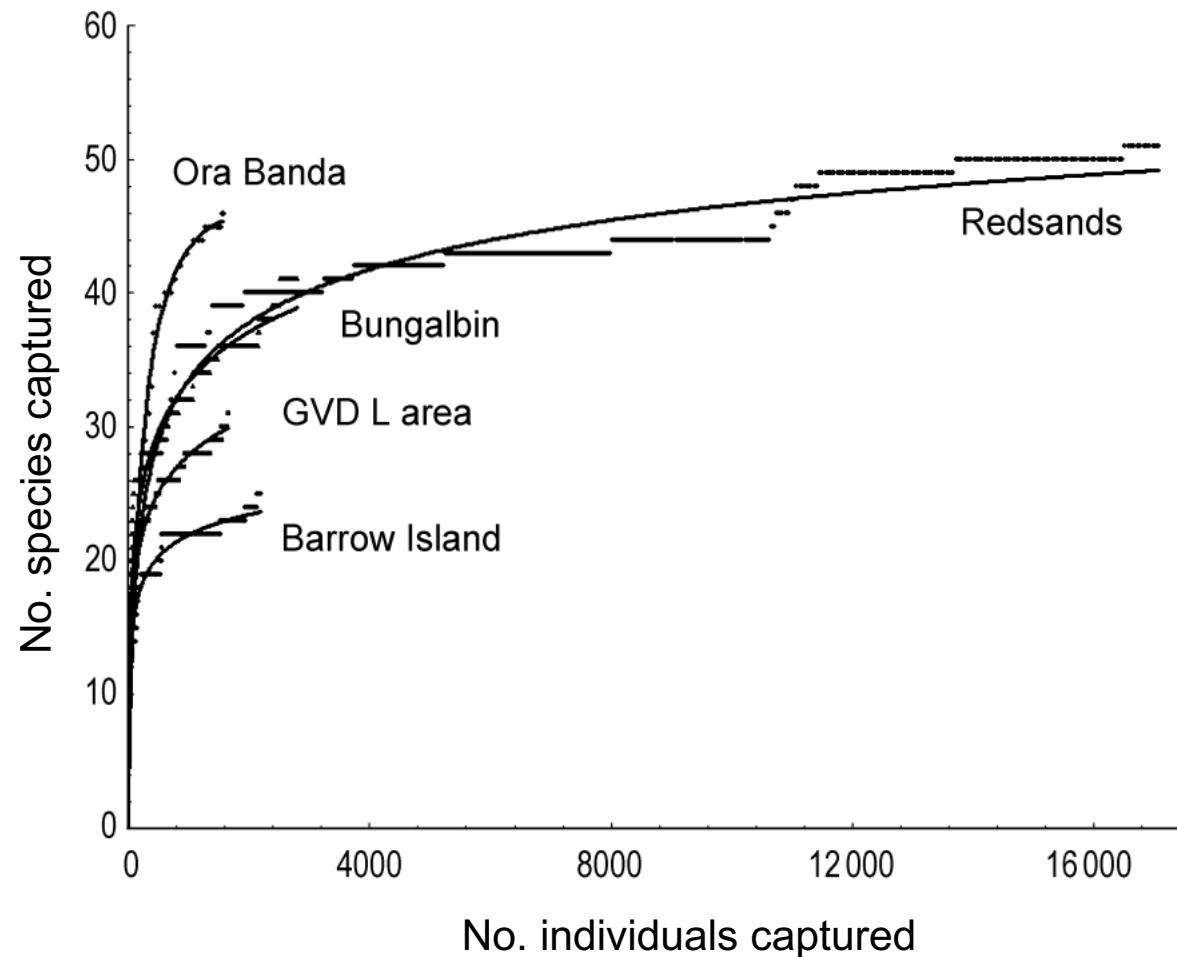
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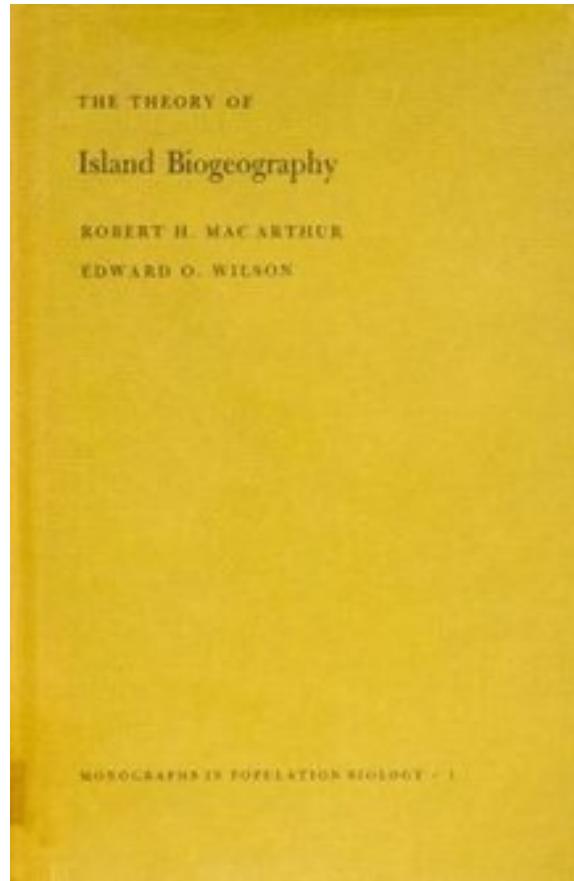


We can use the **species-area relationship (SAR)** to build **species accumulation curves** to understand if we have representatively sampled a population in field studies.



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.



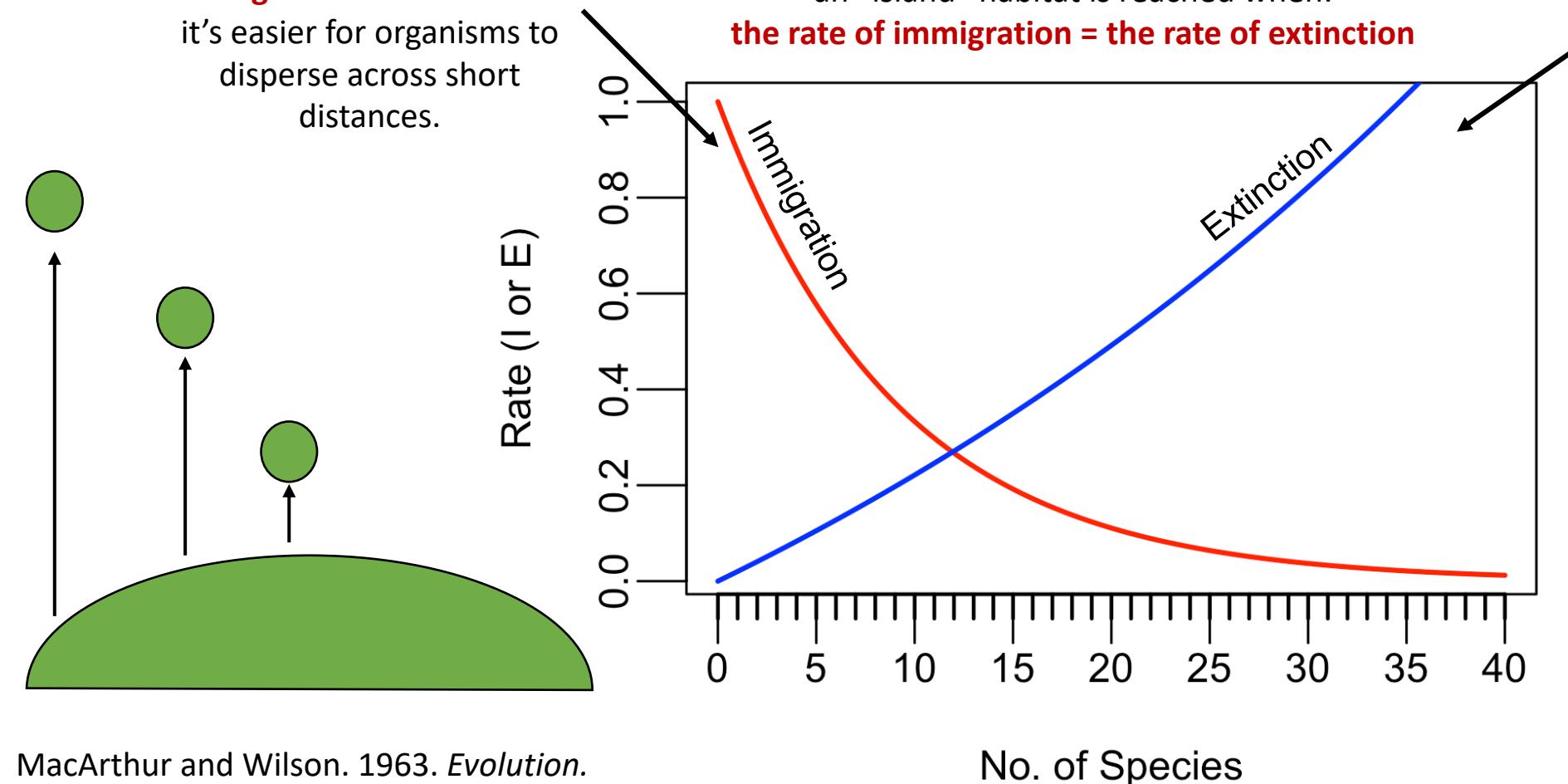
MacArthur and Wilson. 1963. *Evolution*.  
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The **theory of island biogeography** offers a null model for the number of species found in a given habitat, predictable from both the **size** of the habitat and its **distance** from a source population.

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**

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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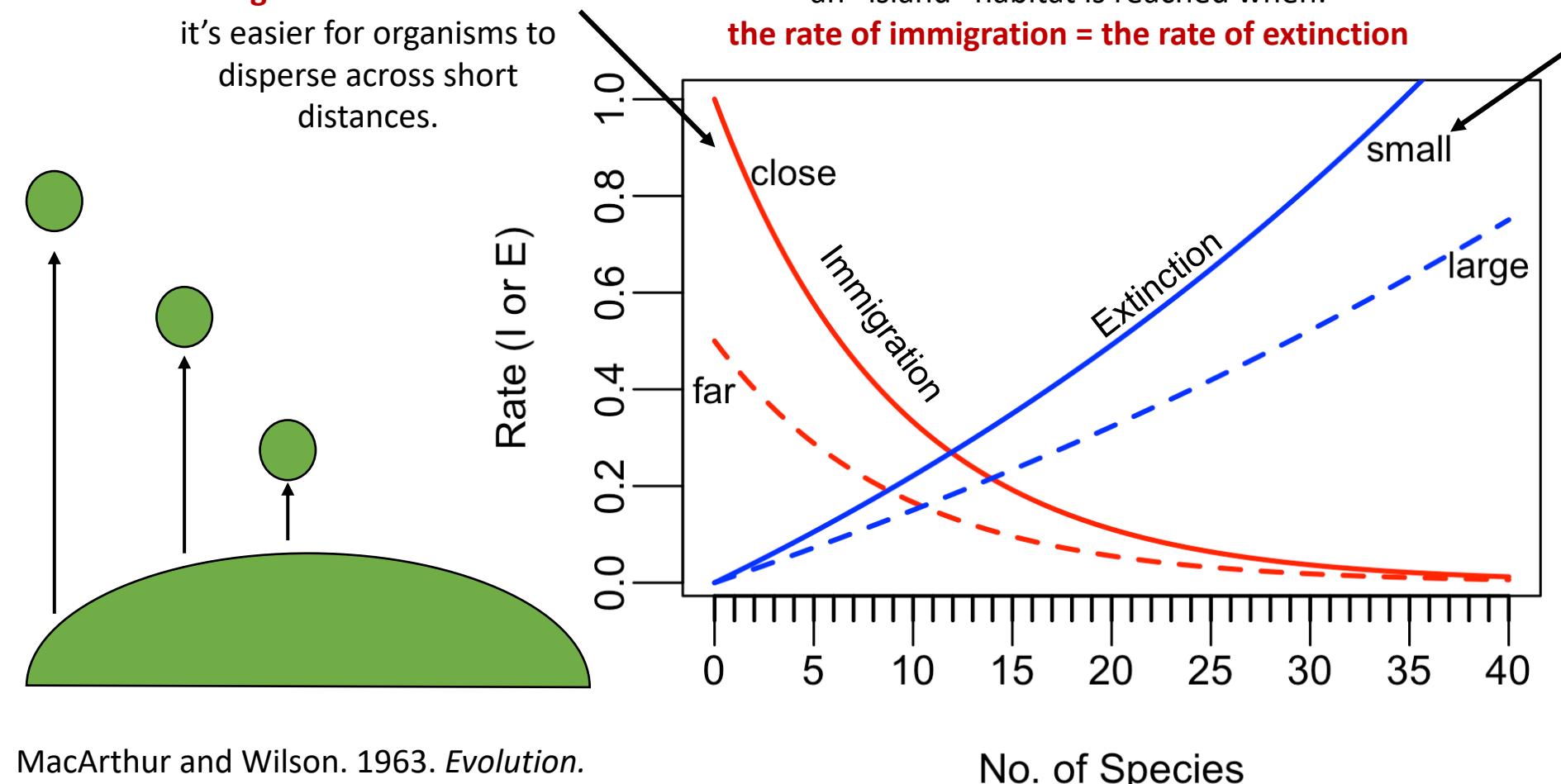
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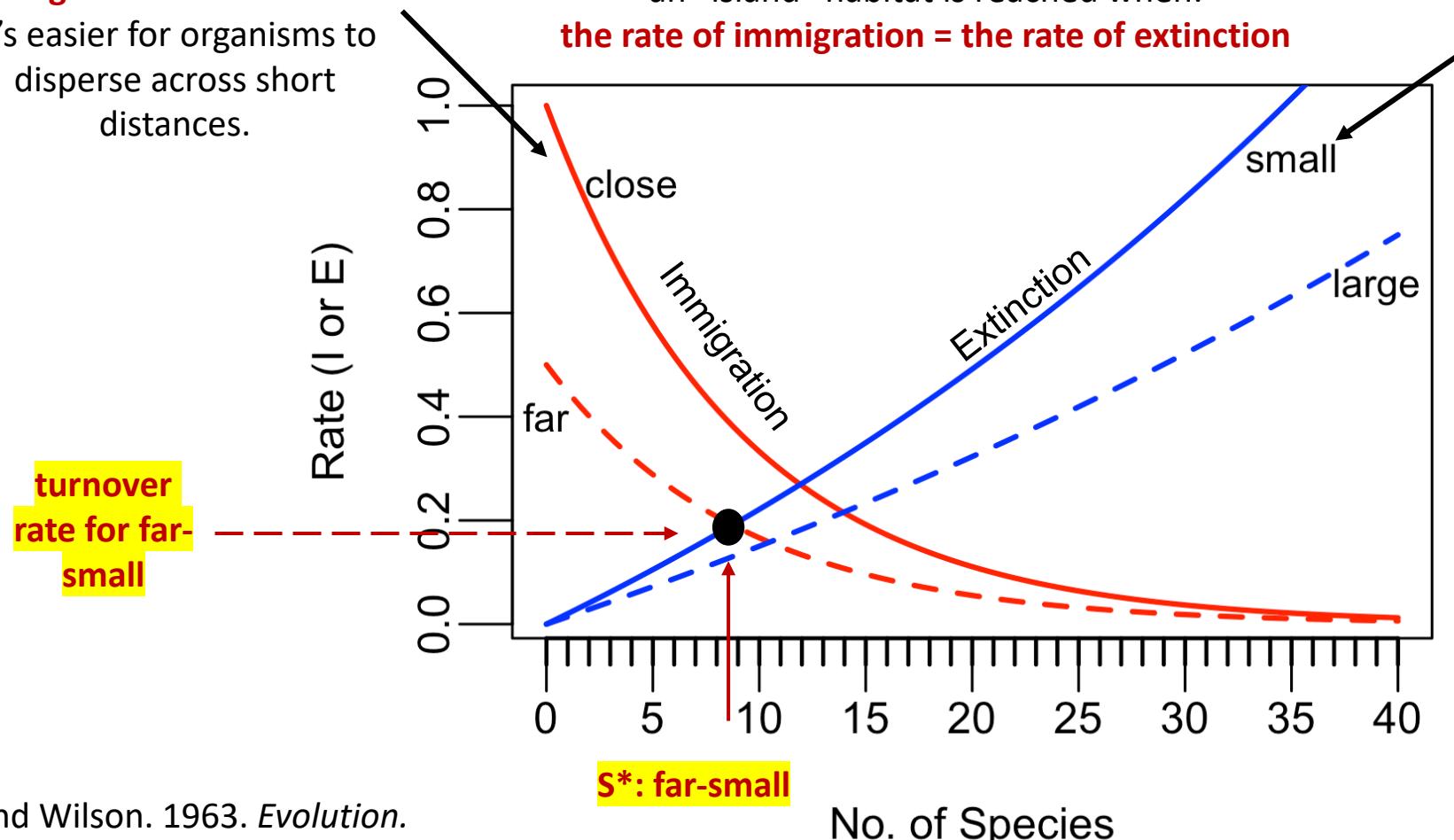


