Fundamentals of Ecology

Week 9, Ecology Lecture 8

Cara Brook

March 6, 2025

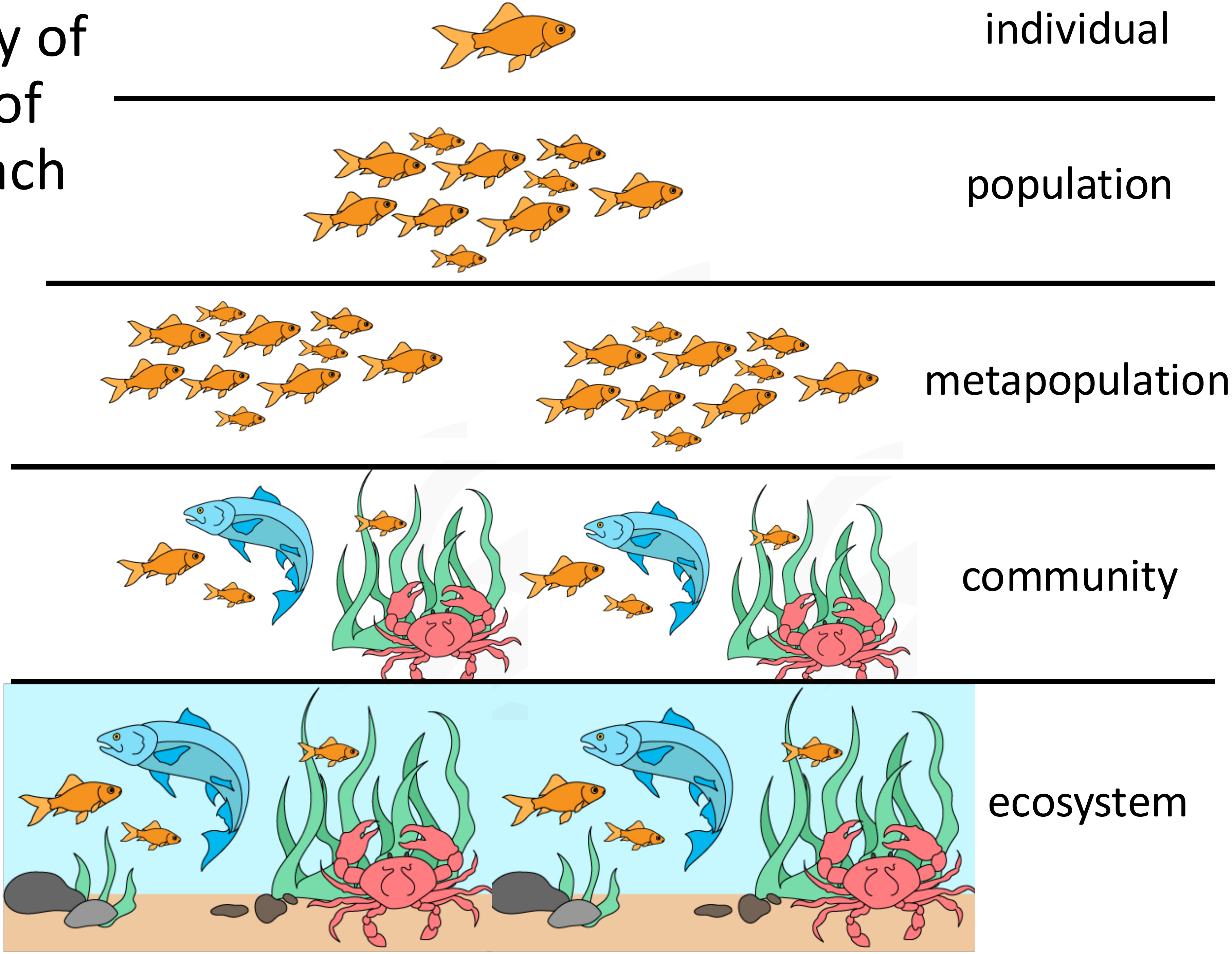
Office hours: On ZOOM
Thursday, March 6, 2025
4-5pm
See link in Canvas!

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.**

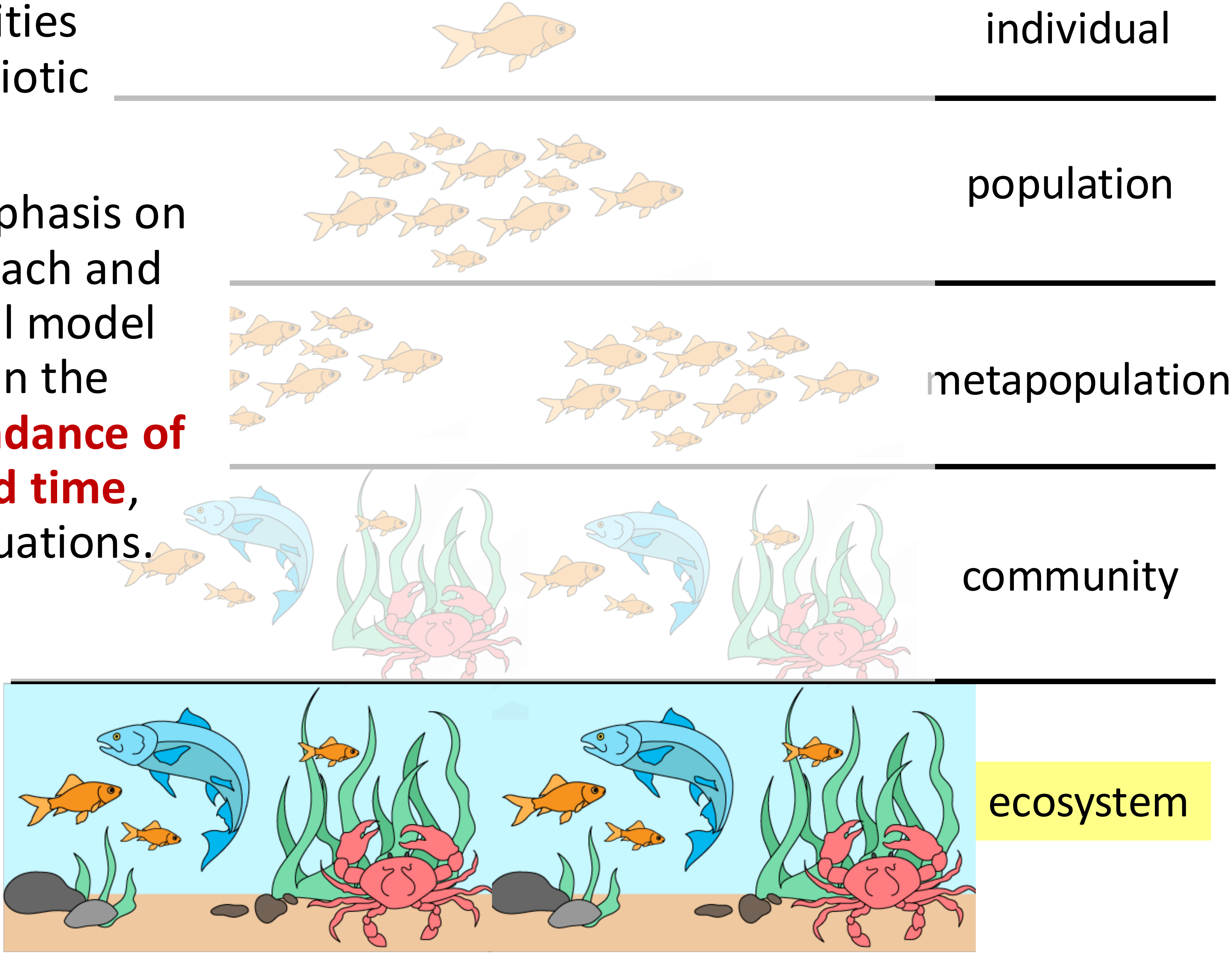


Ecosystem = communities interacting with the abiotic environment

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.

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

Mathematical

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

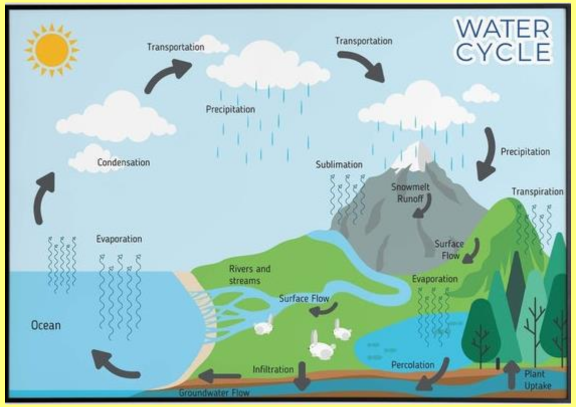
$$\frac{dI}{dt} = \beta S I - \gamma I$$

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

Human Genetics

Human Disease

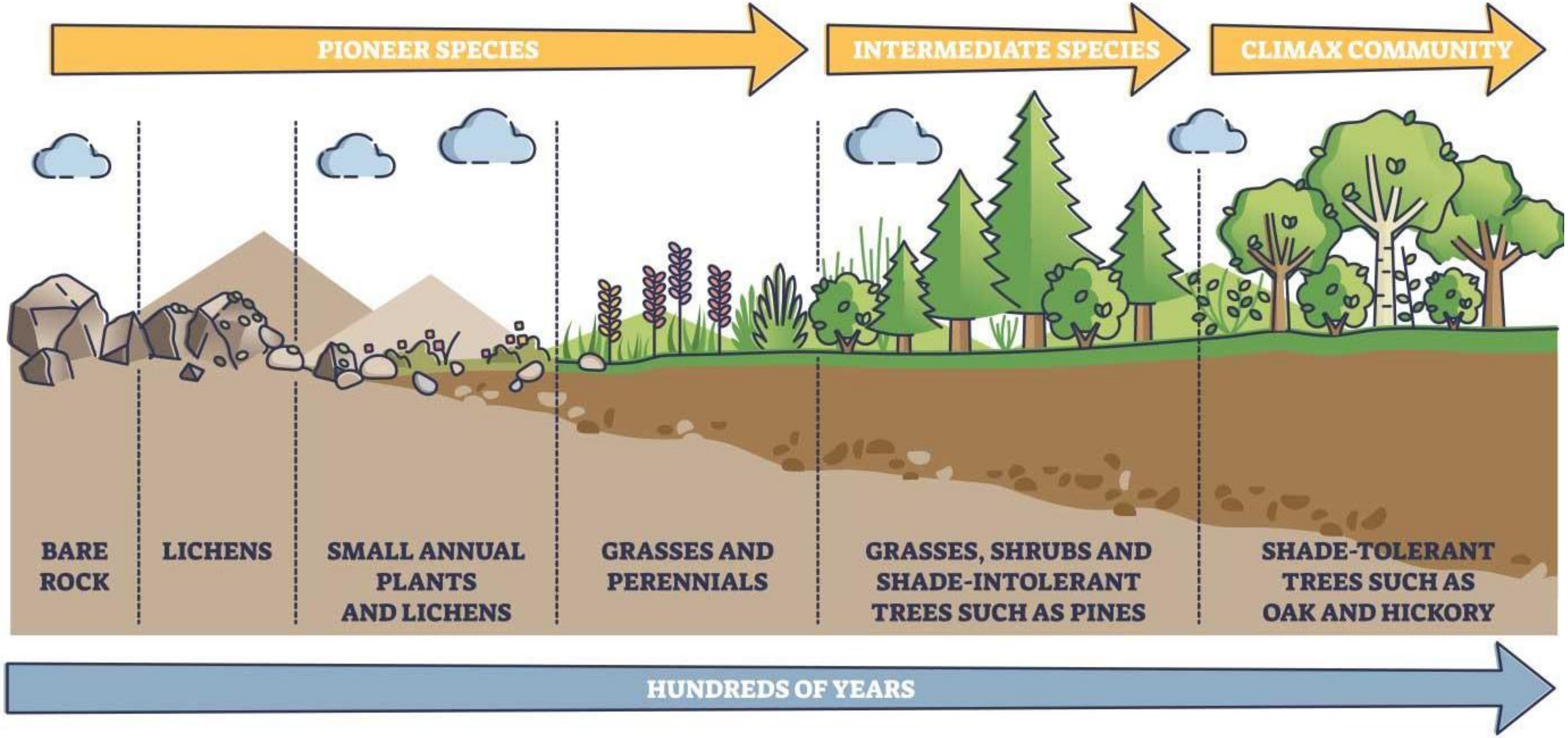
Conceptual



One process of community assembly is ecological **succession**.

- 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.



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

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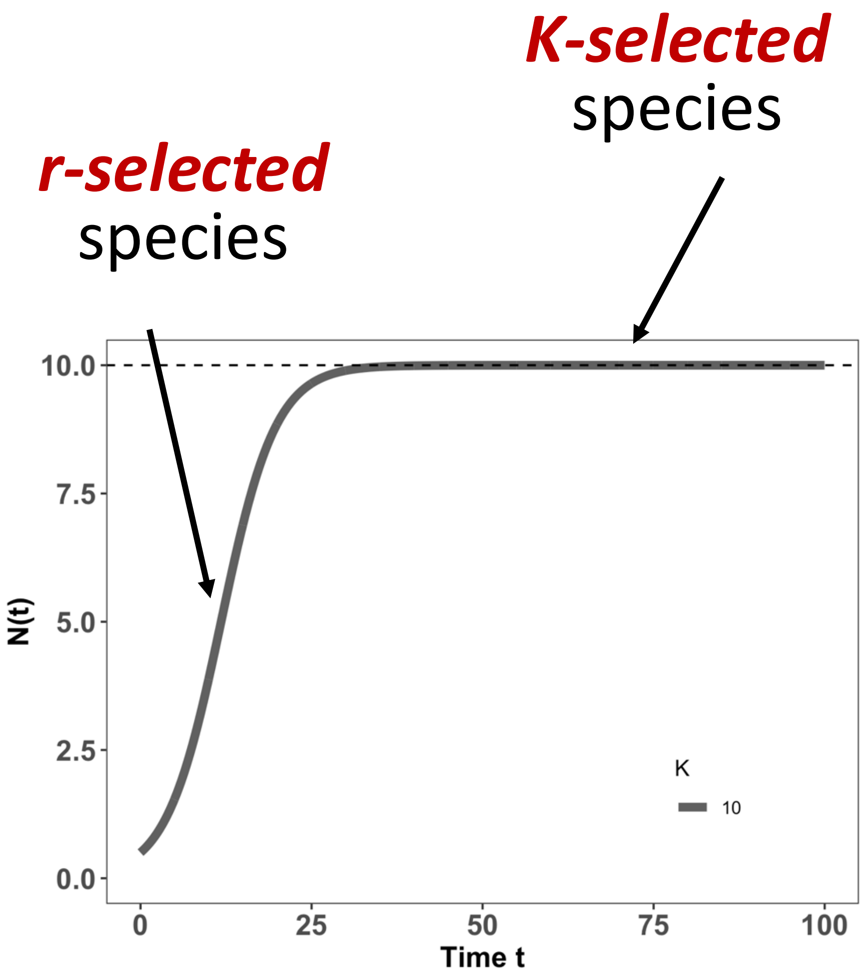
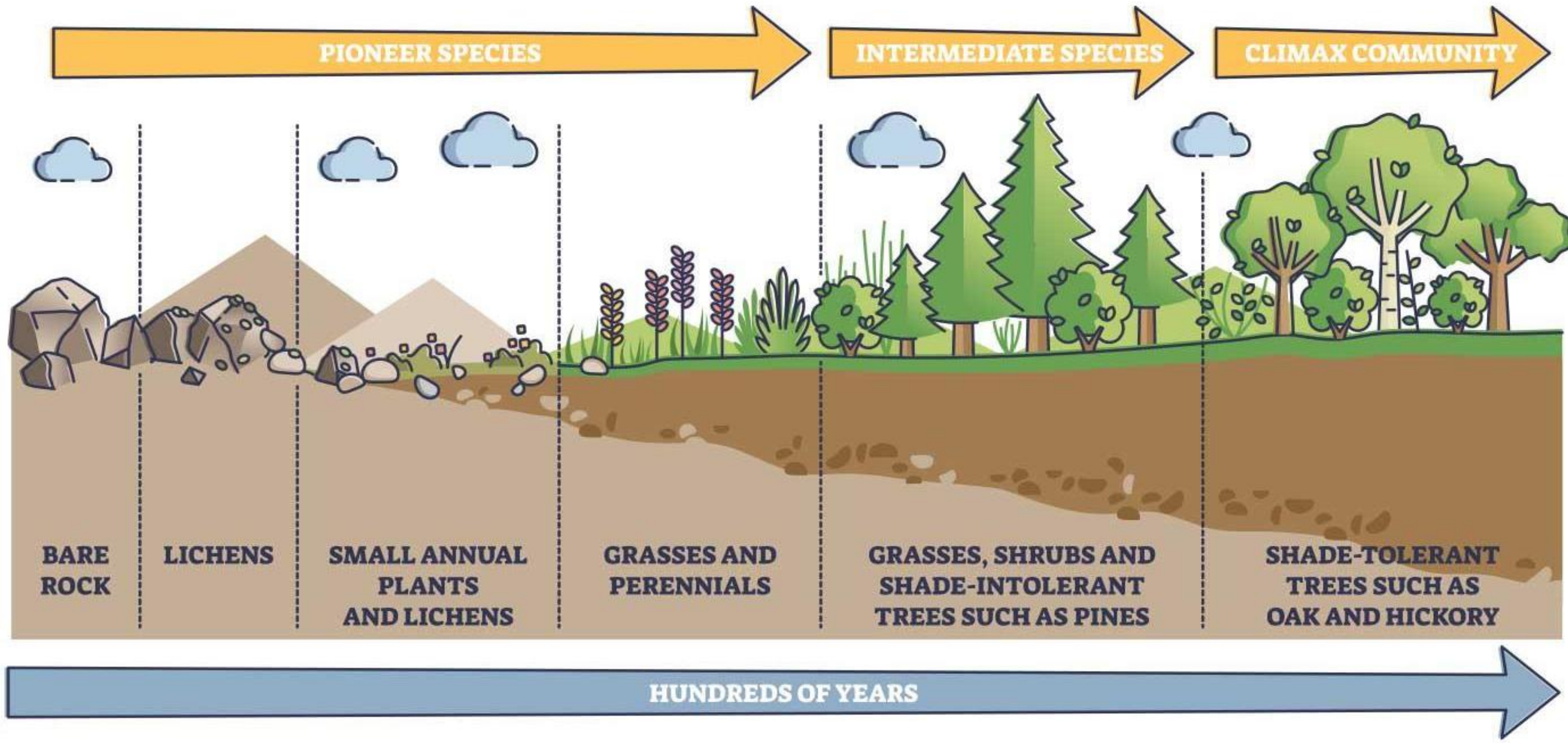
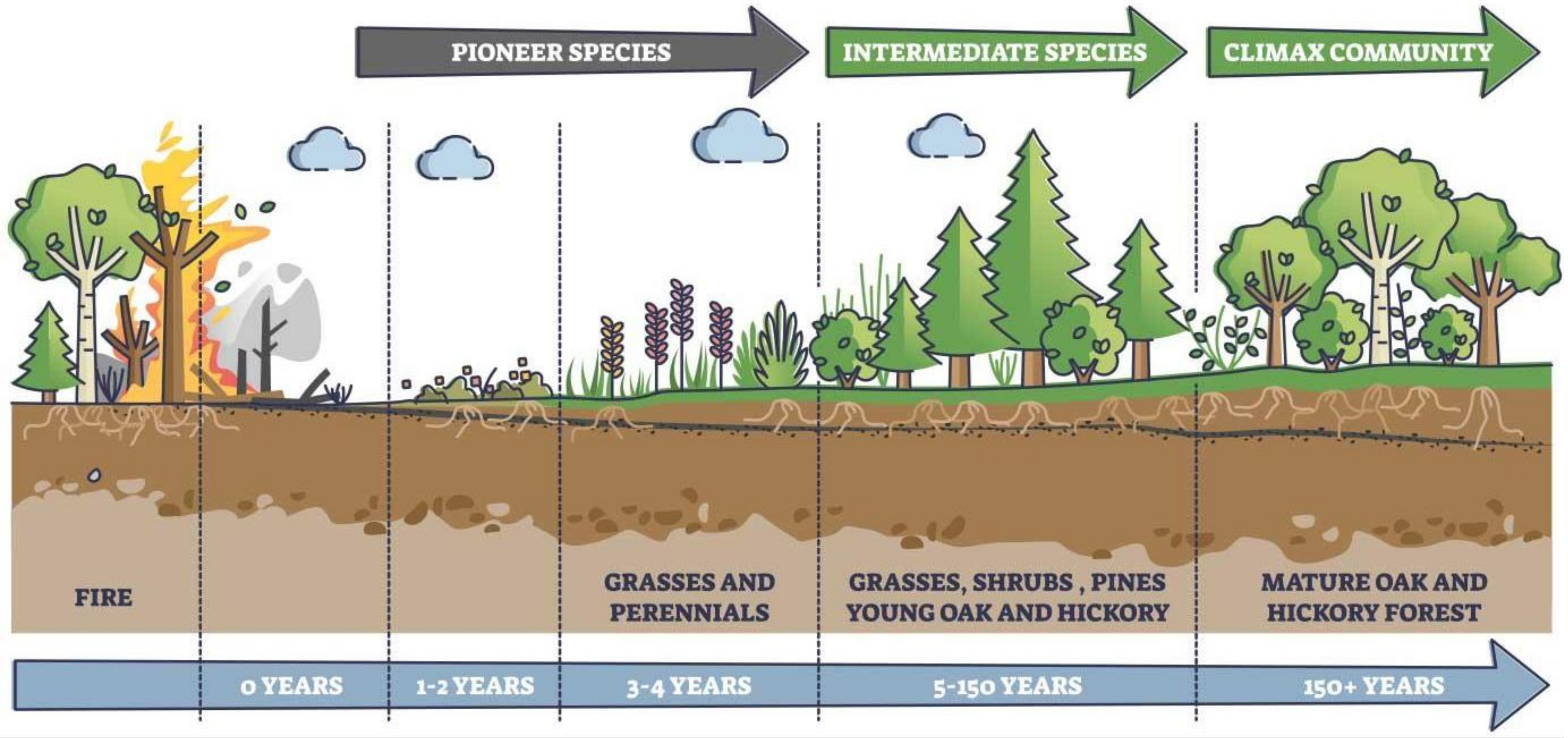


