Imperial College London

MARIE CURIE ACTIONS

Advanced topics in population and community ecology and conservation

Lecture 3

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Outline: Theoretical concepts in community ecology

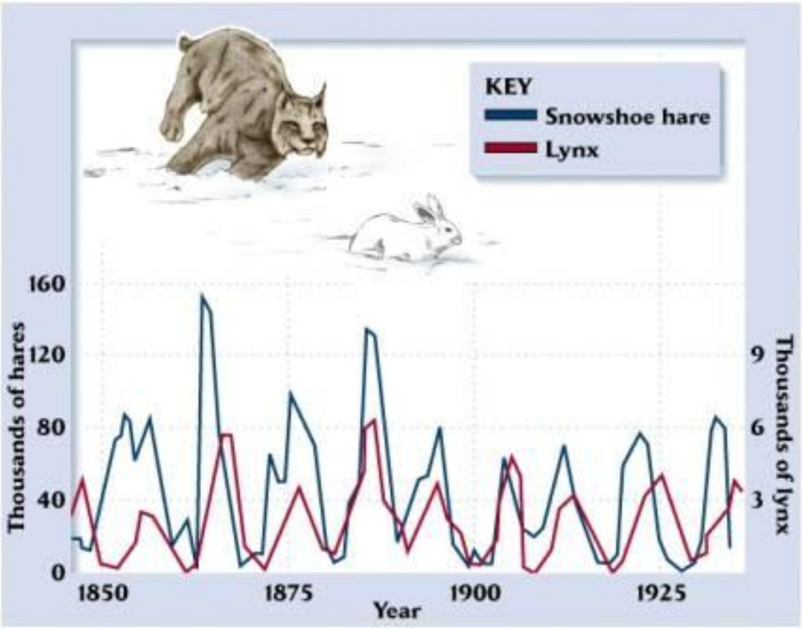
- From populations to communities

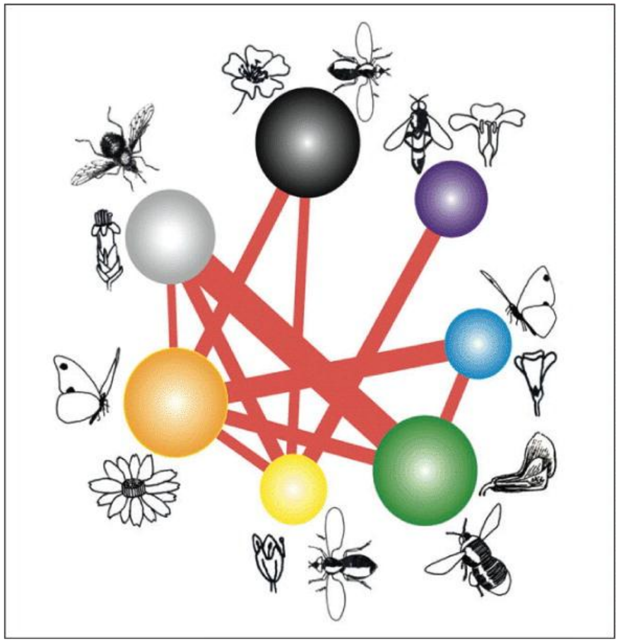
Understanding community assembly

- Island Biogeography Theory
- Unified Neutral Theory of Biodiversity and Biogeography
- Niche theory
- Phylogenetic community assembly

From population to community ecology: multi-species systems

Antagonistic & Mutualistic interactions





http://denalibiomeproject.wikispaces.com/Predator-Prey+Relationships

Bascompte. 2009 FEE **7**: 429–436

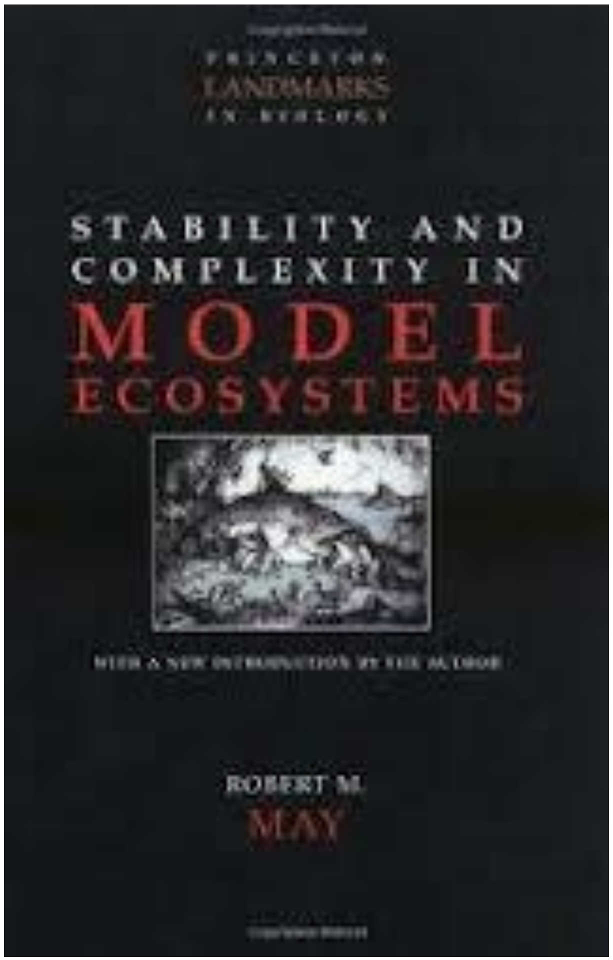
Stability *vs.* Complexity

- Multiple definitions for stability and complexity

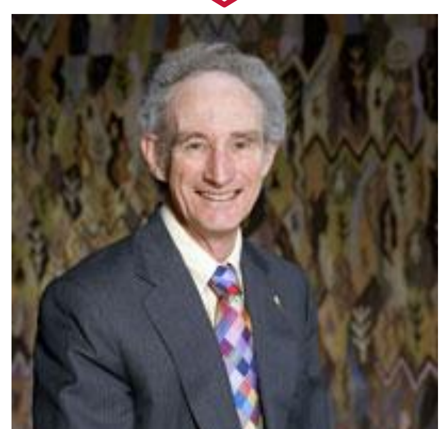
Variability
Resilience
Resistance

Species richness
Connectance
Interaction strength

Multi-species systems



“Large complex ecosystems assembled at random are expected to be stable only up to a certain level of connectance and then suddenly become unstable”



Diversity of Intercation Types and Ecological Community Stability

A. Mougi and M. Kondoh

Science 337, 349 (2012)

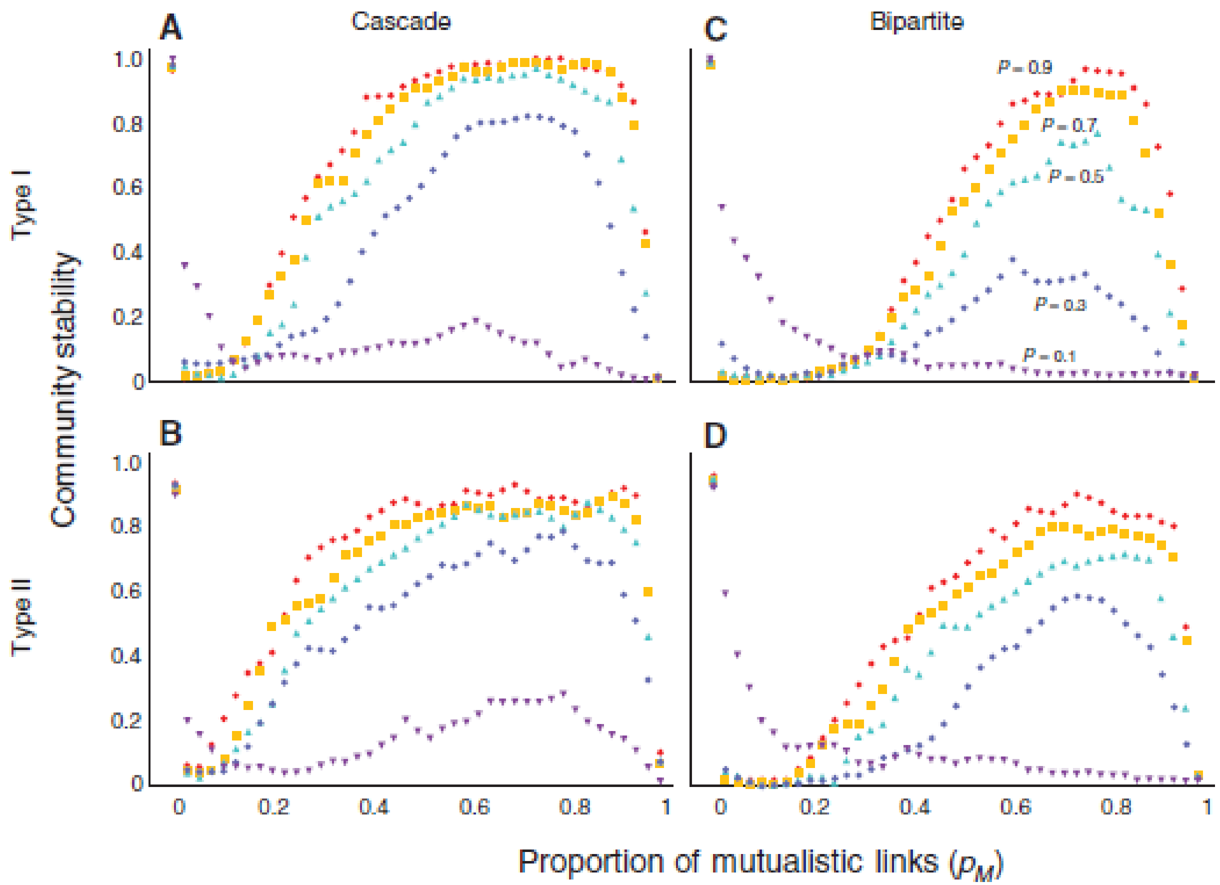
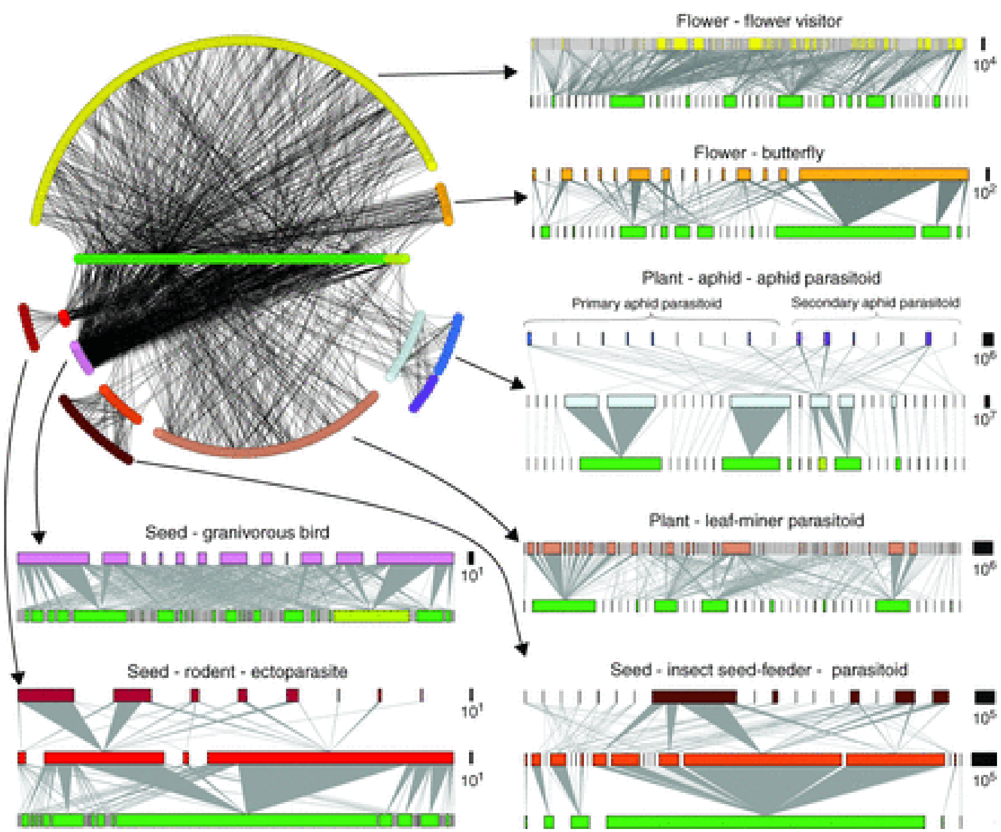


Fig. 1. (**A** to **D**) Relationships between the proportion of mutualistic links (p_M) and stability with varying proportions of connected pairs (P) in four models with different network structures and functional responses. Colors indicate different values of P. We assume $N = 50$.

