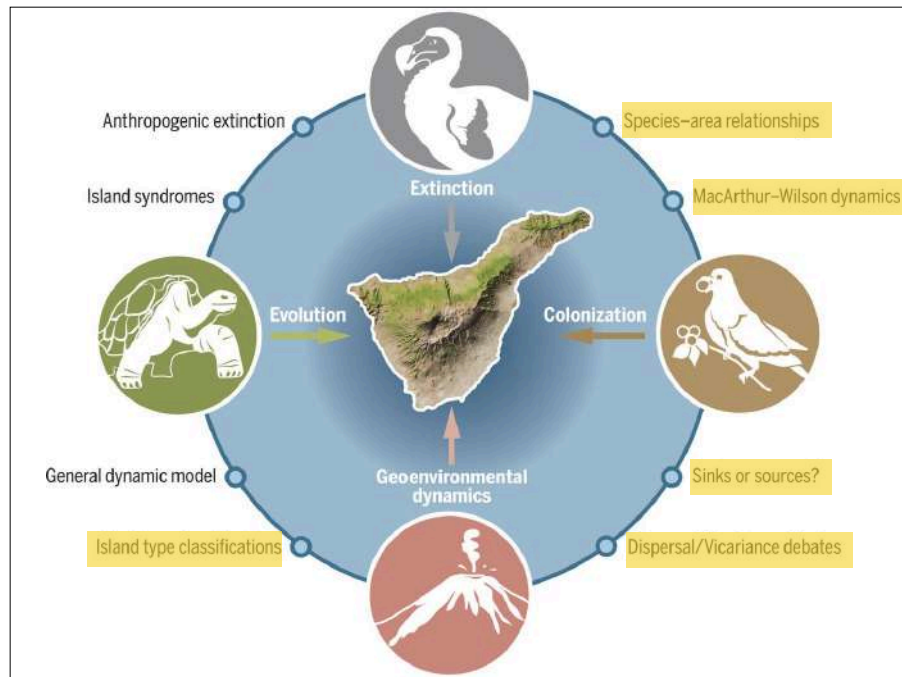
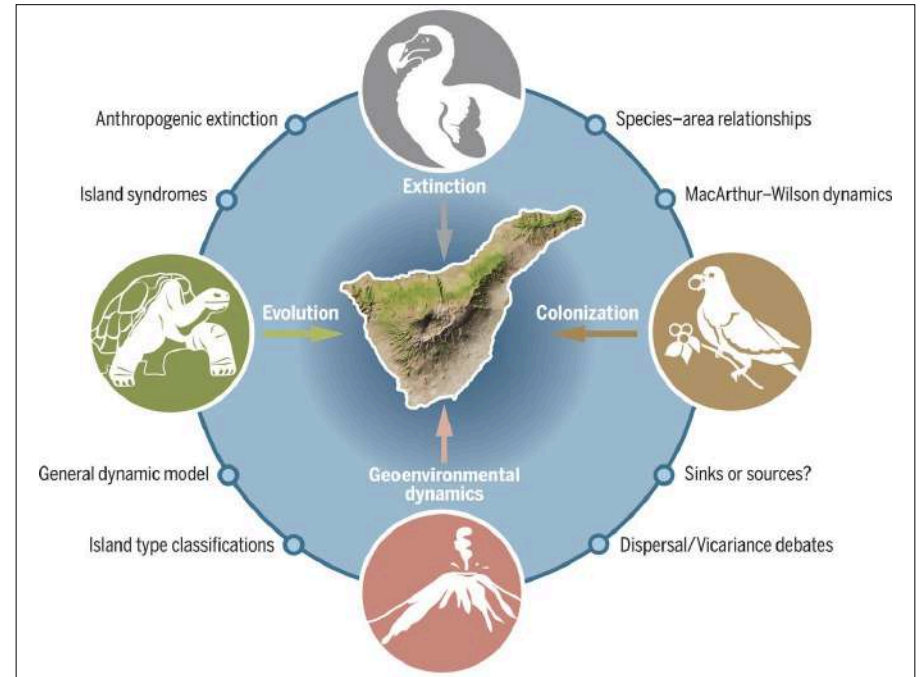




ISLAND BIOGEOGRAPHY

MARINE EVOLUTION AND BIOGEOGRAPHY
RITA CASTILHO



outline

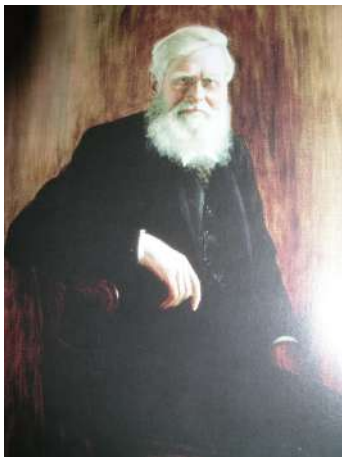
- Basic concepts and history
- Equilibrium Theory of Island Biogeography
- Violations to the assumptions
- Research
- Additional patterns of insular biota

Why are islands relevant in Evolution?

Unique biotas attracted biologists for centuries



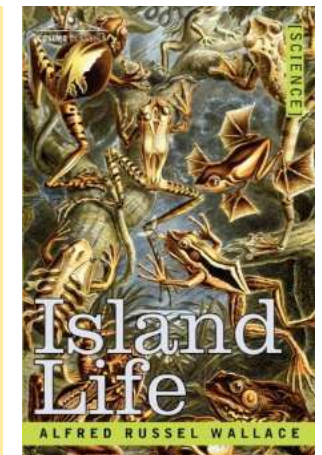
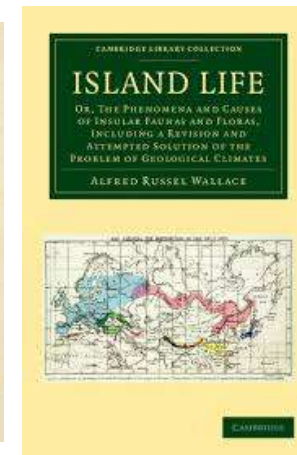
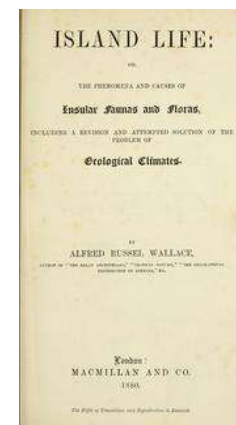
Island Biogeography



“ . . . it is not too much to say that when we have mastered the difficulties presented by the peculiarities of **island life** we shall find it comparatively easy to deal with the more **complex and less clearly defined problems of continental distribution . . .**”

Alfred Russel Wallace *Island Life*
(1902: 242 in Whittaker 1998)

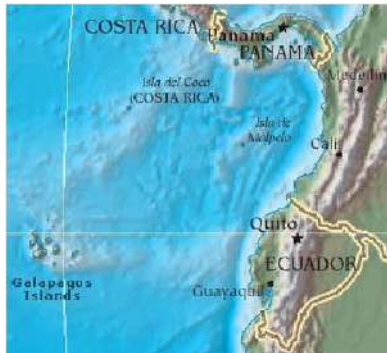
Island Biogeography



Island Biogeography

Why?