$$\frac{dN}{dt} = \mathbf{r}N\left(1 - \frac{N}{\mathbf{K}}\right)$$



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

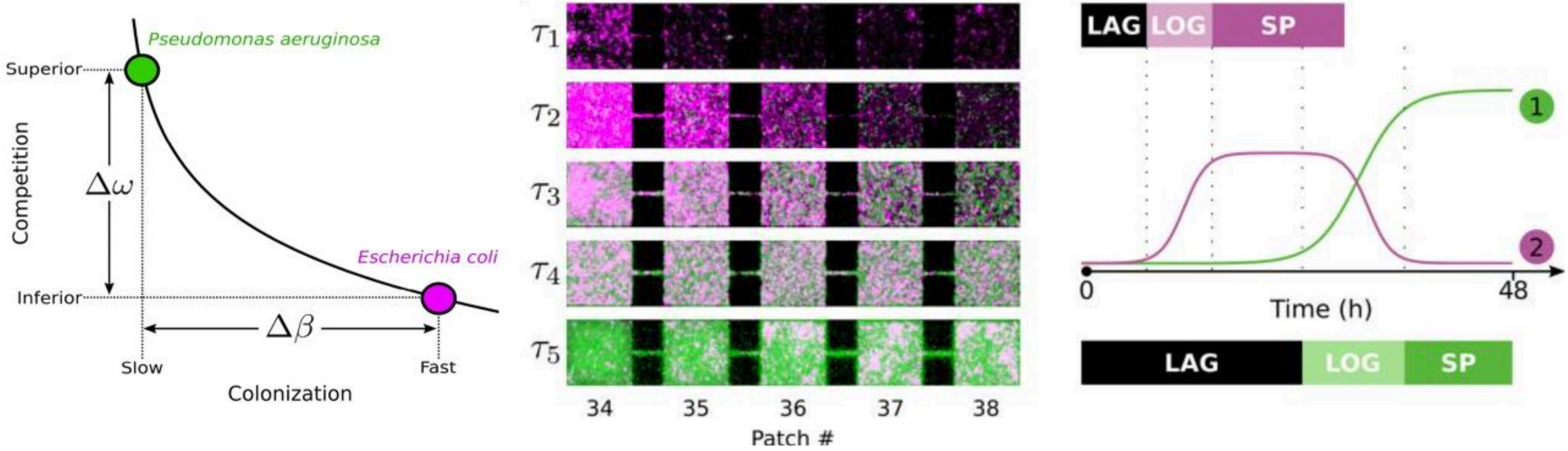
Secondary succession occurs when an environmental disturbance displaces a climax community, but soil and nutrients are still retained.



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

Succession also occurs in microbial systems.

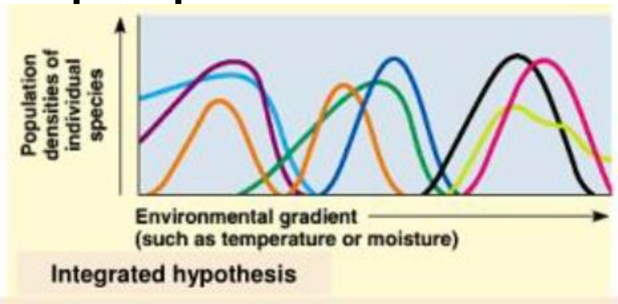
Here, the "*K-selected*" superior competitor eventually replaces the "*r-selected*" fast colonizer.



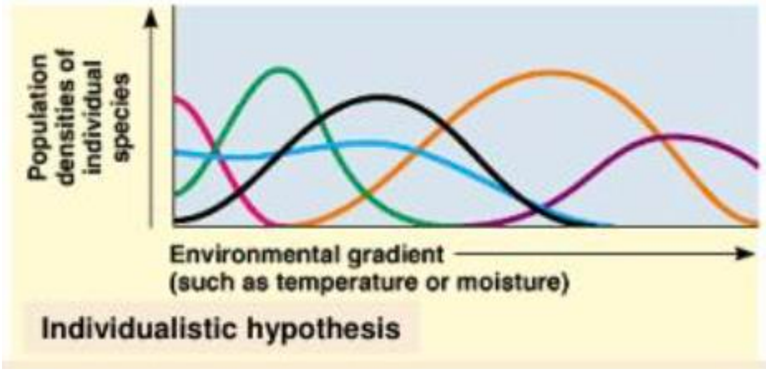
Wetherington et al. 2022. *BMC Biology*

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.
- **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



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

- Larger areas have more species!

$$S = cA^z$$

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

Preston 1964. *Ecology*

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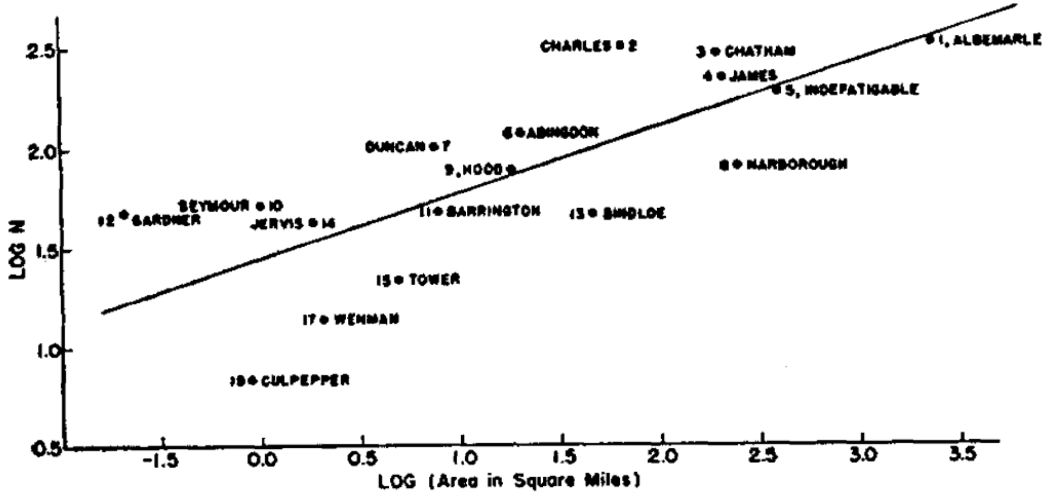
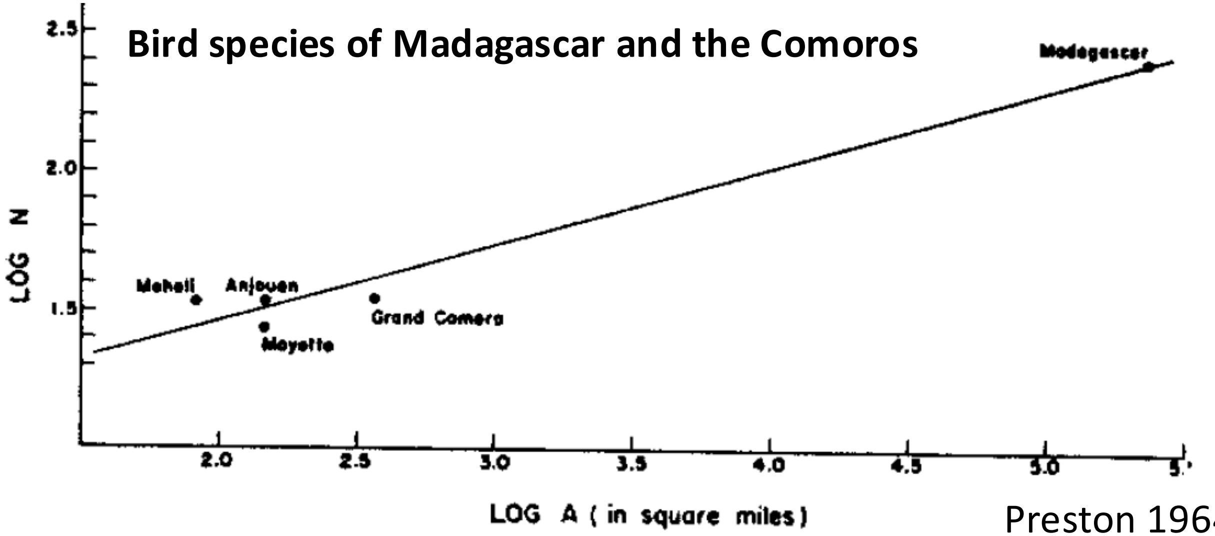
Plant species of the Galapagos islands



Bird species of Madagascar and the Comoros



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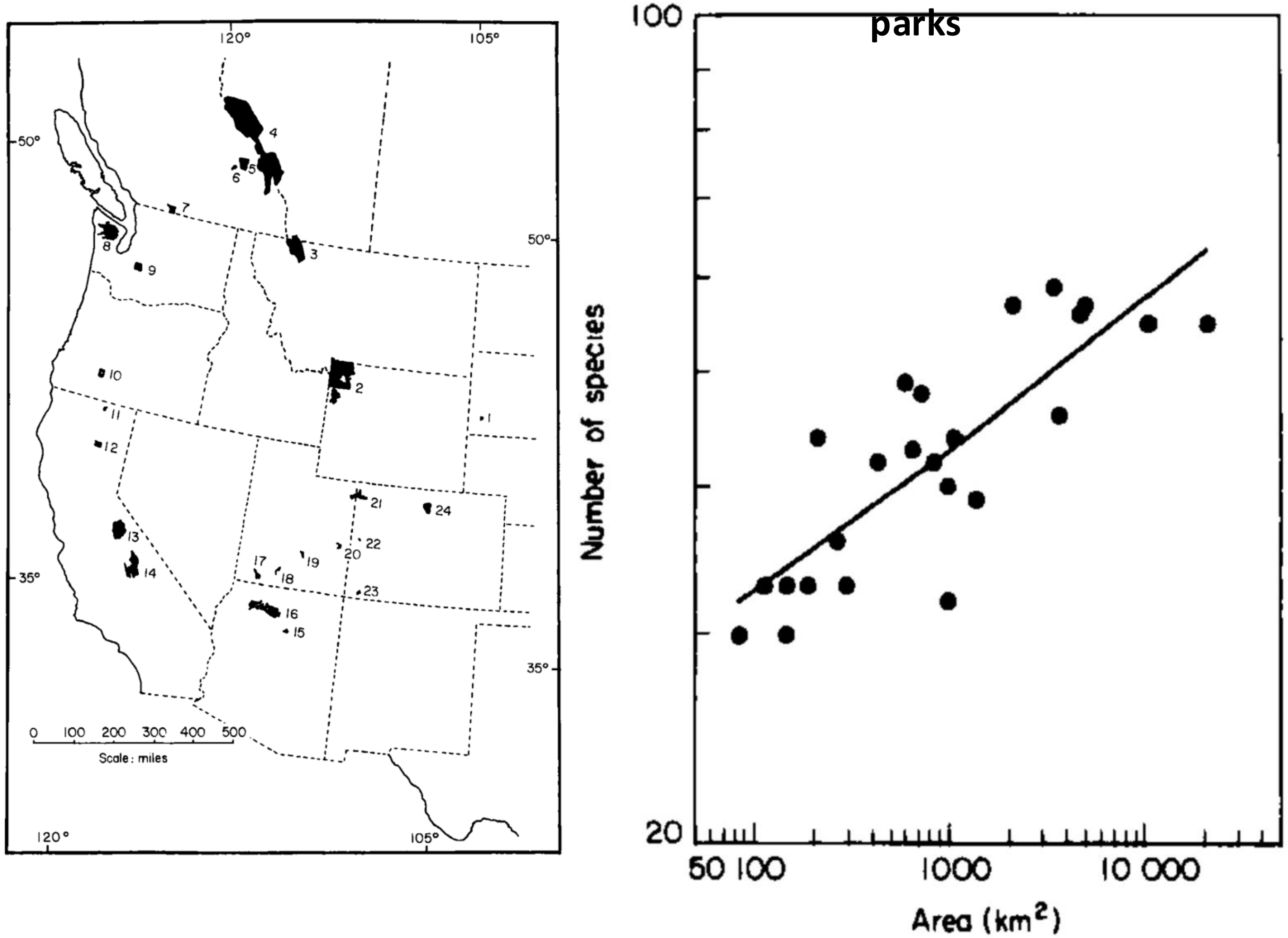
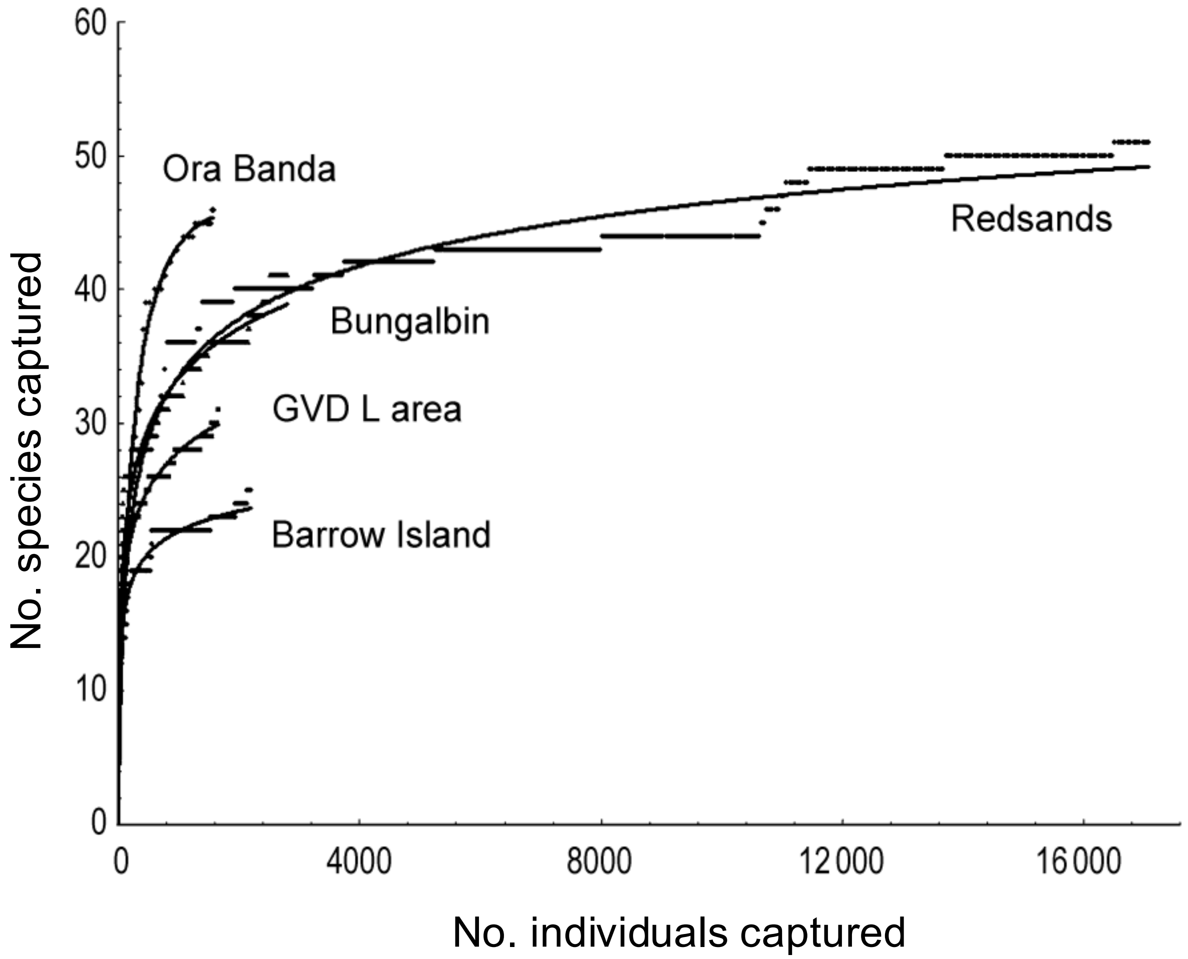
Mammal species of western US national parks



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

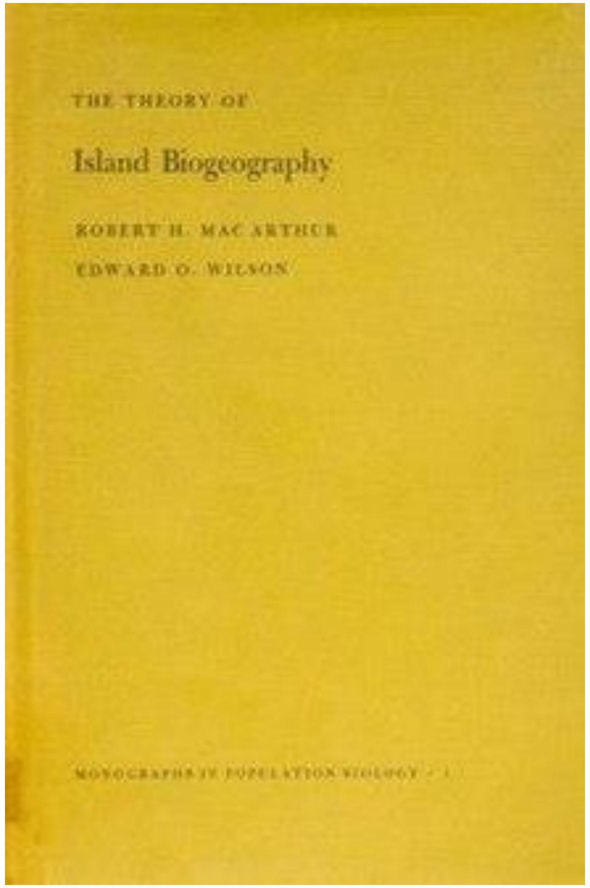
We can use the **species-area relationship** (**SAR**) to build **species accumulation curves** to understand if we have representatively sampled a population in field studies.