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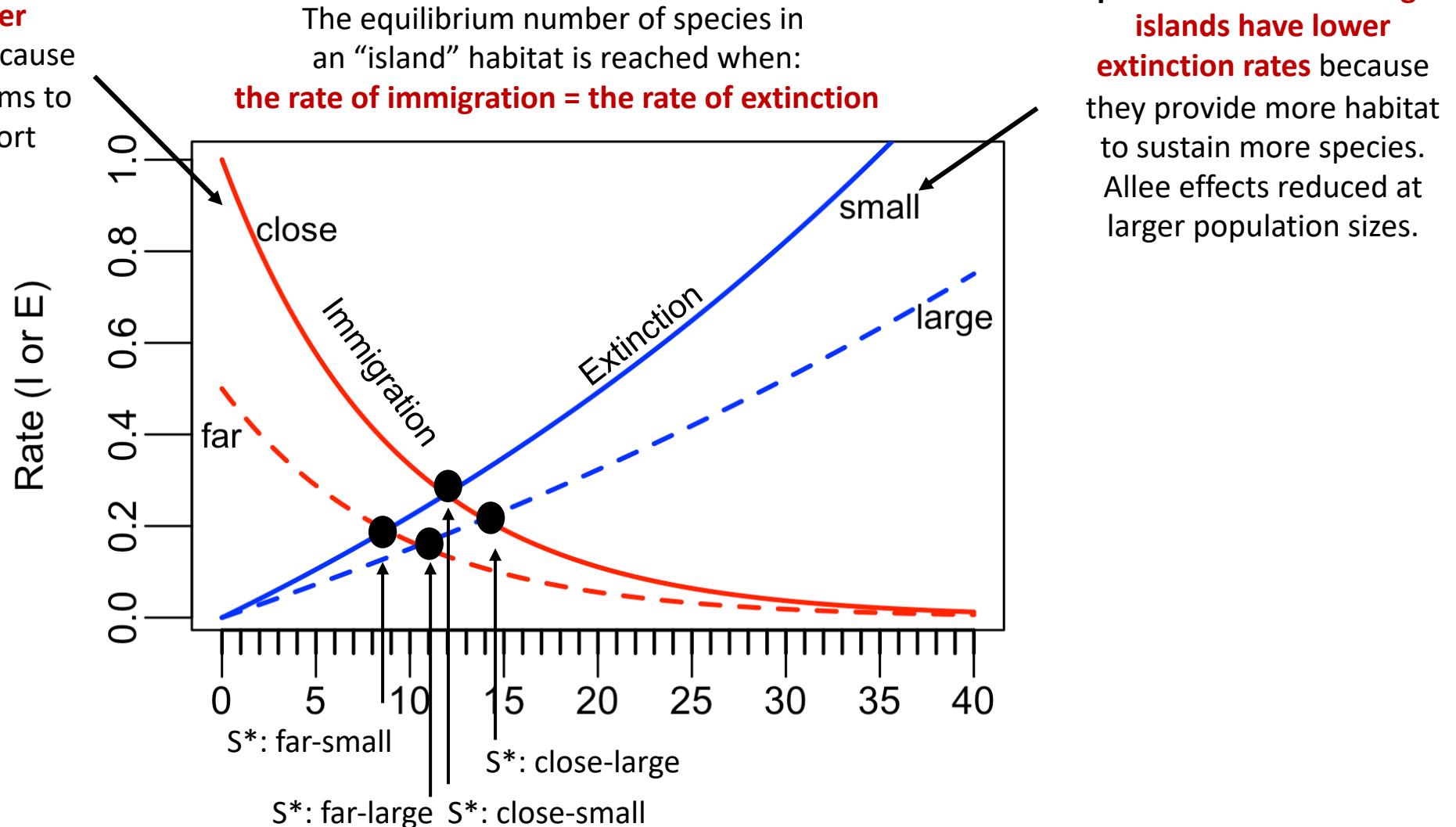
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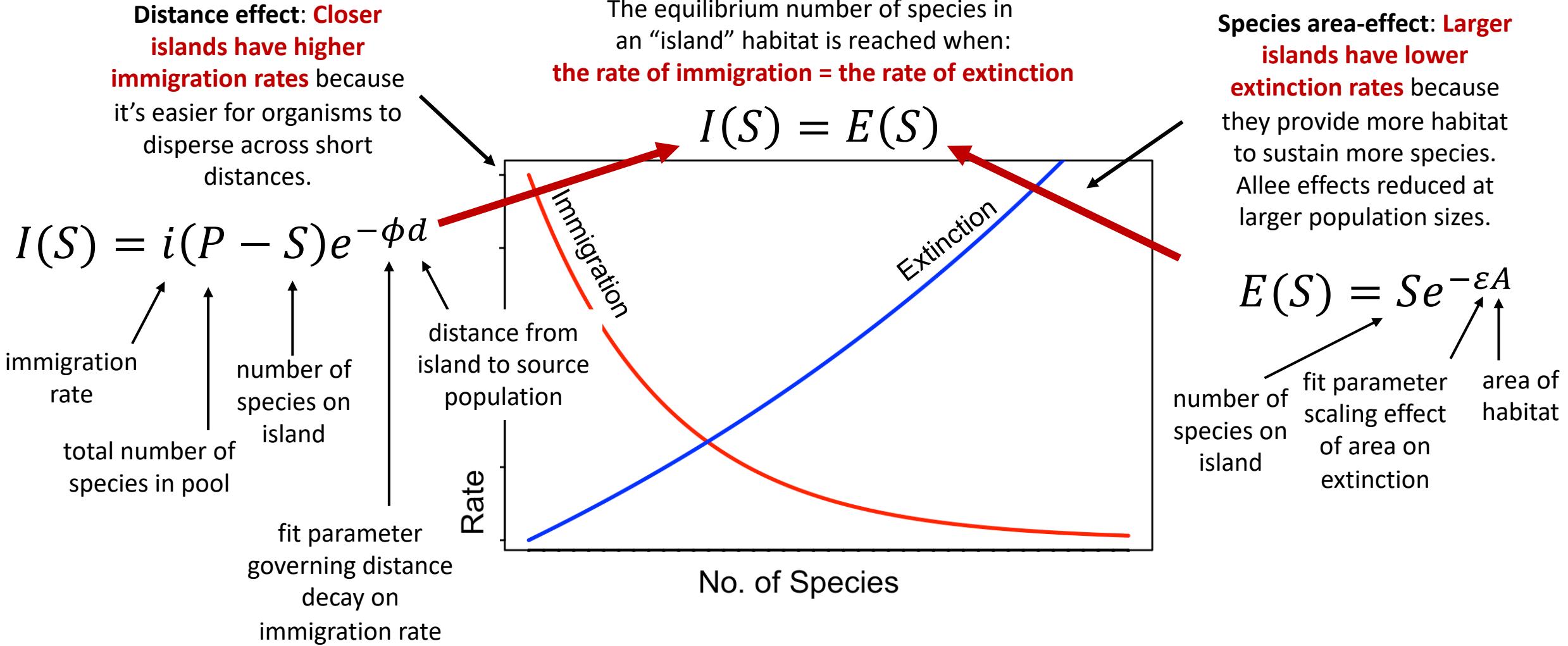


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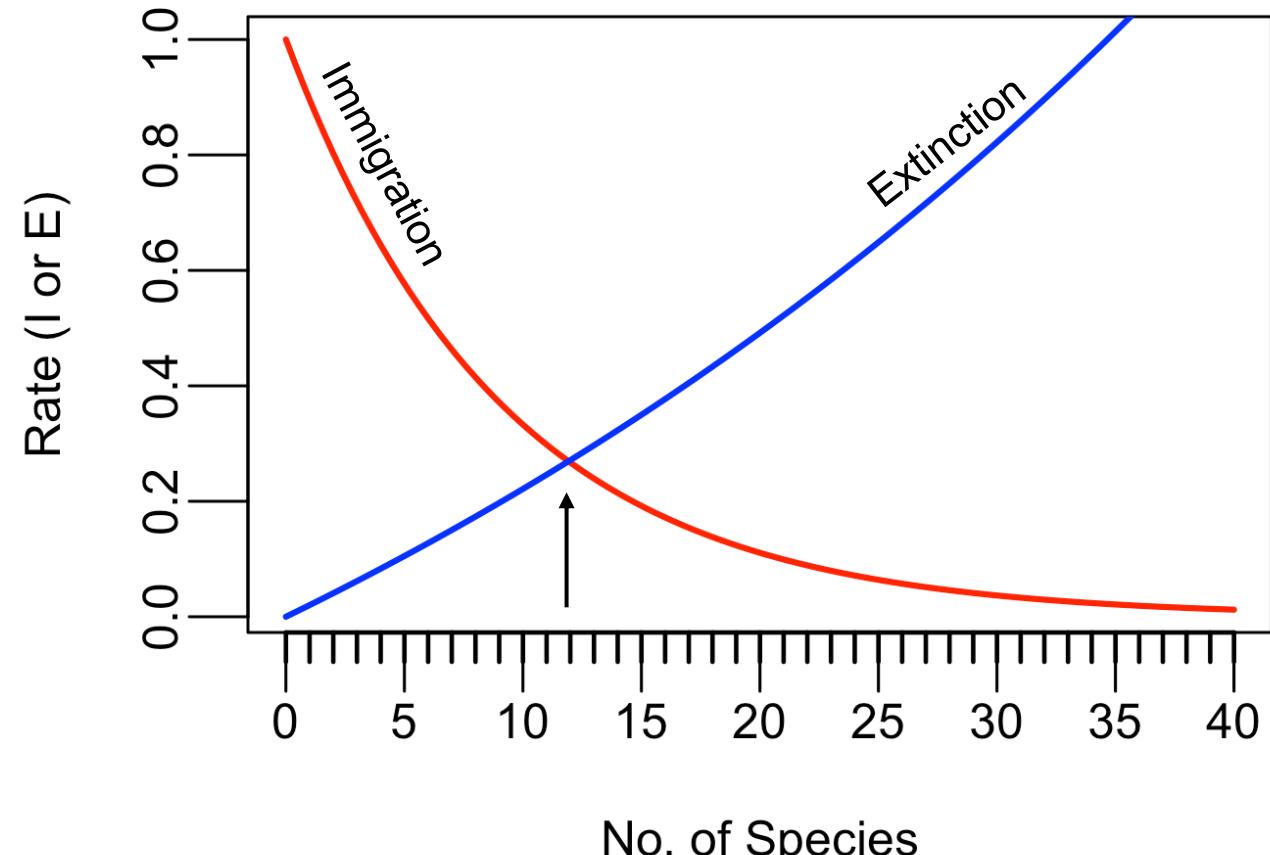
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$$I(S) = E(S)$$

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



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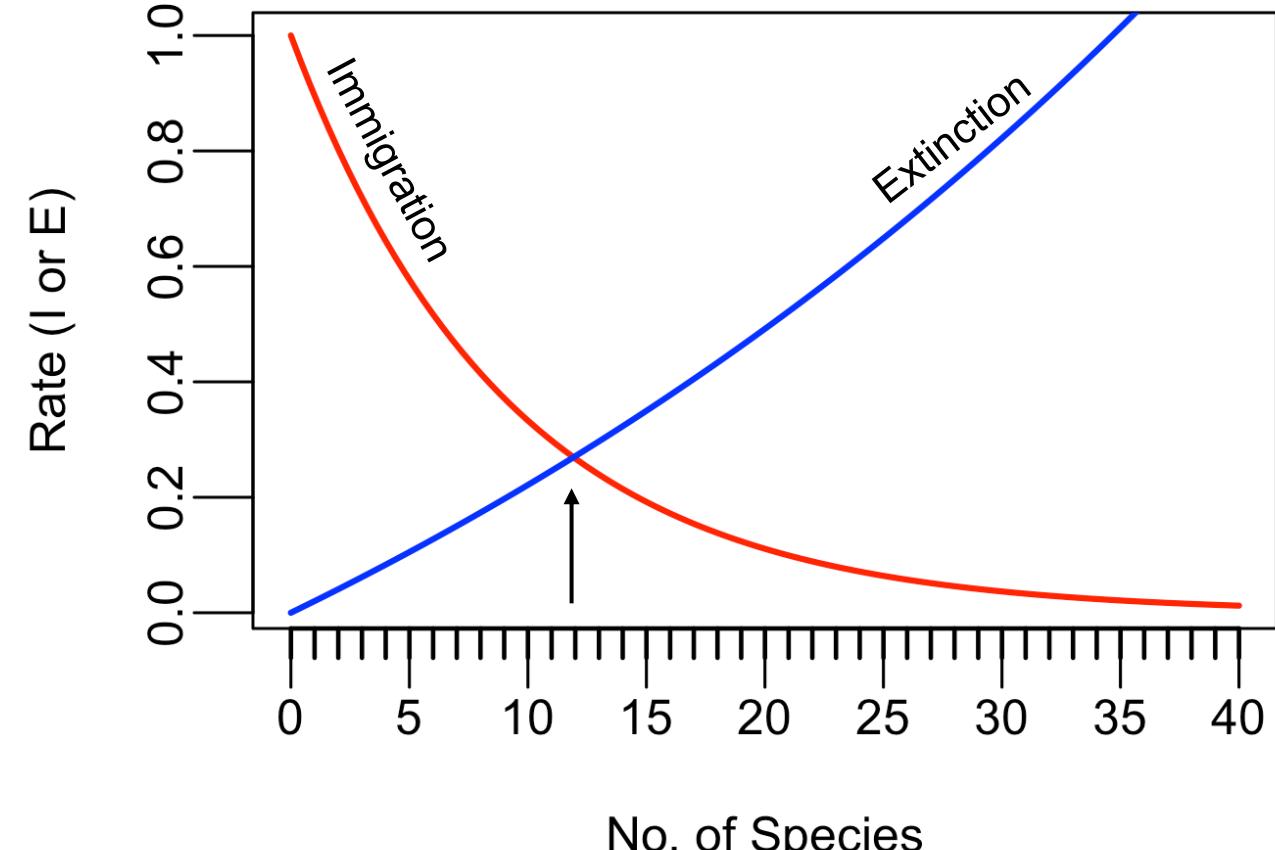
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↑ equilibrium number of species