Isolated



Island Biogeography

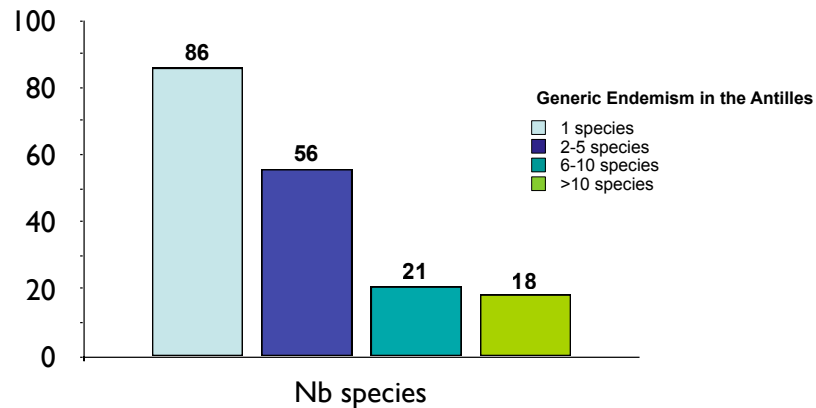
Islands as laboratories for the study of **evolution and co-evolution (HIGH ENDEMISM)**.



More than 20 (!!)
percent of Hawaiian
reef fishes are found
nowhere else in the
world.

Island Biogeography

Islands as laboratories for the study of **evolution and co-evolution (HIGH ENDEMISM)**.



Island Biogeography

Why?



Island Biogeography

Why?

Many



Island Biogeography

Why?



Island Biogeography

Why?

Varied characteristics



Island Biogeography

Why islands?

virtual islands



Island Biogeography

Historical Background

Island Biogeography

Historical Background

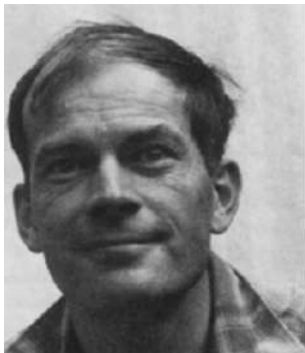
“There are only two possible hypotheses to account for the stocking of an oceanic island with plants from a continent:

- Dispersal or vicariance?
- Historical, evolutionary, static theory of islands

Island Biogeography

Robert MacArthur (1930 - 1972)

- Doctoral dissertation, Yale (1958) on competition and coexistence of warblers
- Hypothesis testing



To do science is to search for repeated patterns, not simply to accumulate facts.

— Robert MacArthur —

Island Biogeography

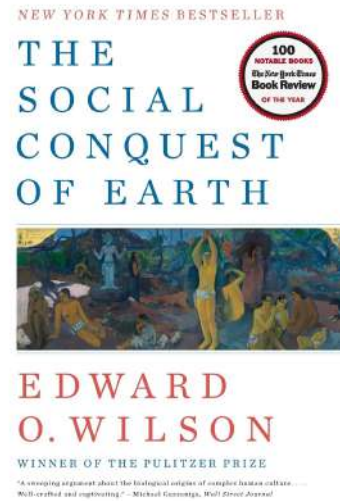
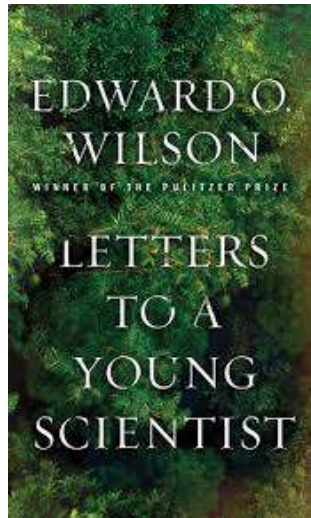
Edward O. Wilson (1929 - ...)

- BS, MS, PhD Harvard
- Origin and relationships of ants on islands in East Indies and South Pacific
- Biogeography and animal behaviour
- Conservation of biodiversity

Check him out!



Island Biogeography



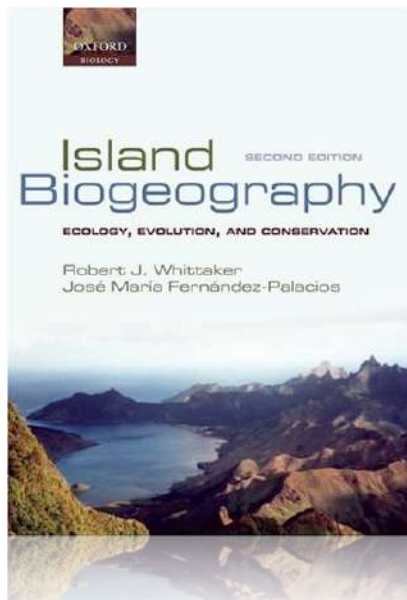
Equilibrium Theory of Island Biogeography

Equilibrium theory of island biogeography (MacArthur and Wilson, 1967)

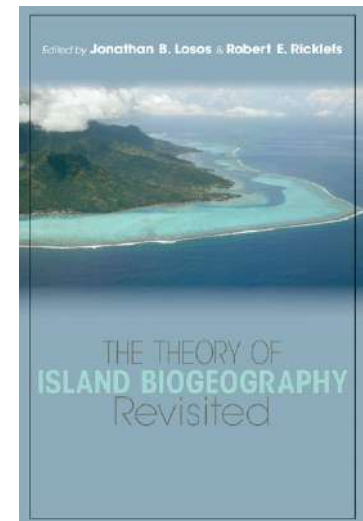
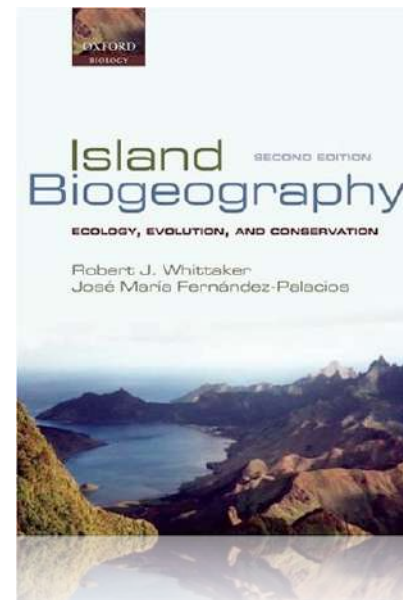


MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Island Biogeography



Island Biogeography



Island Types

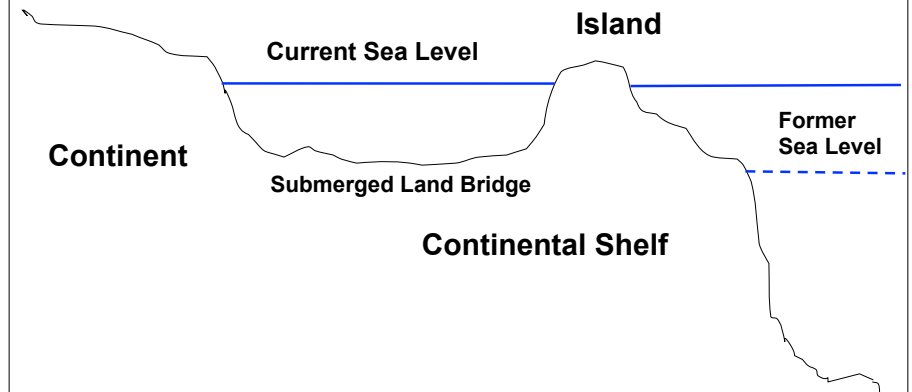
Types of islands



Island Types

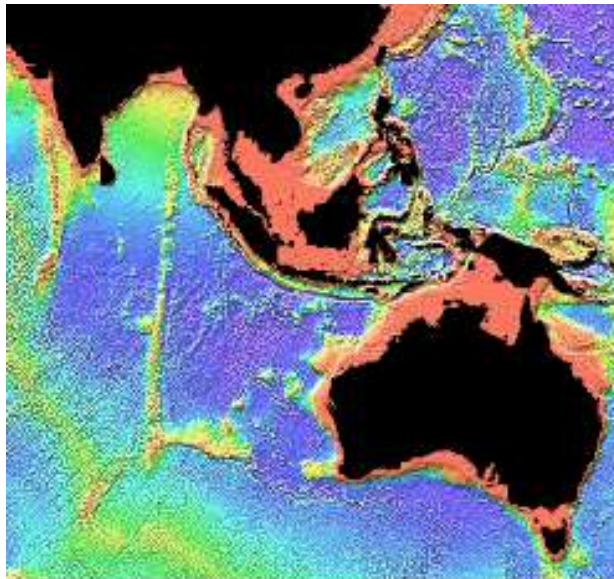
Continental Islands

Formed on continent; may have formerly been connected to mainland by **land bridge**.



Island Types

Areas in orange: land exposed during the LGM



Island Types

British Isles: Land mass is part of European continent. During the last ice age, Britain was connected to Europe by a plateau called Doggerland.



Source: New Scientist, 8 Nov. 2008

Island Types

California Channel Islands: Group of eight islands off the California coast; during last ice age, some were connected to mainland by land bridge.



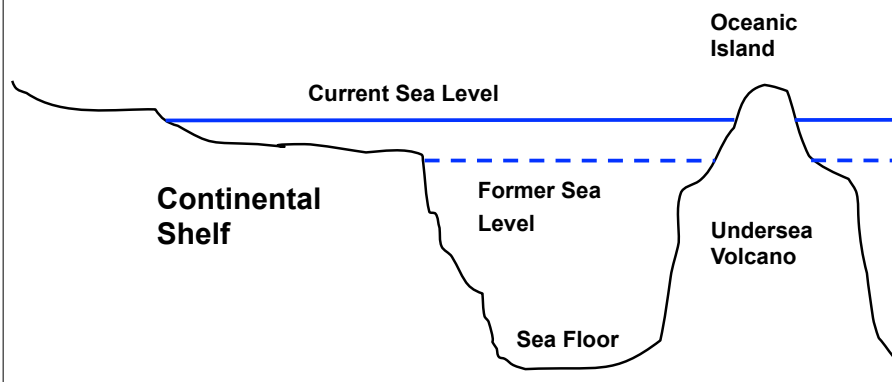
Island Types



Island Types

Oceanic Islands

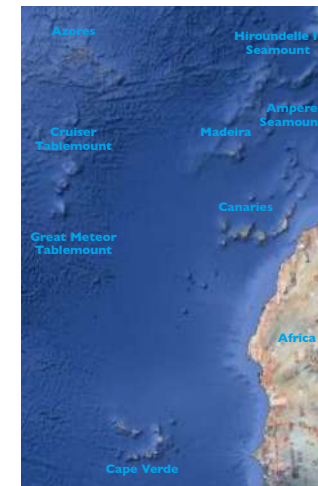
Never connected to continent; usually formed by volcanic activity and isolated from continent by deep ocean.



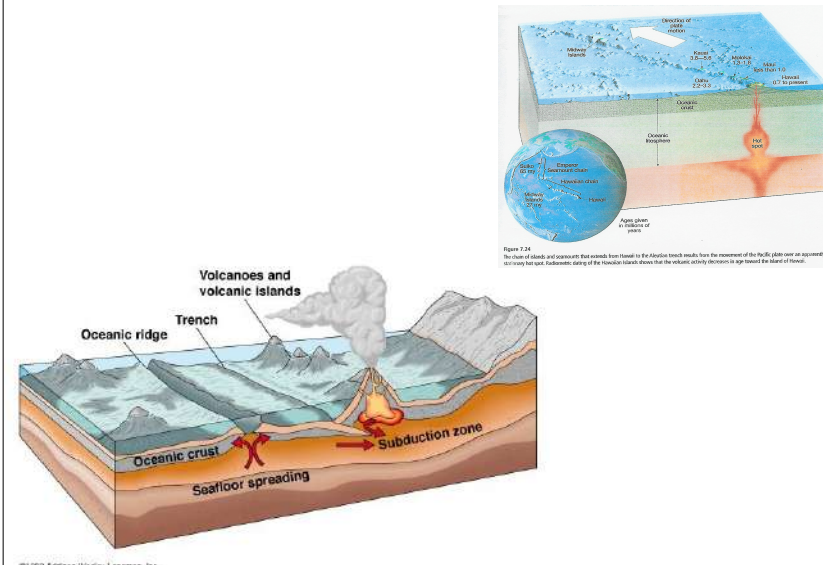
Island Types

Examples of Oceanic Islands

- Iceland
- Japan
- Aleutians
- Bermuda
- Caribbean Islands
- Hawaiian Islands
- South Pacific Atolls
- **Azores**
- **Madeira**
- **Canaries**



Island Types



Island Types

San Salvador's offshore cays: Rising sea level caused erosion of San Salvador, leaving many small, erosion-resistant islands, or cays ("keys").



Island Types

Bahamas banks: Some of the coastal rocks are actually the remains of ancient coral reefs. It is believed that the formation of the Bahama banks began roughly 160 million years ago in what is known as the Jurassic period.