Thompson 2003. *Animal Ecology.*

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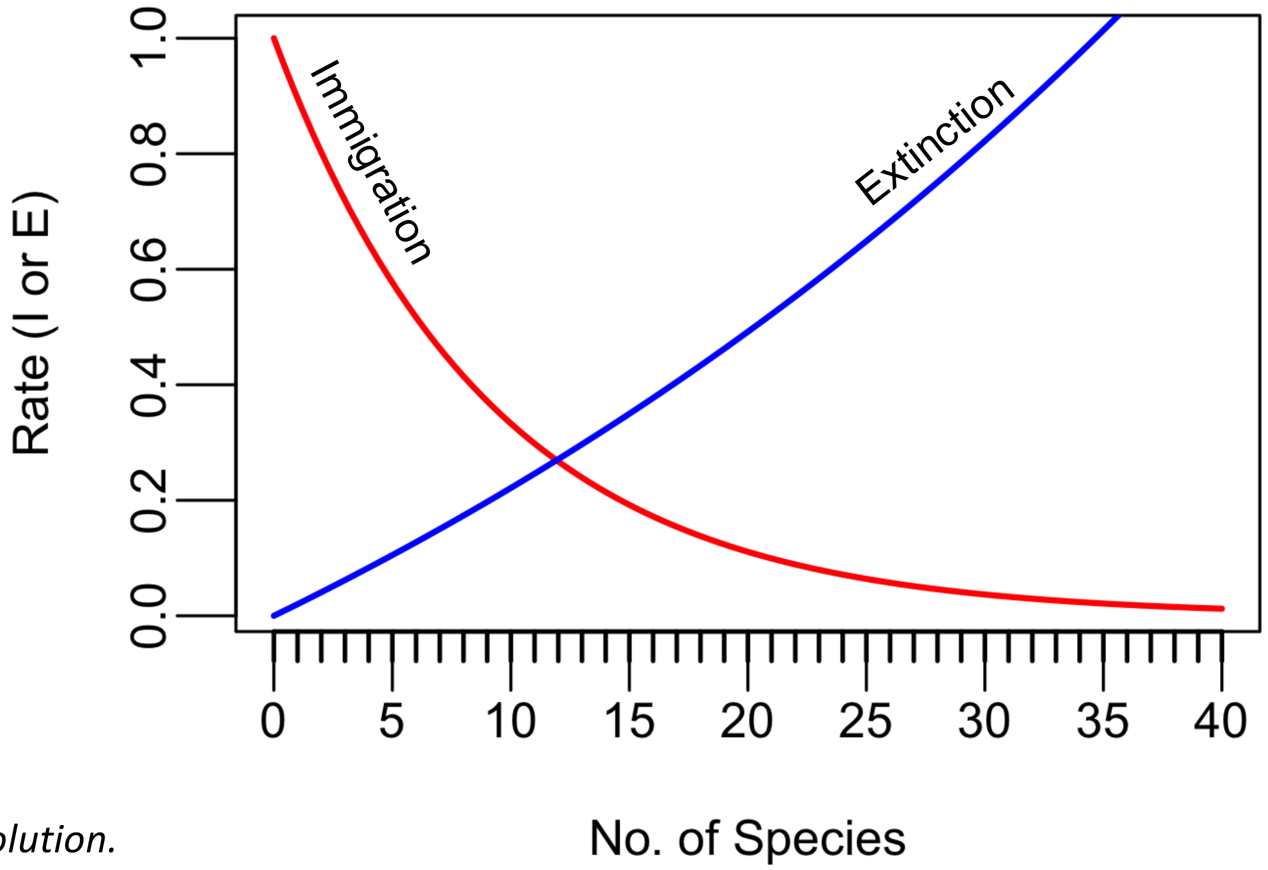
The equilibrium number of species in an "island" habitat is reached when:
the rate of immigration = the rate of extinction



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

Extinction rates (species leaving) are **higher when the number of species is high**.

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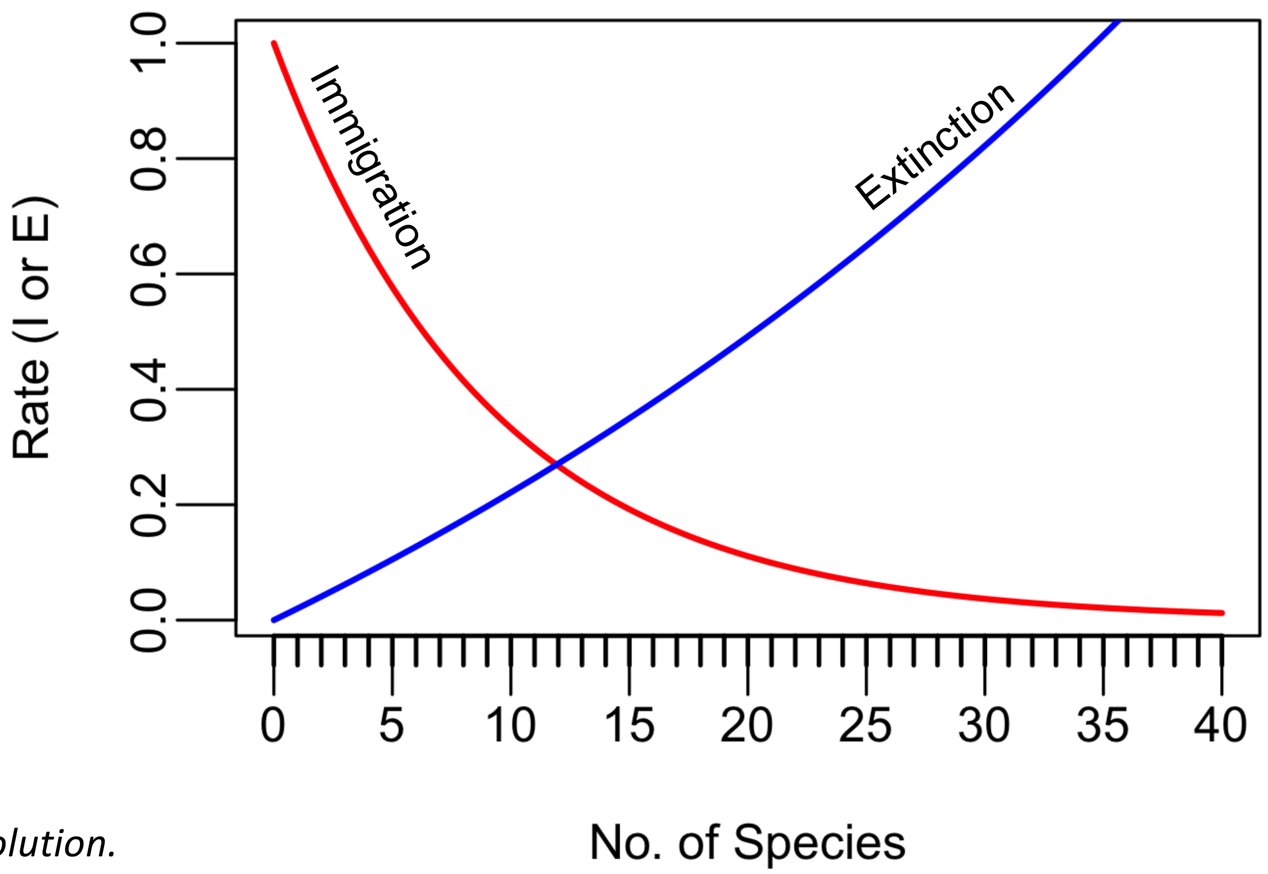
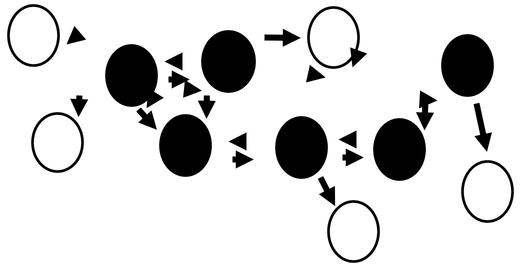


Conceptually similar to Levins' metapopulation model – and to density dependence in logistic growth!



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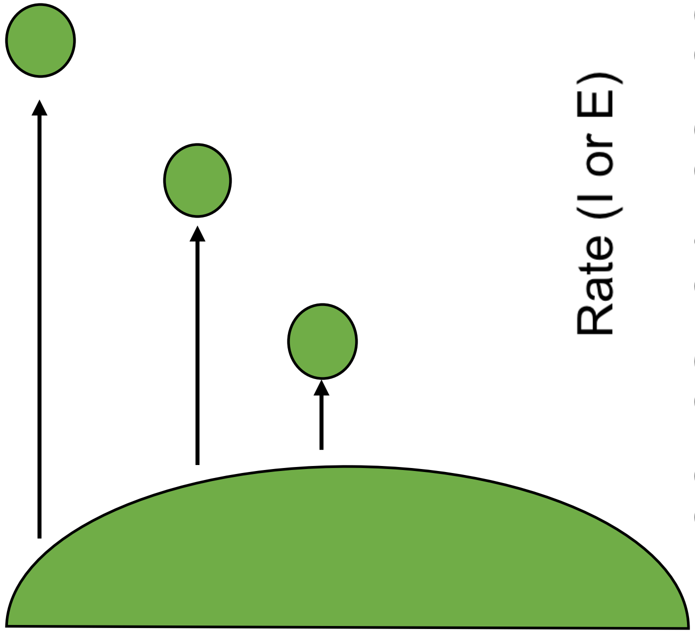
Distance effect: **Closer islands have higher immigration rates** because it's easier for organisms to disperse across short distances.



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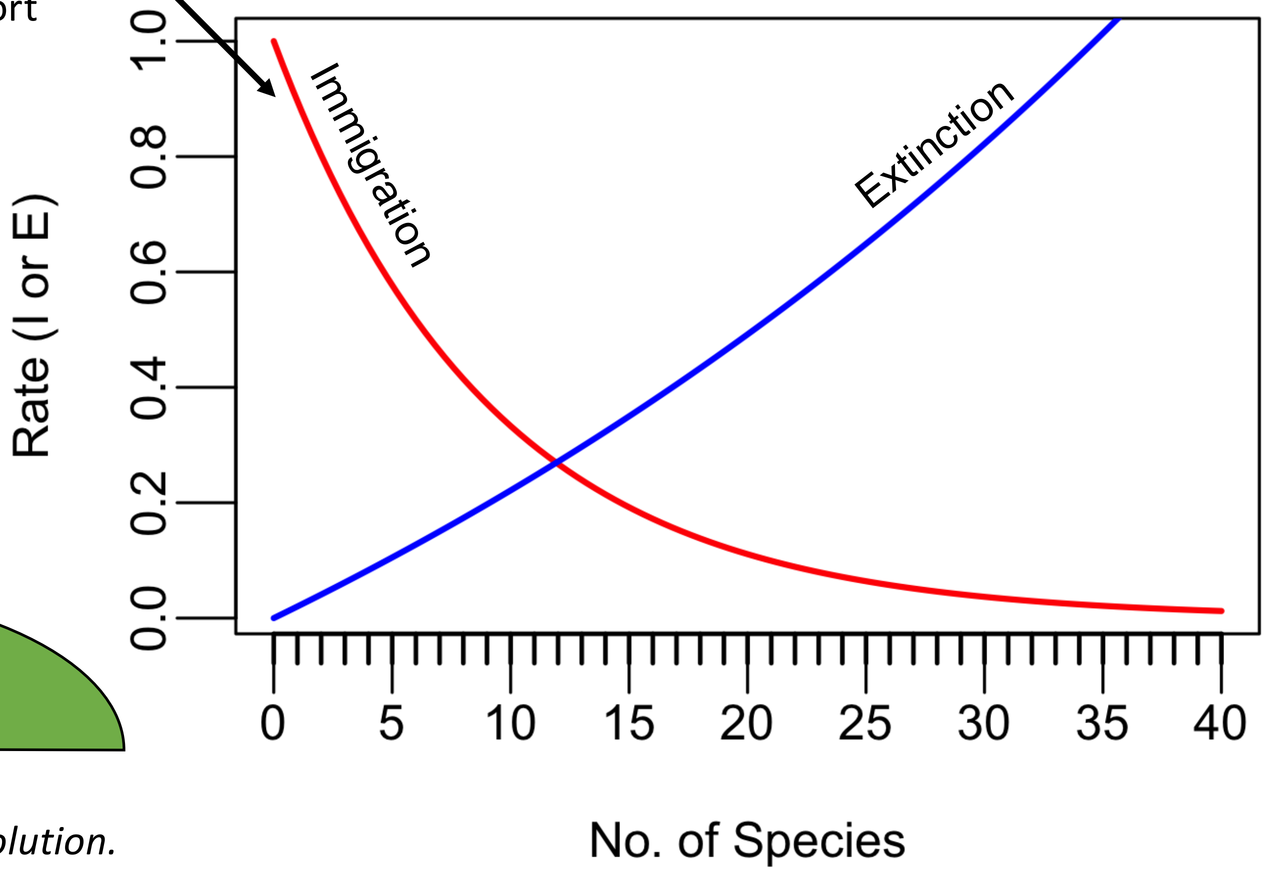

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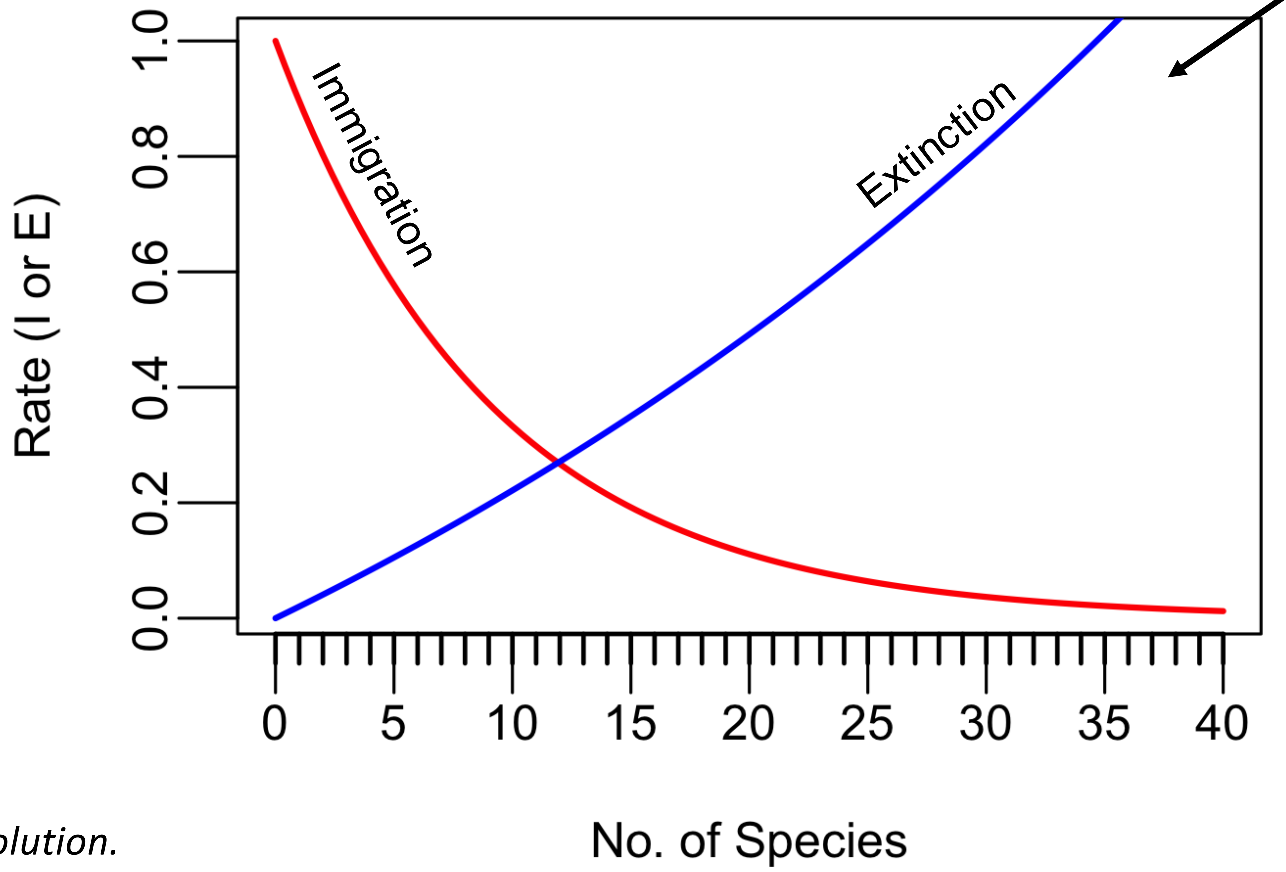
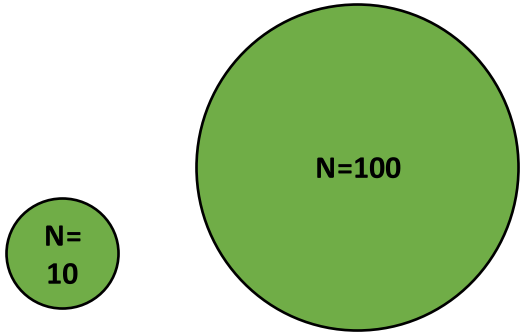


Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.



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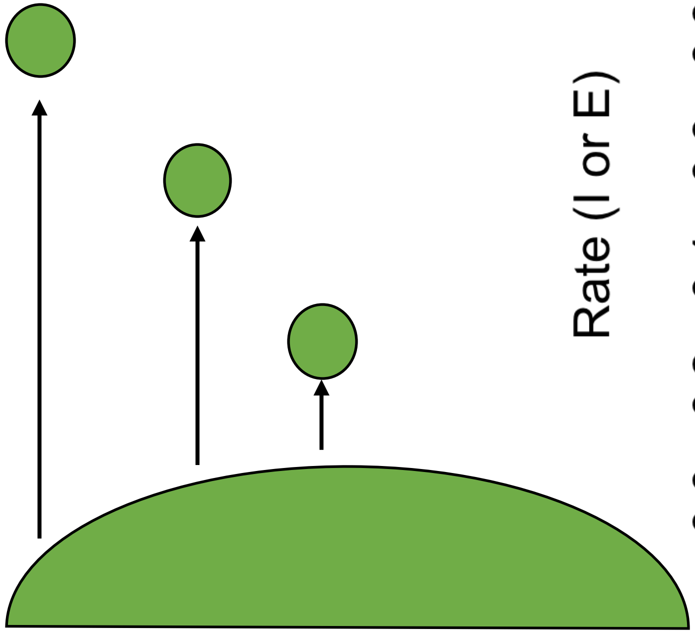