Conclusions:

"Additional empirical study of the structure and dynamics of hybrid communities composed of various types of interactions must be pursued".

Difficulties collecting data in the field



In our study, we overcame the logistical constraints of studying multiple species' interaction networks in order to more fully test for variation in their robustness and fragility. Our networks comprised 1501 quantified unique interactions between a total of 560 taxa, comprising plants and 11 groups of animals: those feeding on plants (butterflies and other flower visitors, aphids, seed-feeding insects, and granivorous birds and mammals) and their dependants (primary and secondary aphid parasitoids, leaf-miner parasitoids, parasitoids of seed-feeding insects, and rodent ectoparasites) (Fig. 1). We selected these groups

The Robustness and Restoration of a Network of Ecological Networks
Michael J. O. Pocock *et al.*
Science **335**, 973 (2012);

What is a community?

- A community is an assemblage of species that occur together in space and time.
- Sum of properties of individuals and species plus their interactions.
- Can be defined at any spatial or temporal scale.

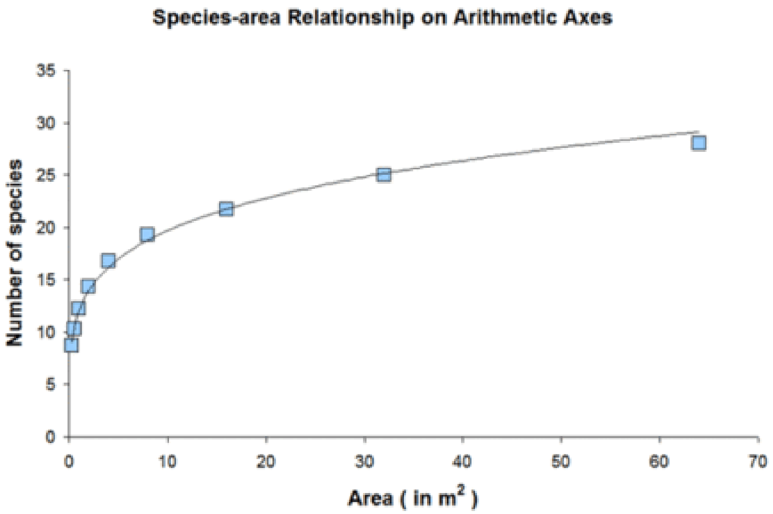
Community data

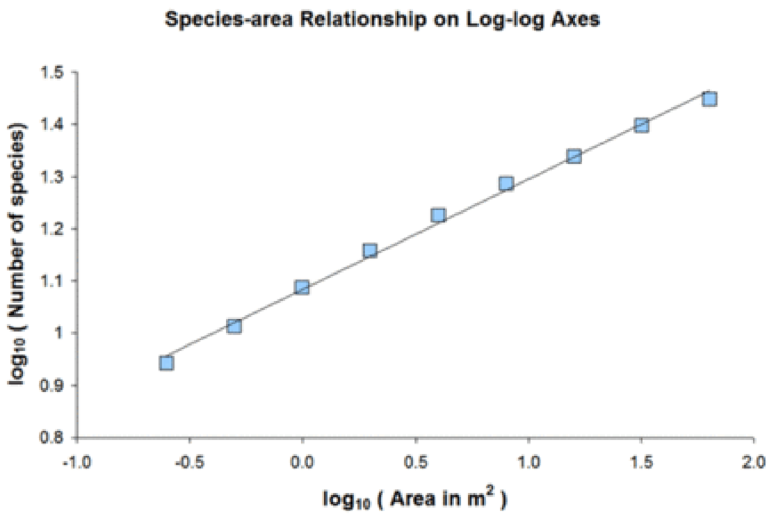
- Species richness
- Species abundances
- Species identity

Community assembly: Predicting the number of species present in a community

- **Species richness**
- Species abundances
- Species identity

Species richness and the species-area curve (Arrhenius 1920s)



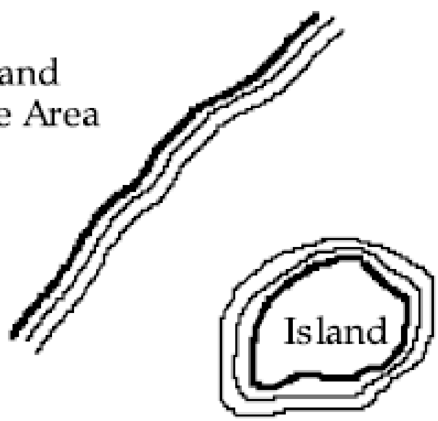


$$S = cA^z$$

$$\log(S) = \log(c) + z \log(A)$$

Theory of Island Biogeography - MacArthur & Wilson 1967

$$S = cA^z$$



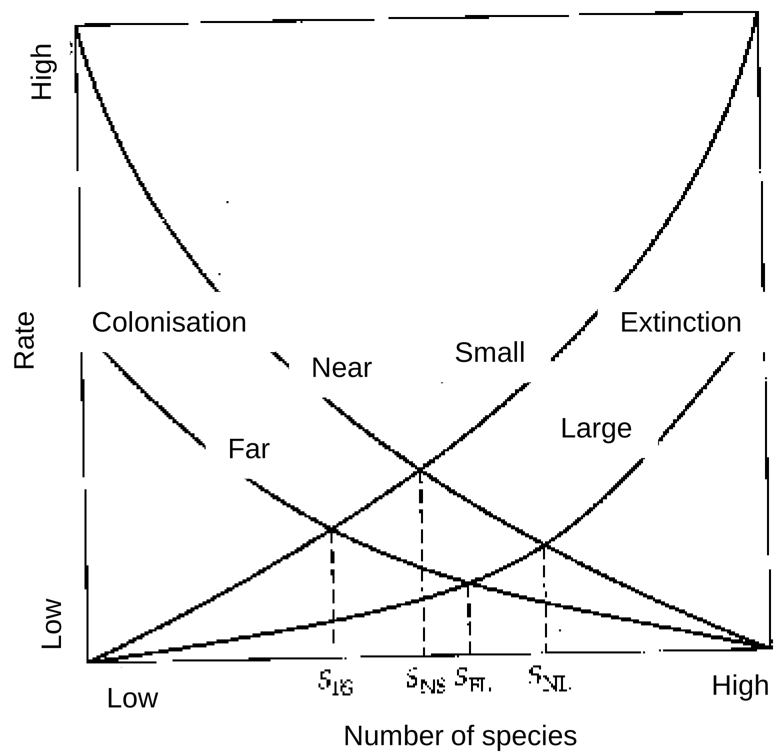


Figure from Brown and Gibson -Biogeography

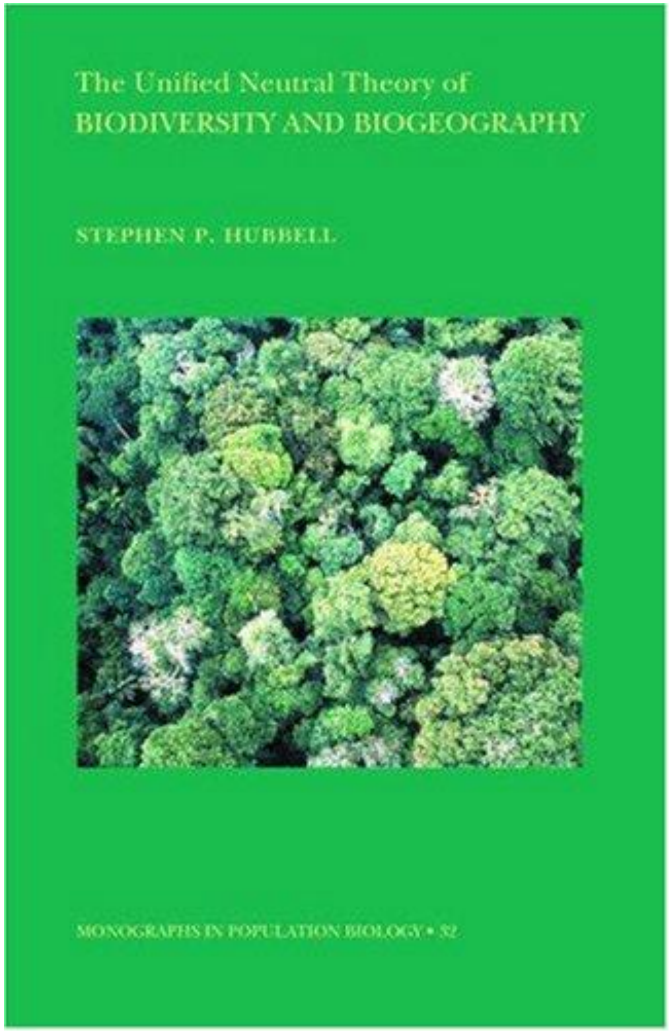
Island biogeography as a neutral theory

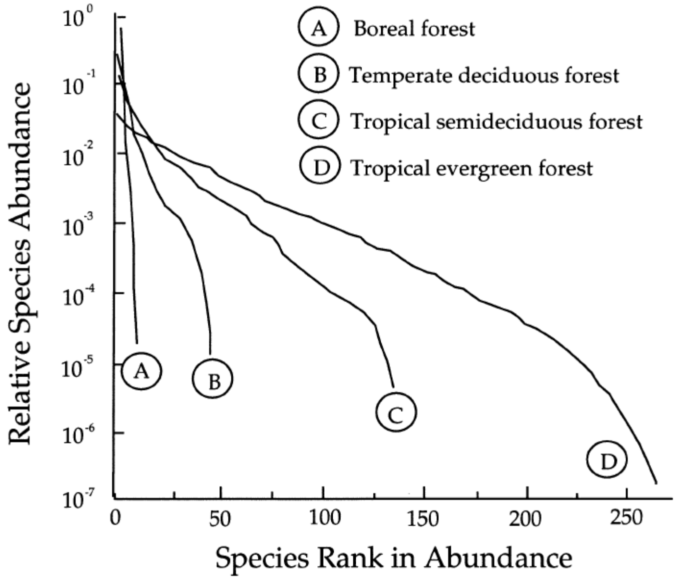
- Species differences are not considered to be important
- All species obey same rules and affected in the same way
- Communities are dispersal assembled (immigration)
- Communities are not stable but in constant turnover through repeated immigrations and local extinctions

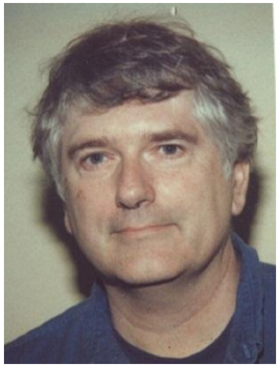
Community assembly: Predicting relative species-abundance in a community

- Species richness
- **Species abundances**
- Species identity

The Unified Neutral Theory of Biodiversity and Biogeography







What does *neutral* mean?