increases with number of species in source pool

increases with area of island

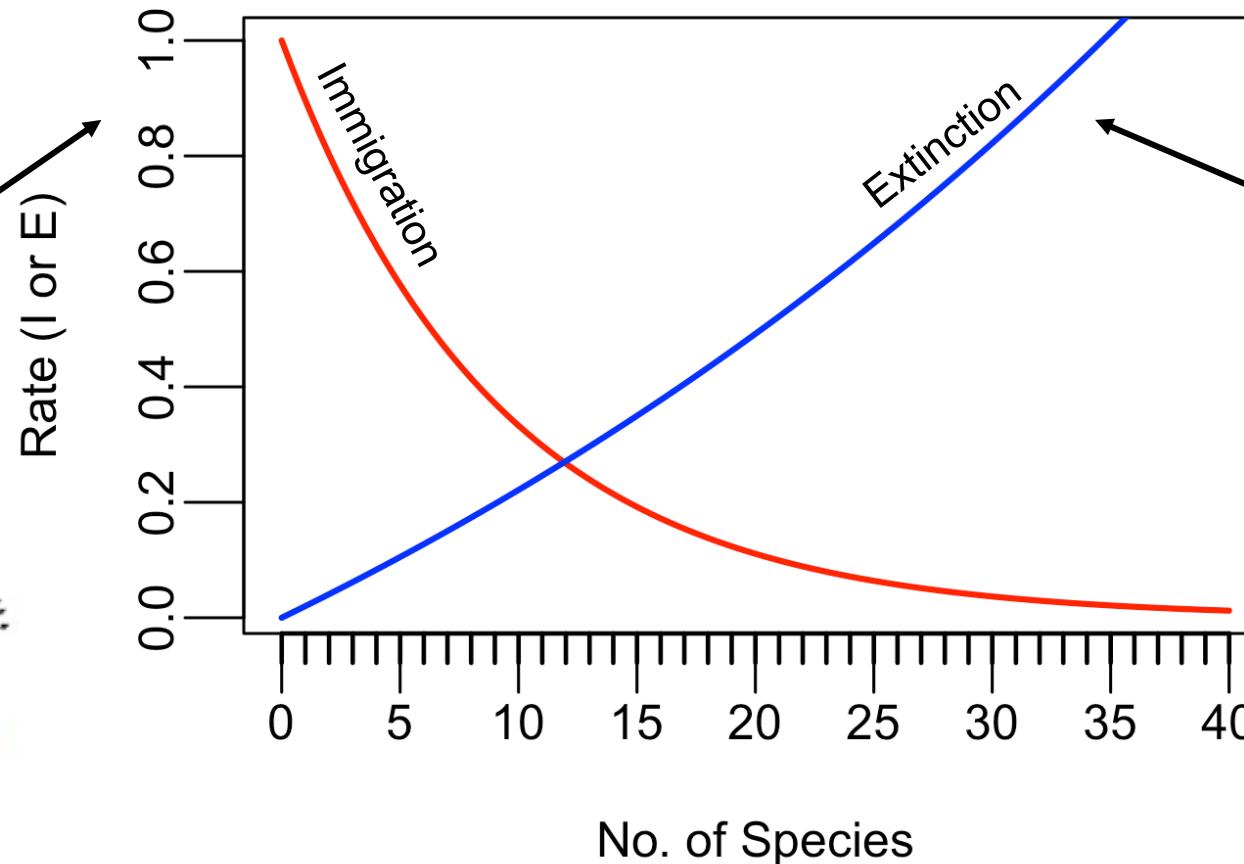
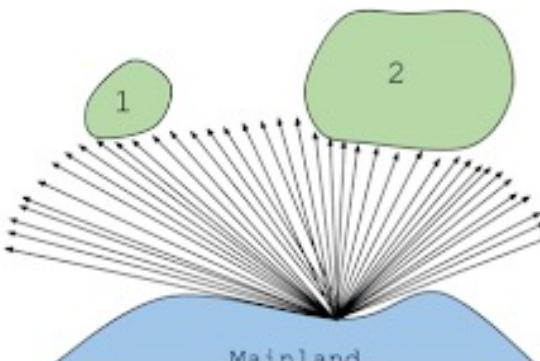
decreases with distance from mainland



# 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.

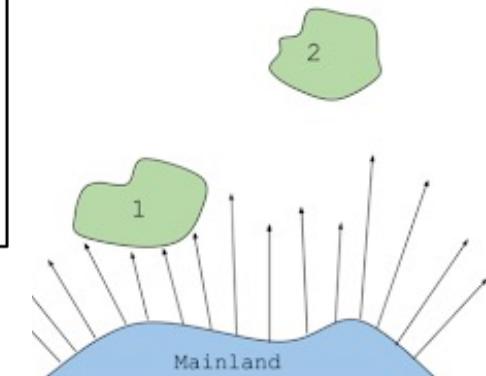
**Target effect:** larger islands have higher immigration rates because they offer a bigger target to land on!



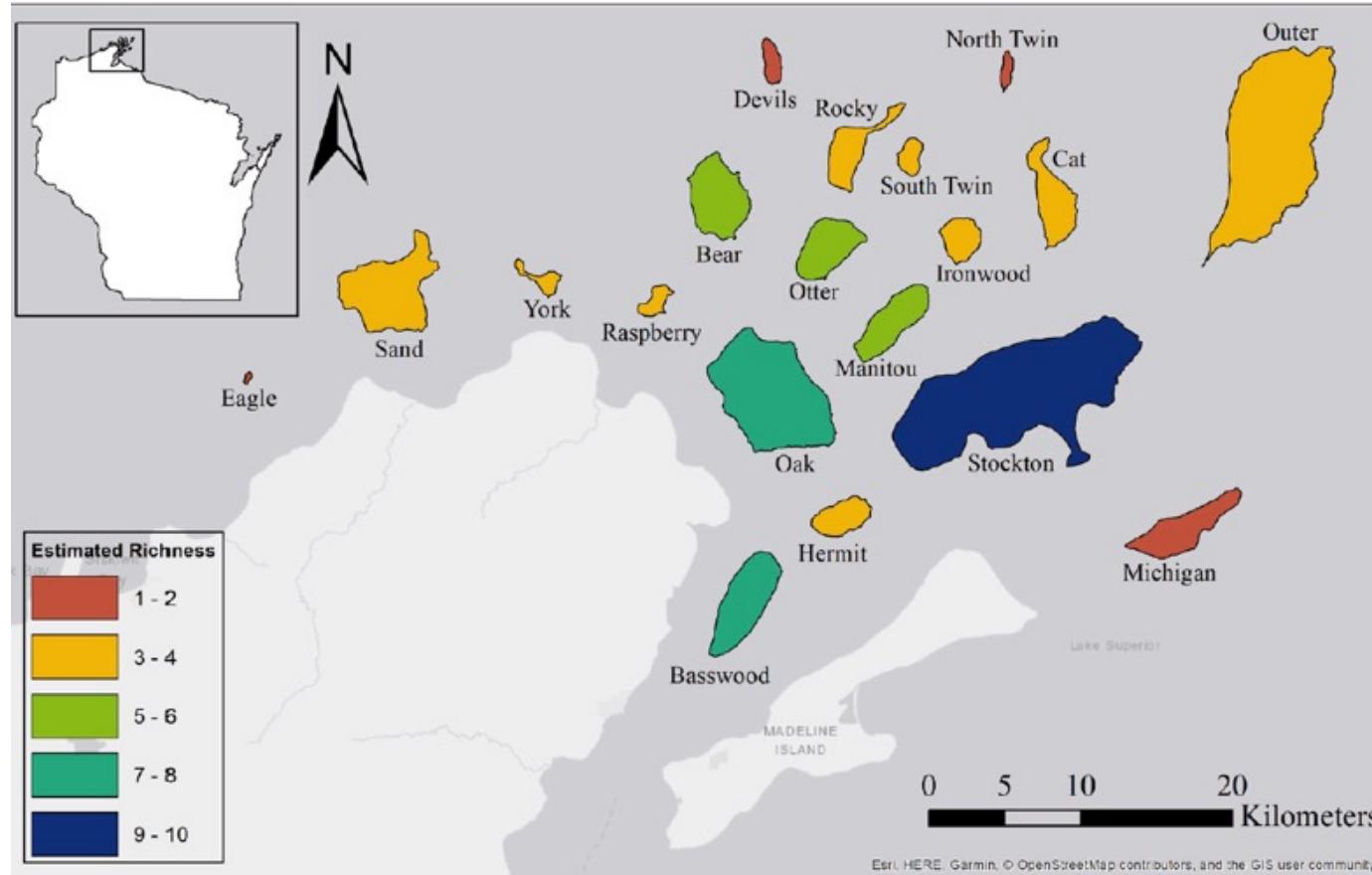
The equilibrium number of species in an “island” habitat is reached when:  
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**Species area-effect:** Larger islands have lower extinction rates because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.

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



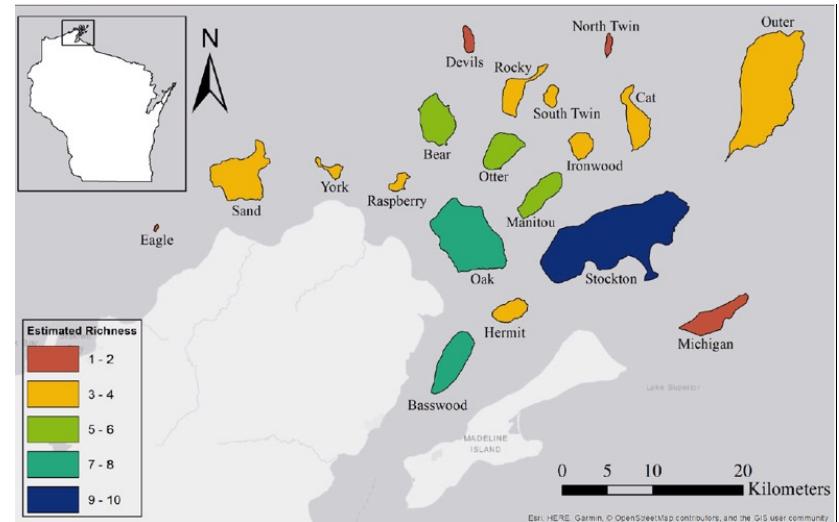
# The importance of island size vs. distance varied for different species!



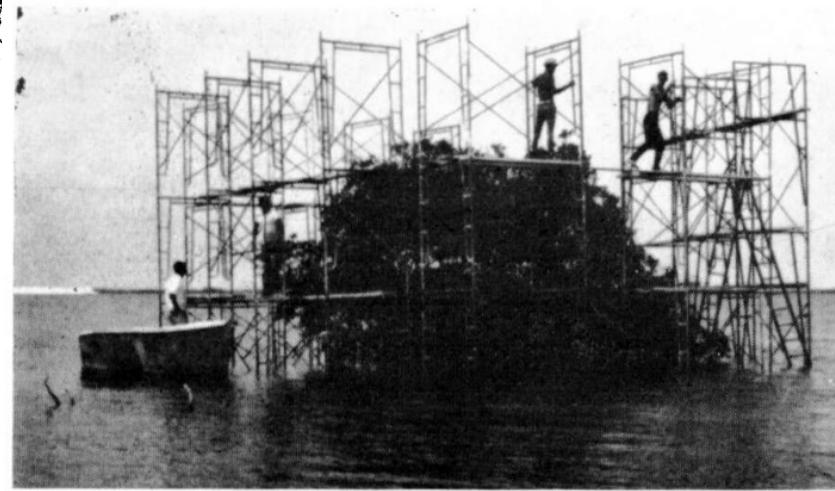
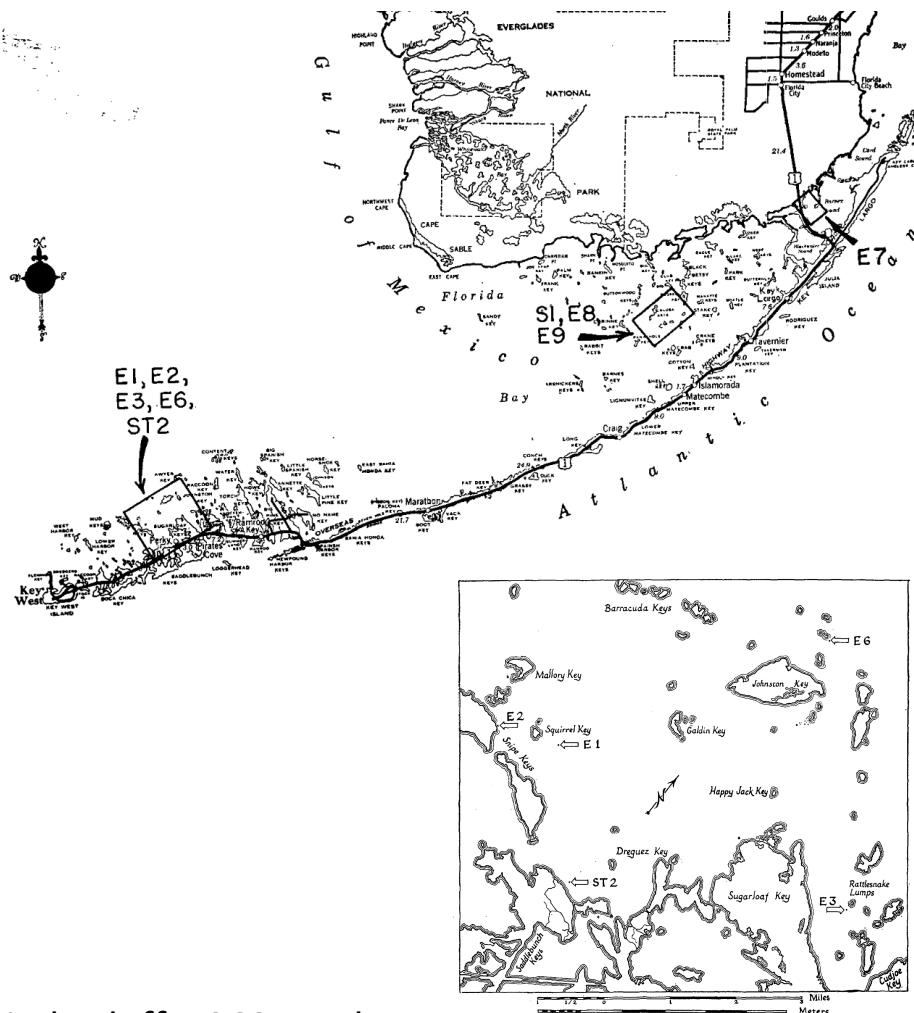
# The importance of island size vs. distance varied for different species!