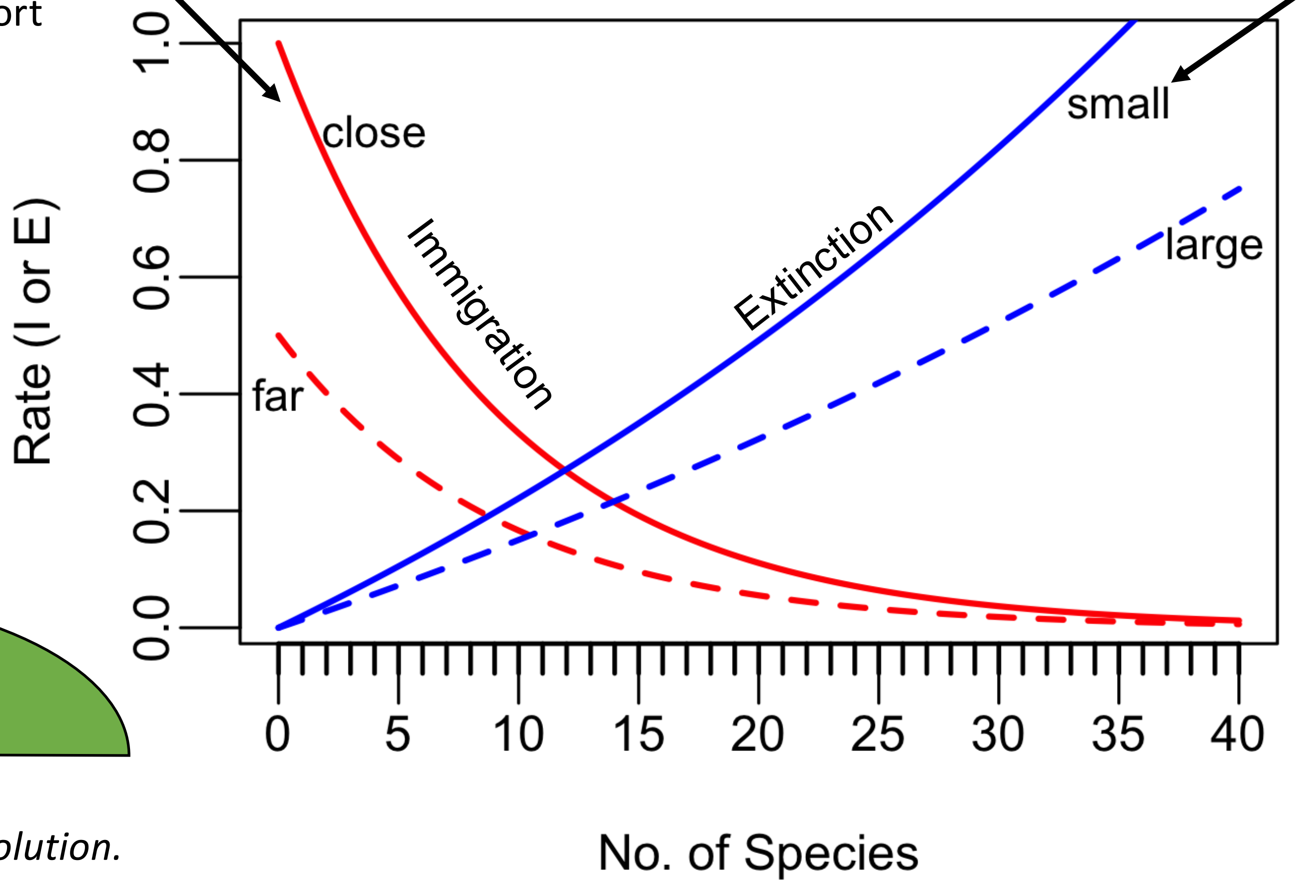

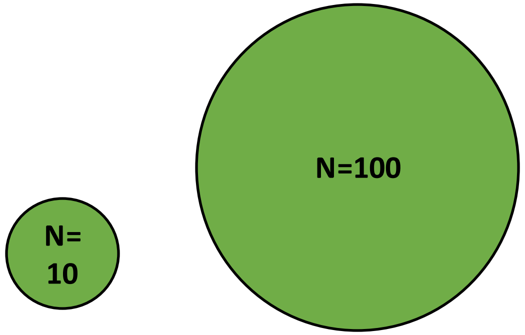

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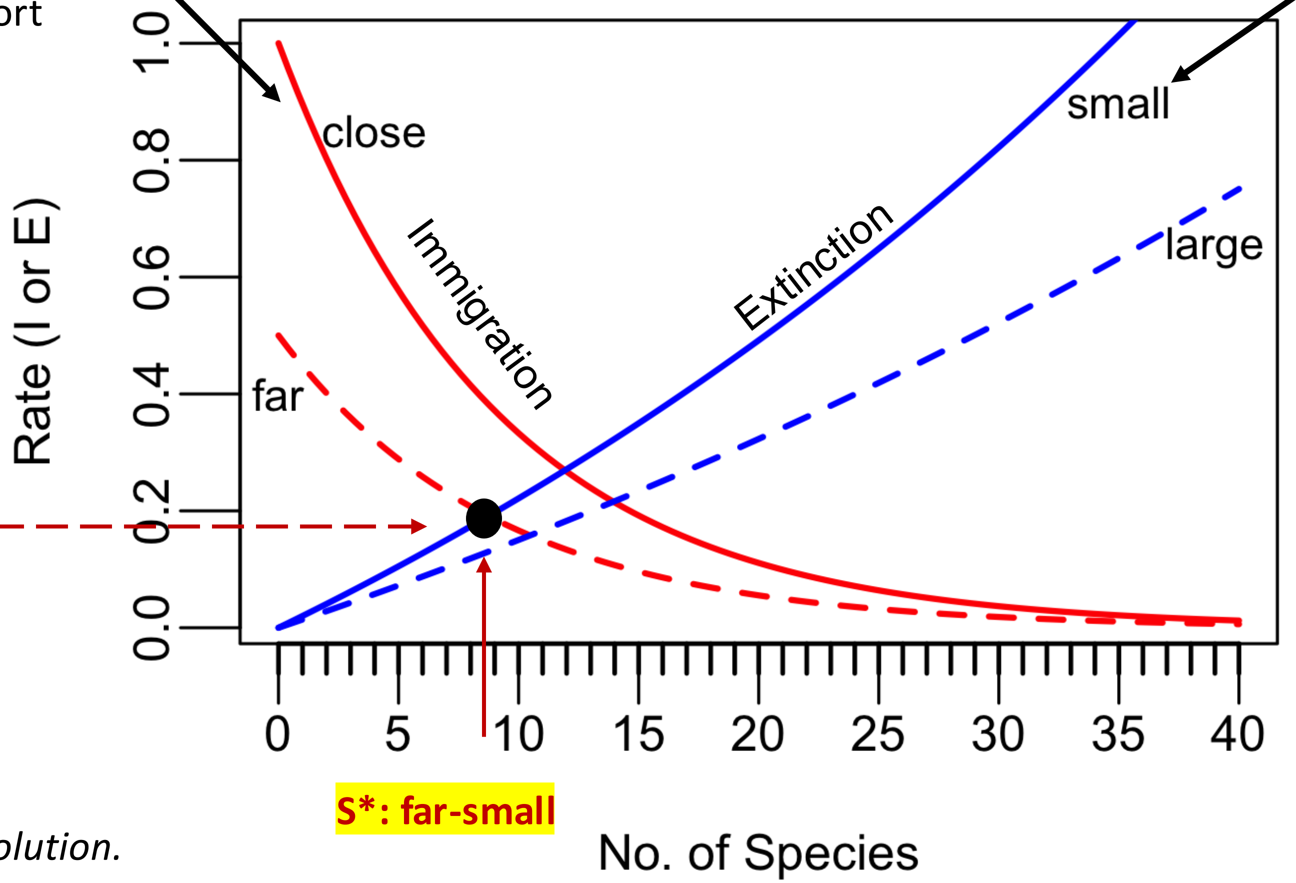
turnover rate for far-small



S*: far-small

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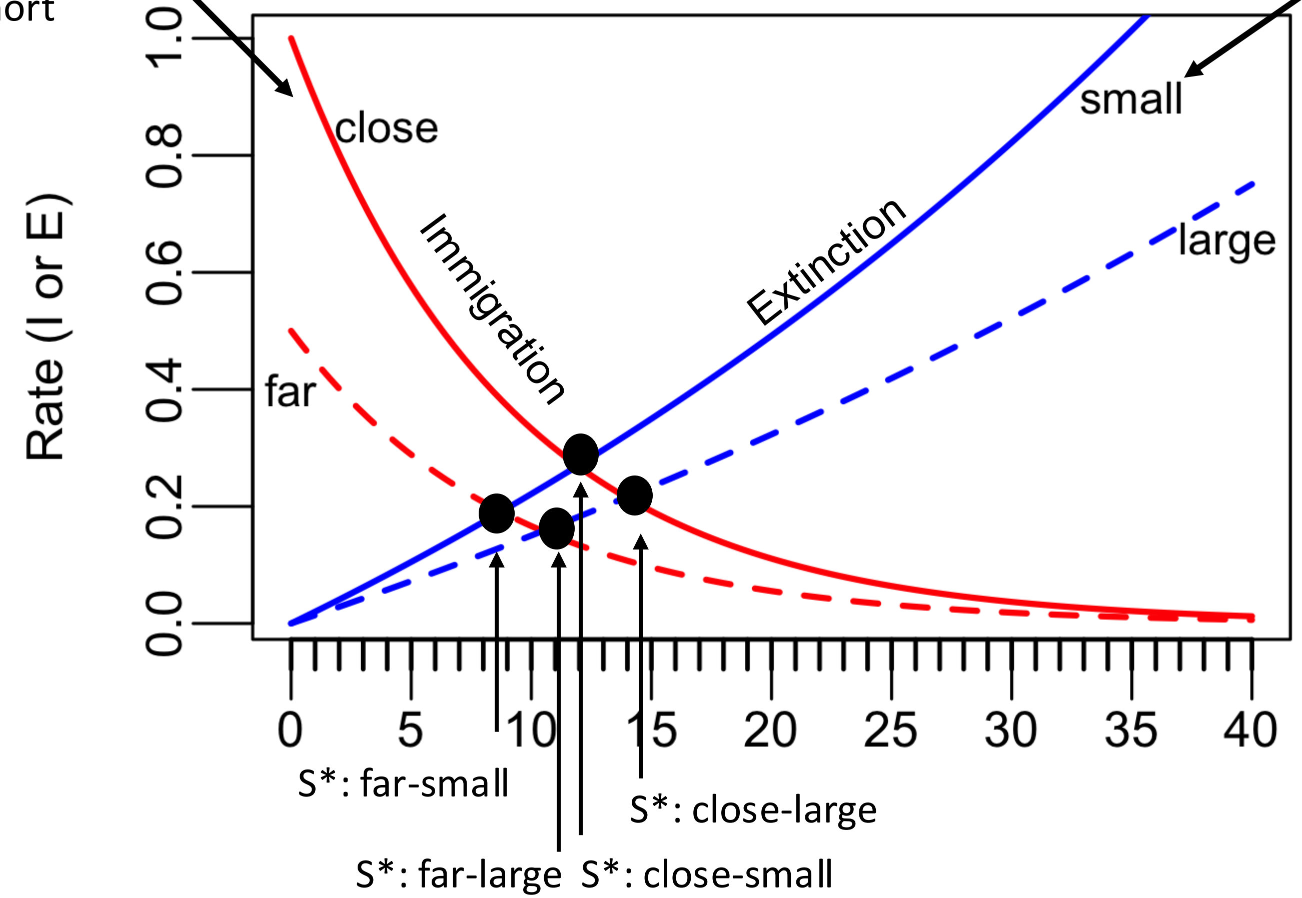

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$$I(S) = E(S)$$

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.

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

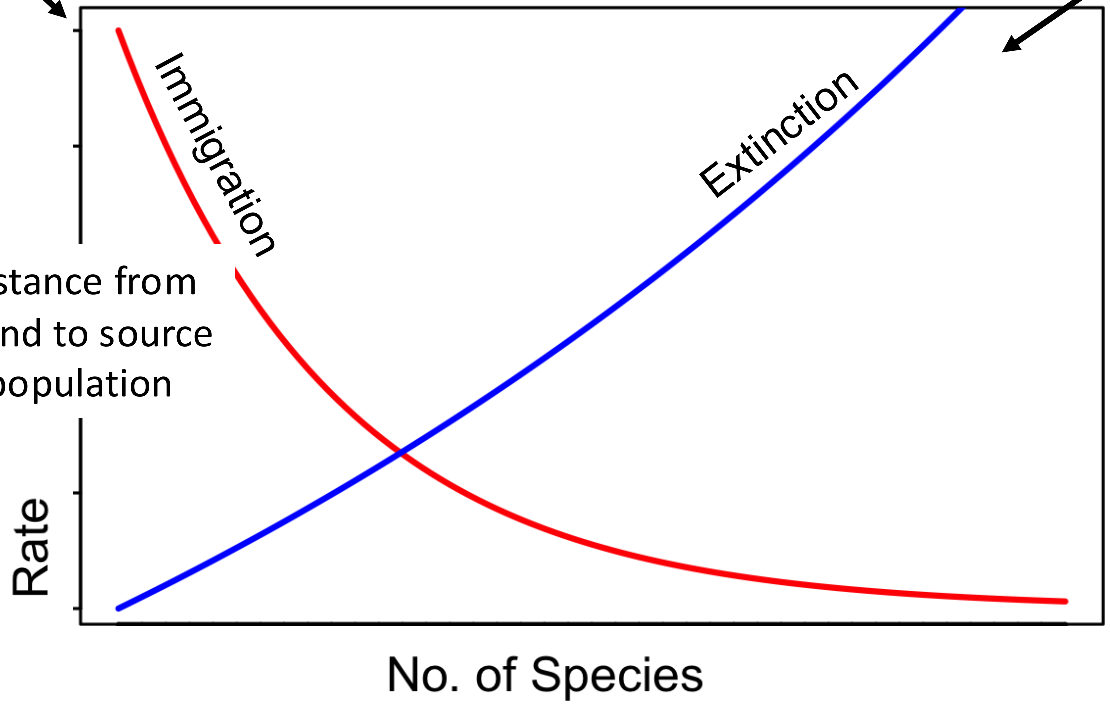
immigration rate

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



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

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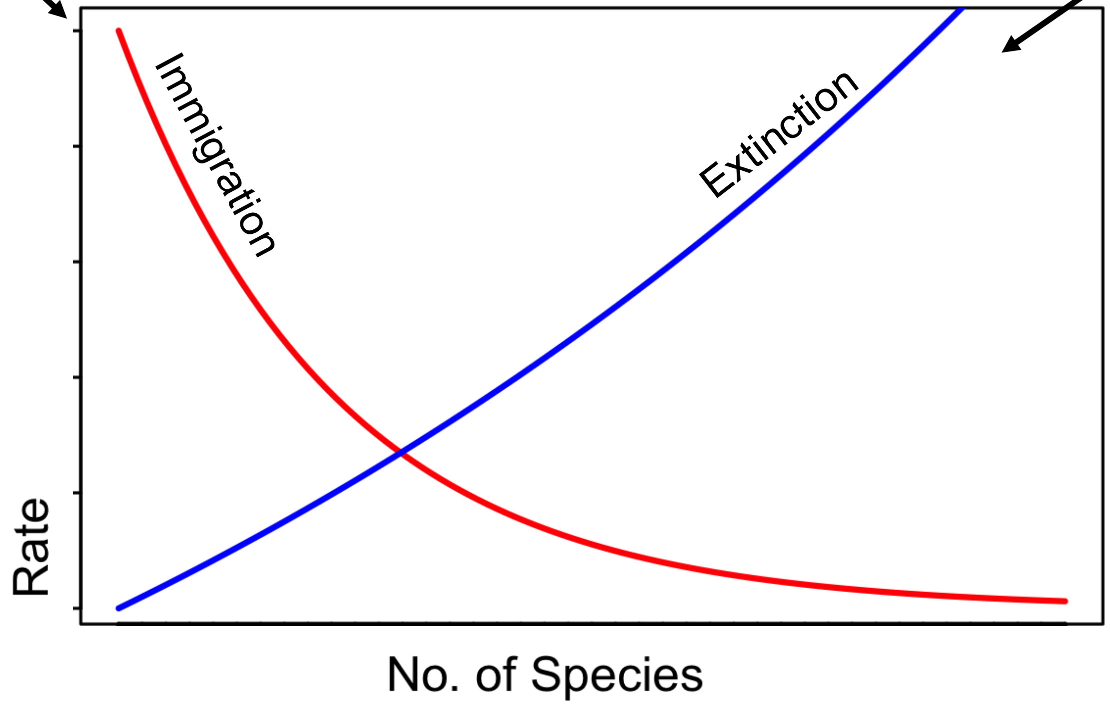

Species area-effect: **Larger islands have lower extinction rates** because they provide more habitat to sustain more species. Allee effects reduced at larger population sizes.

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

number of species on island

fit parameter scaling effect of area on extinction

area of habitat

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

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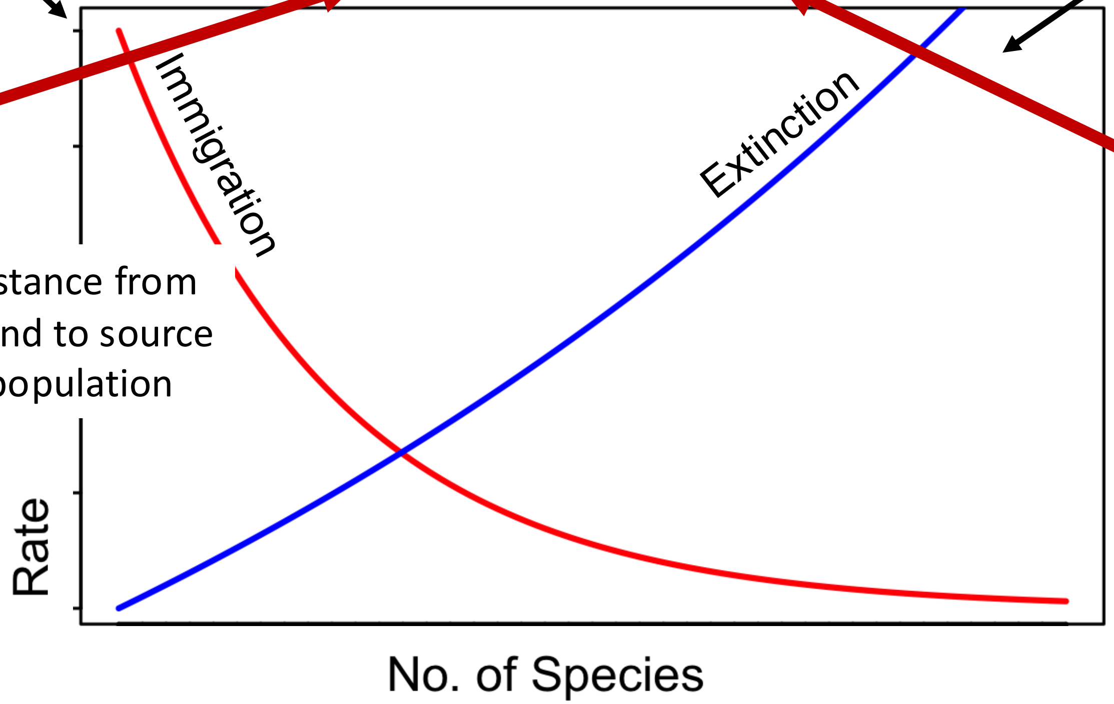

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area of habitat

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.

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

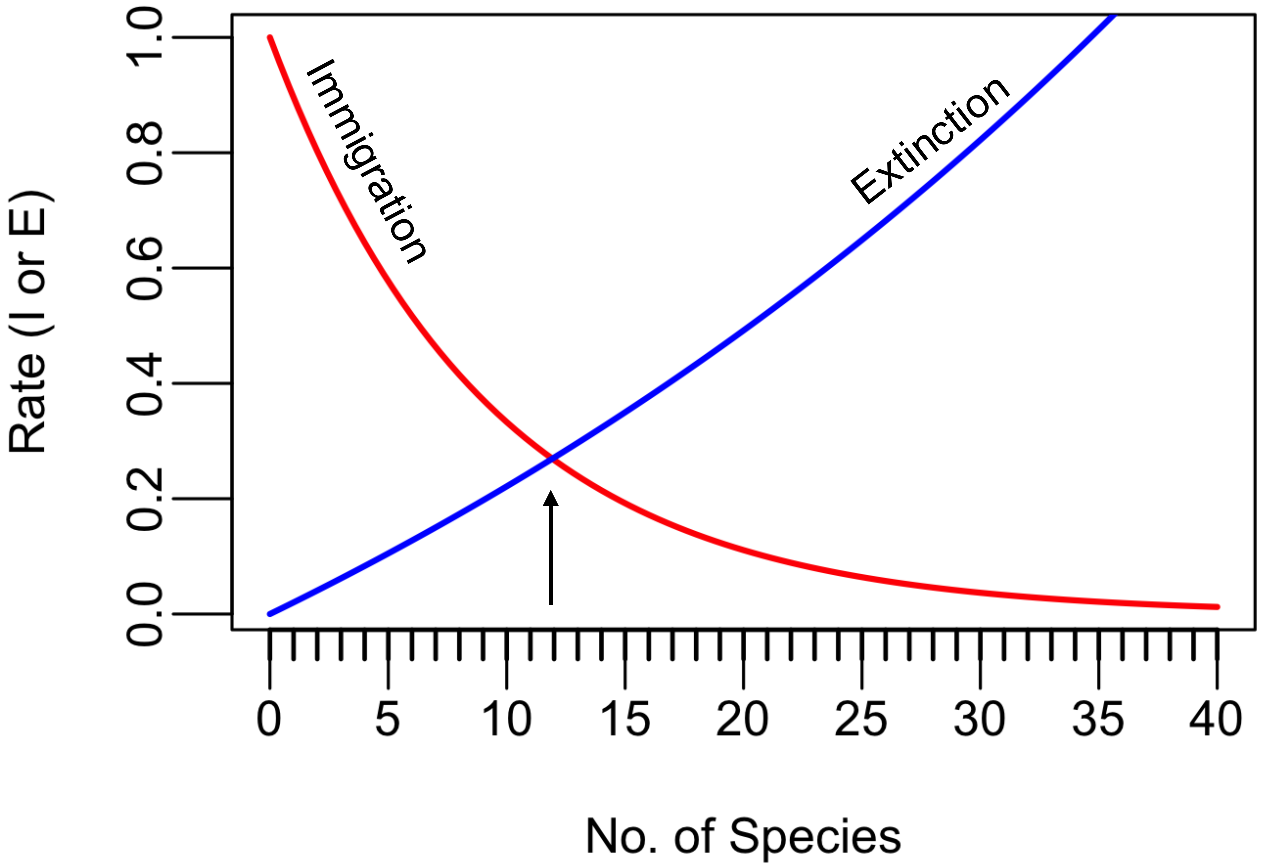
increases with number of species in source pool

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



MacArthur and Wilson. 1963. *Evolution.*
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Extensions to the **theory of island biogeography**…

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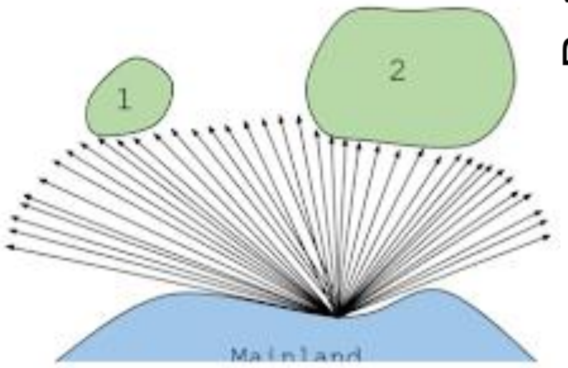
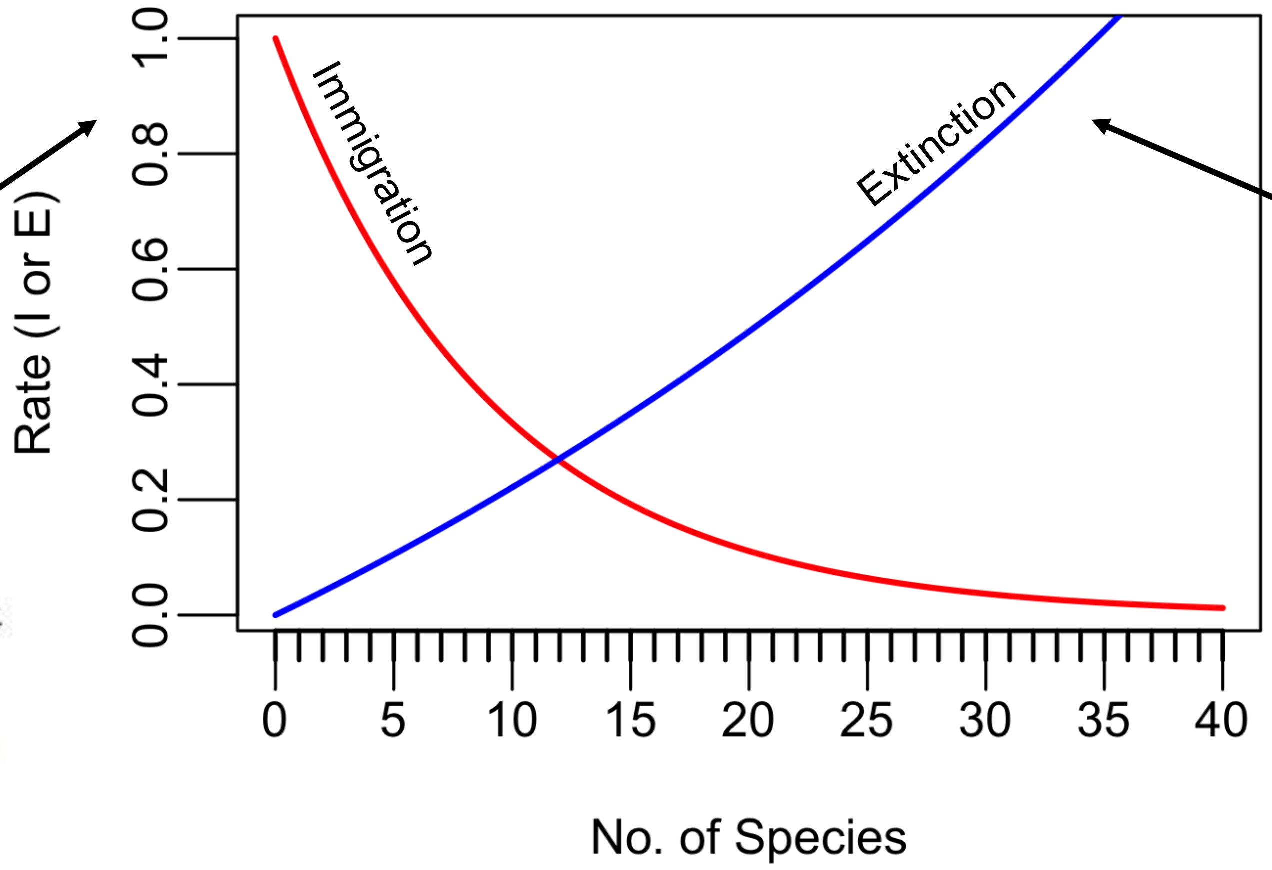
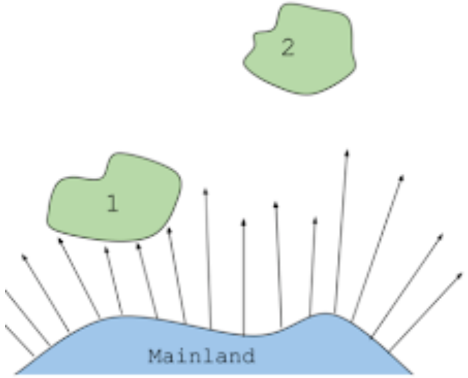
Target effect: **larger islands have higher immigration rates** because they offer a bigger target to land on!