Per capita ecological equivalence

- Birth
- Death
- Migration
- Speciation

All individuals of all species obey exactly the same rules

but

<u>individuals and species are NOT the same</u>

Assumptions of neutral theory: saturation and zero-sum dynamics

Finite community size (J)

All resources are used

No new individuals can be added (reproduction or immigration) until some have been removed (mortality)

Sum of all abundance changes is zero

Neutral theory

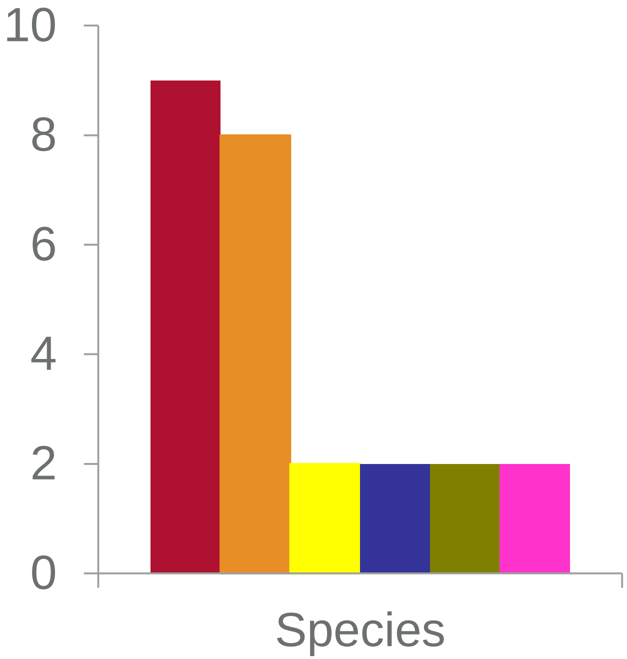
Ecological communities are structured by:

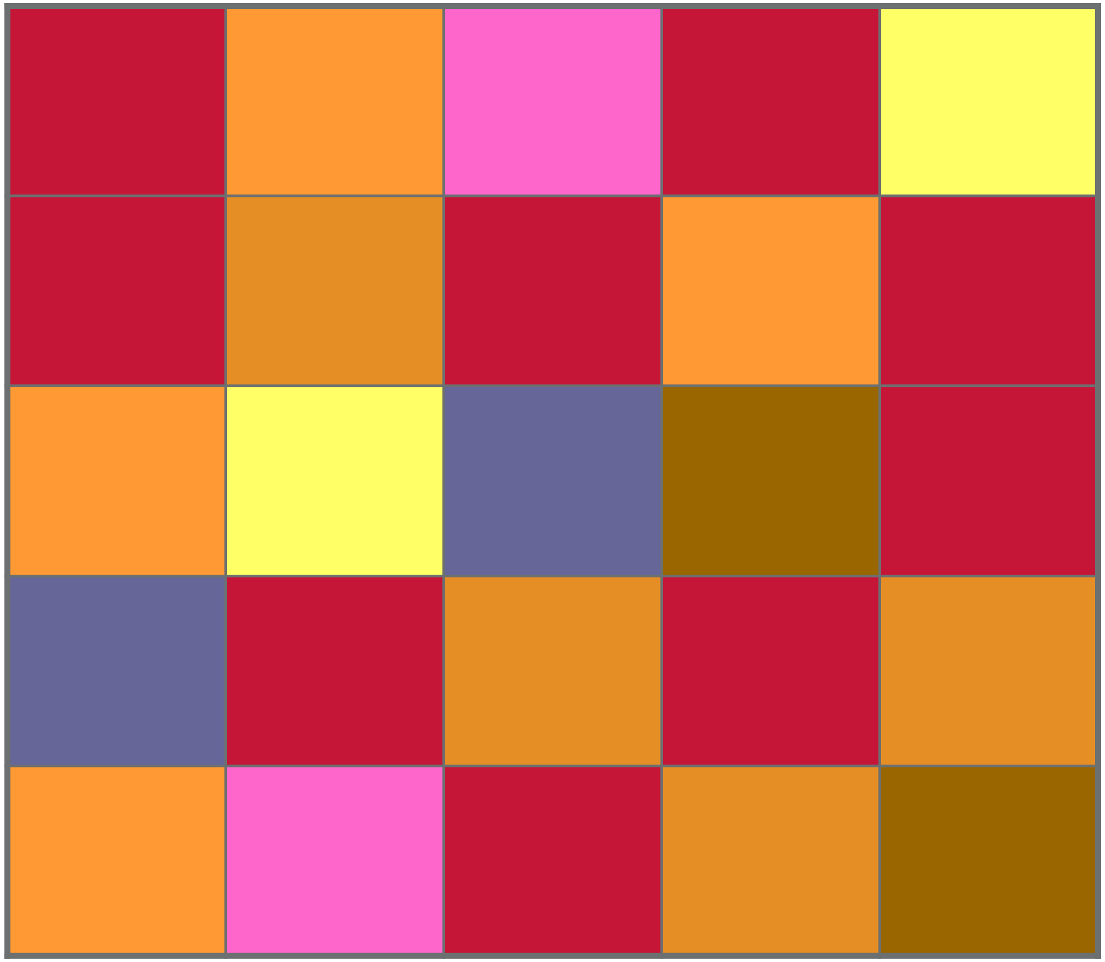
1. Ecological drift
2. Random migration
3. Random speciation