Island	Island size (km <sup>2</sup> )	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



# Wilson and Simberloff field-tested island biogeography theory in the Florida Keys!



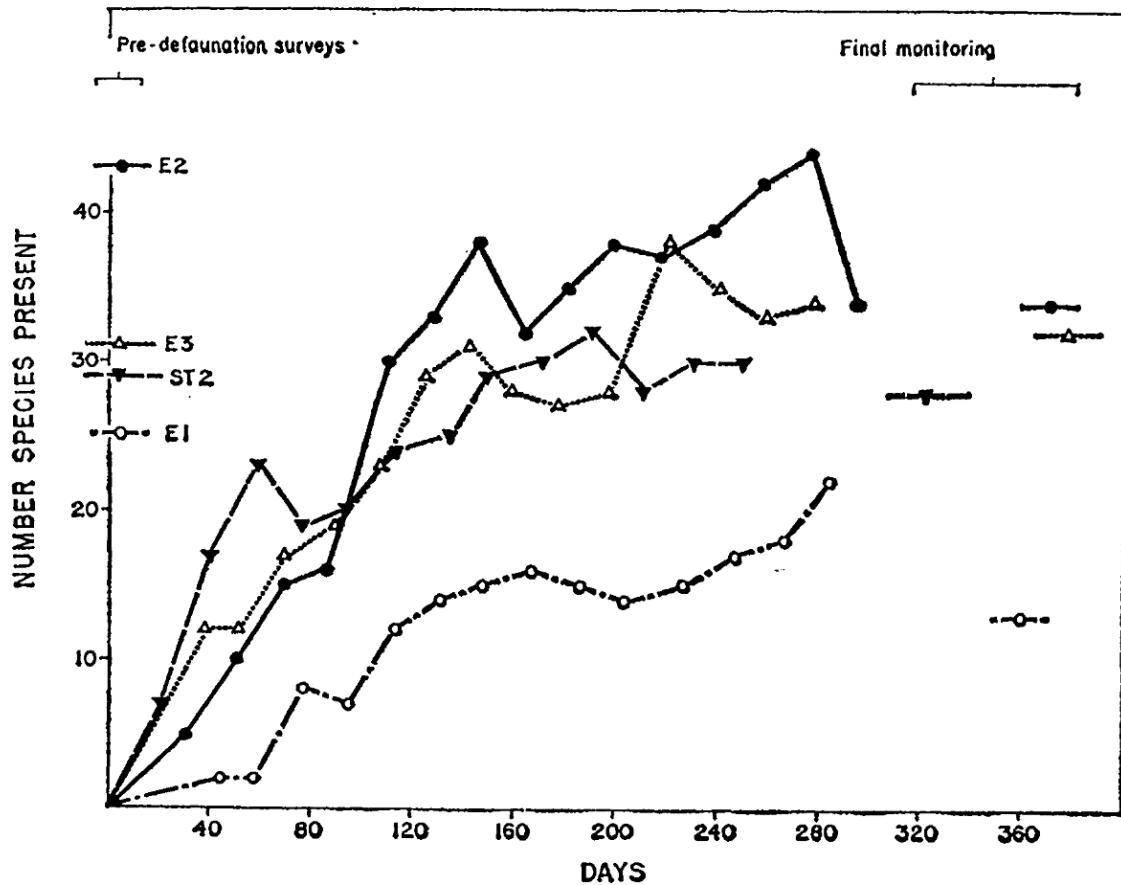
- Wilson and Simberloff identified seven mangrove islands in the Florida Keys varying in size from 11-18m in diameter and catalogued their fauna (all arthropods).
- They also conducted surveys across the keys to quantify the entire possible “source” pool to the islands.
- The experimental islands were 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*.

# Wilson and Simberloff field-tested island biogeography theory in the Florida Keys!



- 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.

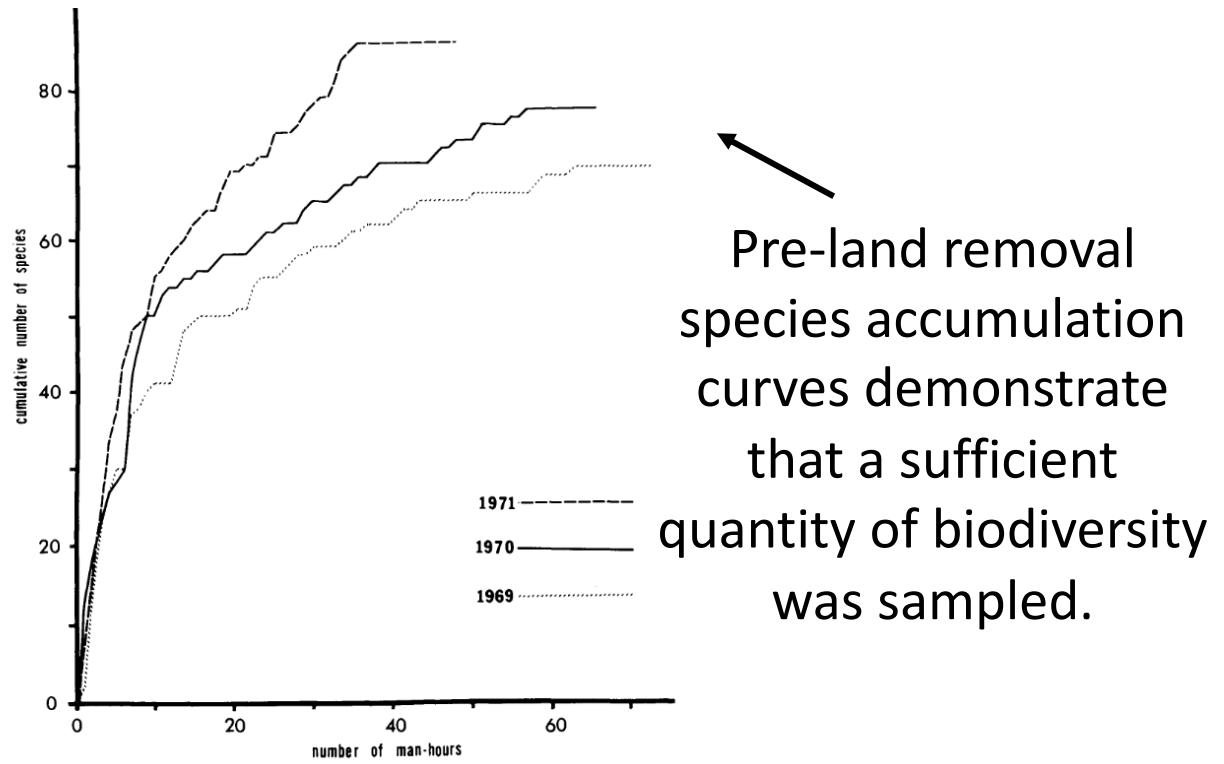


Simberloff. 1969. *Ecology*.

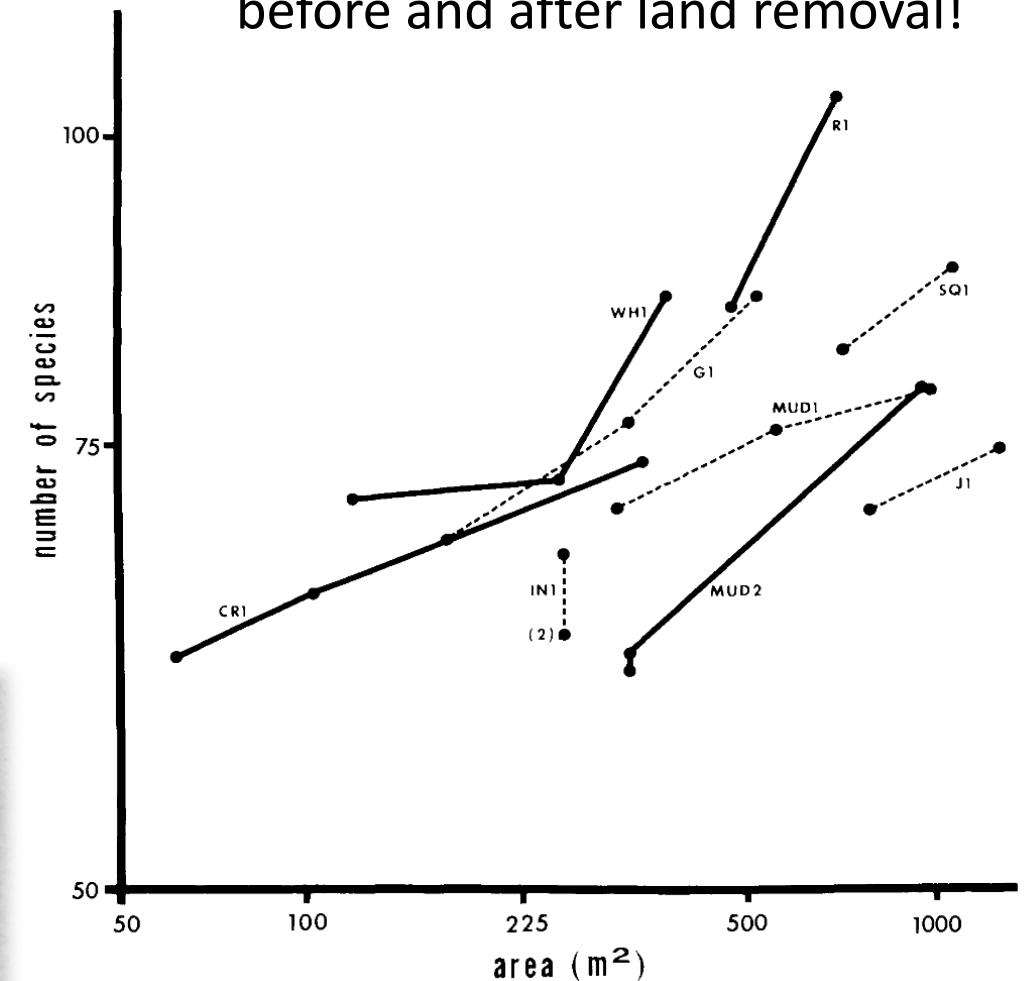
Wilson and Simberloff. 1969. *Ecology*.

Simberloff and Wilson. 1969. *Ecology*.

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

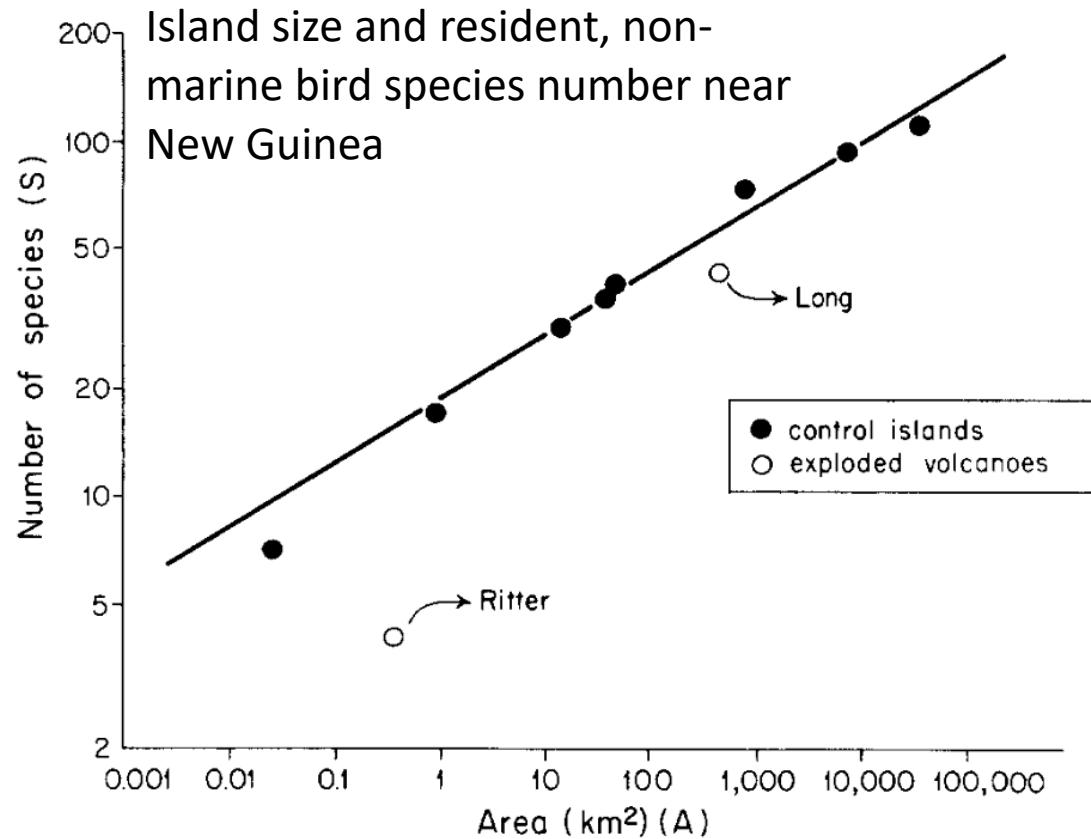


log-log plot of island area and species count before and after land removal!