Island Types

Inland Islands



Terrestrial habitat islands: Isolated region on larger land mass, such as:

- mountain top;
- forest remnant surrounded cleared land;
- forest remnant on island in river or lake;
- water-filled tree hole in forest

Island Types



Terrestrial habitat islands: Isolated region on larger land mass, such as:

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Island Types

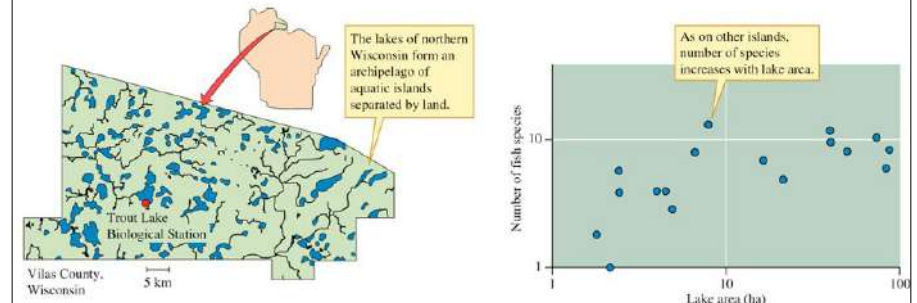
Lakes as Islands

Lakes can be considered as habitat islands.

Differ widely by degree of isolation.

The number of species increases with the area of an insular environment.

Positive relationship between area and fish species richness.



Equilibrium Theory of Island Biogeography

Why does this matter?

Oceanic islands are volcanic islands, recent origin, never connected to any continent, so main processes will be:

1. Dispersal
2. Speciation
3. Extinction

Initially no species present; entire biota acquired either through dispersal or speciation

Equilibrium Theory of Island Biogeography

Why does this matter?

Continental islands are formed as part of a continent, subsequently separated from mainland, so main processes will be:

1. Vicariance (inherit their initial biota from the mainland)
2. Speciation
3. Extinction
4. Dispersal

Equilibrium Theory of Island Biogeography

Purpose of model:

- Develop unifying theory to predict species diversity for all “island” systems

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Equilibrium Theory of Island Biogeography

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Equilibrium Theory of Island Biogeography

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- Predict species diversity (not abundance)
- Include only the most important factors explaining species diversity on islands
- Assume all other factors have small influence
- Replace previous research unable to predict patterns

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Equilibrium Theory of Island Biogeography

Central concepts:

- **Dynamic Equilibrium:** opposing forces (immigration and extinction) maintain some constancy or equilibrium of species number despite species turnover
- **Informed by basic characteristics of insular biota:**
 - Species area-relationship
 - Species isolation-relationship
 - Species turnover

Equilibrium Theory of Island Biogeography



MacArthur



Wilson

Species richness on an island represents a dynamic equilibrium controlled by the rate of immigration of new species and the rate of extinction of previously established species.

Equilibrium Theory of Island Biogeography

Model Assumptions

- 1. Diversity is driven by two factors**
 - Distance from mainland
 - Island size
- 2. Species are equal**
 - Dispersal abilities
 - Survival abilities
- 3. Evolutionary history is not important**
- 4. Characteristics of island habitats do not matter**

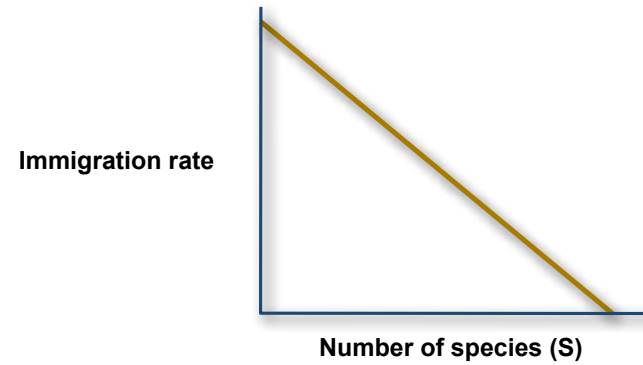
MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Equilibrium Theory of Island Biogeography

WHAT IS THE ETIB?

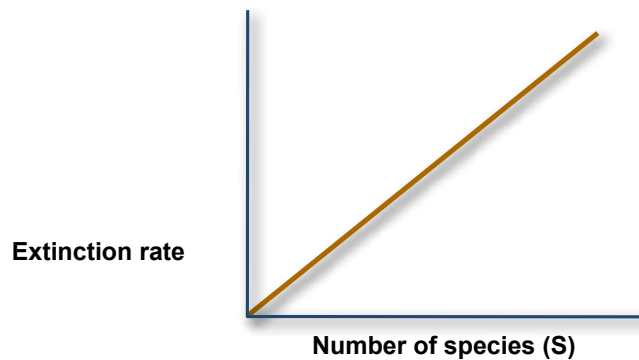
Equilibrium Theory of Island Biogeography

Equilibrium Theory of Island Biogeography

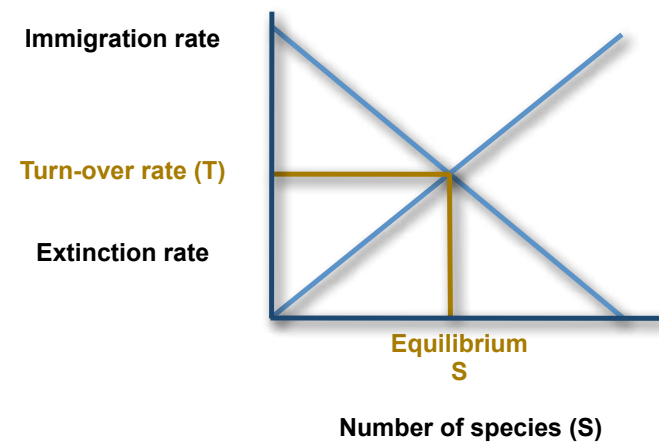


How is the immigration rate measured?
Why does the immigration rate decline as a function of S?

Equilibrium Theory of Island Biogeography



Equilibrium Theory of Island Biogeography

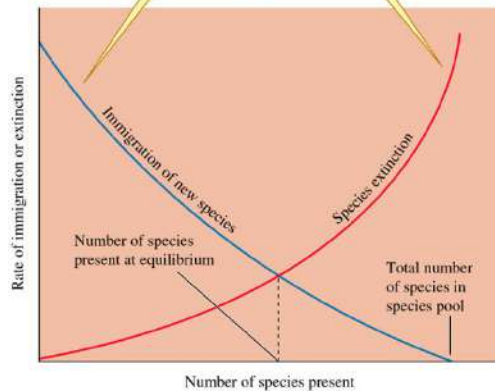


Equilibrium Theory of Island Biogeography

According to the equilibrium model of island biogeography, the number of species on an island is determined by a balance between species immigration and extinction.

The rate of immigration of new species to an island decreases as the number of species on the island increases.

Meanwhile, the rate of species extinction on the island increases as the number of species present increases.