Ecological drift

J = 25 individuals

S = 7 species



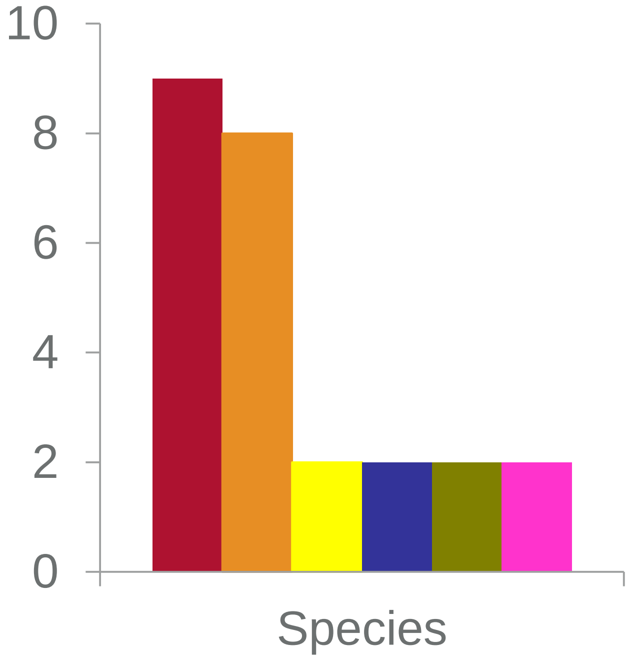


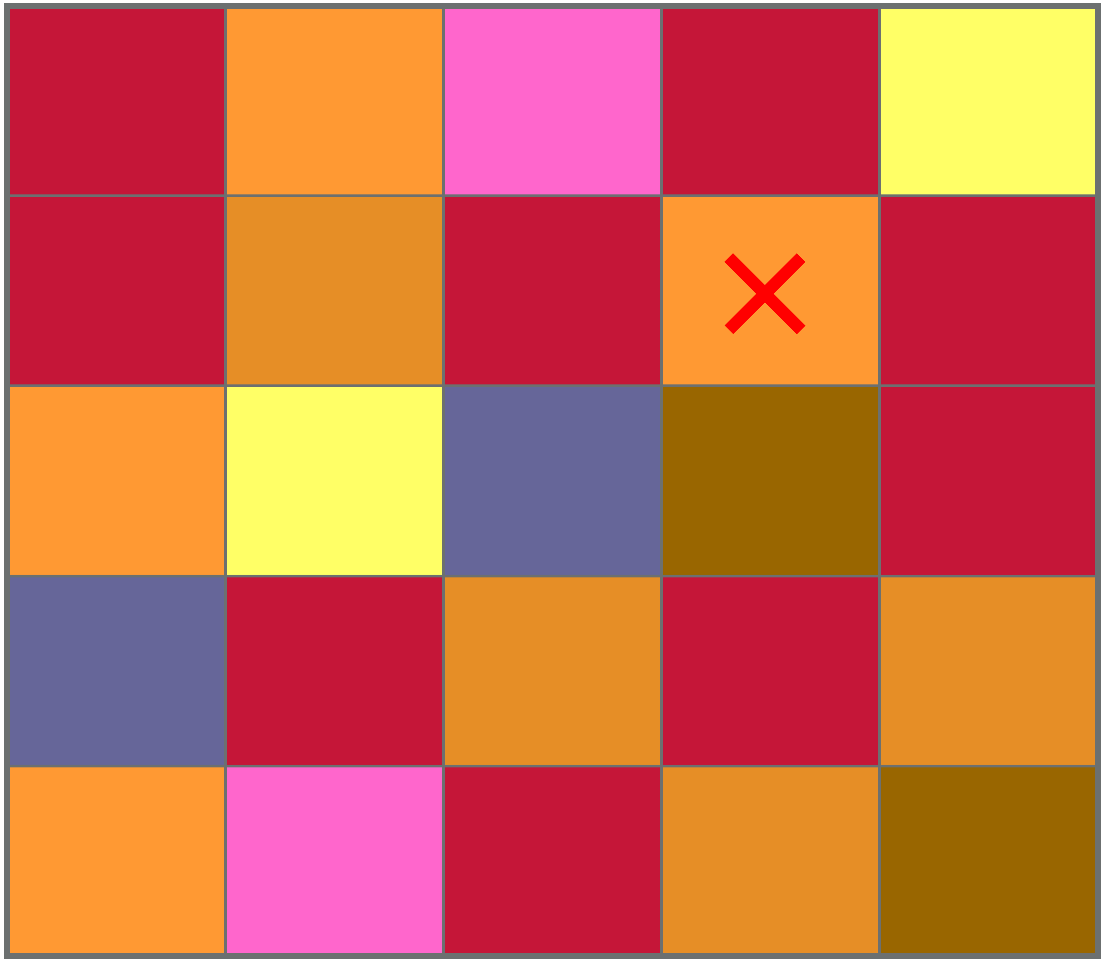
Ecological drift

J = 25 individuals

S = 7 species

Random death





Ecological drift and random migration

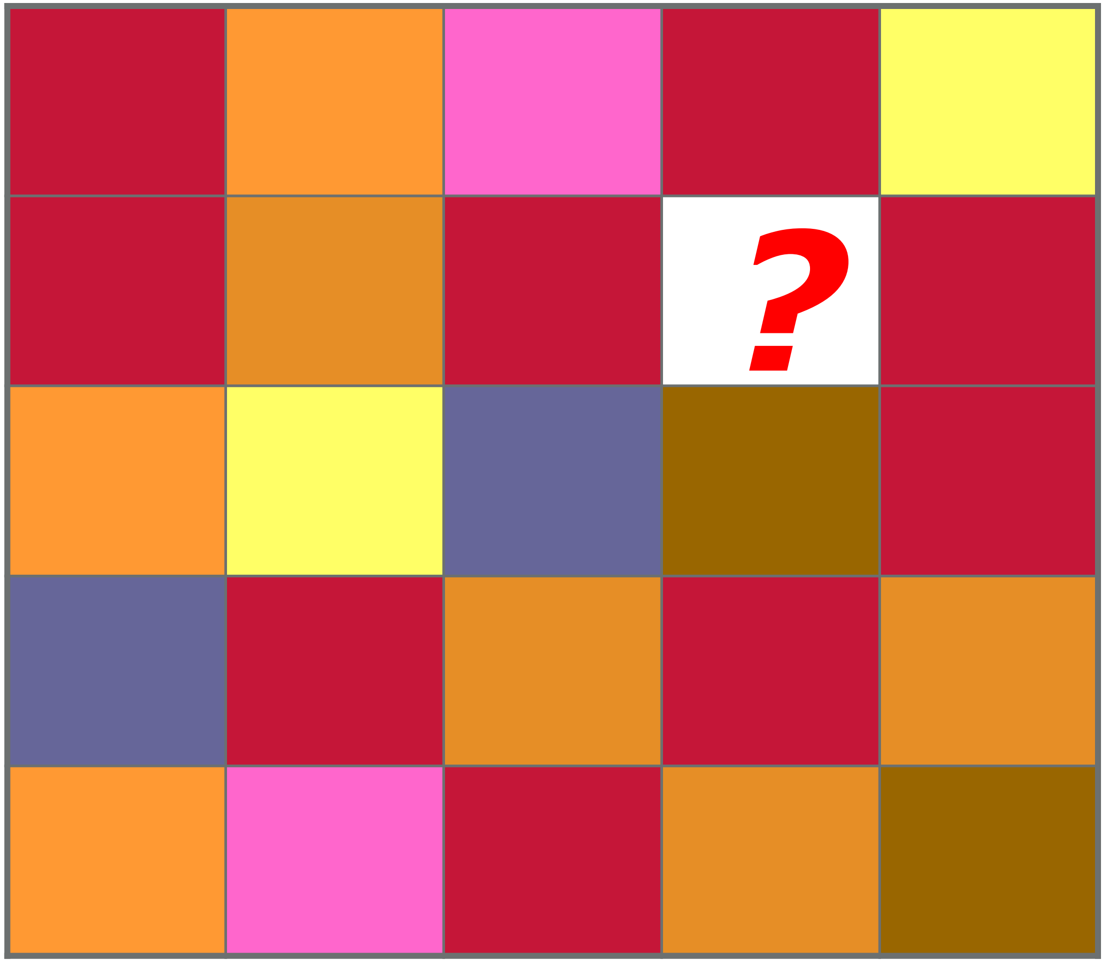
J = 25 individuals

S = 7 species

Random death

Replacement

Random migration

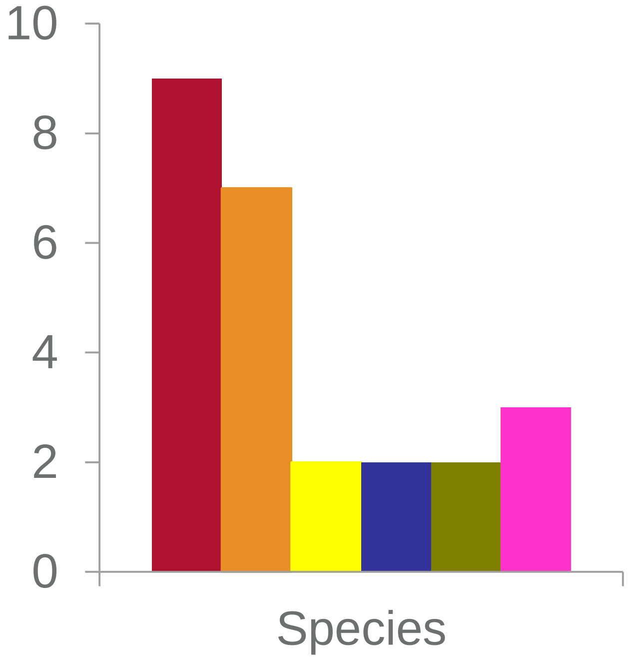


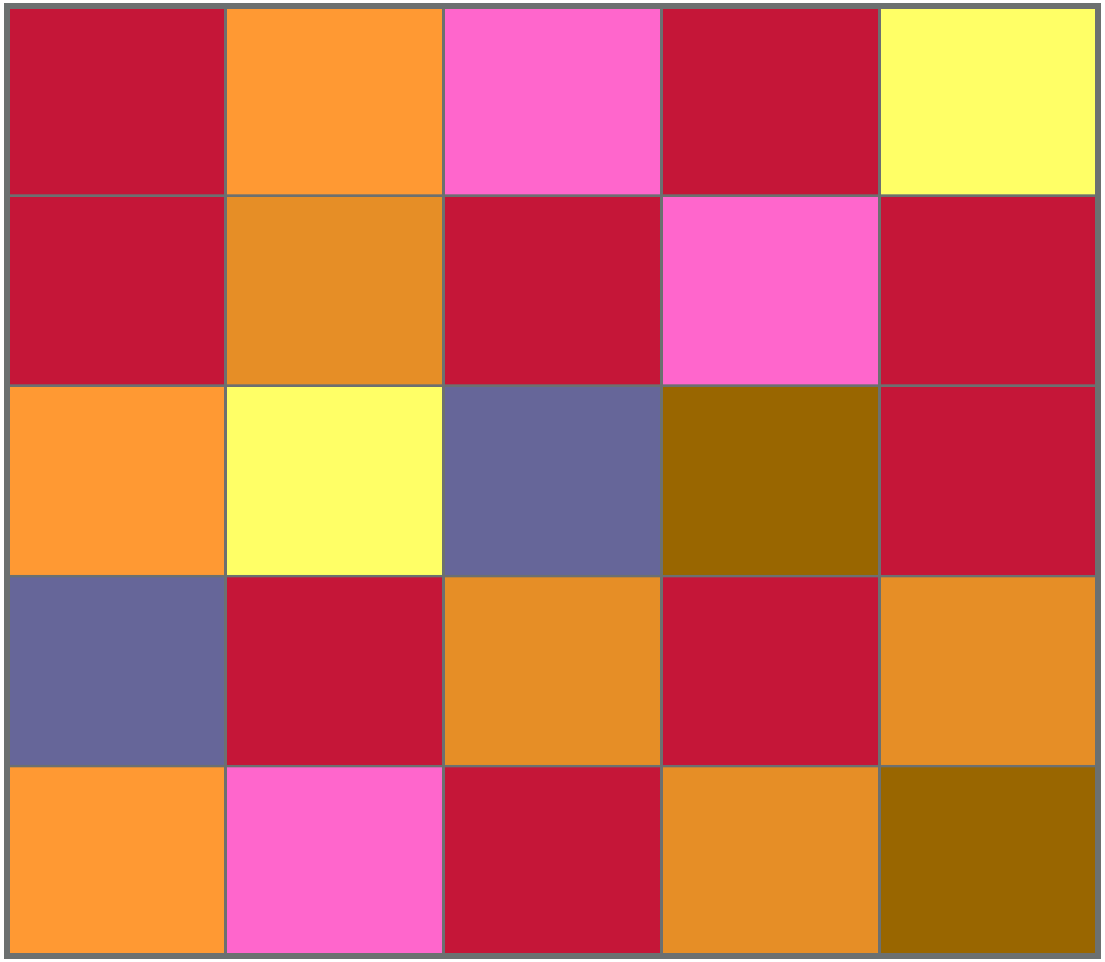
Ecological drift

J = 25 individuals

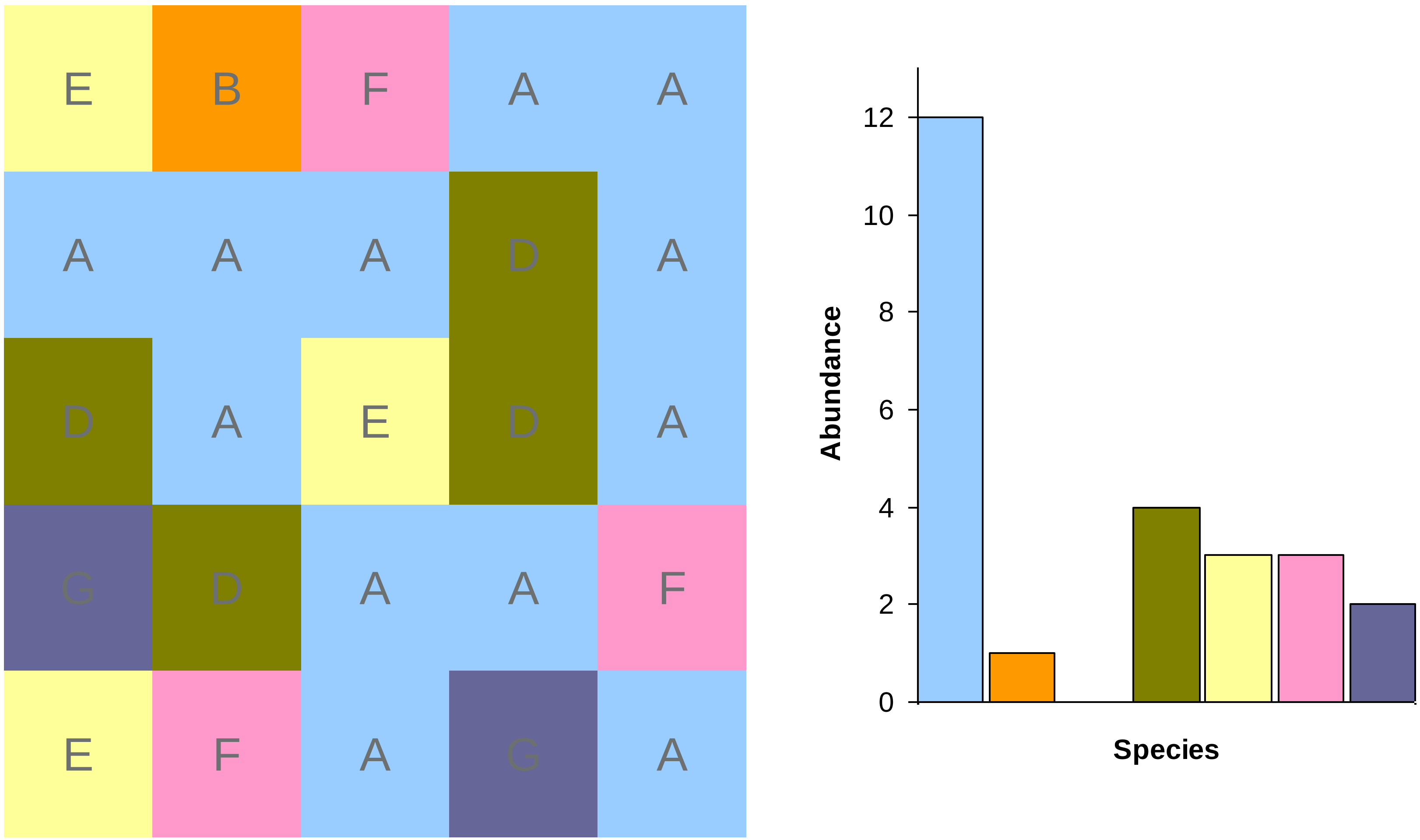
S = 7 species

Replacement





Ecological drift



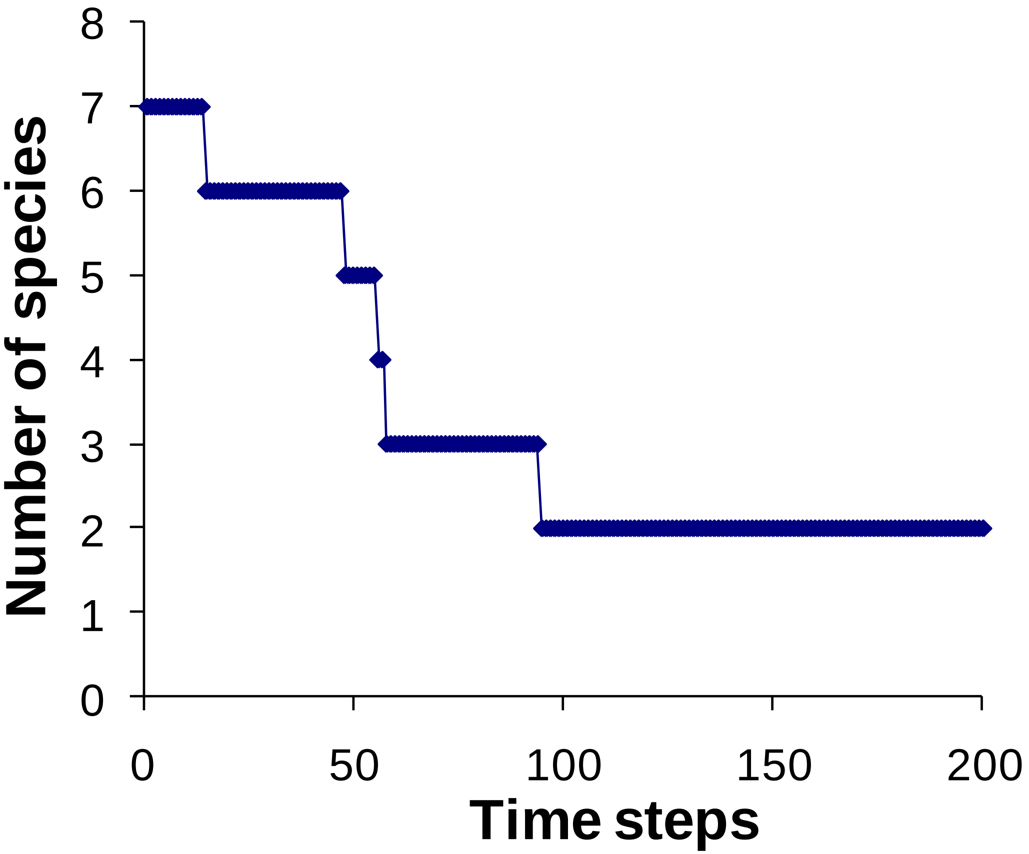
time

0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Ecological drift

Ecological drift leads to local extinction(s)

Community collapses to a single species



Time to fixation

Two possible stable states for any given species

- Local extinction
- Local monodominance

Community size

$$T \cong N_i (J - 1)[1 + \ln(J)]$$

Time to fixation

Initial abundance

Metacommunity

1. Local community
   - Relatively small spatial scale
   - Relatively rapid dynamics

2. Metacommunity
   - Relatively large spatial scale
   - Relatively slow dynamics

Assumption: constant metacommunity


A B F A E
A C A B A
B E G D A
G A C A C
B F A C D