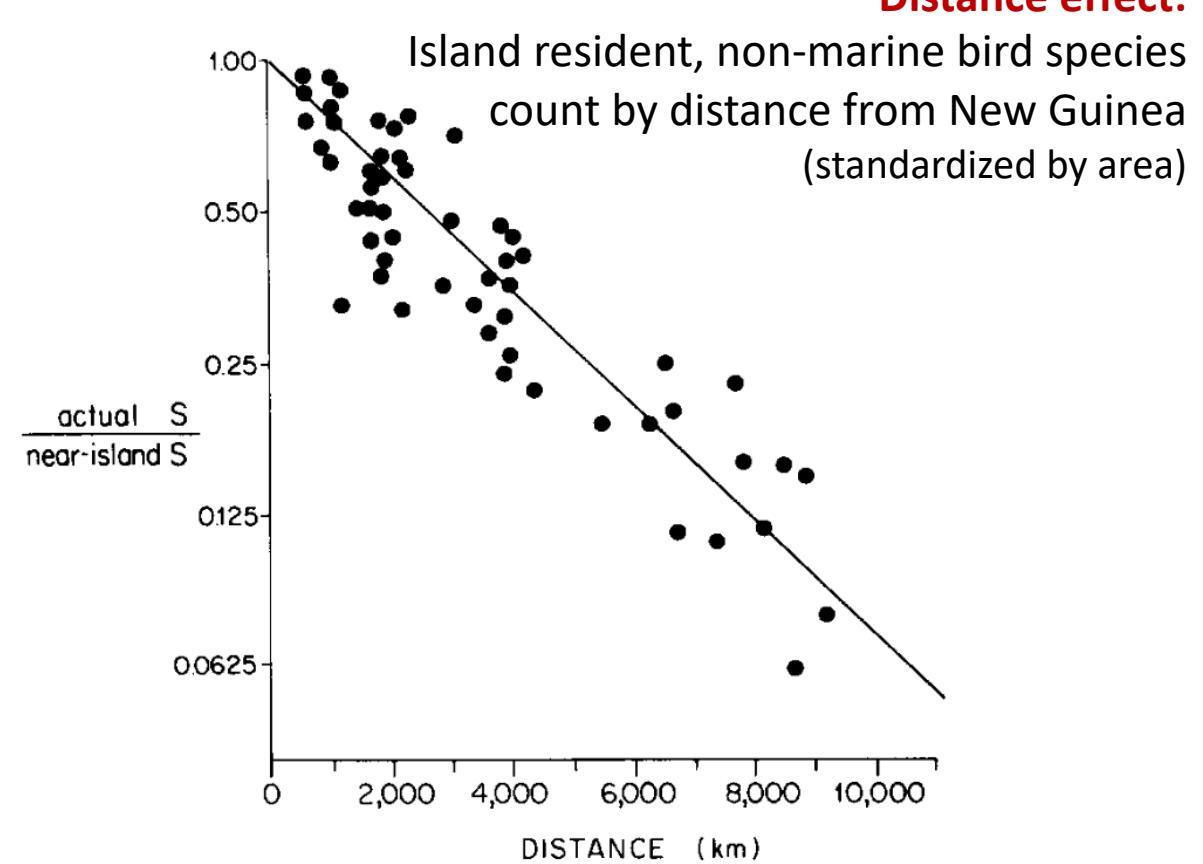


# Island biogeography has greatly influenced the design of protected area reserves

## Area effect:

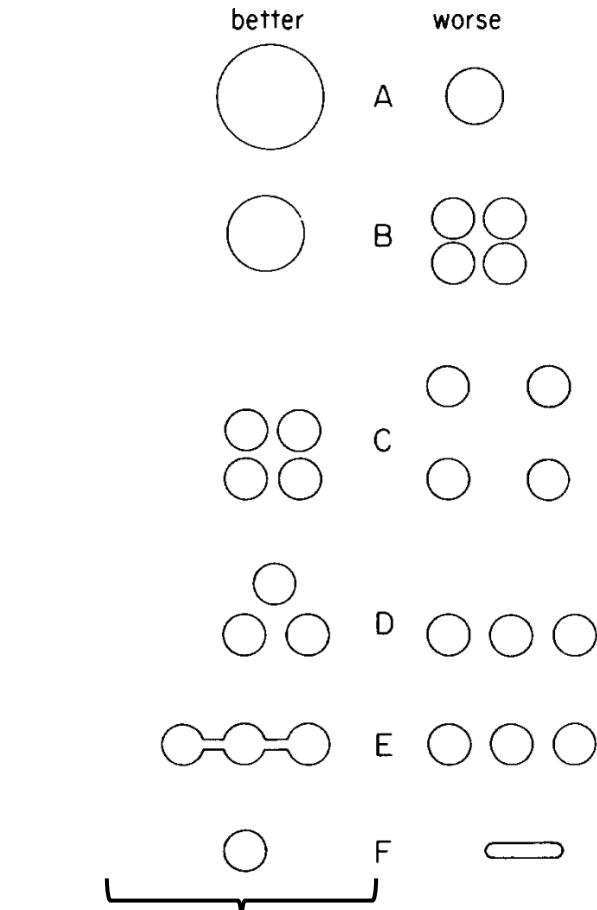
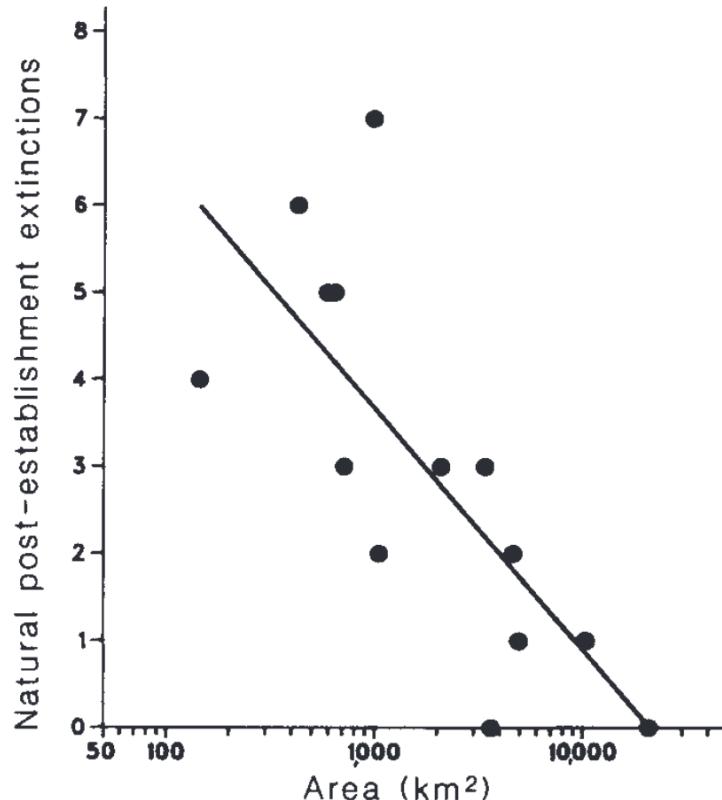


## Distance effect:

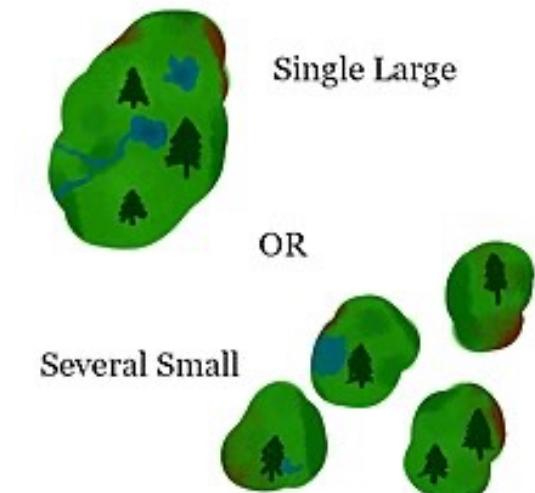


# Island biogeography has greatly influenced the design of protected area reserves

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)

# *Population Biology*

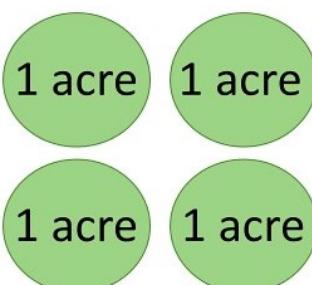
## Conservation Biology

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

Single Large

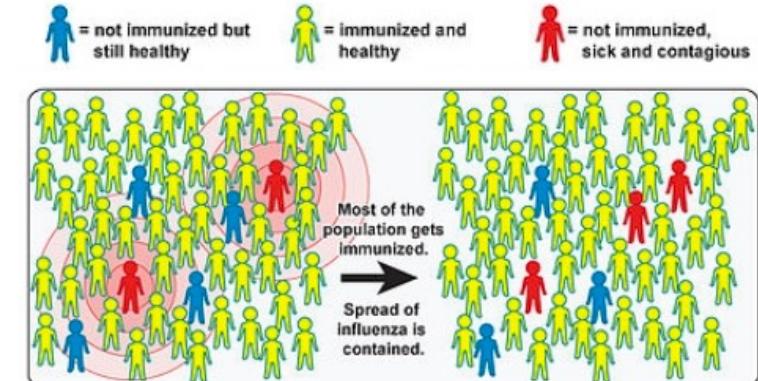


Several Small



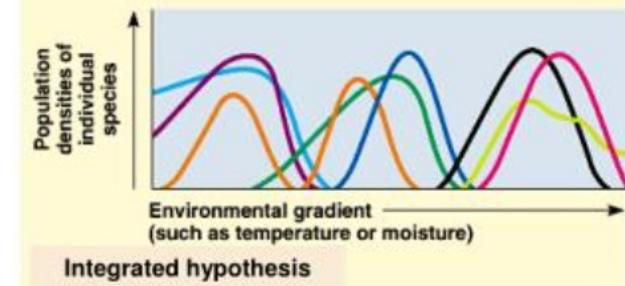
## Disease Ecology

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

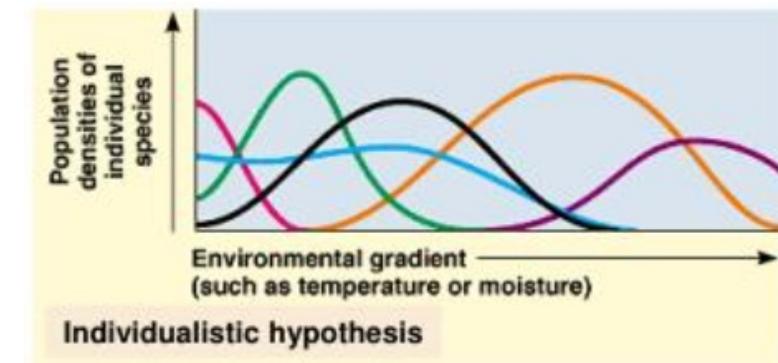


# Superorganisms vs. Loose Collections of Species?

- 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.<sup>1</sup>

BY JOSEPH GRINNELL.



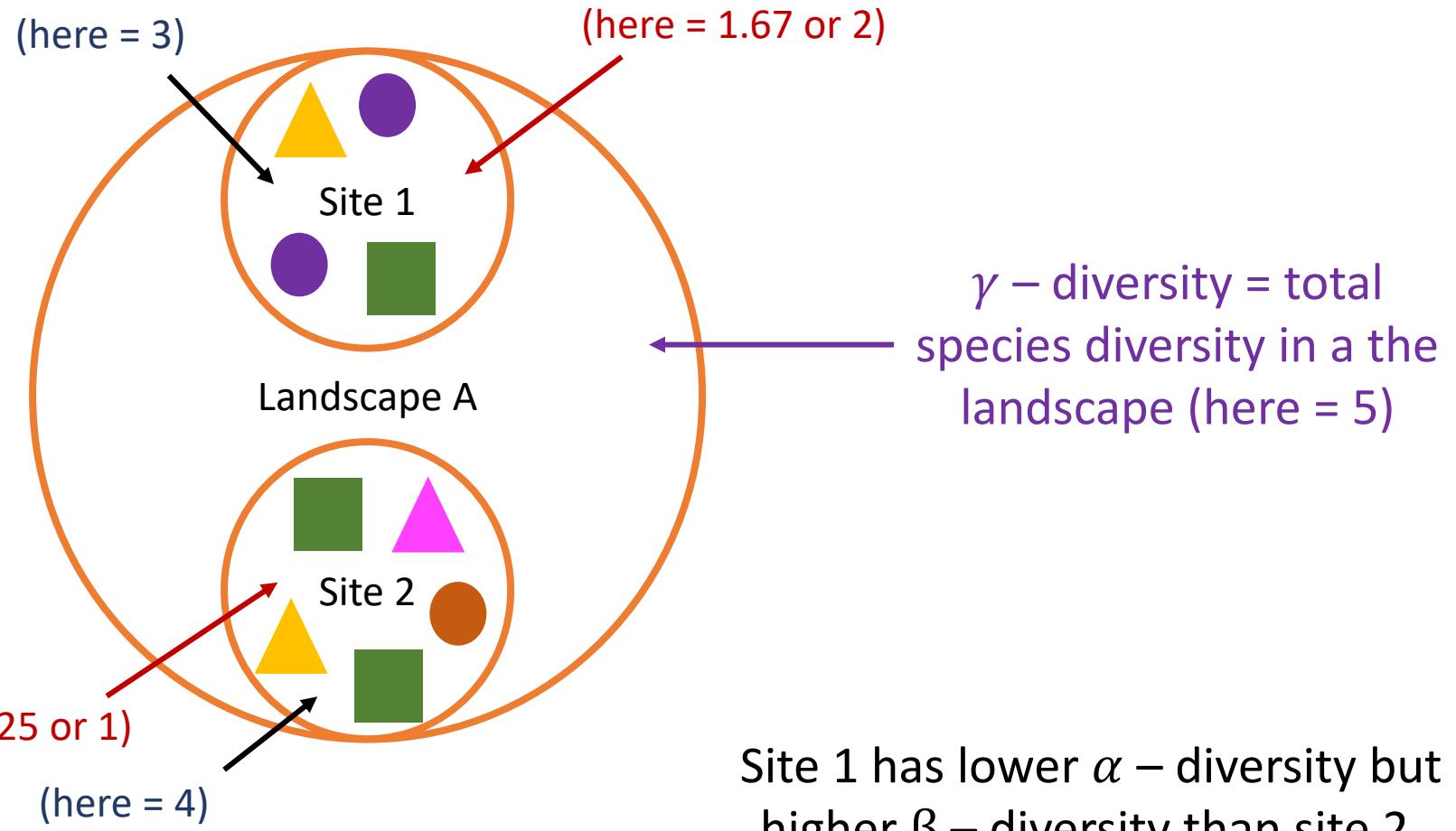
- **Neutral**: species-specific differences within a trophic level will be irrelevant to their success
- Assembly will be **stochastic**
- MacArthur and Wilson 1967
- Hubbell (2001) - Unified neutral theory of biodiversity and biogeography (**UNTB**)



# Biodiversity can be measured in several ways!

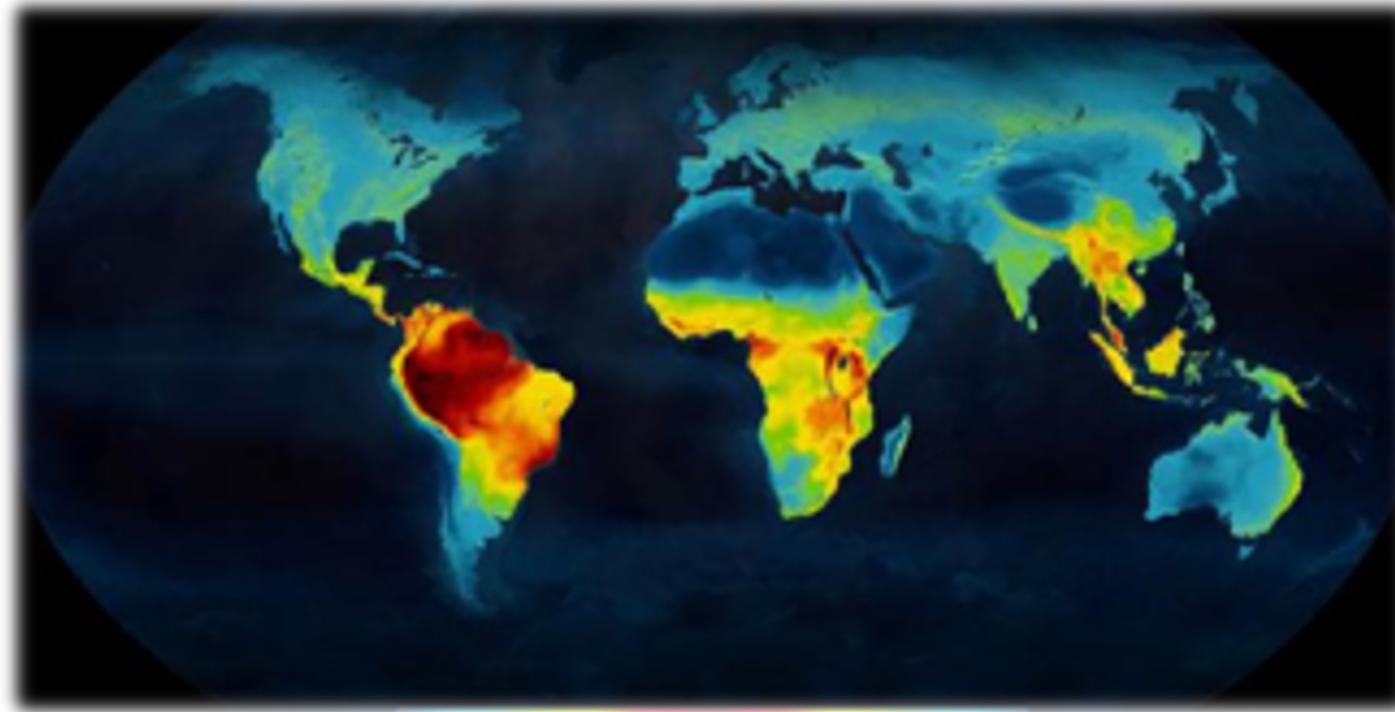
$\alpha$  – diversity = species richness, typically within a small specified region

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



Site 1 has lower  $\alpha$  – diversity but higher  $\beta$  – diversity than site 2. Both are important!