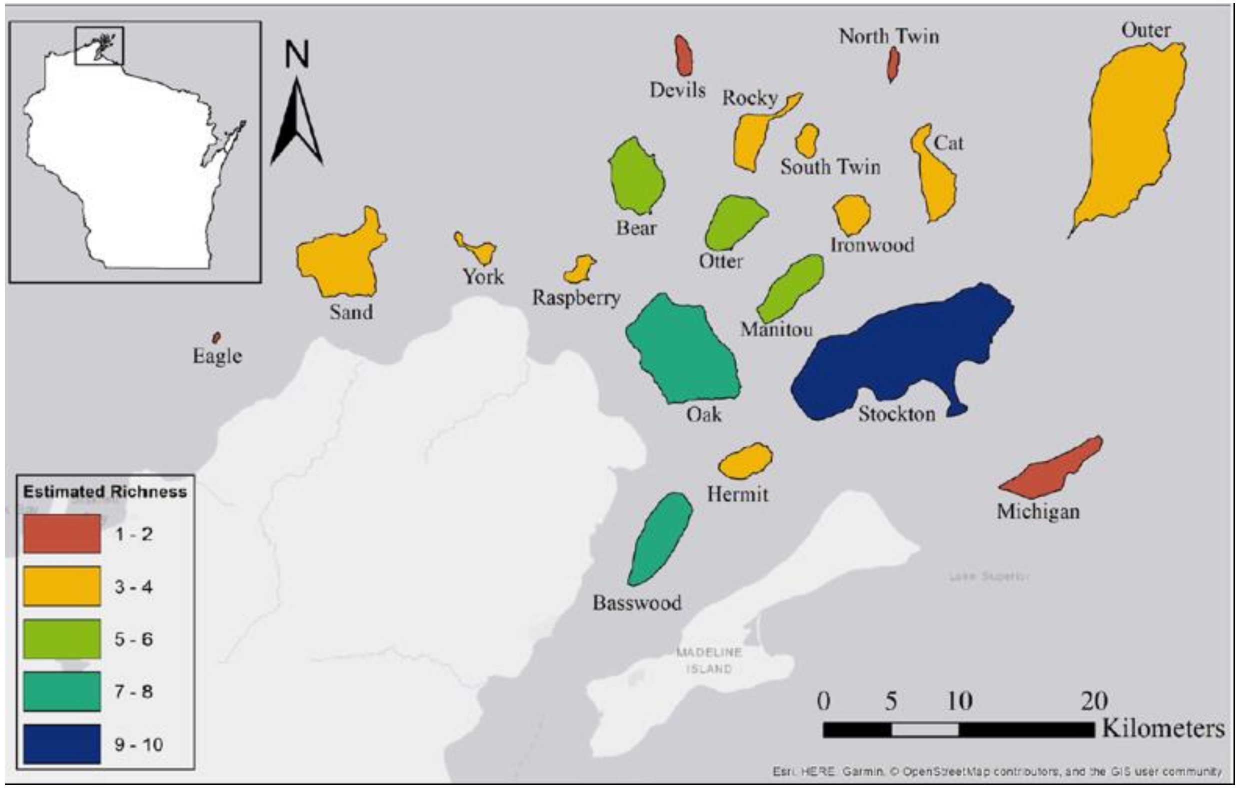




Rescue effect: **Closer islands have lower extinction rates** because they can be repopulated from the mainland!

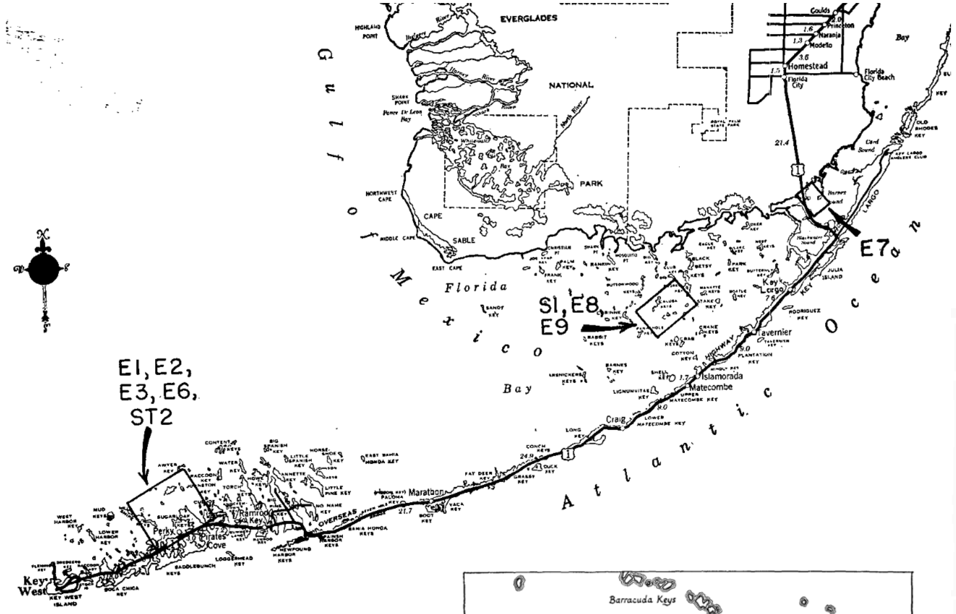


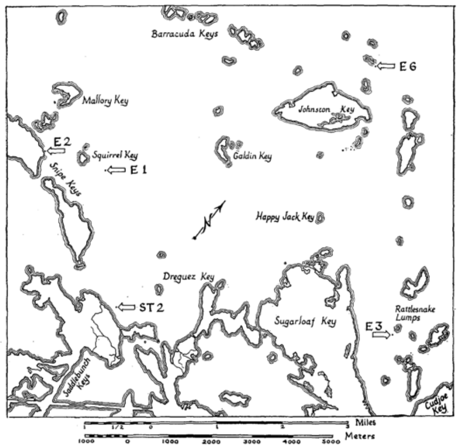
The importance of island size vs. distance varied for different species!

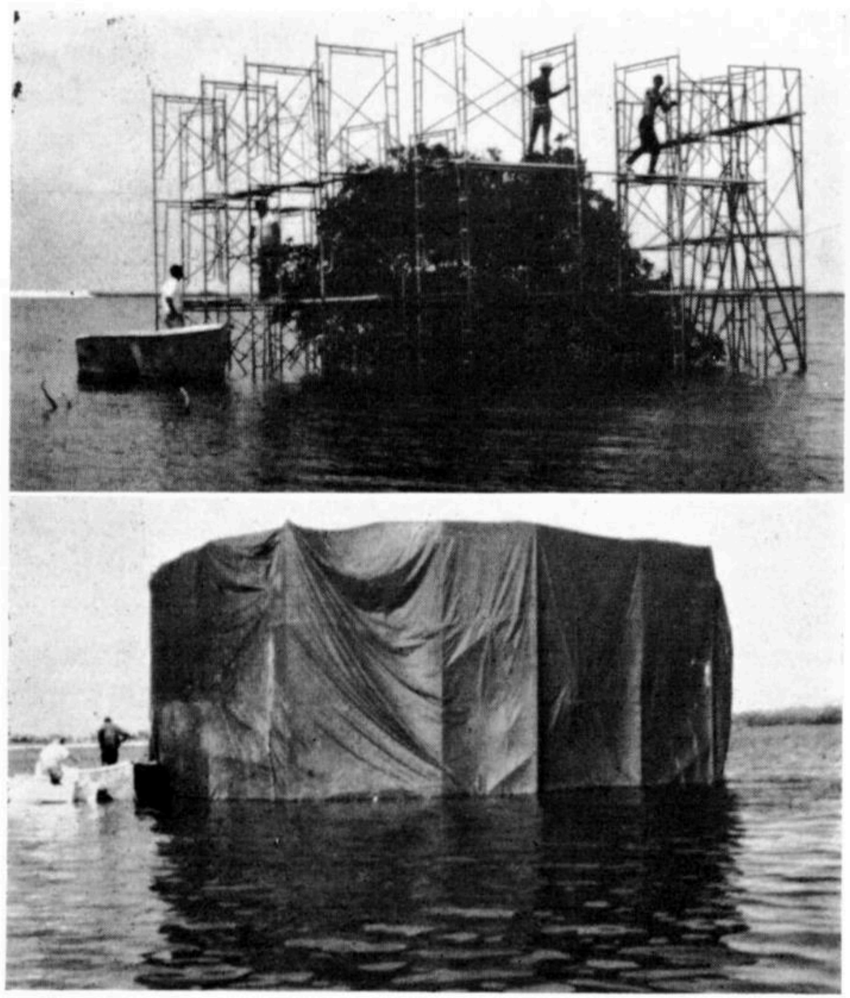


Allen et al. 2018. *Community Ecology.*

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).
- 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.*
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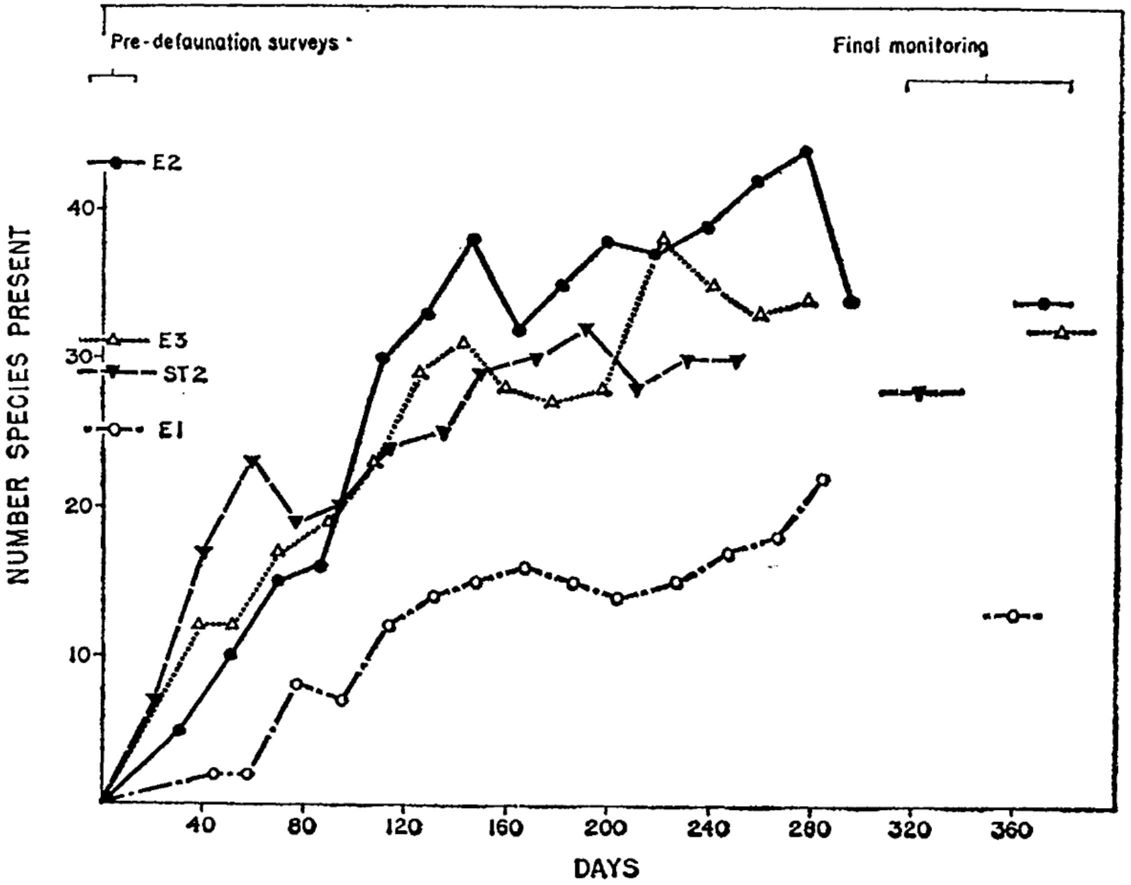
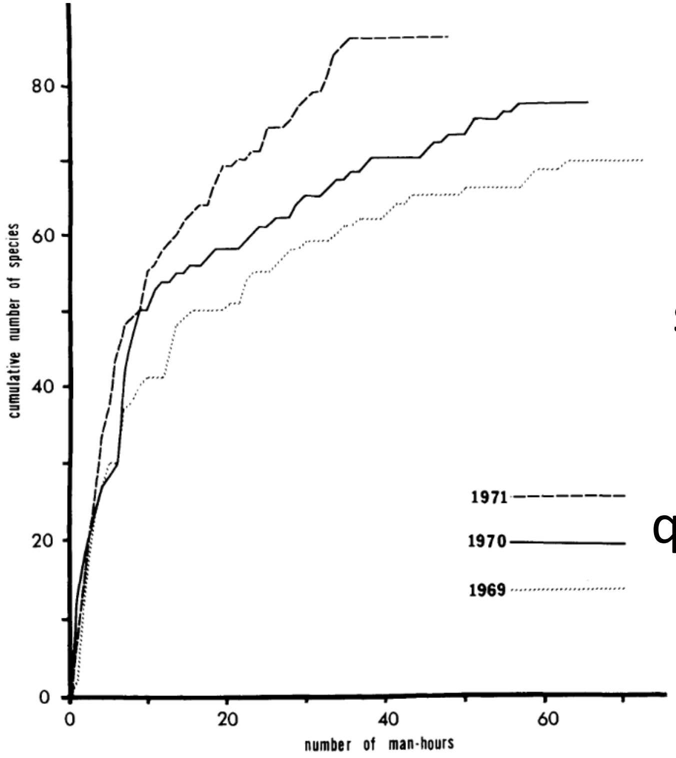


- Islands were recolonized to pre-defaunation levels rapidly, within a year!
- Though the equilibrium number of species was the same, the identity was quite different – only about 40% similar to the original censuses.
- Strong flyers recolonized first but were eventually replaced (outcompeted) by better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

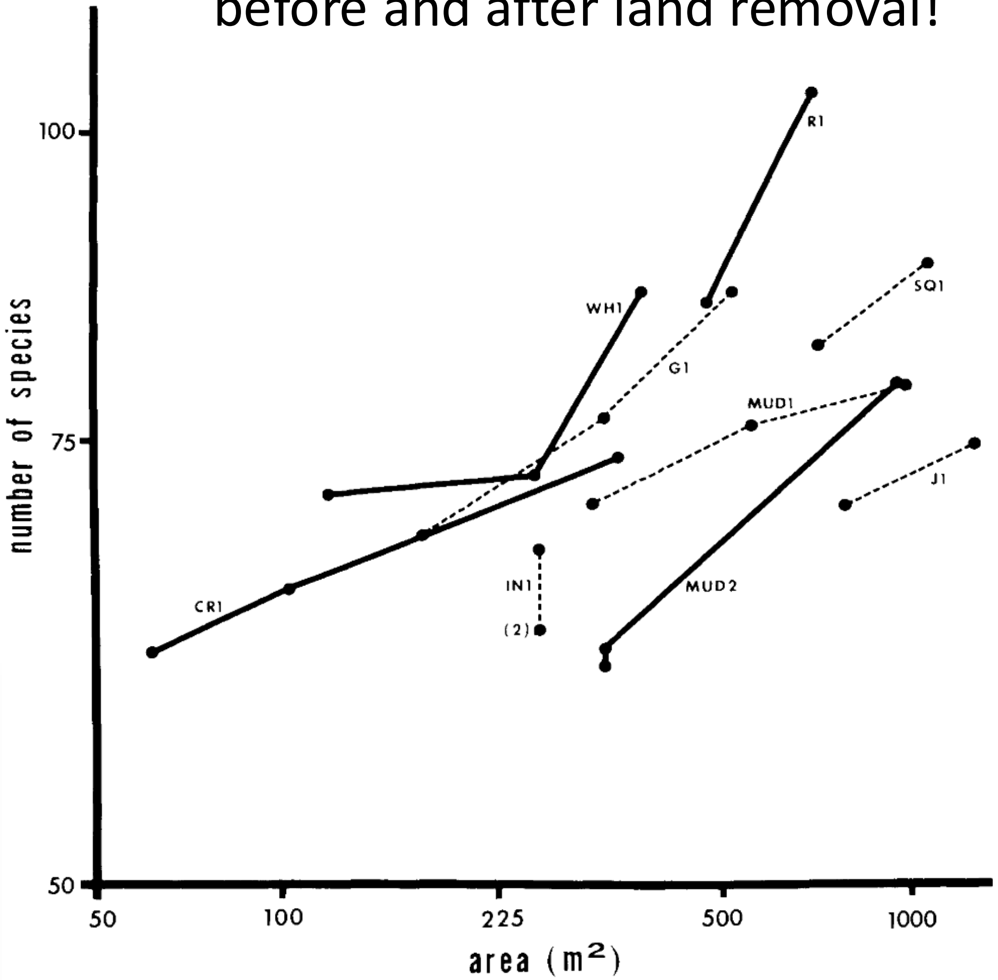
Simberloff. 1969. *Ecology.*
Wilson and Simberloff. 1969. *Ecology.*
Simberloff and Wilson. 1969. *Ecology.*

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!