Island Patterns: species-area relations

Model Assumptions

1. Diversity is driven by two factors

- Island size

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Island Patterns: species-area relations



Hawaii

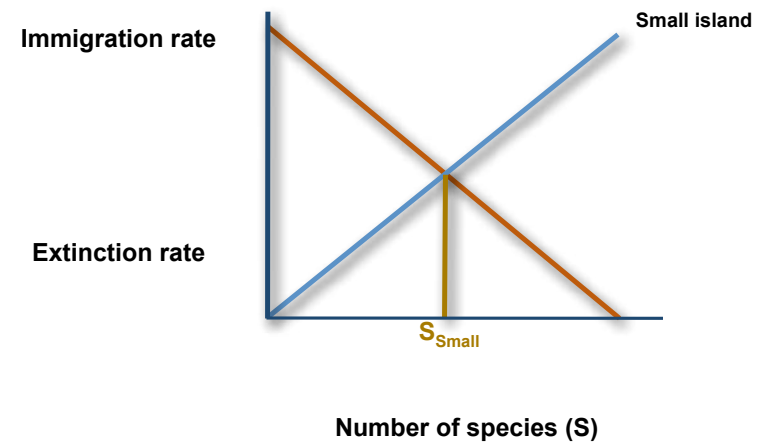


A somewhat smaller island

Much of the variation is explained solely by the size of the island...

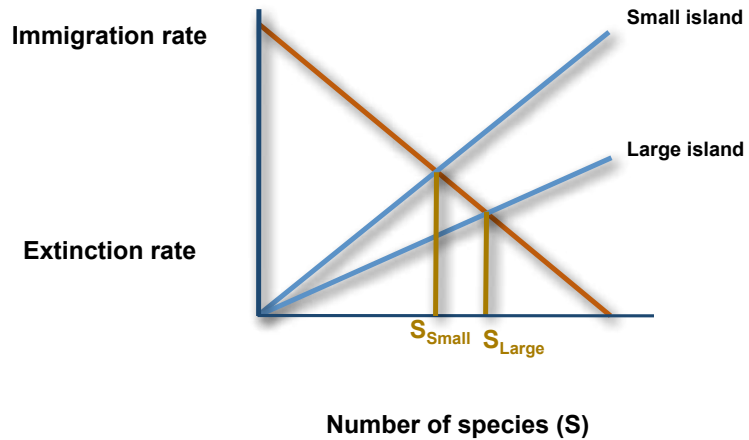
Island Patterns: species-area relations

For the same distance to continent, how does the probability of extinction for each species vary with island size?



Island Patterns: species-area relations

For the same distance to continent, how does the probability of extinction for each species vary with island size?



Island Patterns: species-isolation

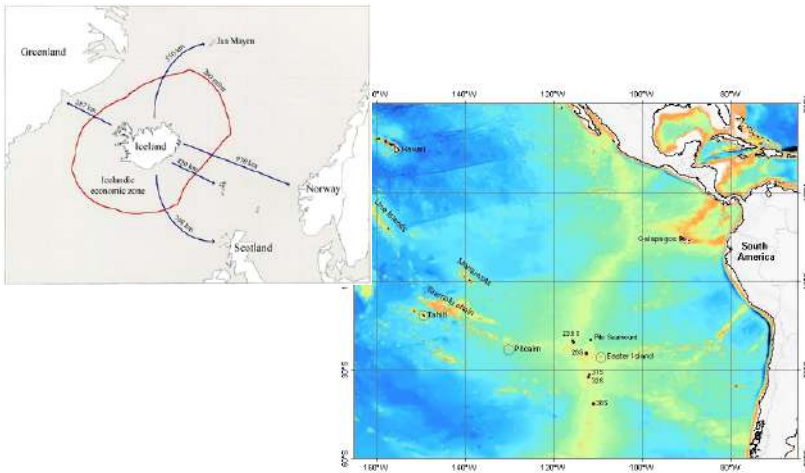
Model Assumptions

1. Diversity is driven by two factors

- Island size
- Distance from mainland

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Island Patterns: species-isolation

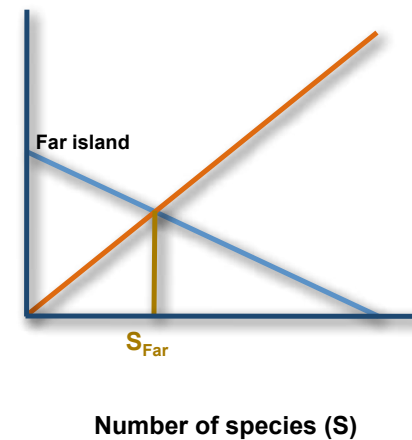


Much of the variation is explained solely by the distance of island to continent....

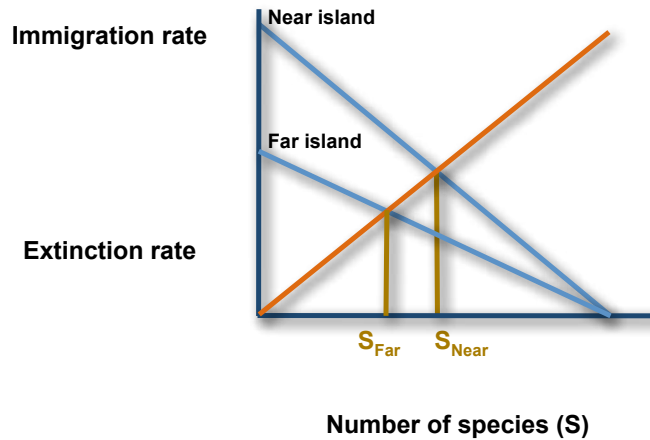
Island Patterns: species-isolation

Immigration rate

Extinction rate



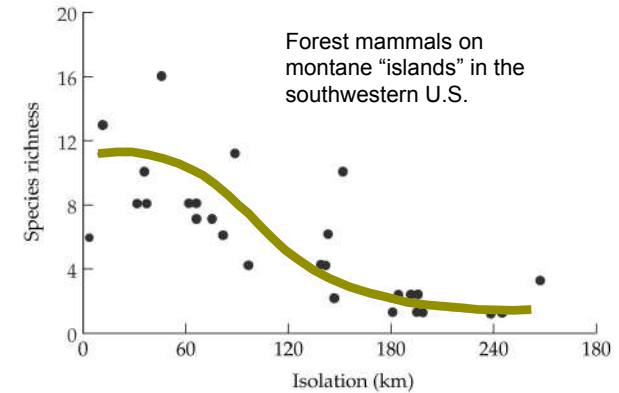
Island Patterns: species-isolation



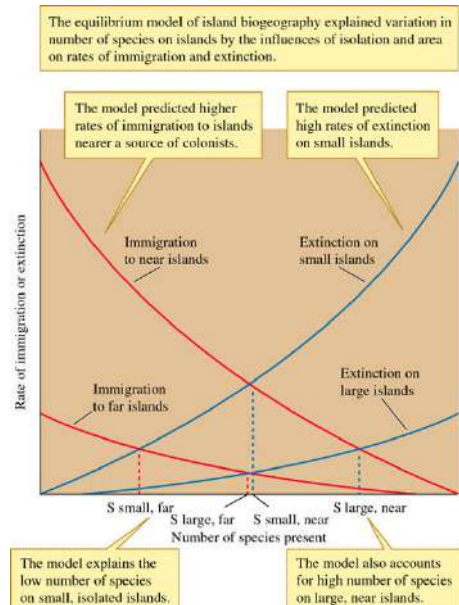
Island Patterns: species-isolation

Species-isolation relationship

Species richness declines as isolation increases, as a negative exponential or sigmoidal function



Equilibrium Theory of Island Biogeography



Equilibrium Theory of Island Biogeography

HOW TO TEST THIS THEORY?