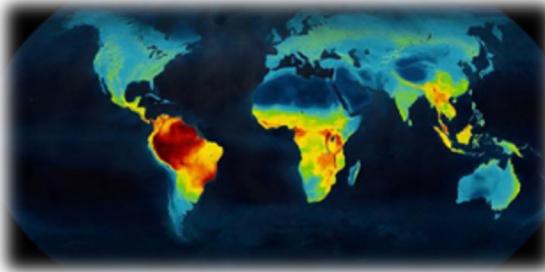
# Biodiversity is concentrated in the tropics.



We still lack a satisfying model to explain why.

(terrestrial vertebrate diversity)

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



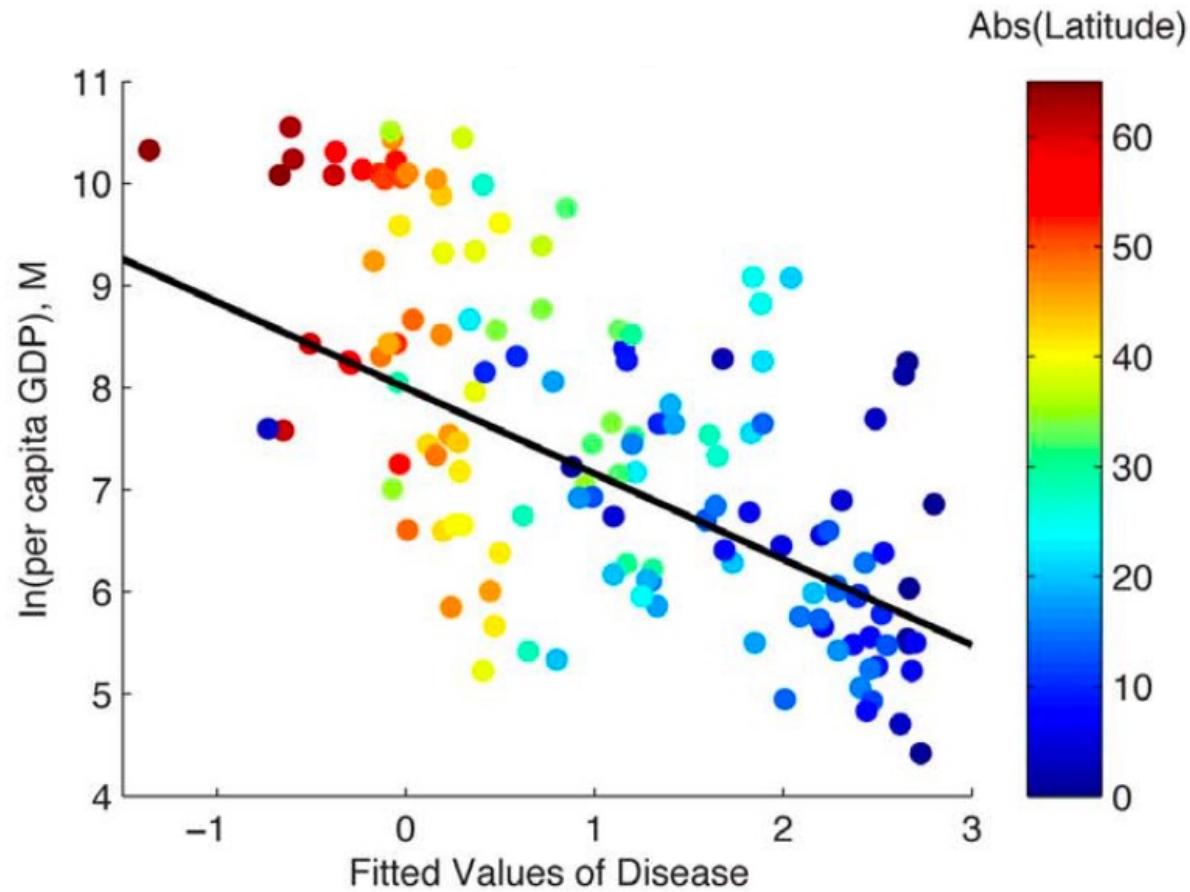
# Biodiversity is concentrated in the tropics.

We still lack a satisfying model to explain why.