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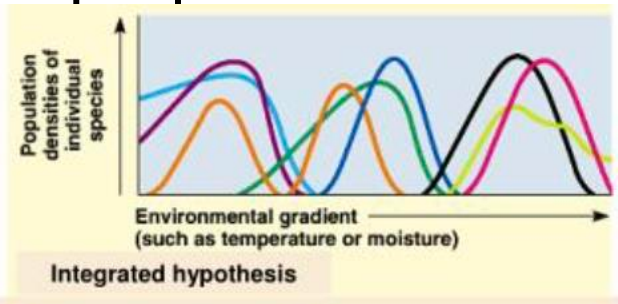
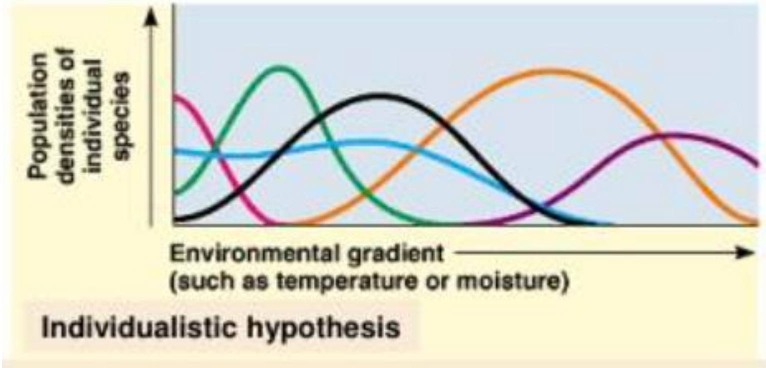


- Henry Gleason (1926) argued instead that chance favored the dispersal of nearby species into available habitat for succession, leading to **stochastic** assembly of communities
- Closer to Cowles' original thinking



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]

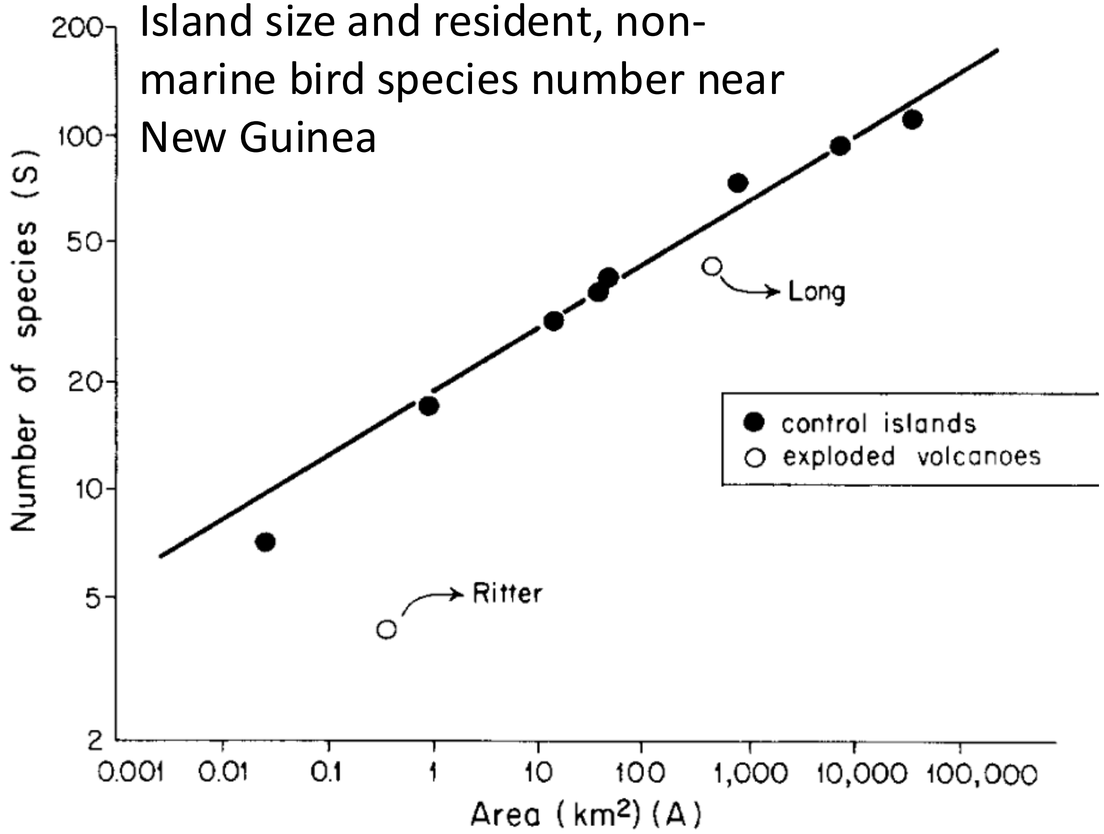
BY JOSEPH GRINNELL.

- **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**

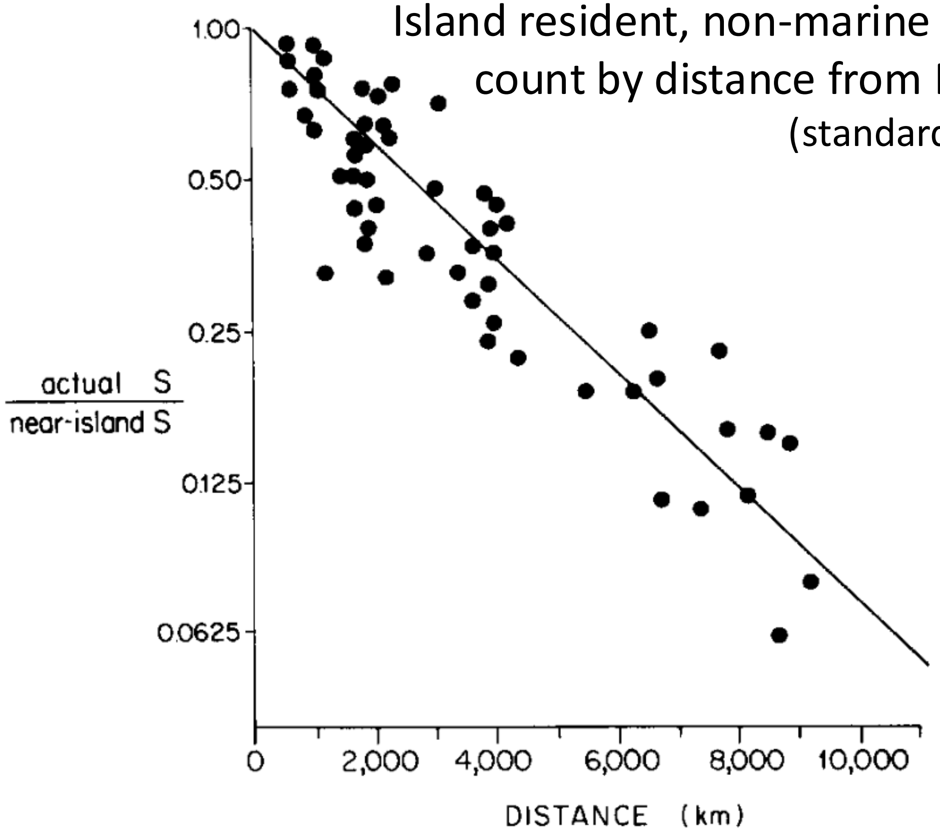
Area effect:

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



Distance effect:

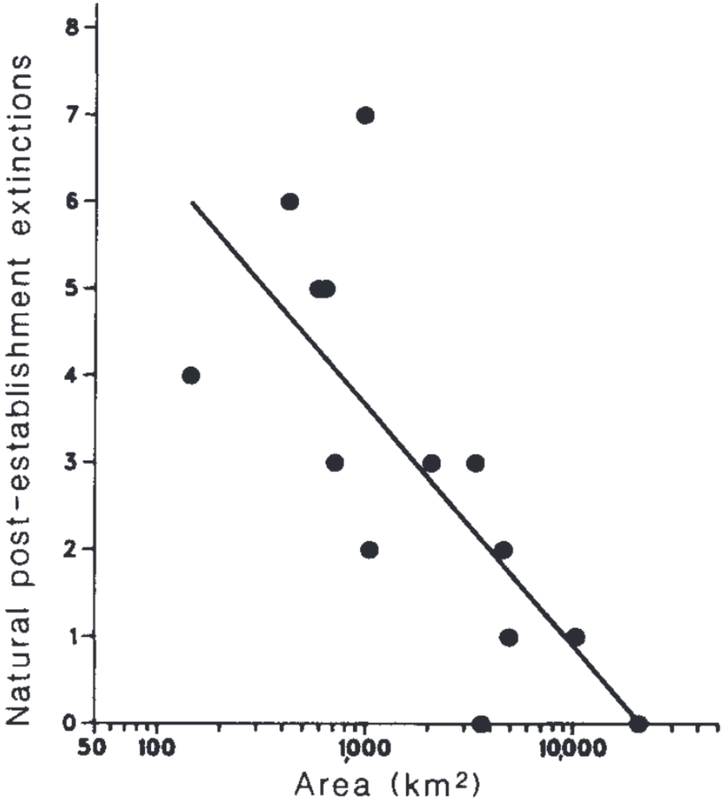
Island resident, non-marine bird species count by distance from New Guinea (standardized by area)



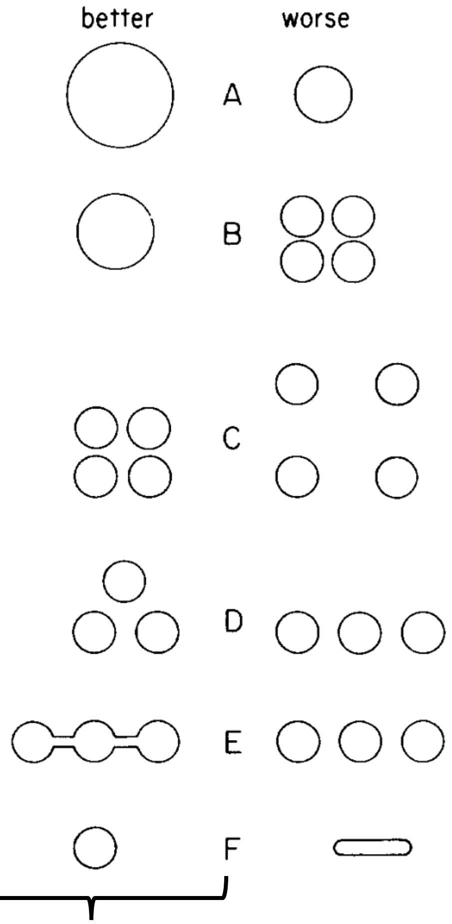
Diamond. 1975. *Biological Conservation.*

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

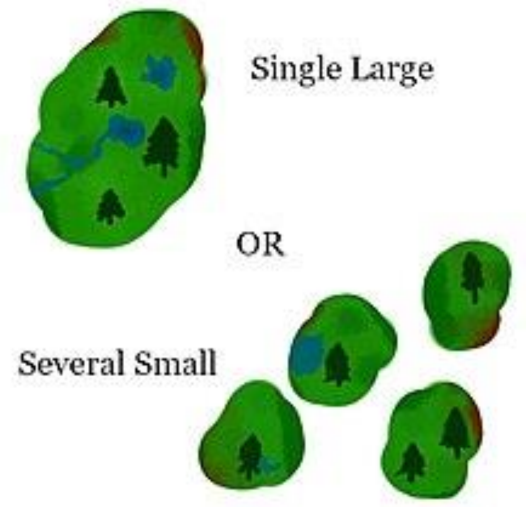
Mammalian extirpations post-establishment by area size in western North American national parks



Newmark. 1987. *Nature.*



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



"**SLOSS**" debate

(1970s-1980s)

Diamond. 1975. *Biological Conservation.*

Population Biology

Conservation Biology

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

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

Disease Ecology

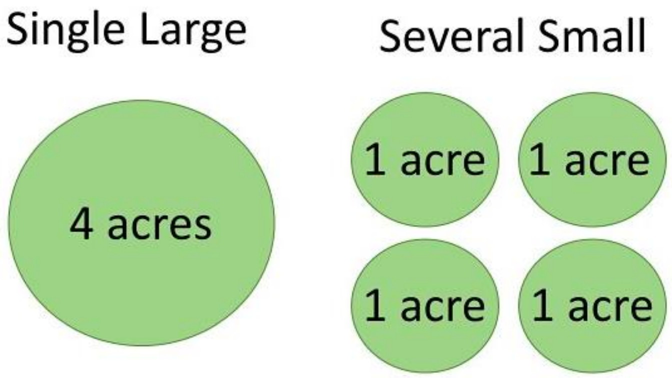
- **Goal:**
  - protect **populations** from disease via pathogen **extinction**
- **Concept:**
  - **Critical Community Size** (CCS)

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

Population Biology

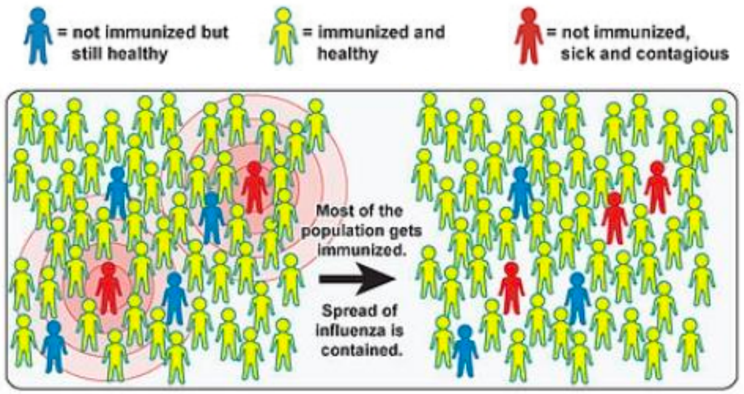
Conservation Biology

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



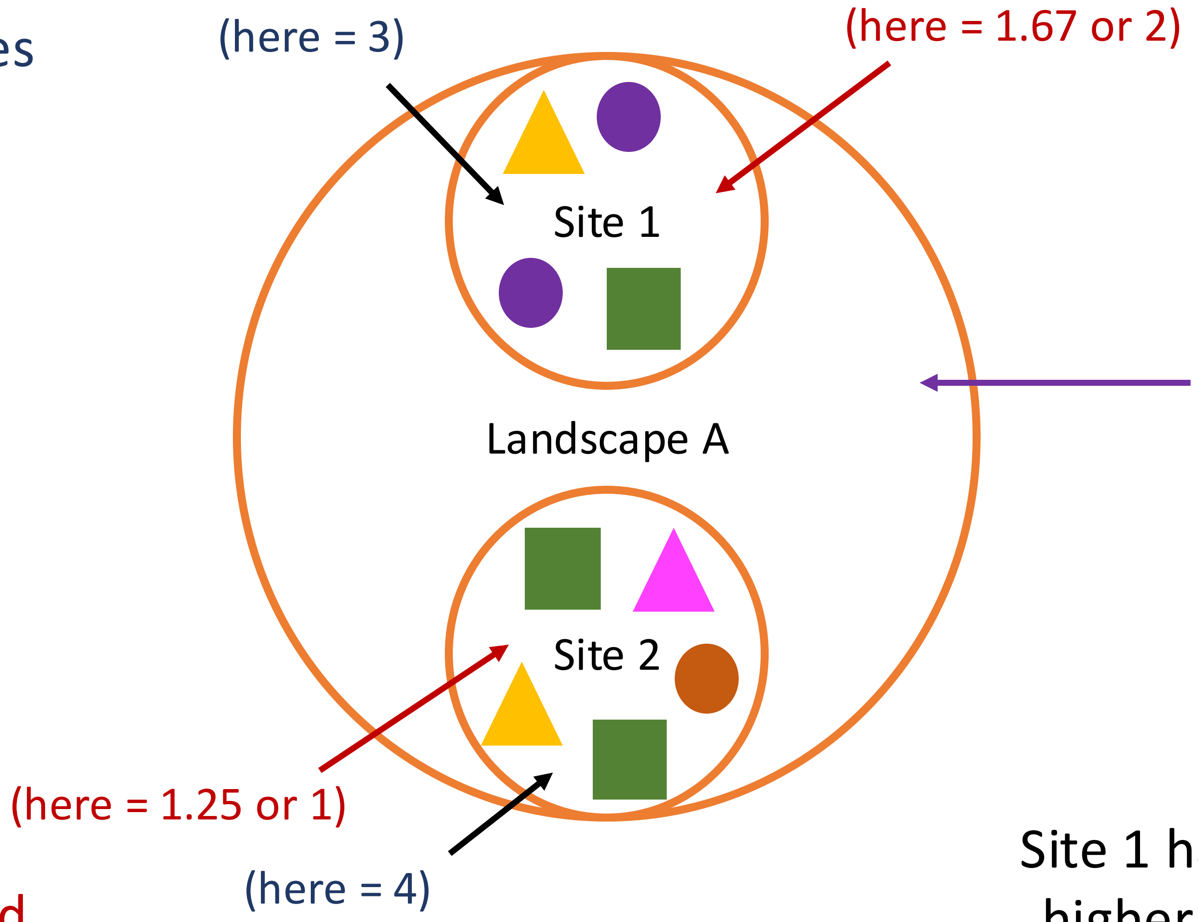
Disease Ecology

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



Biodiversity can be measured in several ways!

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



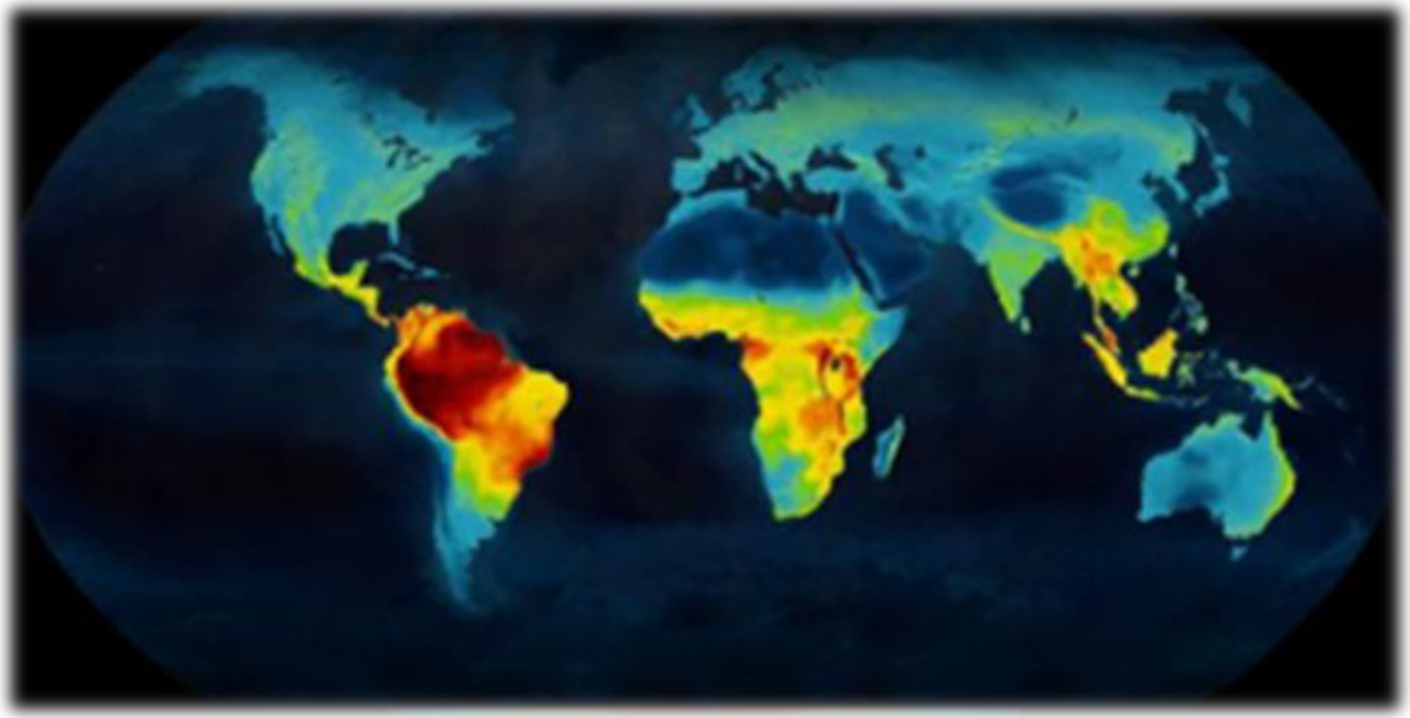
γ – diversity = total species diversity in the landscape (here = 5)

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*.

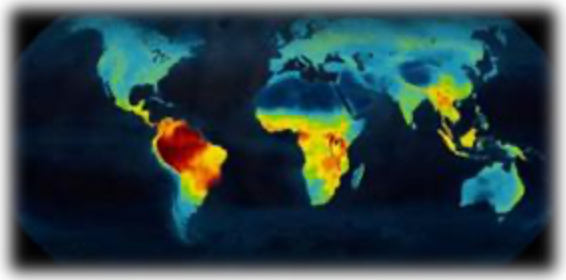
Biodiversity is concentrated in the tropics.



We still lack a satisfying model to explain why.

(terrestrial vertebrate diversity)

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



Biodiversity is concentrated in the tropics.