E B F A A
A A A D A
D A E D A
G D A A F
E F A G A

Random speciation and the fundamental biodiversity number

Size of the metacommunity

$$\theta = 2 J_M v$$

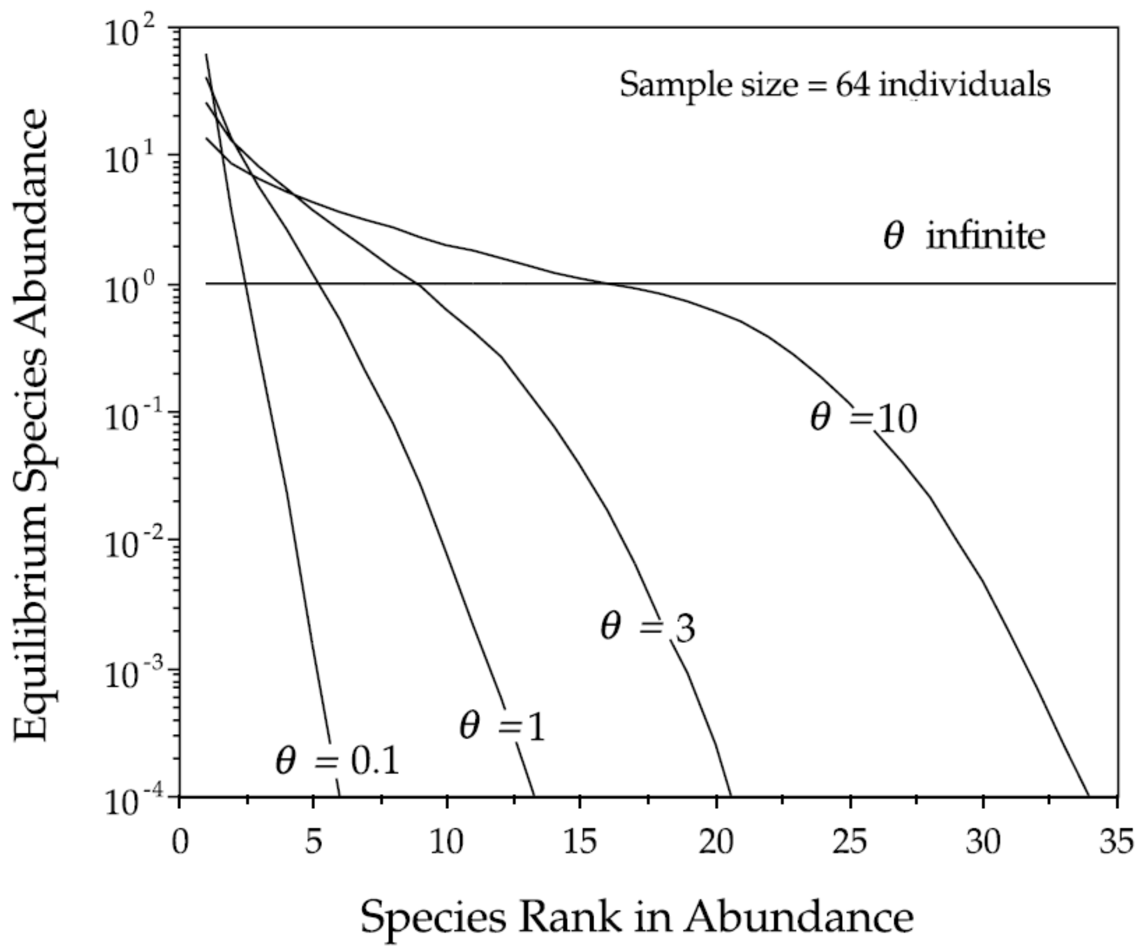
Fundamental biodiversity number

Speciation rate

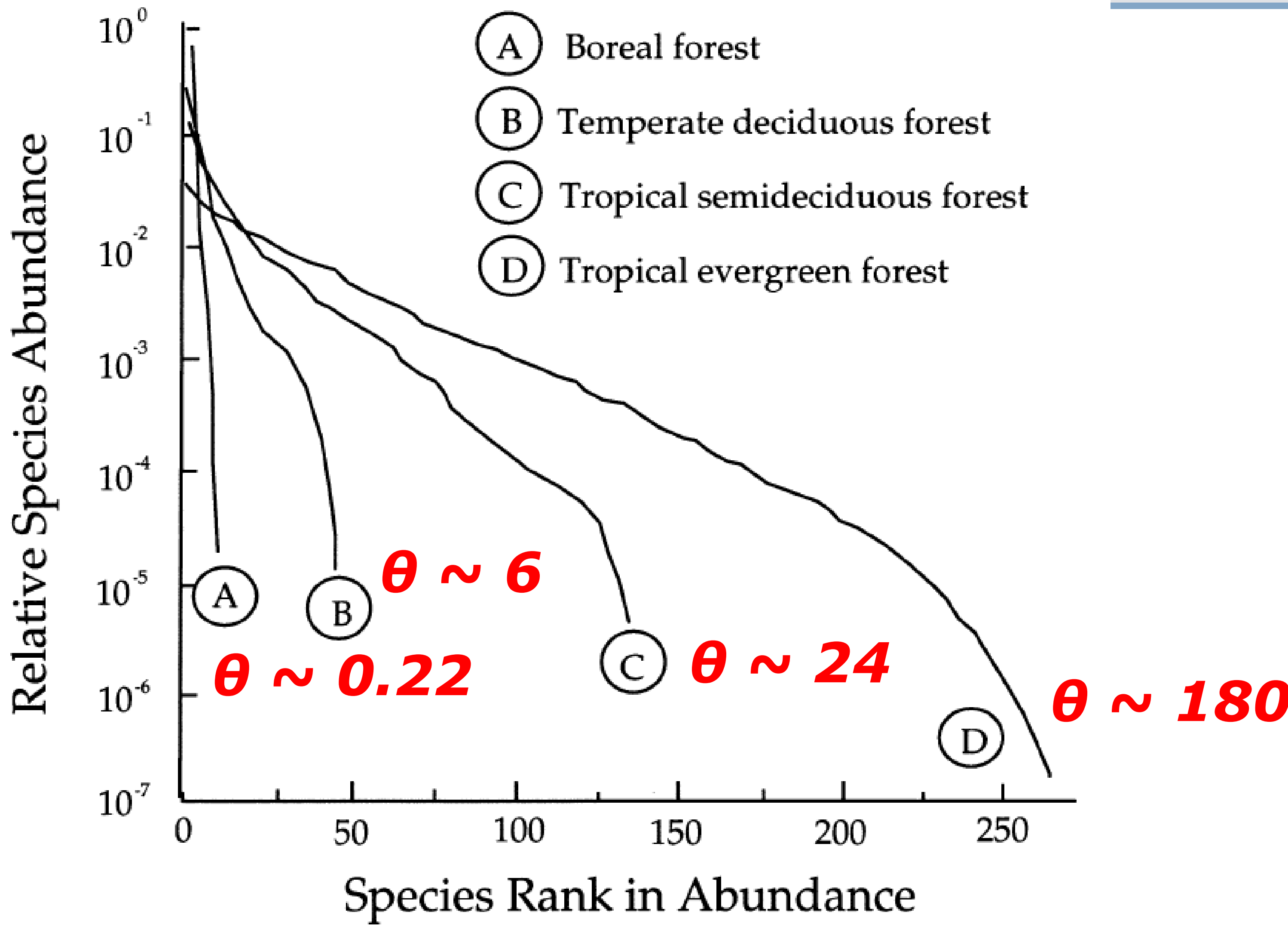
Fundamental biodiversity number

Fundamental biodiversity number (θ)

- Controls the SAD
- Equivalent to Fisher's α (and Simpson's diversity index)



Fundamental biodiversity number



Community assembly: Predicting which species will be present in a community

- Species richness
- Species abundances
- **Species identity**

Species differences and similarities

Conopophaga lineata

Conopophaga melanops

Darwin & the paradox of phenotypic similarity in closely related species

Conopophoga lineata **Conopophoga melanops**

Similar traits

↓

Adaptation to specific environment

Darwin & the paradox of phenotypic similarity in closely related species

Similar traits

↓

Competition

Environment A | Environment B

Divergent traits

Niche theory

Joseph Grinnell 1924 – defined the concept of niche

distribuional limits of species set by physical or climatic barriers

no species interactions

species potential distribution in nature (before species interaction)