## Some candidate hypotheses:

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!*

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



lower relative  
disease burden

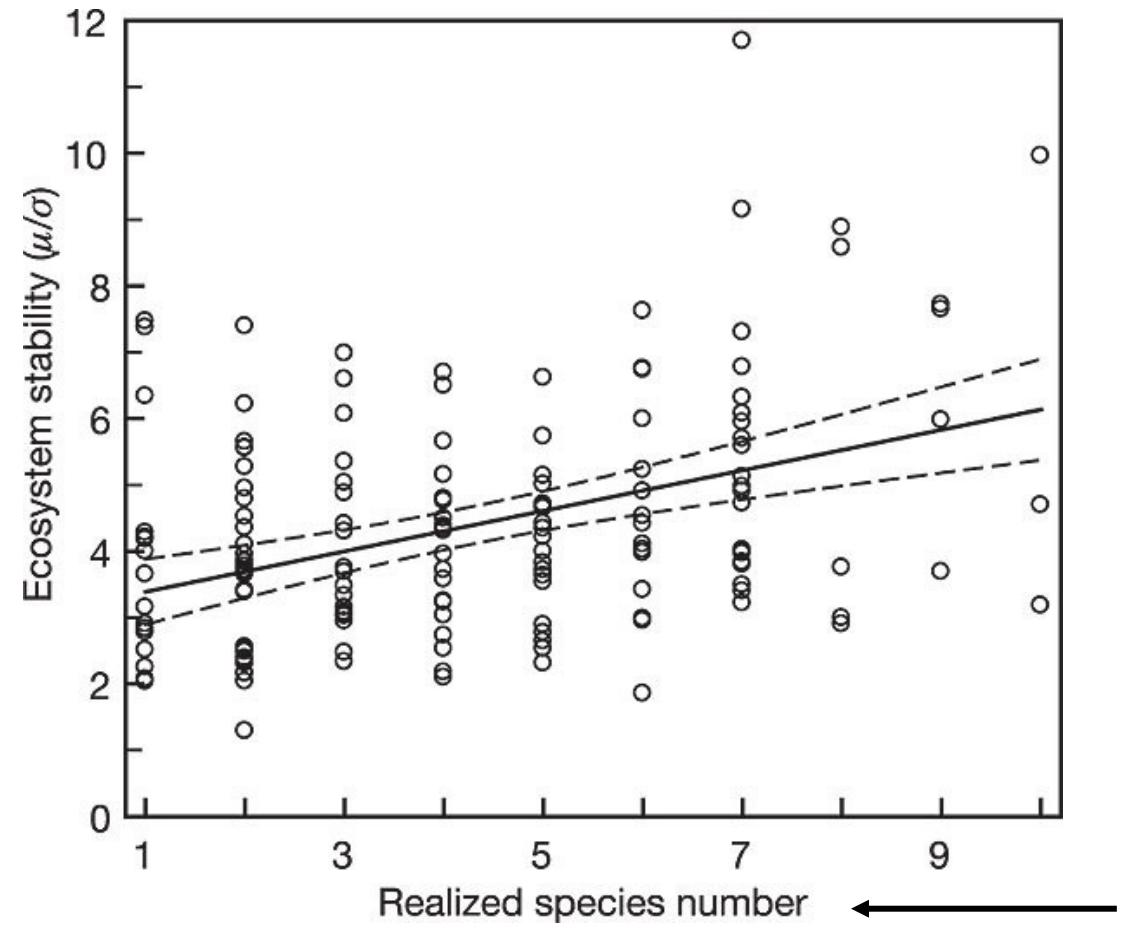
higher relative  
disease burden

# Why do we care about biodiversity?



# Why do we care about biodiversity?

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

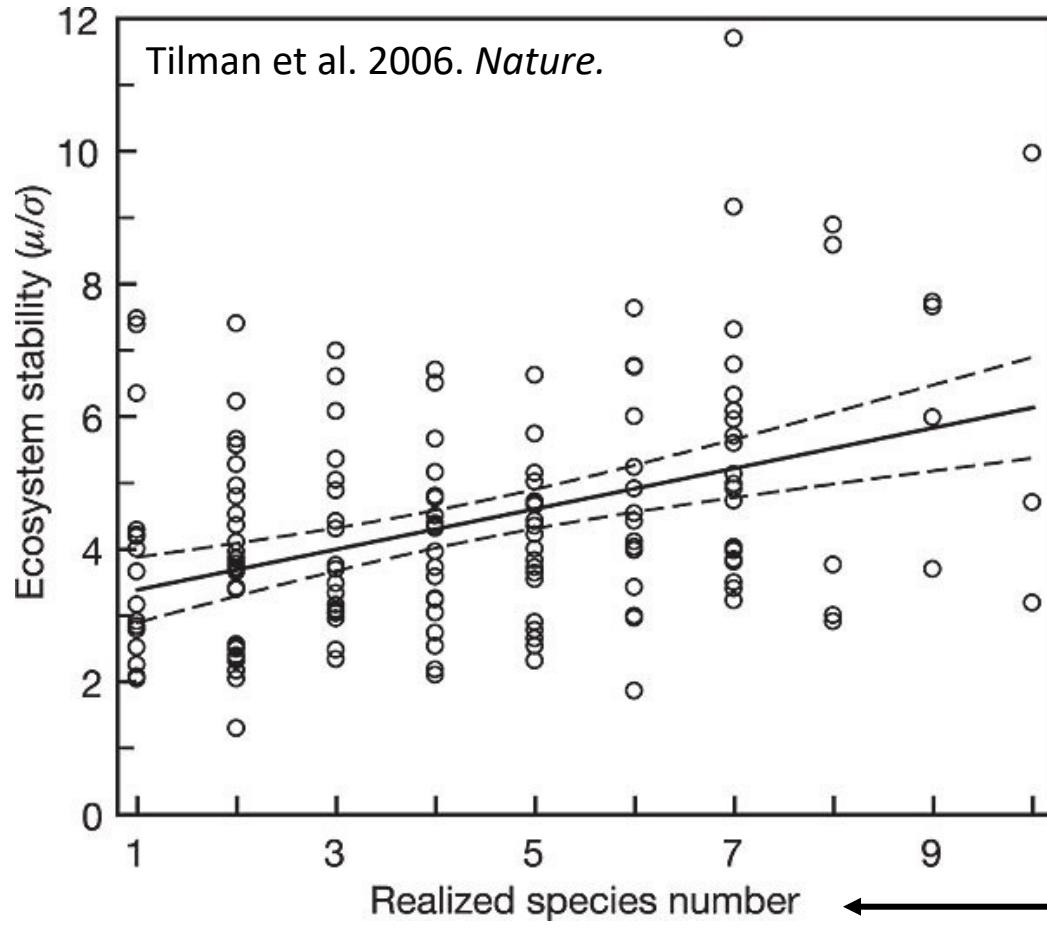


Cedar Creek experiment from the  
University of Minnesota

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

# Why do we care about biodiversity?

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



***"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

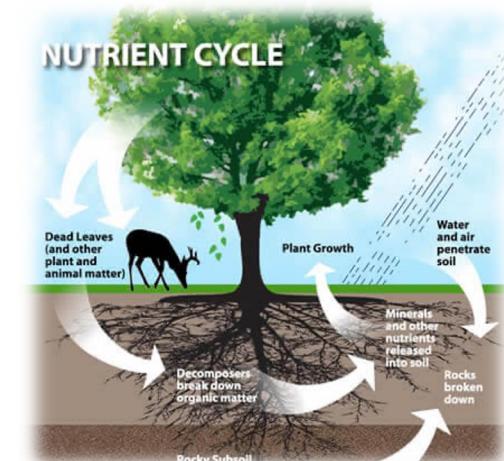
## cultural services

- ecotourism
- therapeutic services
- historical and cultural values



## supporting services

- nutrient cycling
- primary productivity
- habitat provisioning

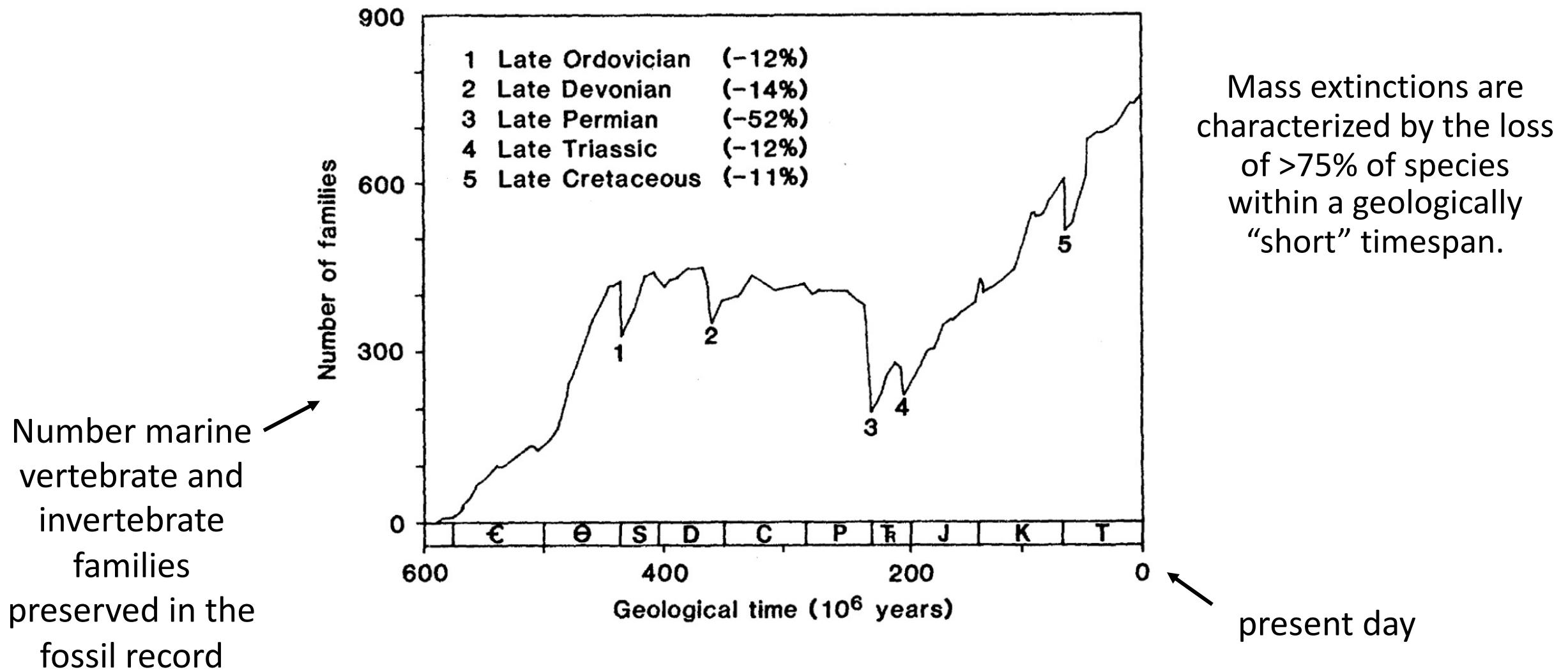


# The **Natural Capital Project** seeks to value the economic benefits of ecosystem services for humans.

- The Catskill-Delaware watershed supplies 1.2 billion gallons of drinking water daily to 9 million residents of New York City.
- Through the 1980s, NYC water remained the purest in the nation, regularly beating bottled waters in blind taste and purity tests, and was even imported to England for tea tasting.
- Towards the late 1980s early 1990s, the water quality began to decline, and NYC faced the prospect of building a water filtration plant, costing ~\$6 billion to build and another \$250 million annually to maintain.
- 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**.

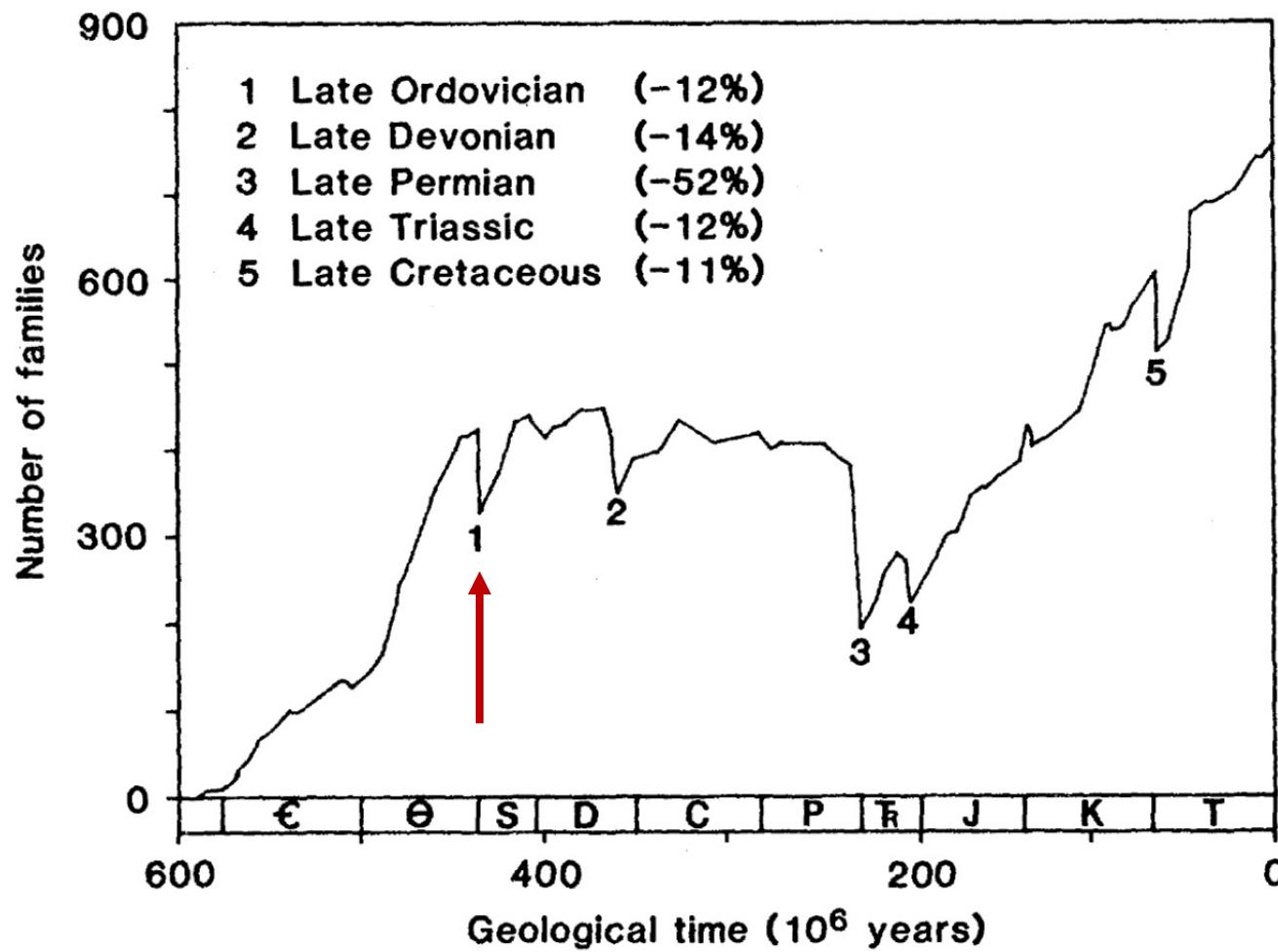


Five major **mass extinction events** are recognized in geologic time.



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

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

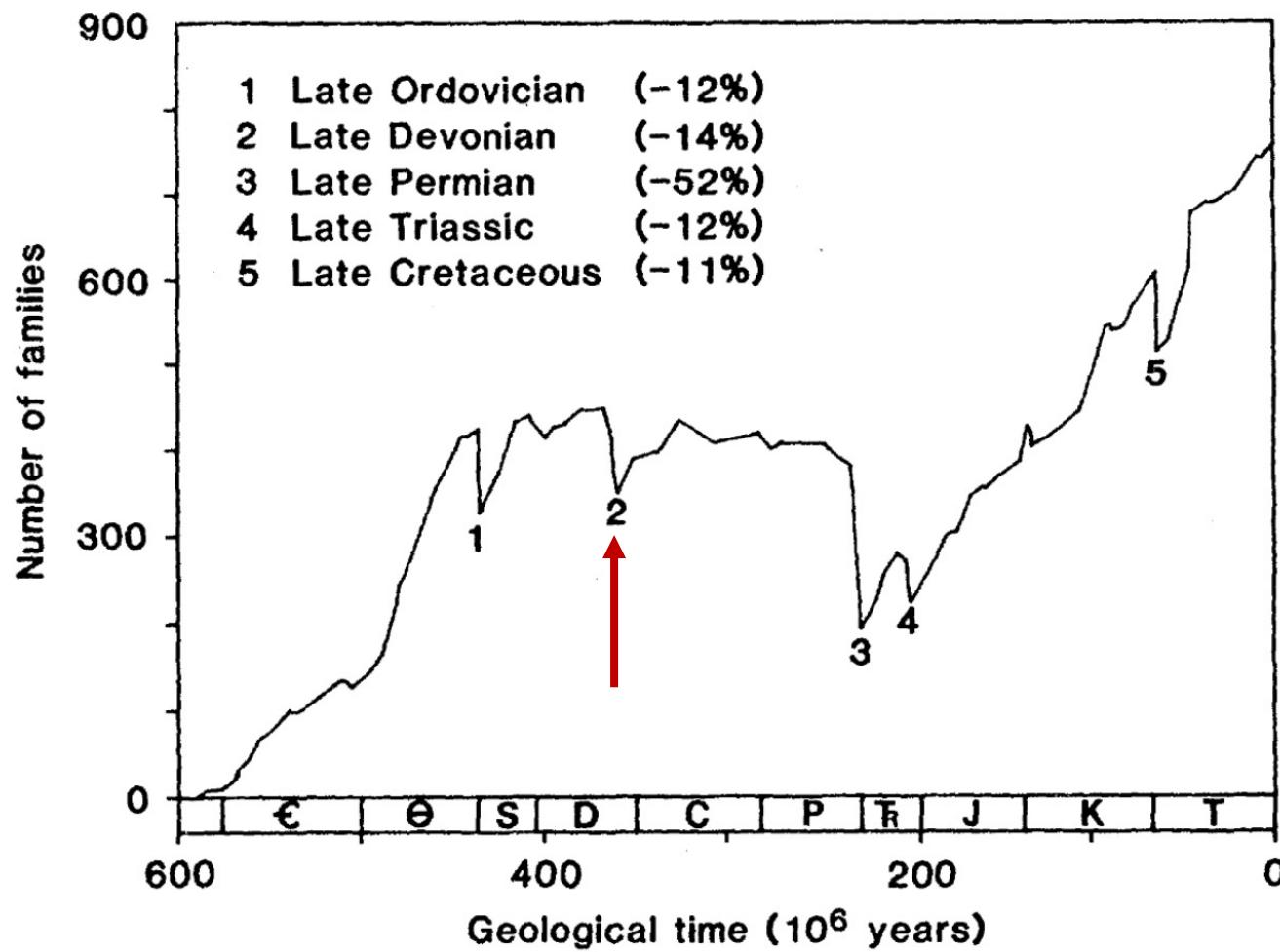


1. **Late Ordovician-Silurian** – 445-444 MYA  
– second largest extinction in history.

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

Proposed causes:  
global warming,  
volcanism, anoxia.

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

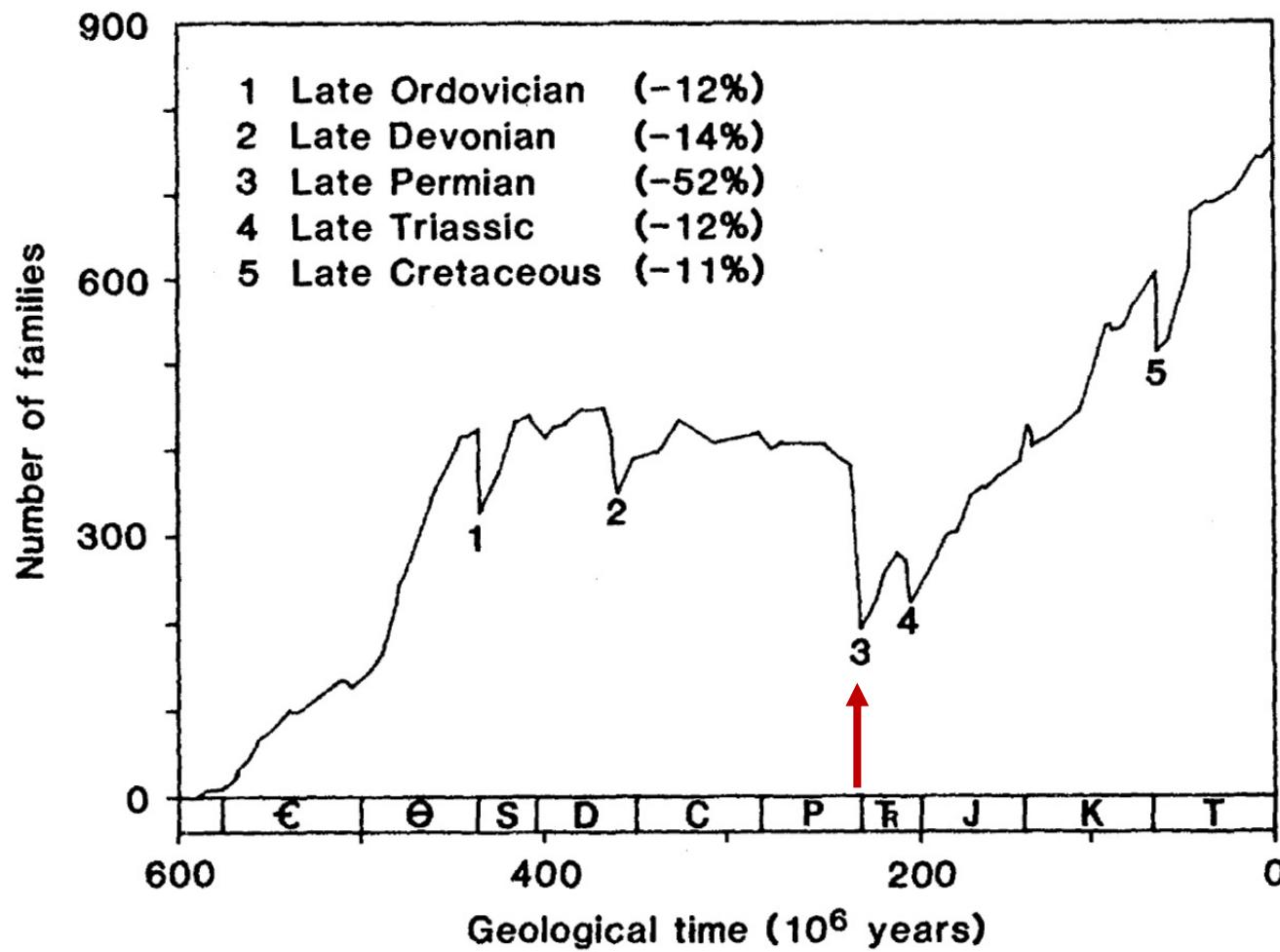


2. **Late Devonian** –  
372-359 MYA – two  
subsequent extinction  
events.

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

Proposed causes:  
global cooling, anoxia,  
meteor impacts.