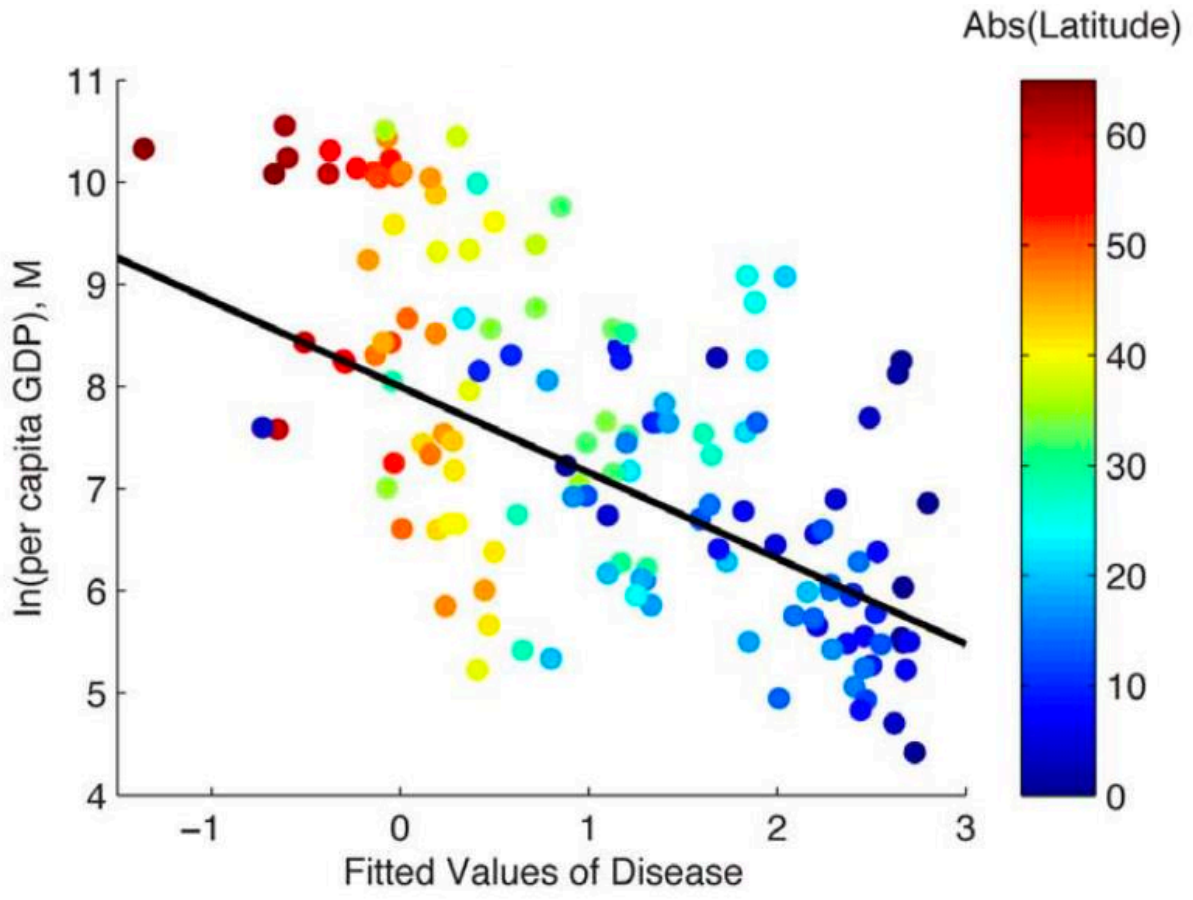
We still lack a satisfying model to explain why.

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!*

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

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



lower relative disease burden

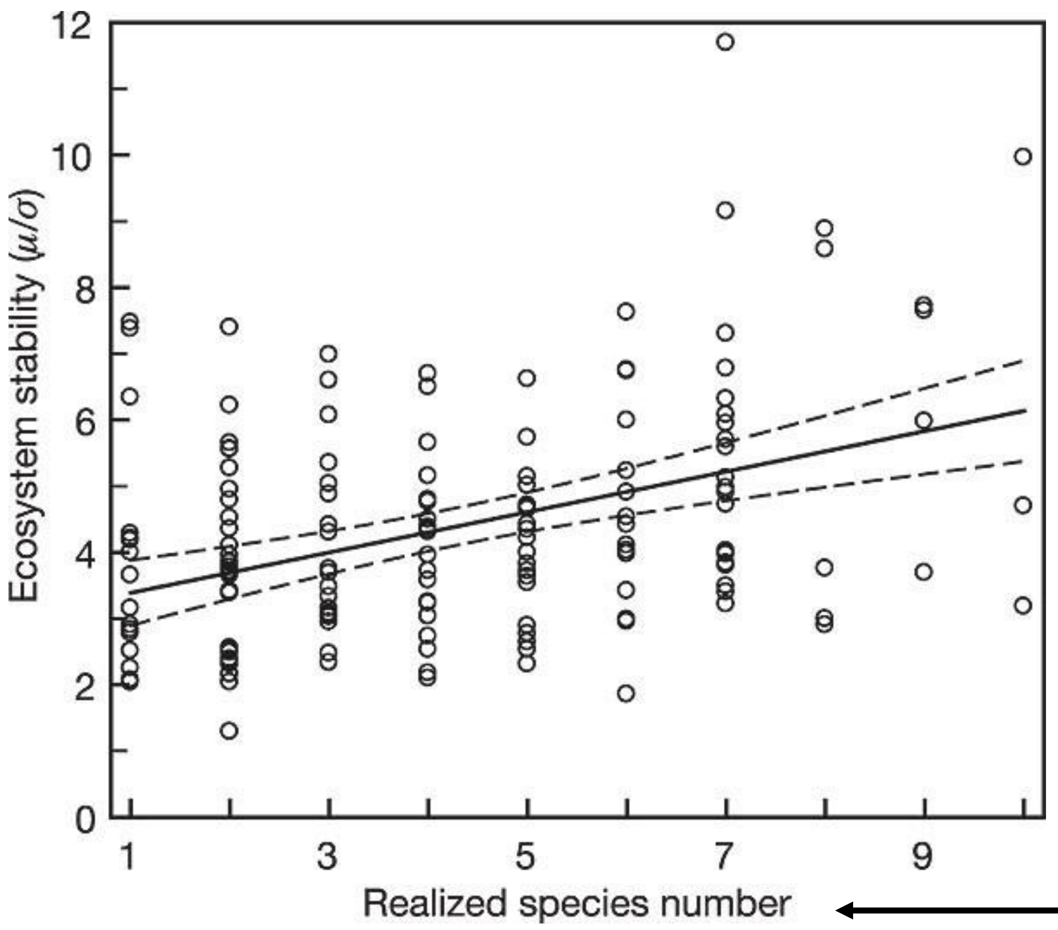
higher relative disease burden

Bonds et al. 2012. *PLoS Biology.*

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)



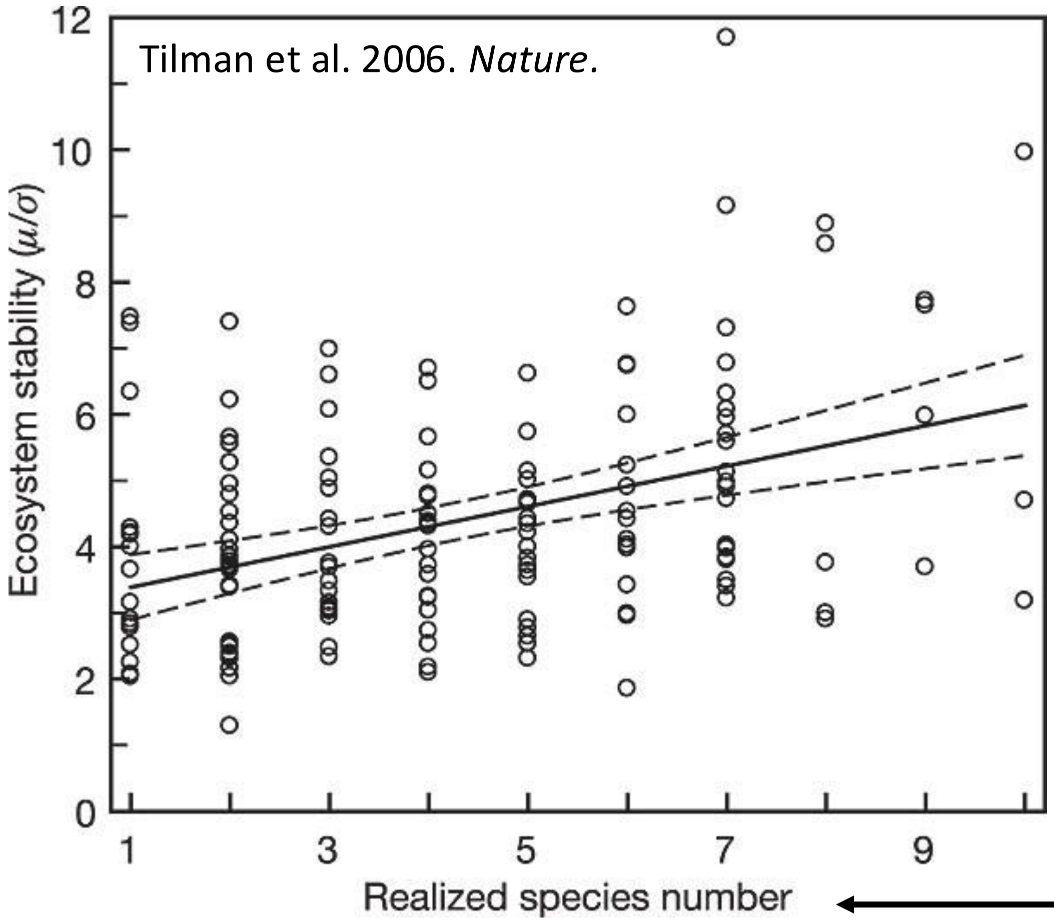
number of species comprising 90% of aboveground biomass
(very rare species excluded)

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)



"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

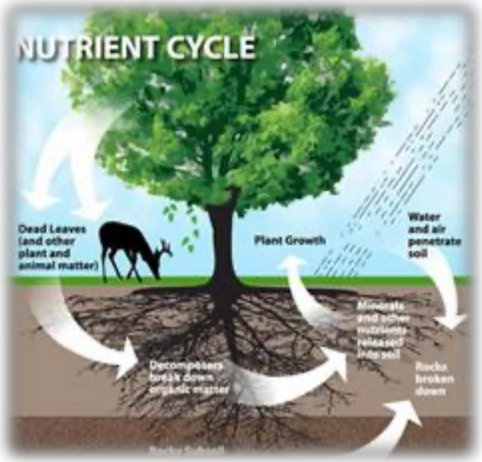
- food (fish, game)
- raw materials (lumber, skins, organic matter)
- medicinal resources
- ornamental resources

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**.

natural capital PROJECT

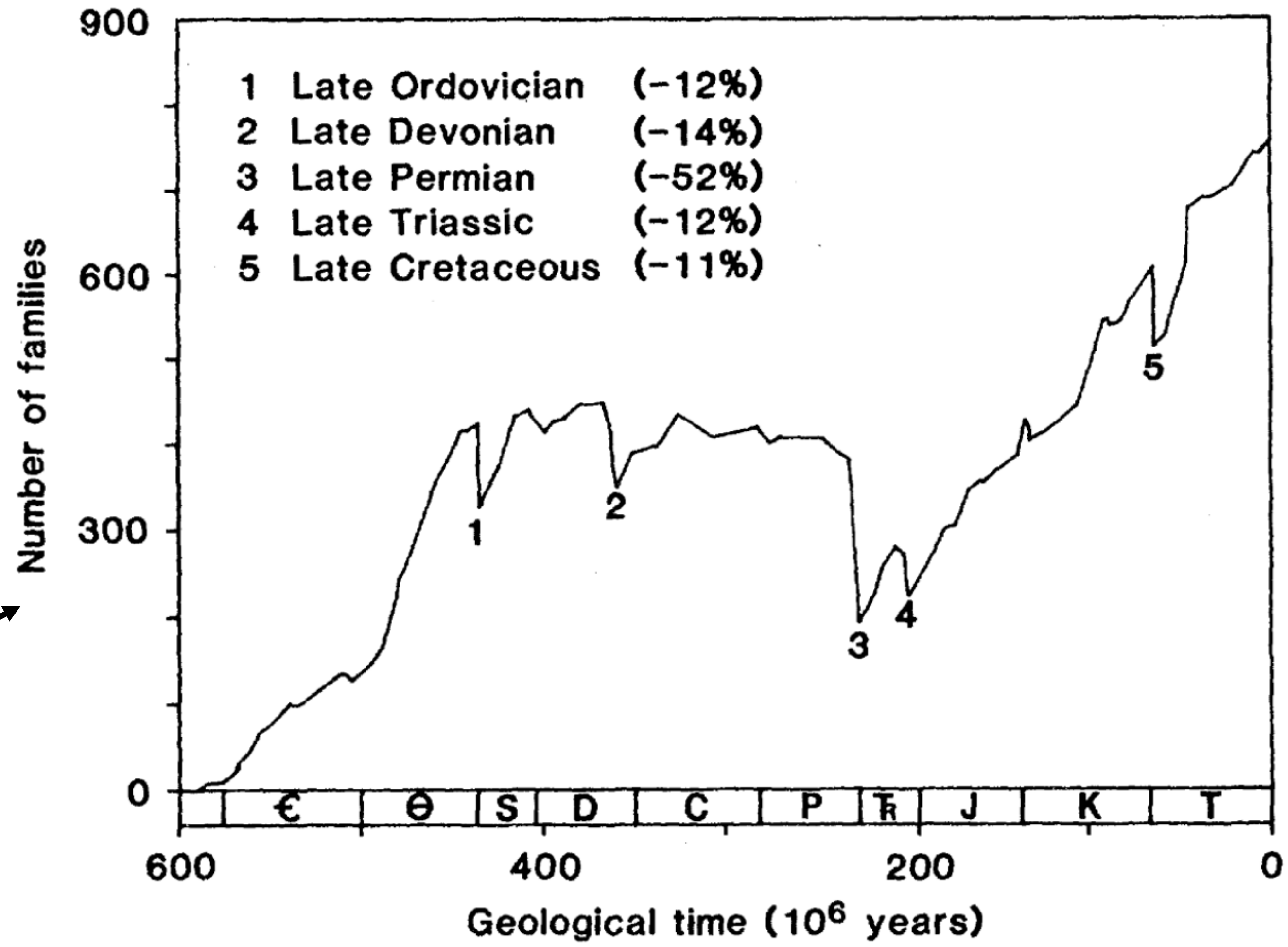
Stanford Woods Institute for the Environment

The Nature Conservancy

Institute on the Environment
University of Minnesota
Driven to Discover℠

WWF

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



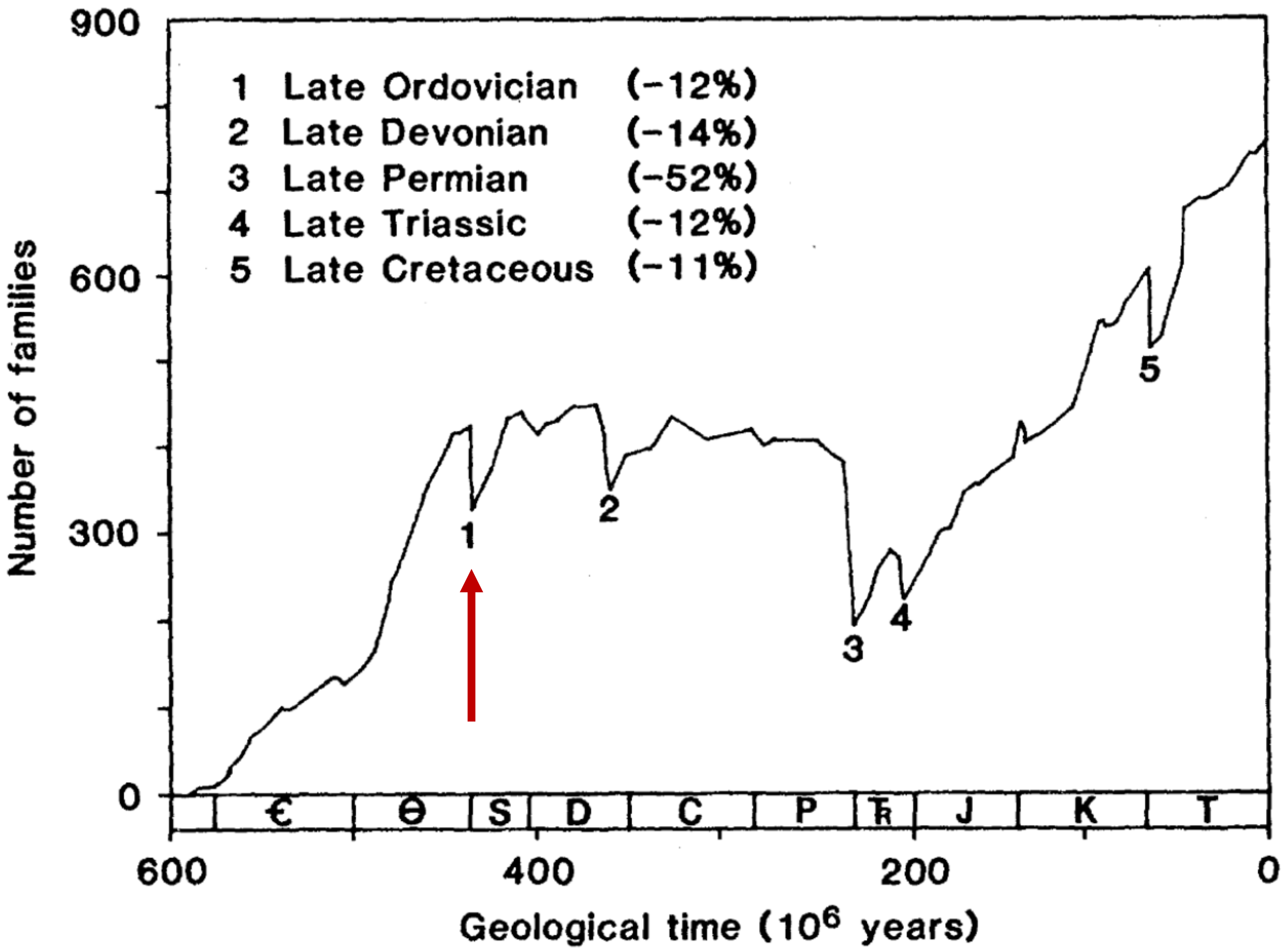
Number marine vertebrate and invertebrate families preserved in the fossil record

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

present day

Raup and Sepkoski. 1982. *Science*

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



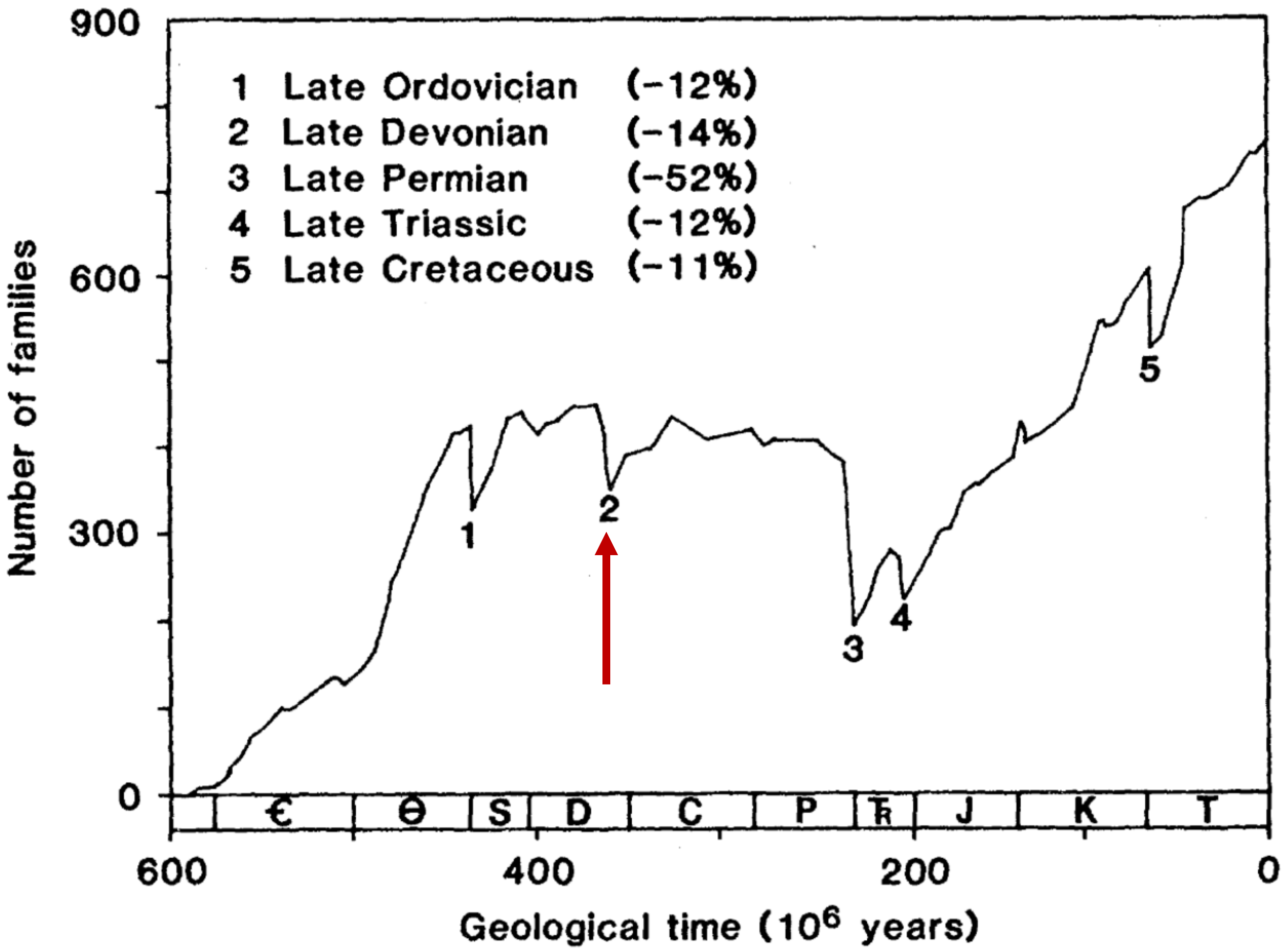
1. **Late Ordovician-Silurian** – 445-444 MYA – second largest extinction in history.