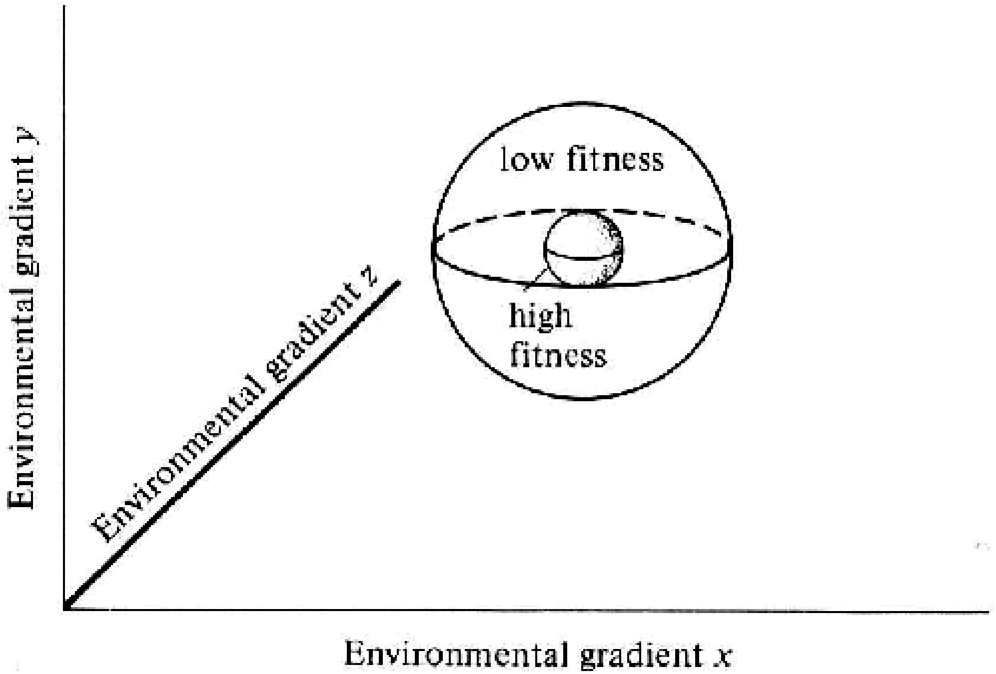
Charles Elton 1927 - niche is defined by body size and food habits

species actual distribution in nature (post-interactive)

Niche theory

G. Evelyn Hutchinson 1950s – niche as a n-dimensional hypervolume

Realised niche = fundamental niche – species interactions



Niche theory

Gause's theorem or axiom (1930-1950) – "no two species can occupy the same ecological niche"

differentiation

competitive exclusion

Relatedness, trait similarity & Darwin's paradox

Closely related species have shared evolutionary history

Closely related species should be ecologically similar

Closely related species should compete more heavily

Island Biogeography & Evolutionary theory

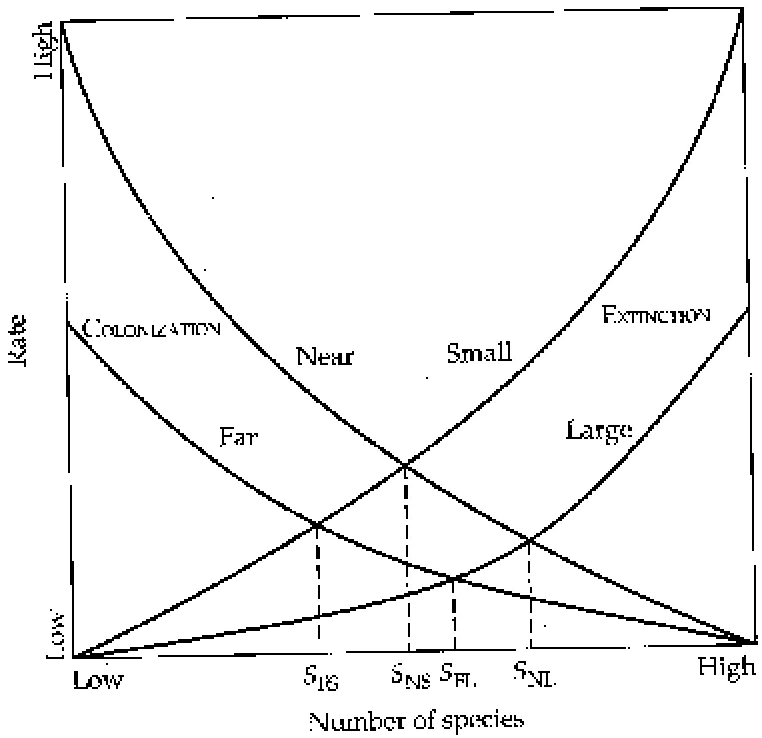
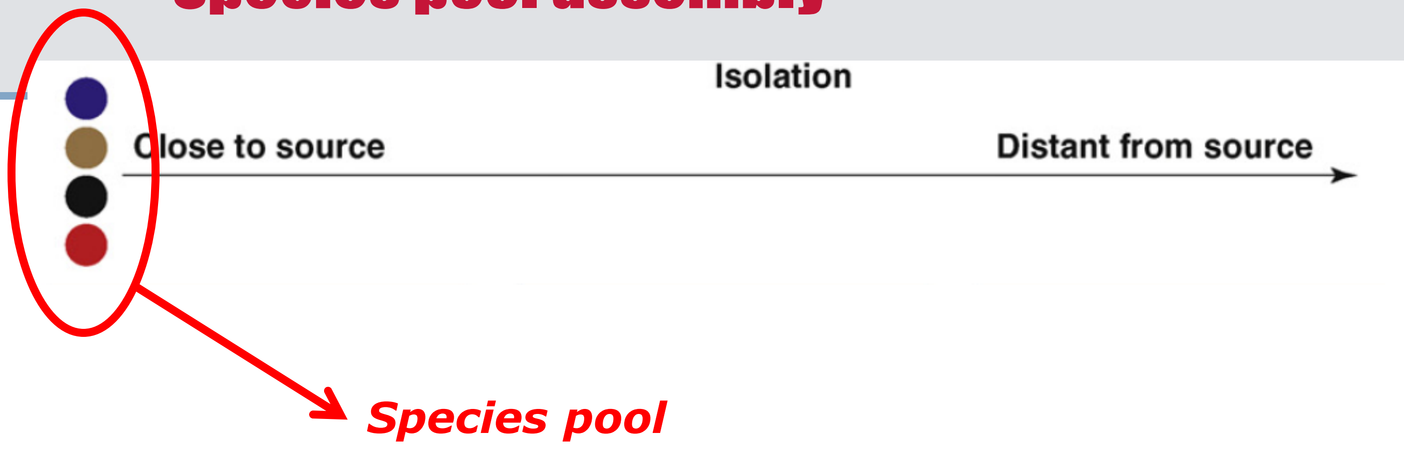