FIG. 3. Upper: Control mangrove island IN1. Lower: Experimental mangrove island SQ1 (arrow), near Squirrel Key. Tiny fumigated island E1 is in foreground.

Equilibrium Theory of Island Biogeography

Everglades National Park Photo



An empirical test: Insects on mangrove islands

(Wilson and Simberloff 1969; Simberloff and Wilson 1969)

- Identified 6 mangrove islands of varying size and distance from the mainland
- Carefully censused the arthropod community of each island
- Covered each island with canvas and fumigated to kill all arthropods
- Tracked recolonization of the islands over several years

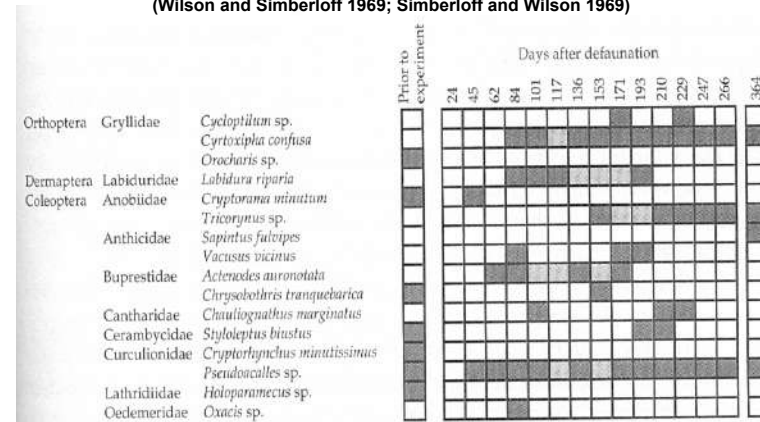
Equilibrium Theory of Island Biogeography



Equilibrium Theory of Island Biogeography

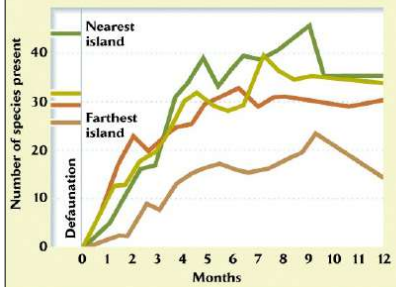
An empirical test: Insects on mangrove islands

(Wilson and Simberloff 1969; Simberloff and Wilson 1969)



Black squares = species present
Grey squares = species inferred to be present

Equilibrium Theory of Island Biogeography



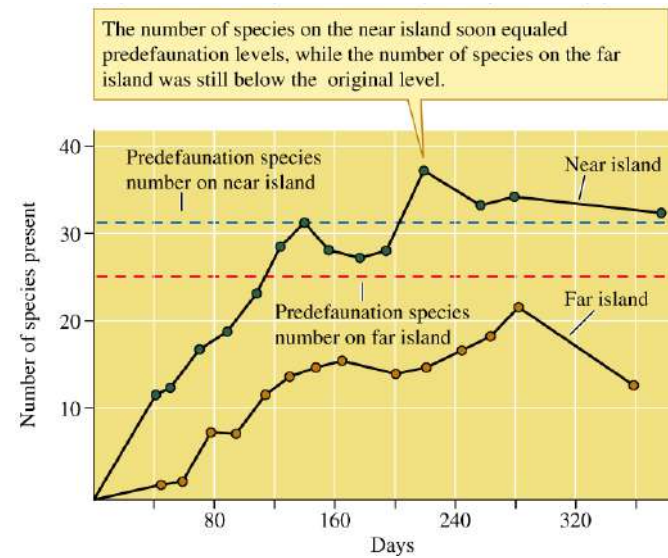
An empirical test: Insects on mangrove islands

(Wilson and Simberloff 1969; Simberloff and Wilson 1969)

- Substantial species turnover occurred over the course of the experiment
- Estimated the turnover rate to be .67 species per day!
- Provides essential support to the equilibrium theory

Taken together, these results support the equilibrium model

Equilibrium Theory of Island Biogeography



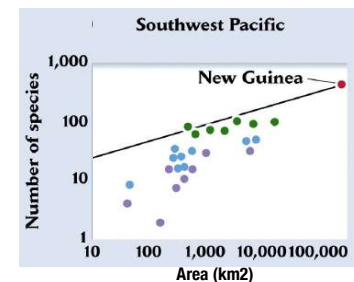
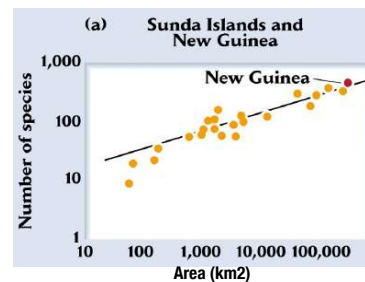
Empirical evidence

EMPIRICAL EVIDENCE

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Empirical evidence

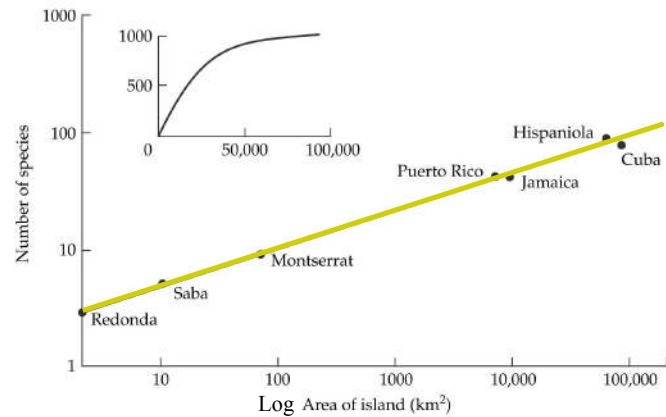
Bird biodiversity



Both area and distance affect bird diversity

Empirical evidence

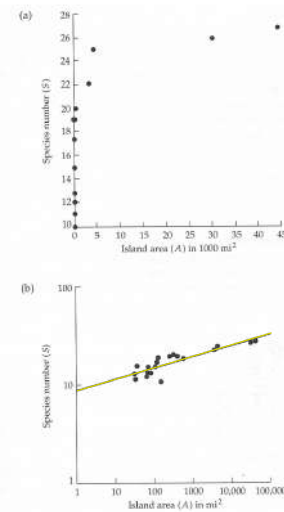
(Breeding land birds of the West Indies; Gotelli and Abele, 1982)



Empirical evidence

A test of the species area relationship

(Breeding land birds of the West Indies; Gotelli and Abele, 1982)



Trend has also been shown to hold for:

Fish in lakes of different areas

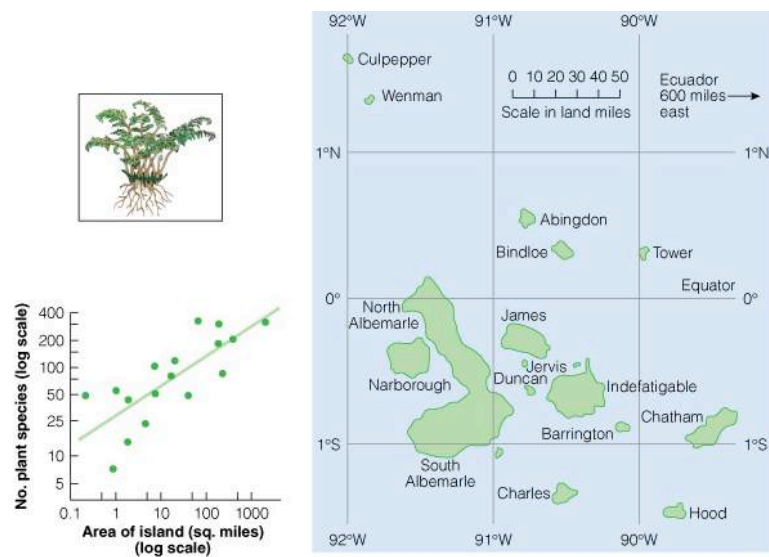
Mammals that occupy isolated mountain tops

Insects that live in thistle heads

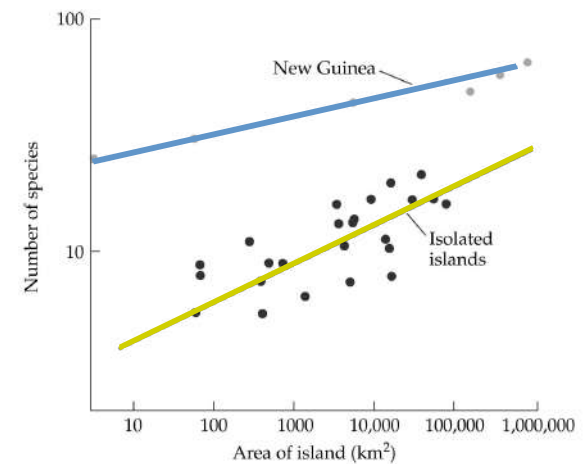
Empirical evidence

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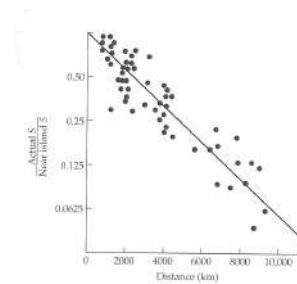
Empirical evidence



Empirical evidence

The equilibrium model may also explain the common observation that species richness decreases with distance from the mainland

Birds of the Bismarck islands (Diamond, 1972)



Species richness decreases with distance from New Guinea (mainland)

Equilibrium Theory of Island Biogeography

Model Assumptions

1. Diversity is driven by two factors

- Distance from mainland
- Island size

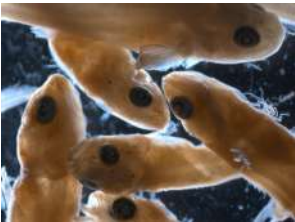
2. Species are equal

- Dispersal abilities

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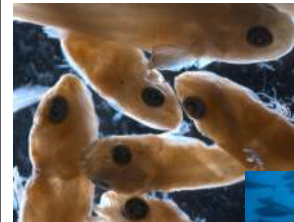
Island Biogeography

Passive transport
CURRENTS



Island Biogeography

Passive transport
CURRENTS



Active transport
SWIMMING



Island Biogeography

Passive transport
CURRENTS



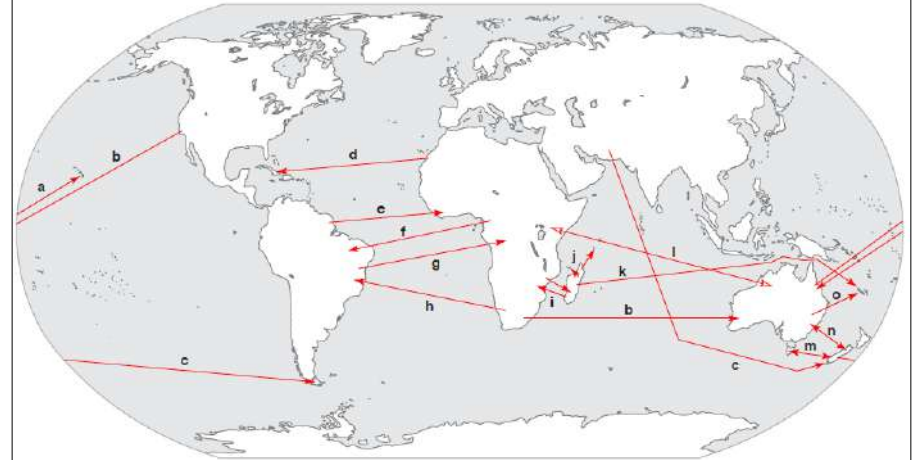
Active transport
SWIMMING



Passive floating
RAFTING



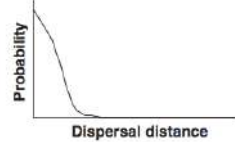
Island Biogeography



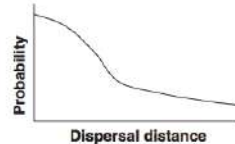
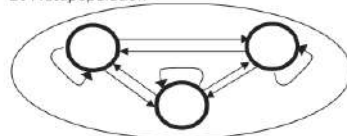
TRENDS in Ecology & Evolution

Island Biogeography

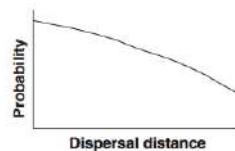
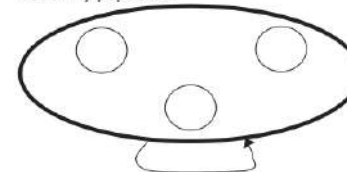
A. Network of closed populations



B. Metapopulation



C. Patchy population



Equilibrium Theory of Island Biogeography

Model Assumptions

1. Diversity is driven by two factors

- Distance from mainland
- Island size

2. Species are equal

- Dispersal abilities
- Survival abilities

Equilibrium Theory of Island Biogeography

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Equilibrium Theory of Island Biogeography

Krakatoa



Equilibrium Theory of Island Biogeography

Krakatoa

In **1883** there was a volcanic eruption on the island of Krakatoa that eliminated **all life** there.

Scientists have visited since collecting data on the colonization and species richness of the island.