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

Proposed causes: global warming, volcanism, anoxia.

Raup and Sepkoski. 1982. *Science*

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



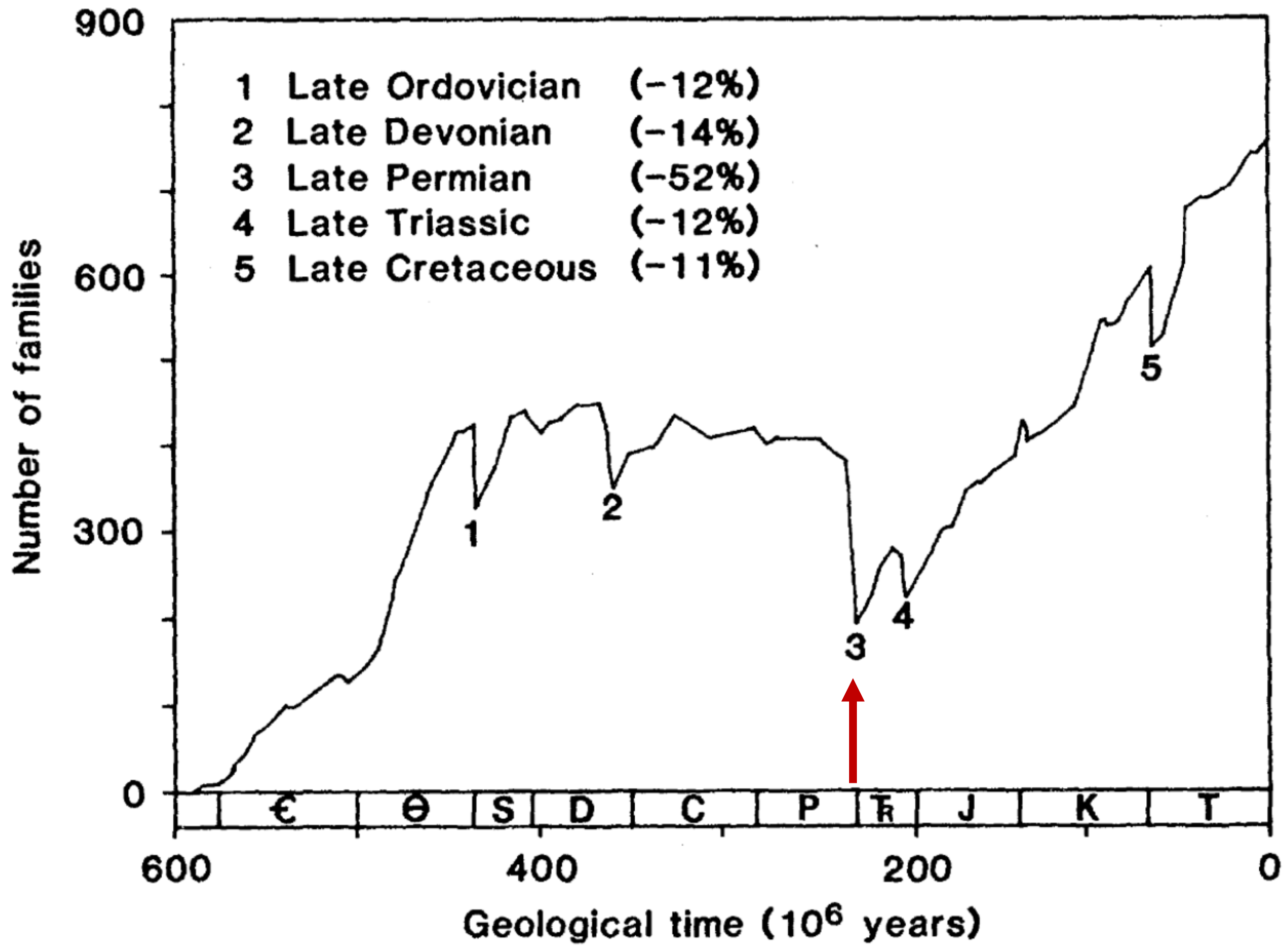
2. **Late Devonian** – 372-359 MYA – two subsequent extinction events.

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

Proposed causes: global cooling, anoxia, meteor impacts.

Raup and Sepkoski. 1982. *Science*

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



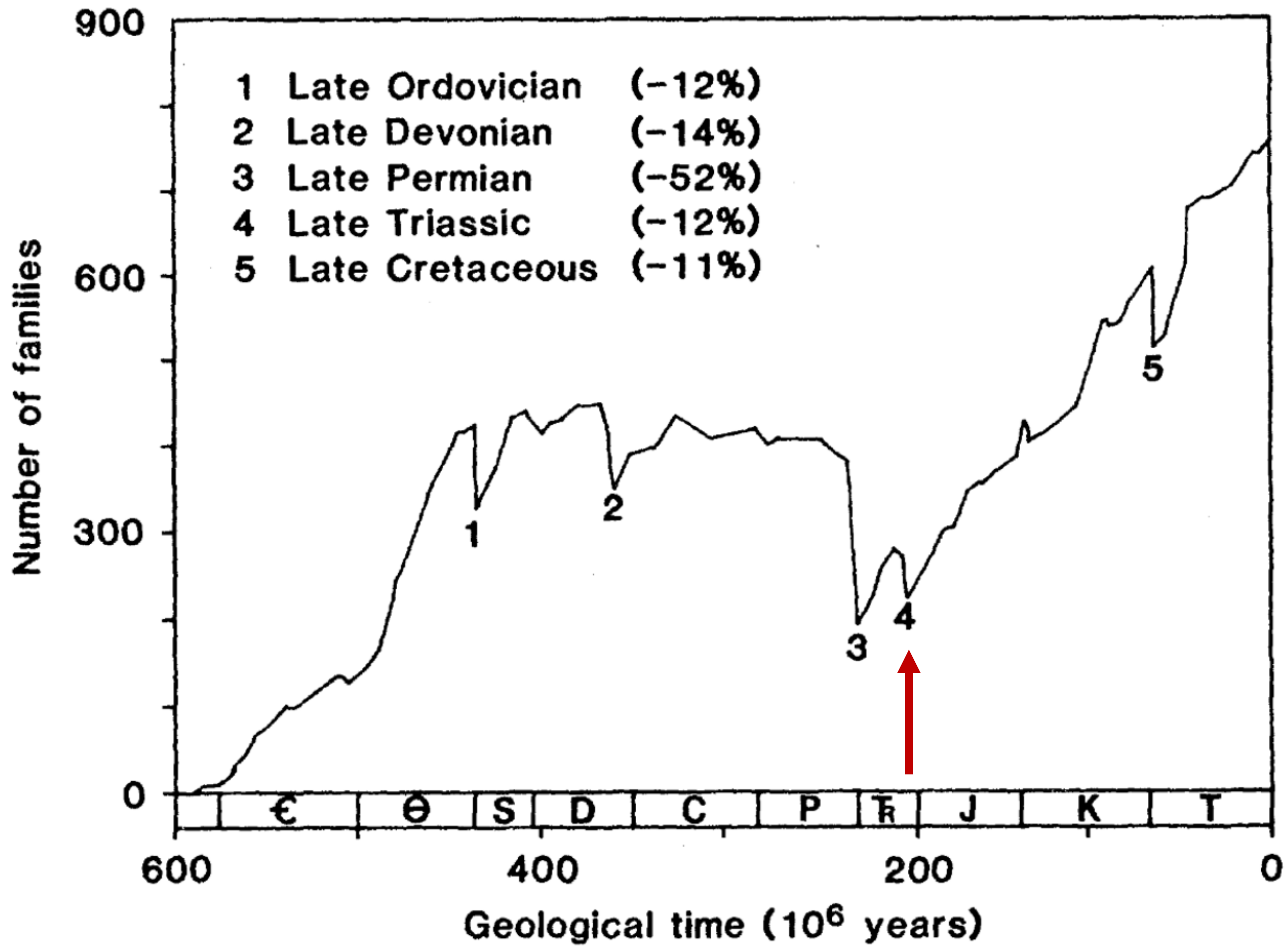
3. **Permian – Triassic** – 252 MYA – largest extinction in history – known as the 'Great Dying'.

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.

Raup and Sepkoski. 1982. *Science*

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



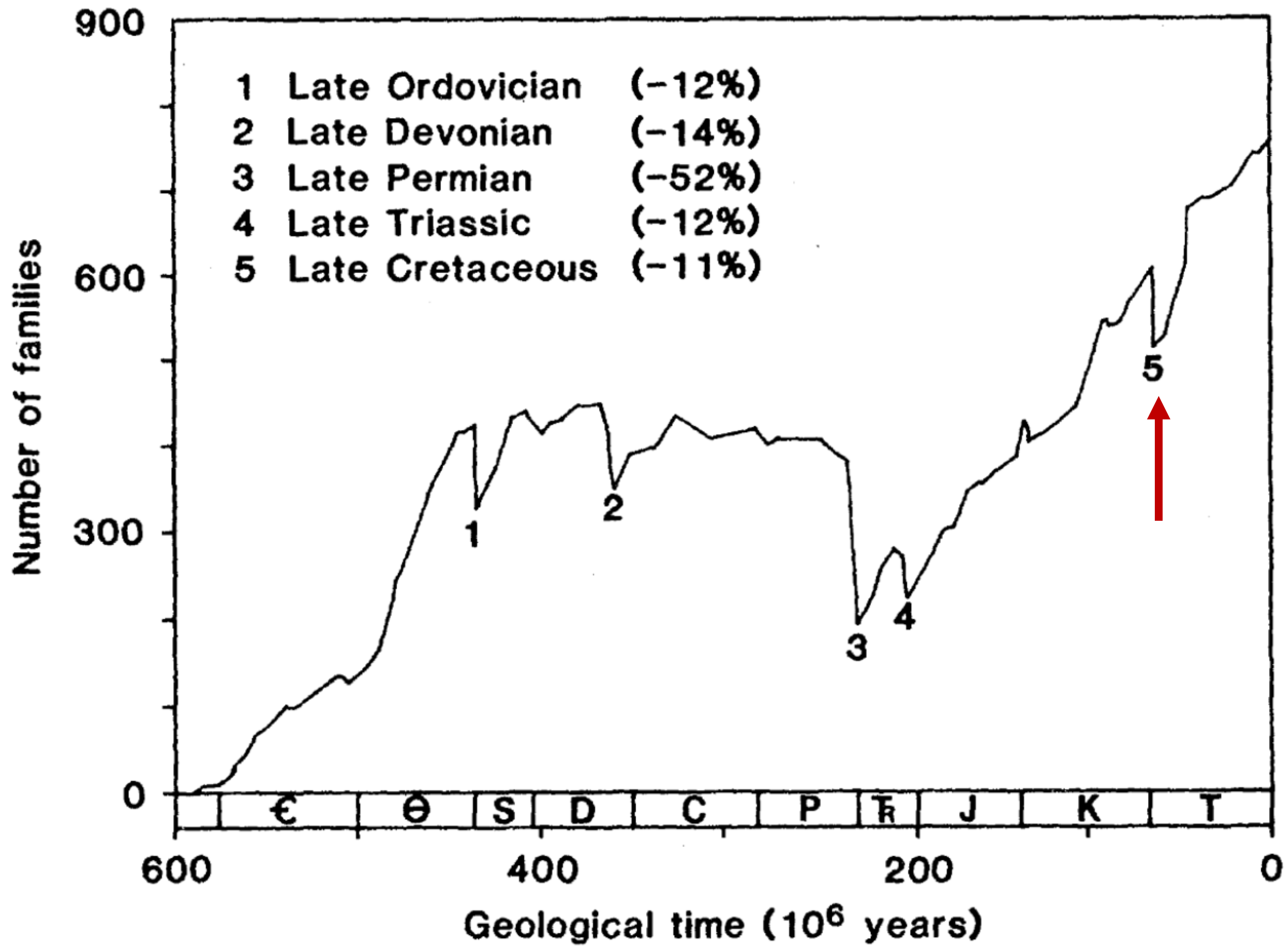
4. **Triassic - Jurassic** – 201 MYA .

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

Proposed causes: global warming, 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 .

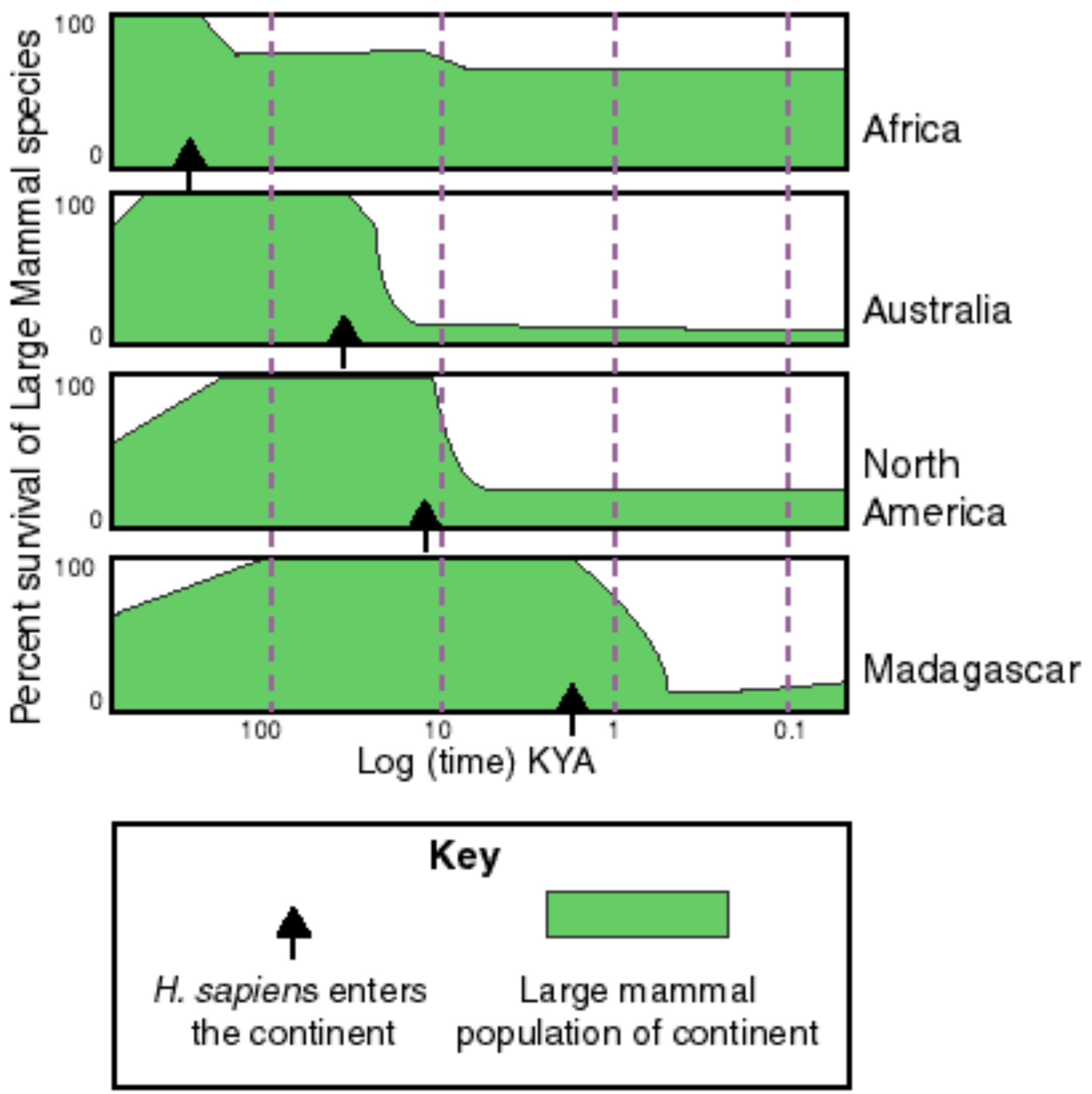
Extinction of all non-avian dinosaurs and 75% of all the planet’s species. Gave way to the age of mammals

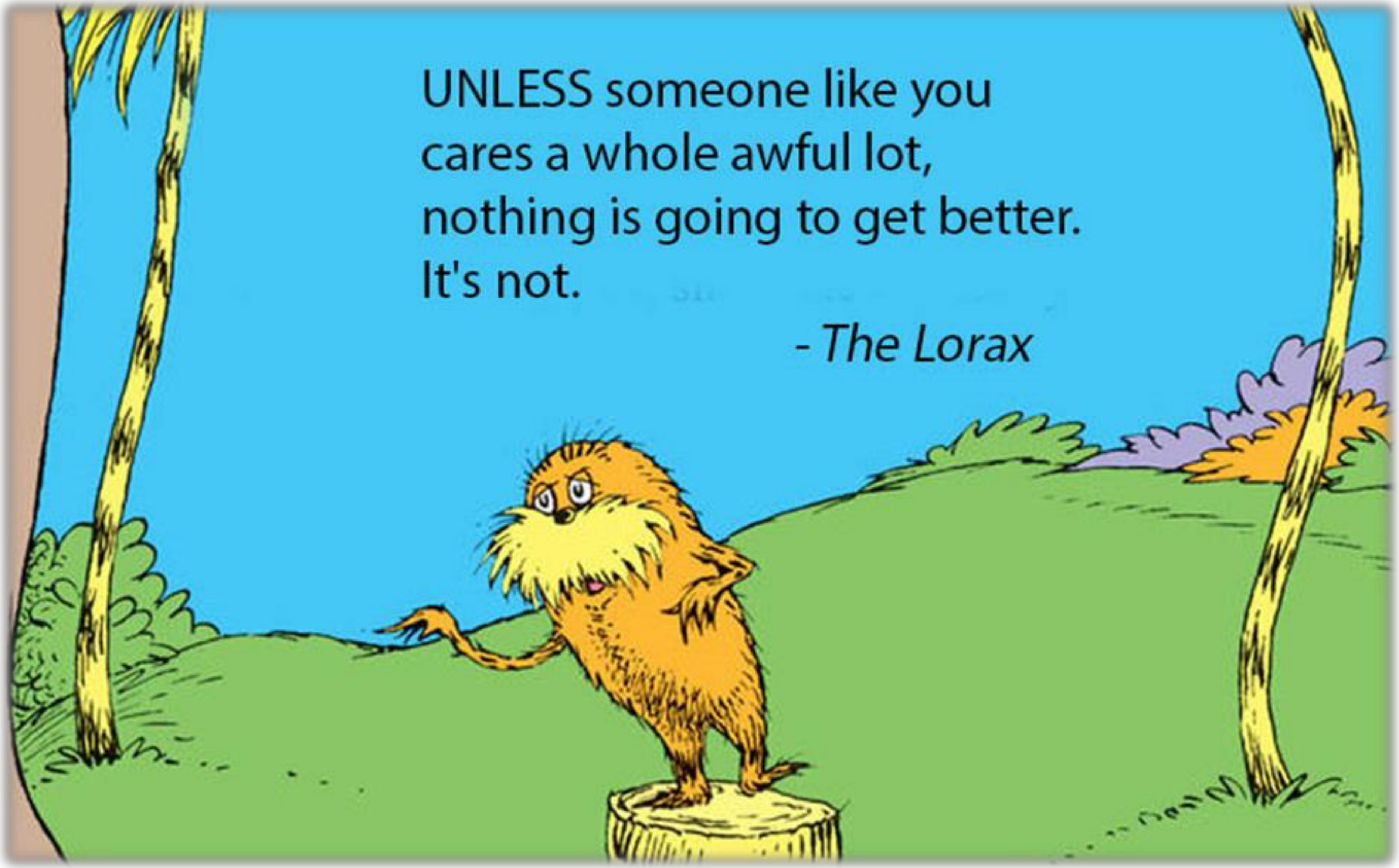
Proposed causes: Chicxulub asteroid impact in present-day Yucatan

Raup and Sepkoski. 1982. *Science*

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

- 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

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