Figure from Brown and Gibson -Biogeography

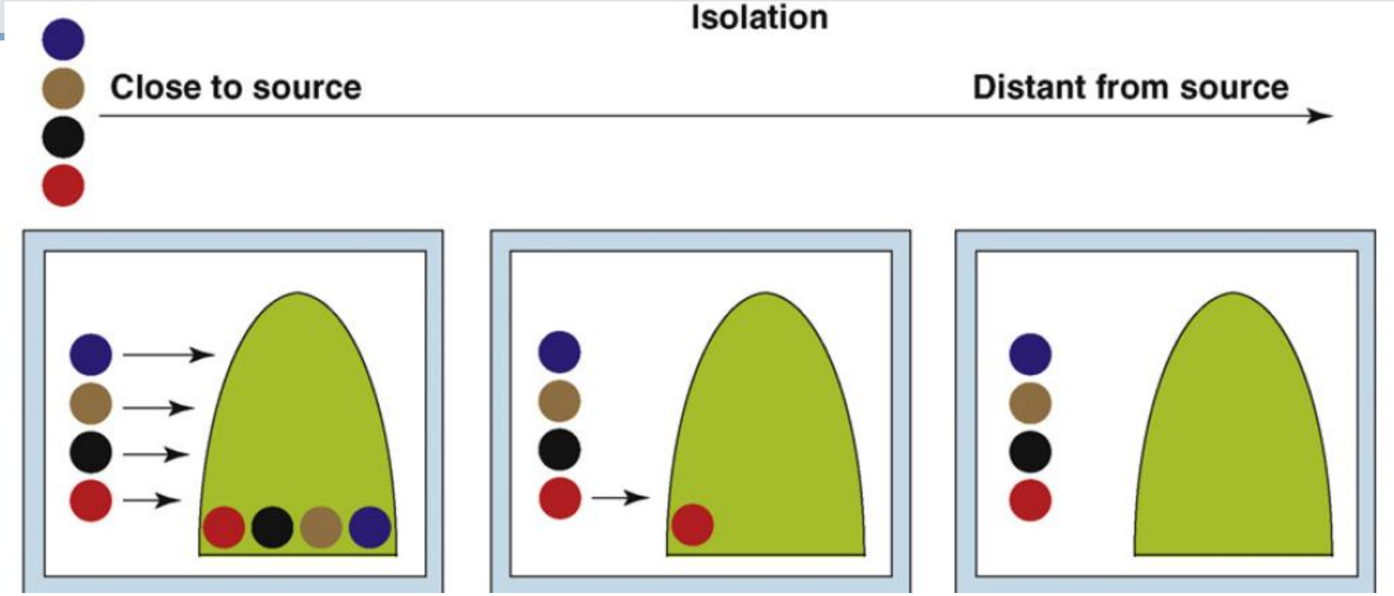
Species pool assembly



- *Time 0*

Emerson & Gillespie 2008 TREE

Species pool assembly

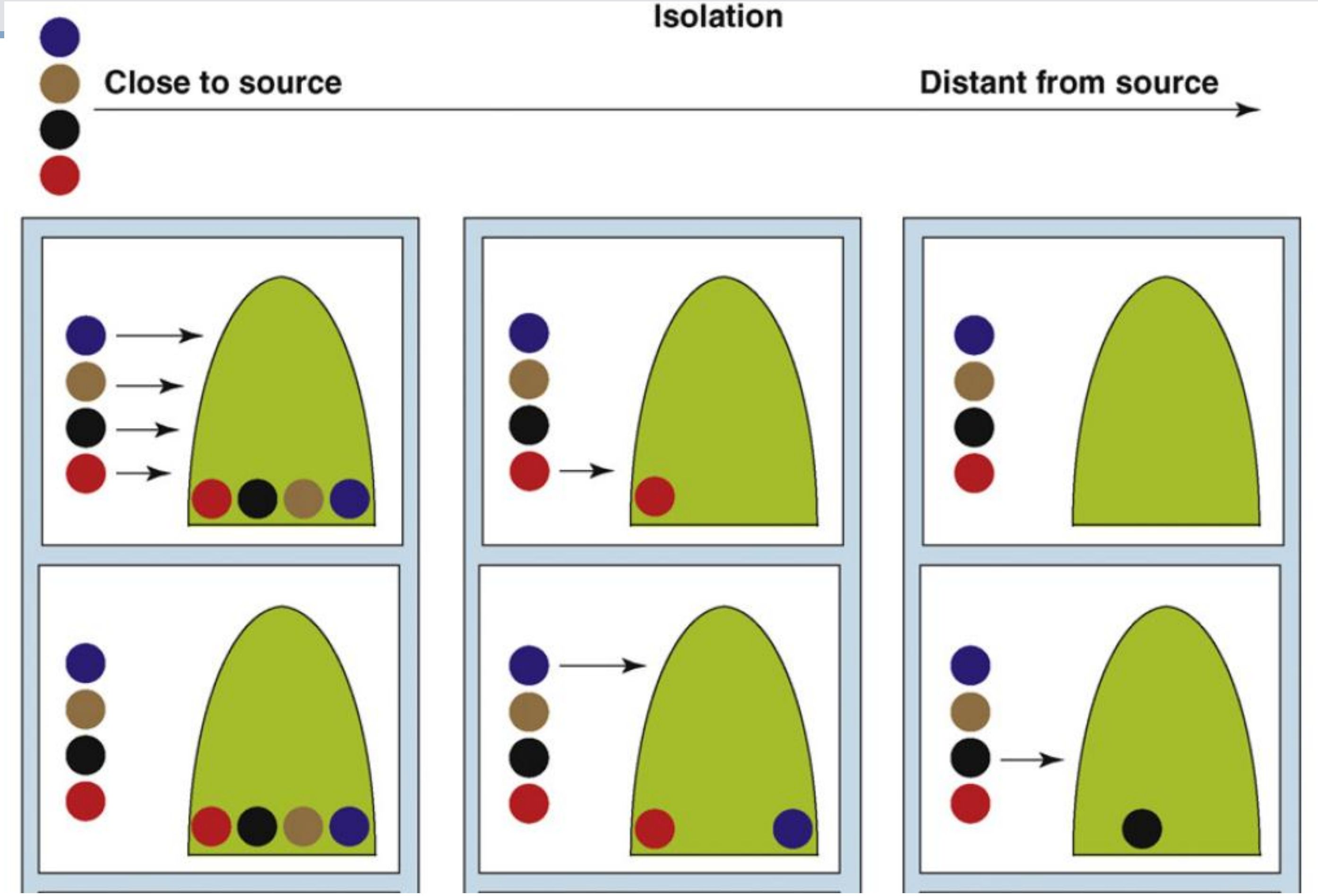


- *Time 0*
- *Time 1*

Areas close to source populations fill more quickly by colonization.

Emerson & Gillespie 2008 TREE

Species pool assembly

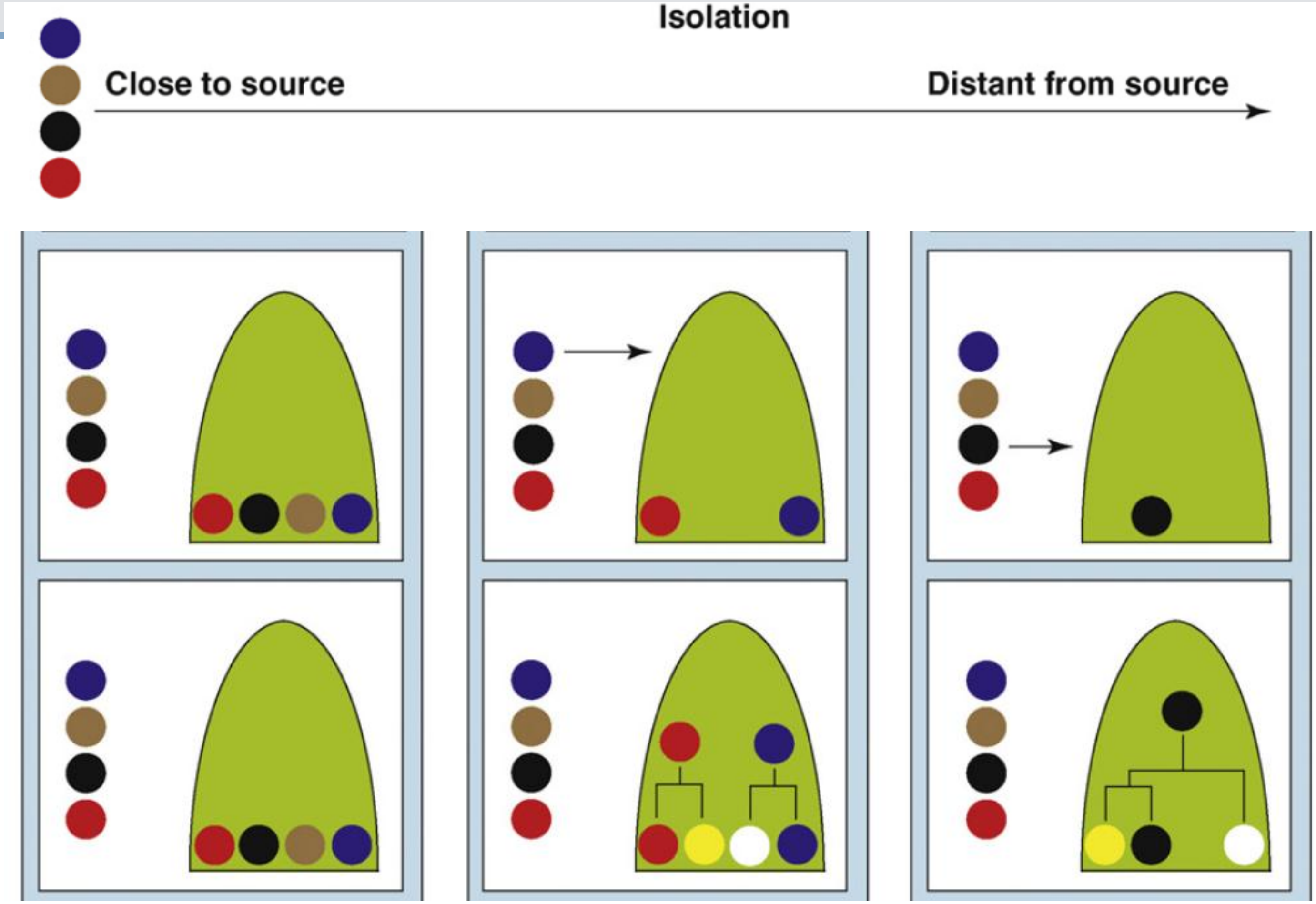


- *Time 0*
- *Time 1*
- *Time 2*

Over time, colonists reach more isolated areas.

Emerson & Gillespie 2008 TREE

Species pool assembly



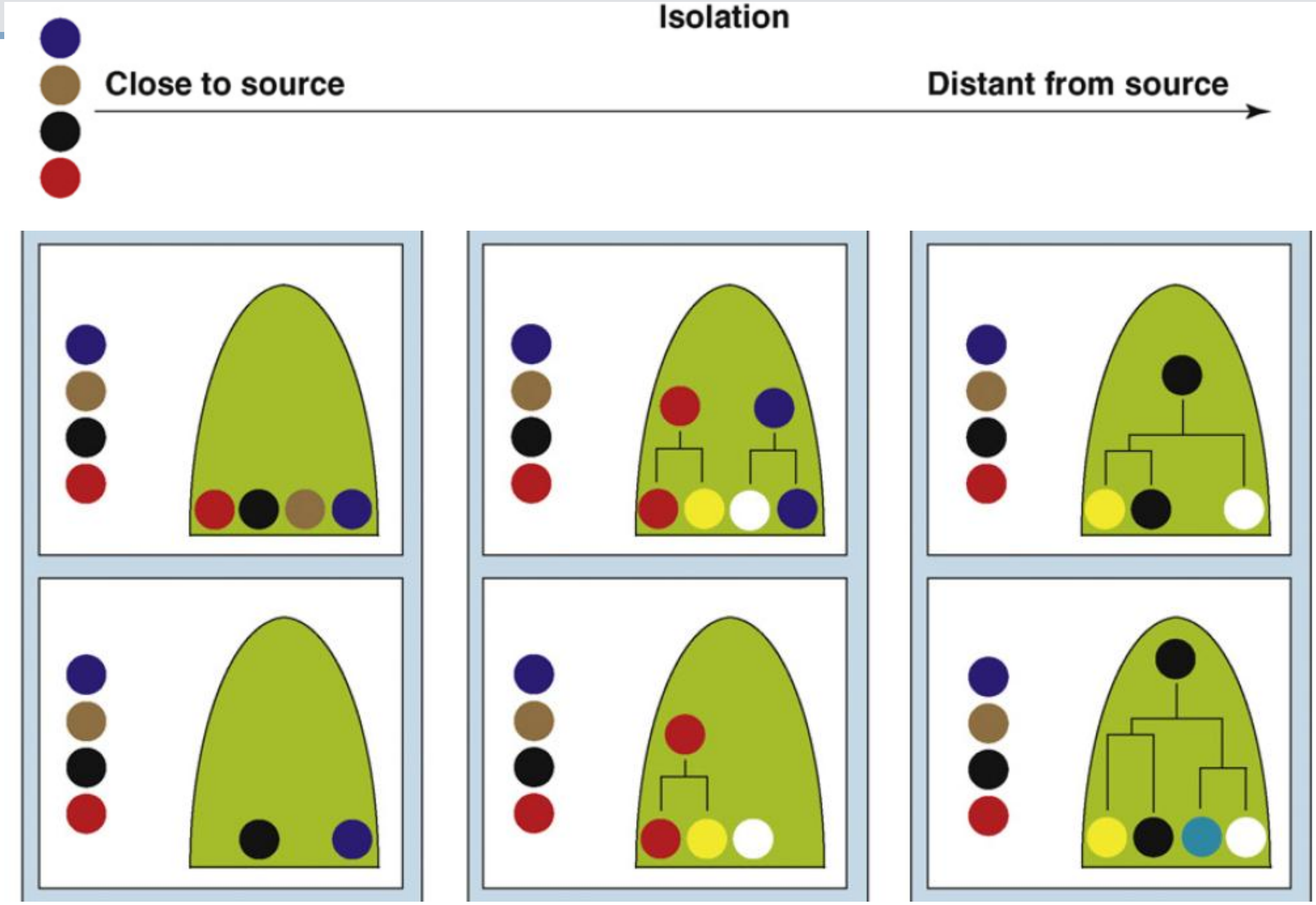
•*Time 2*

•*Time 3*

With more time, open niches on more isolated islands can be filled by evolutionary shifts within successful colonists.