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

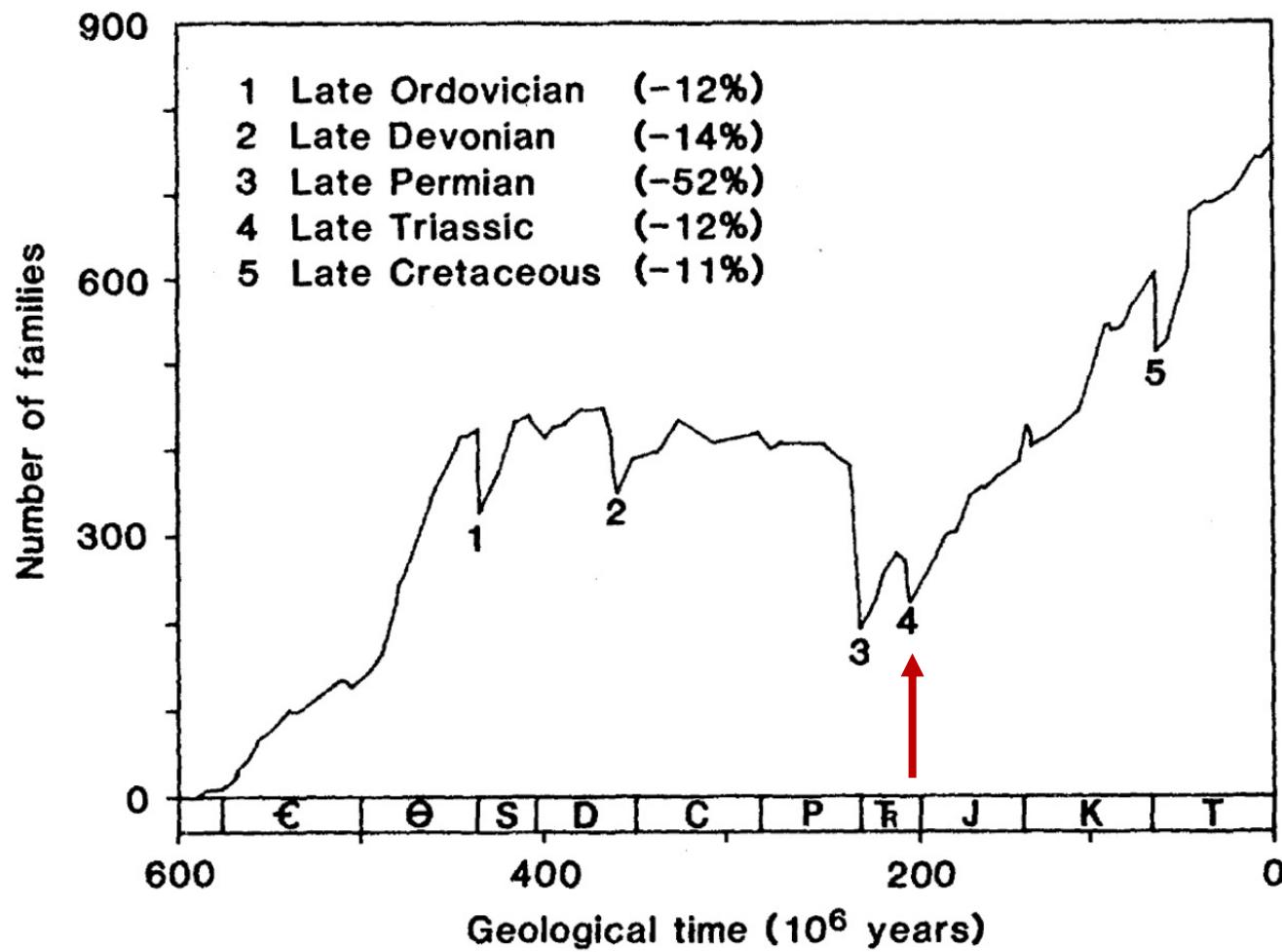


3. **Permian – Triassic** –  
252 MYA – largest  
extinction in history –  
known as the ‘Great  
Dying’.

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.

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

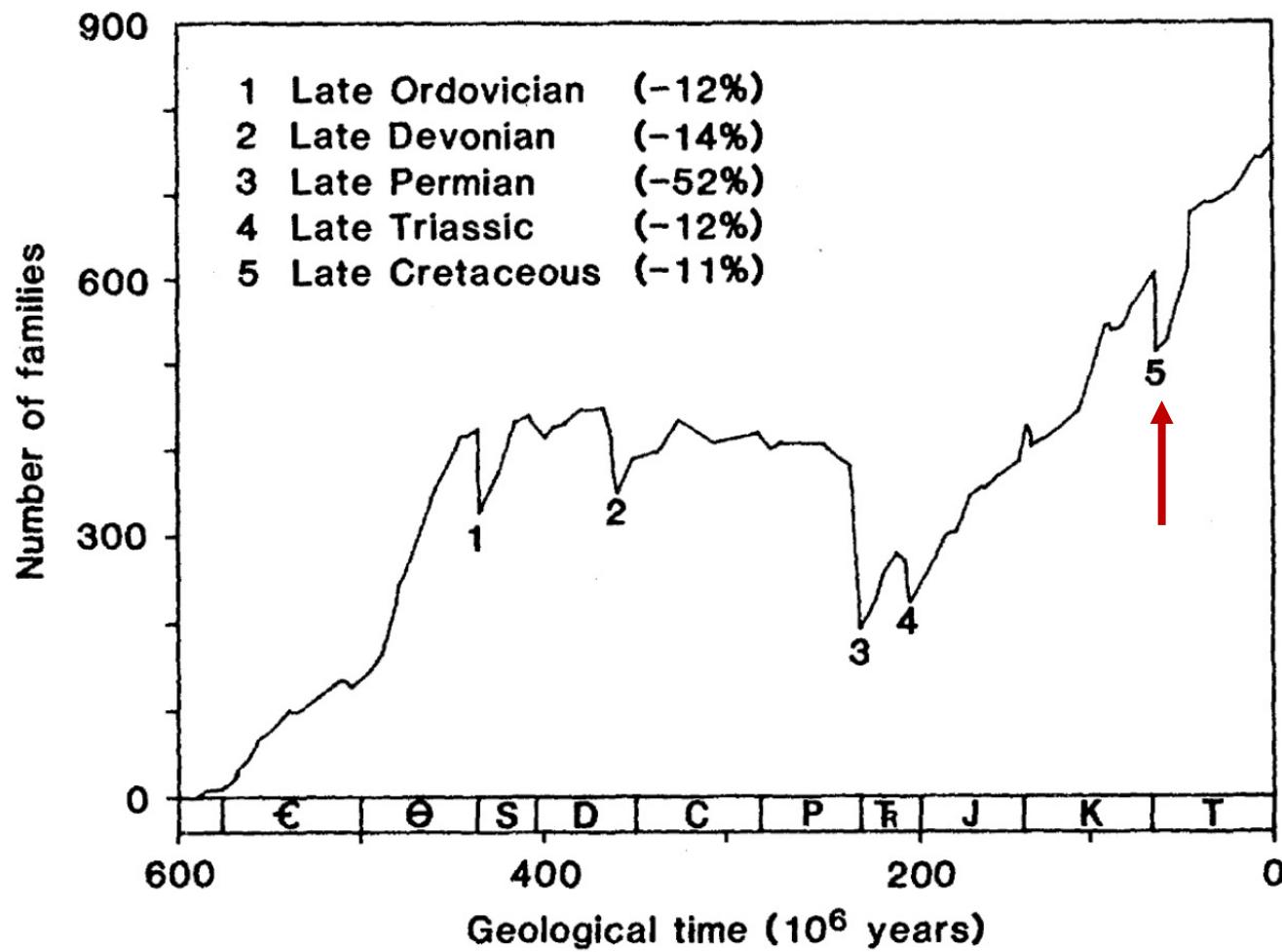


4. **Triassic - Jurassic** –  
201 MYA .

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

Proposed causes:  
global warming, CO<sub>2</sub>  
accumulation, ocean  
acidification

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



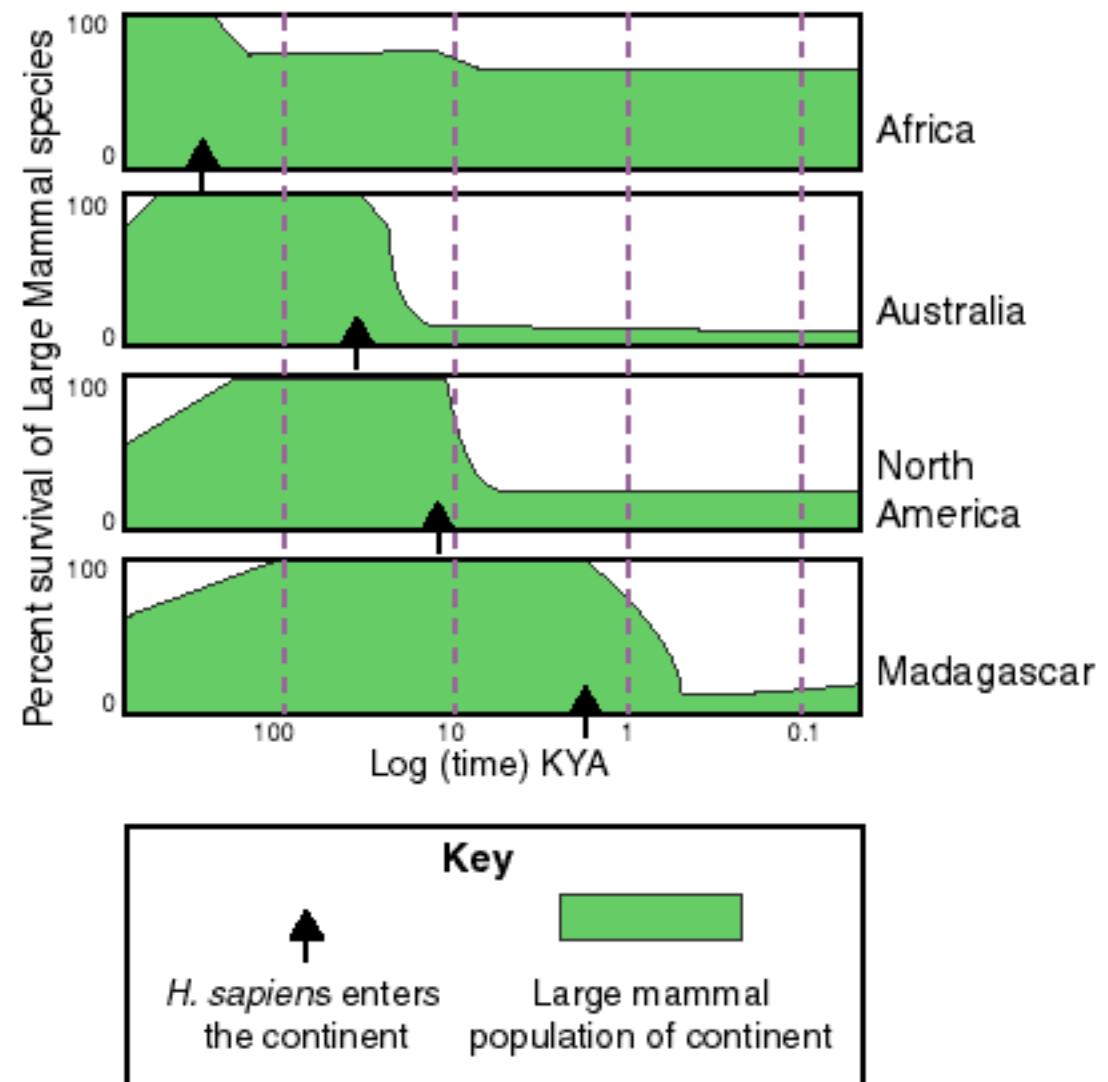
5. **Cretaceous - Paleogene (KT)** – 66 MYA .

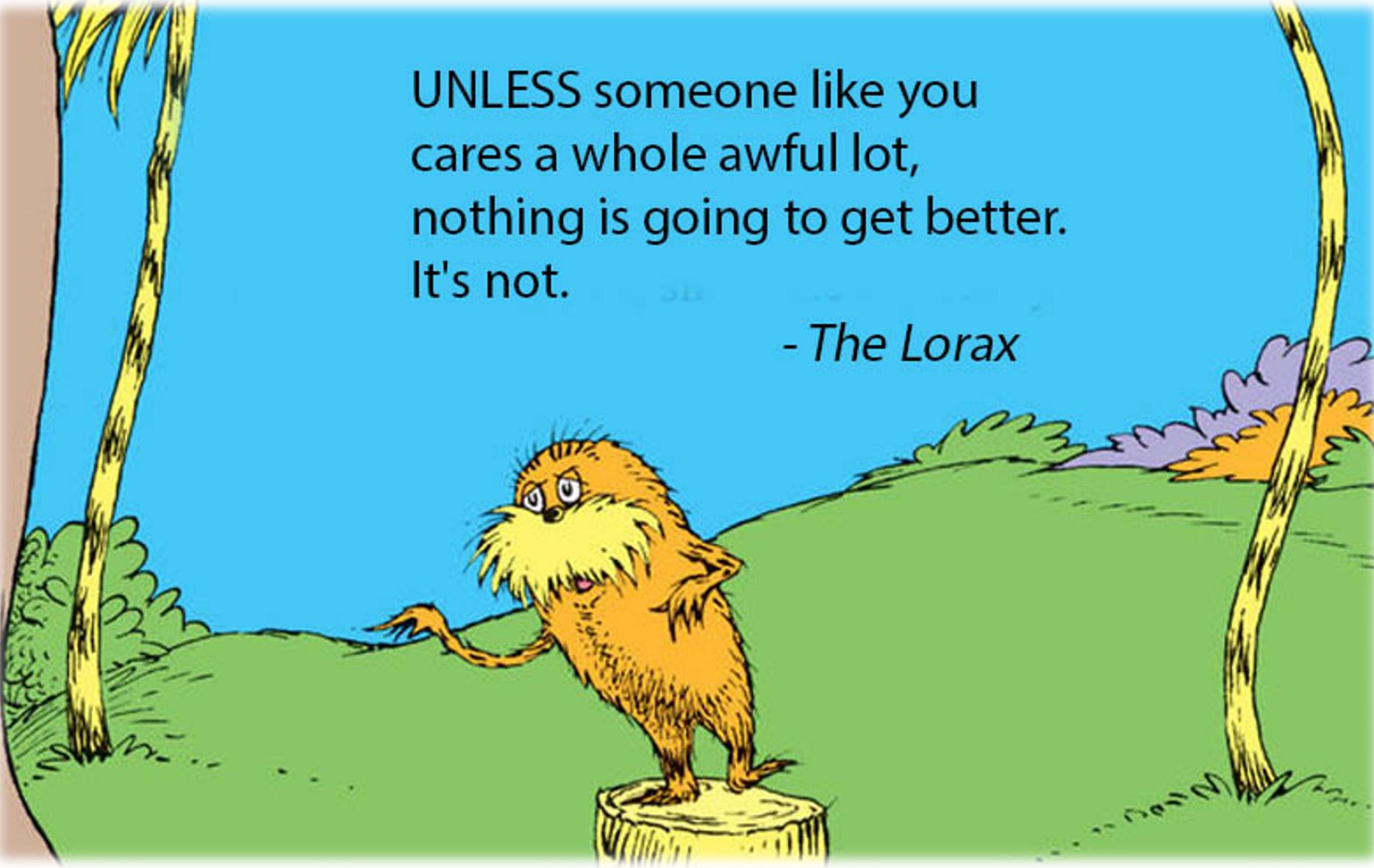
Extinction of all non-avian dinosaurs and 75% of all the planet's species. Gave way to the age of mammals

Proposed causes:  
Chicxulub asteroid impact in present-day Yucatan

# 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 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