Equilibrium Theory of Island Biogeography

Krakatoa

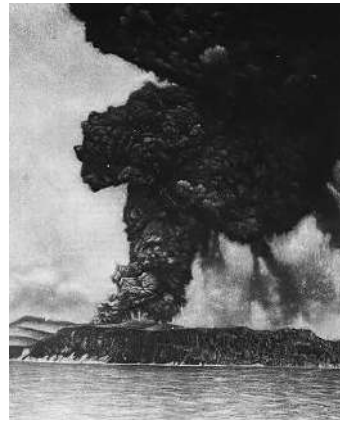
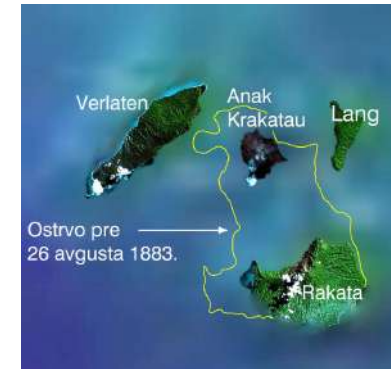


Photo of the Krakatoa eruptive activity a few hours before the major explosions (taken on August 26, 1883 from a ship crossing the Sunda Strait).

Equilibrium Theory of Island Biogeography



MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Equilibrium Theory of Island Biogeography

Krakatoa

MacArthur and Wilson's Theory of Island Biogeography predicted that the equilibrium value for birds species would be 30, that the time to reach equilibrium would be 40 years, and the turnover rate would be 1 species a year.



Equilibrium Theory of Island Biogeography

Krakatoa



Birds Species:
 1908 – 13 species
 1921 – 27 species
 1934 – 27 species
 5 species had been replaced between the 1921 and 1934 surveys

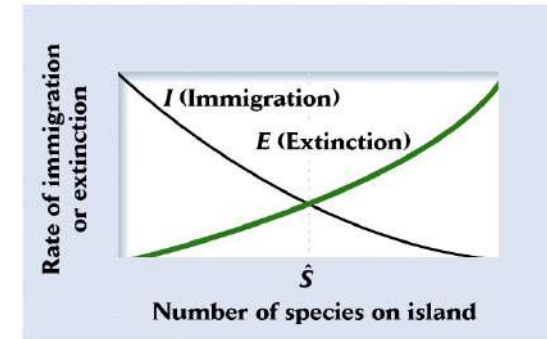
Equilibrium Theory of Island Biogeography

WHAT HAVE WE LEARNED?

MacArthur RH and Wilson EO. The theory of island biogeography. Princeton University Press, 1967.

Equilibrium Theory of Island Biogeography

What have we learned?



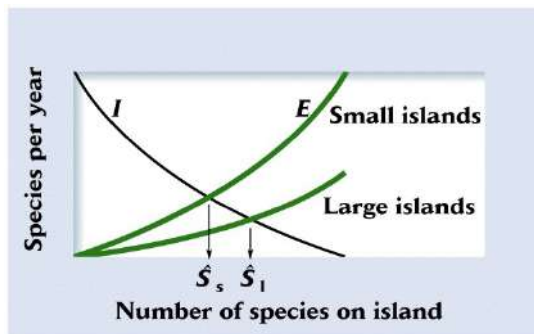
Immigration rate decreases as island diversity increases

Species equilibrium on islands is a balance of immigration and local extinction

Extinction increases as island diversity increases

Equilibrium Theory of Island Biogeography

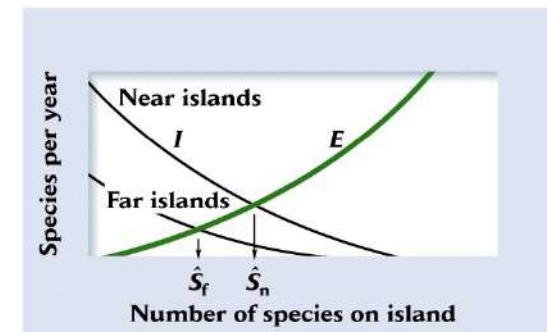
What have we learned?



Smaller islands have lower species diversity
Probability of extinction increases with more species

Equilibrium Theory of Island Biogeography

What have we learned?

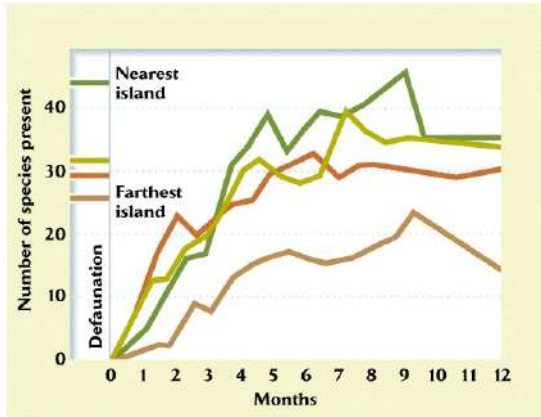


Islands further from mainland have lower immigration rates

More distant islands have lower species diversity

Equilibrium Theory of Island Biogeography

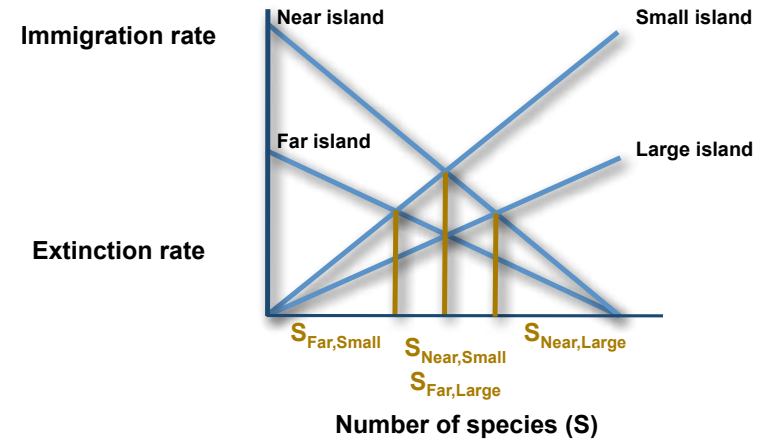
What have we learned?



More distant islands had lower species diversity

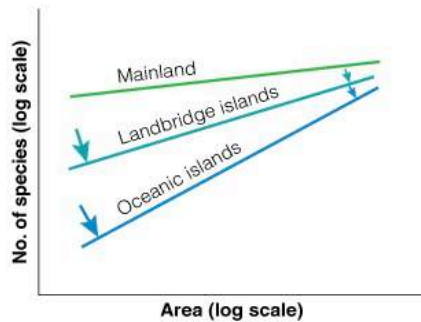
Closer islands had greater rates of immigration and recovered more species faster

Equilibrium Theory of Island Biogeography



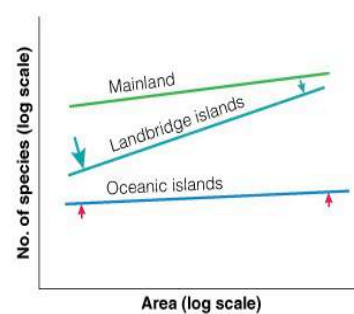
Island Biogeography

Equilibrium



(a) Equilibrium model

Non-equilibrium



(b) Nonequilibrium model

Equilibrium Theory of Island Biogeography

Habitat diversity can confound the area effect

Border effect