Emerson & Gillespie 2008 TREE

Species pool assembly



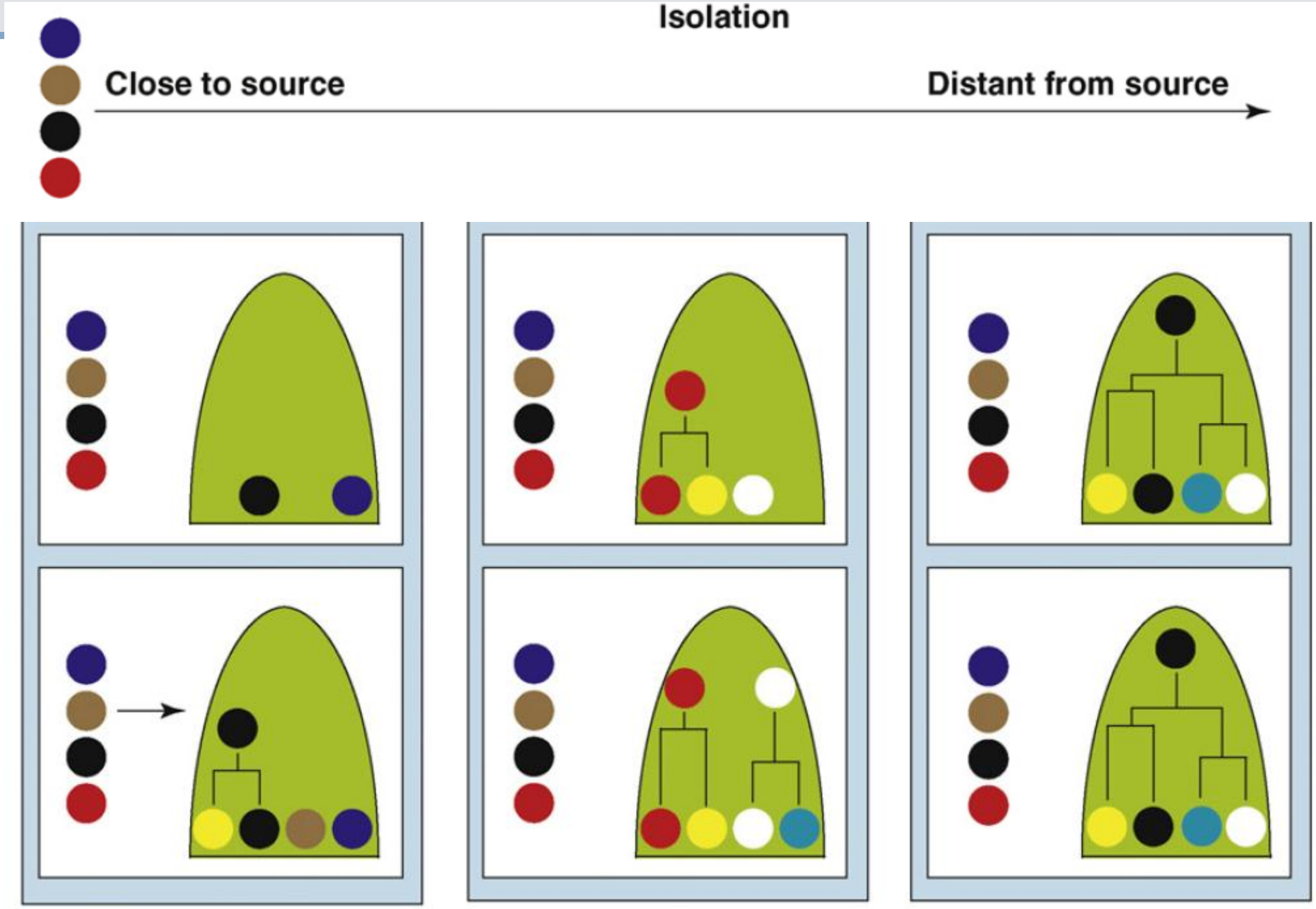
•*Time 3*

•*Time 4*

Niches that remain open continue to be filled by evolutionary shifts while extinction eliminates other species.

Emerson & Gillespie 2008 TREE

Species pool assembly



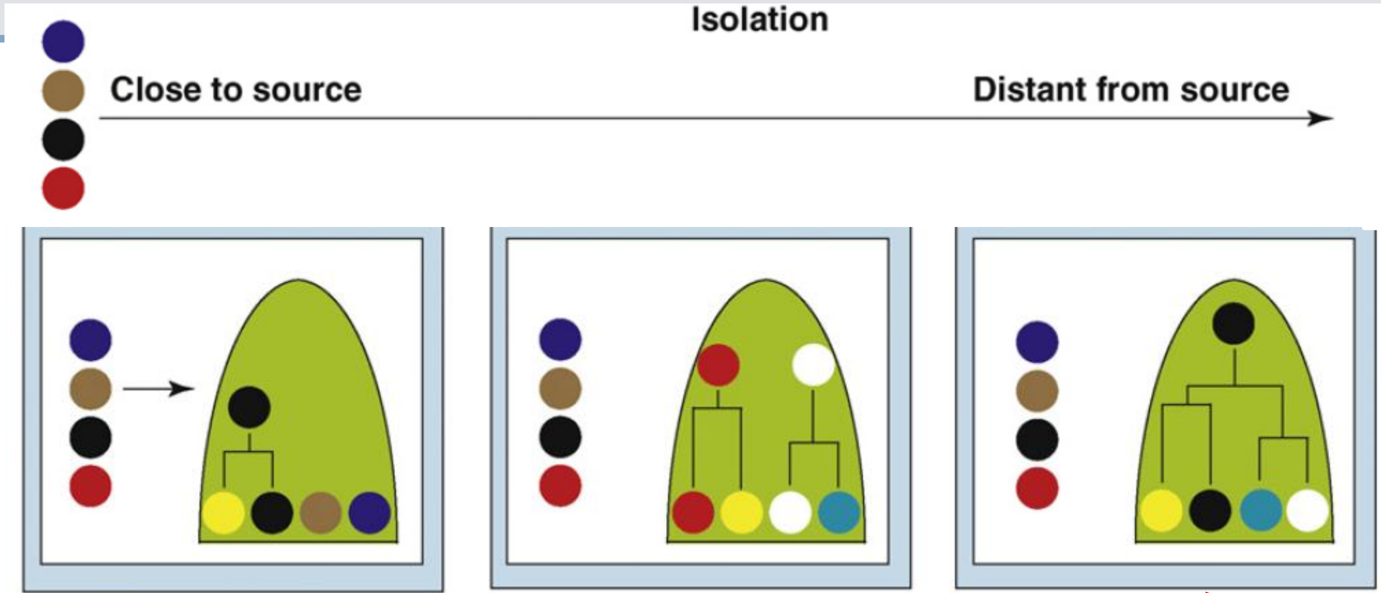
•*Time 4*

•*Time 5*

Colonization and speciation fill niches made vacant by extinction

Emerson & Gillespie 2008 TREE

Species pool assembly



•*Time 5*

Areas close to source populations: niches are filled quickly by colonization. Species subsequently lost by extinction may be replaced by speciation.

Areas more distant from source populations: niches are filled more slowly by colonization. In some cases evolution/adaptation can occur more rapidly than colonization.

Areas most distant from source populations: niches are filled so slowly that evolution/adaptation is the dominant mechanism for filling available niche space.

Emerson & Gillespie 2008 TREE

Species pool to local community

Environmental filter: the set of abiotic and biotic factors (excluding competitors) that an organism must tolerate in order to complete its life cycle.

Competitive interaction: occurs when organisms of the same, or in this case different, species either utilize a common resource that is of limited supply (exploitation), or harm each other in the process of gaining a resource that is not limited (interference).

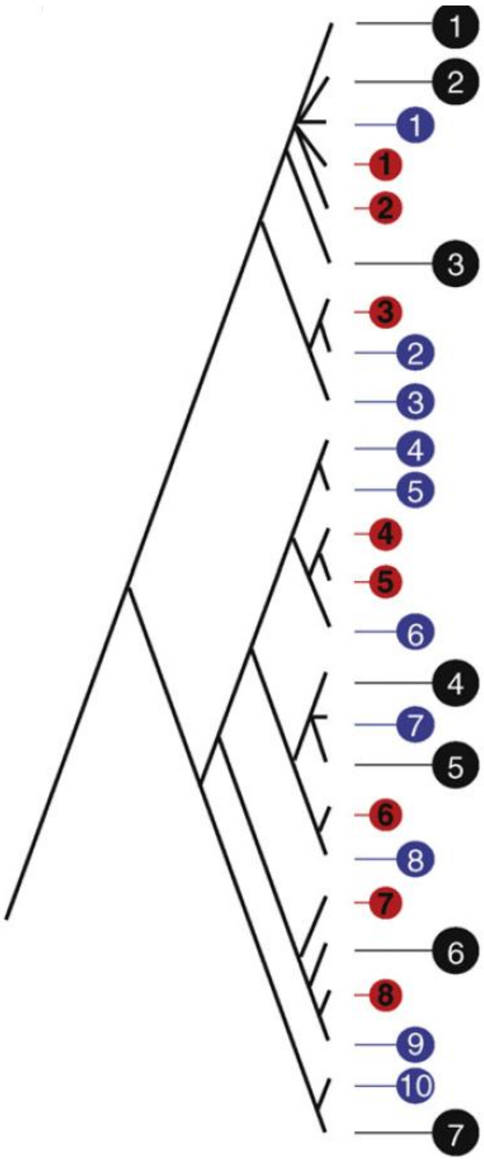
Emerson & Gillespie 2008 TREE

Process of community assembly

Phylogeny of
species in
regional pool

Emerson & Gillespie 2008 TREE

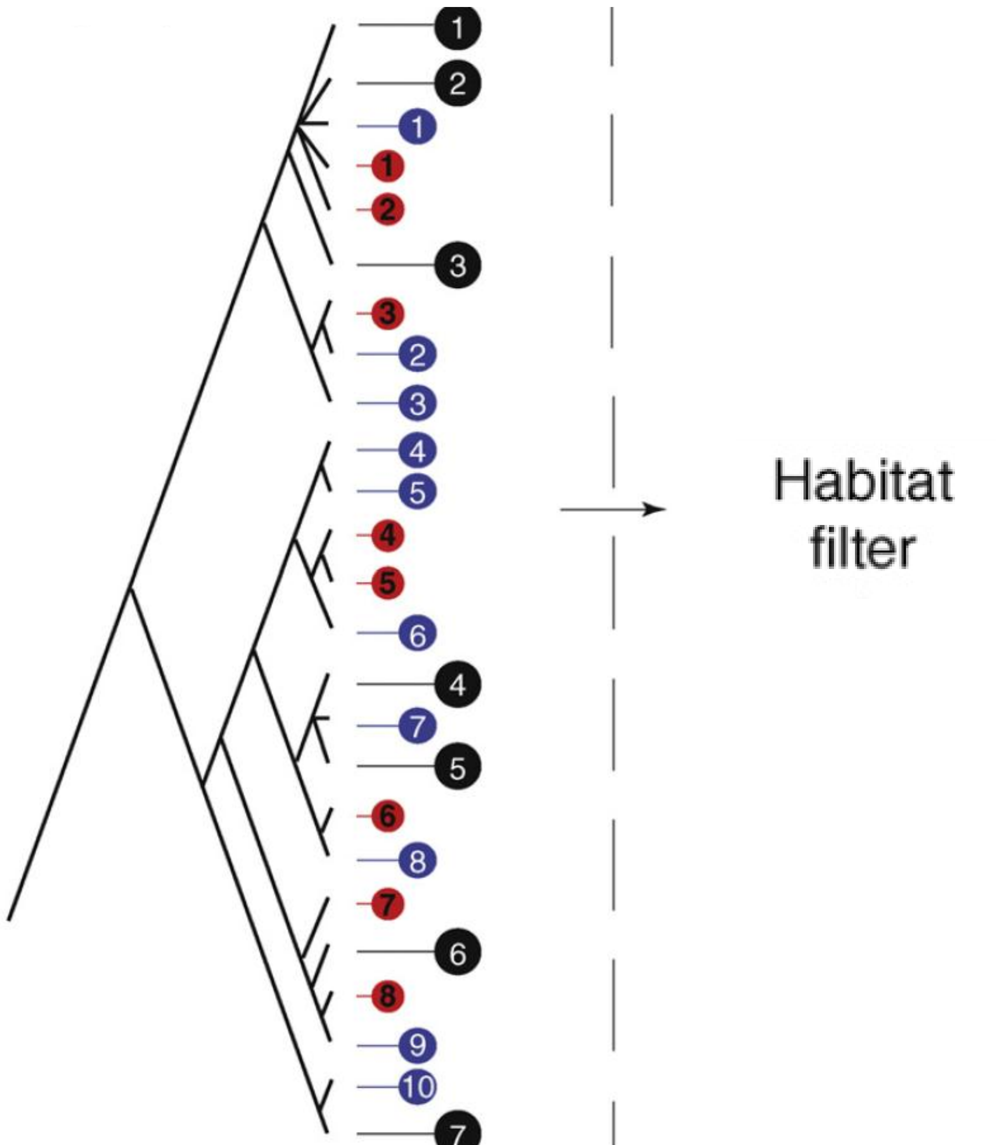
Process of community assembly



Trait
variation

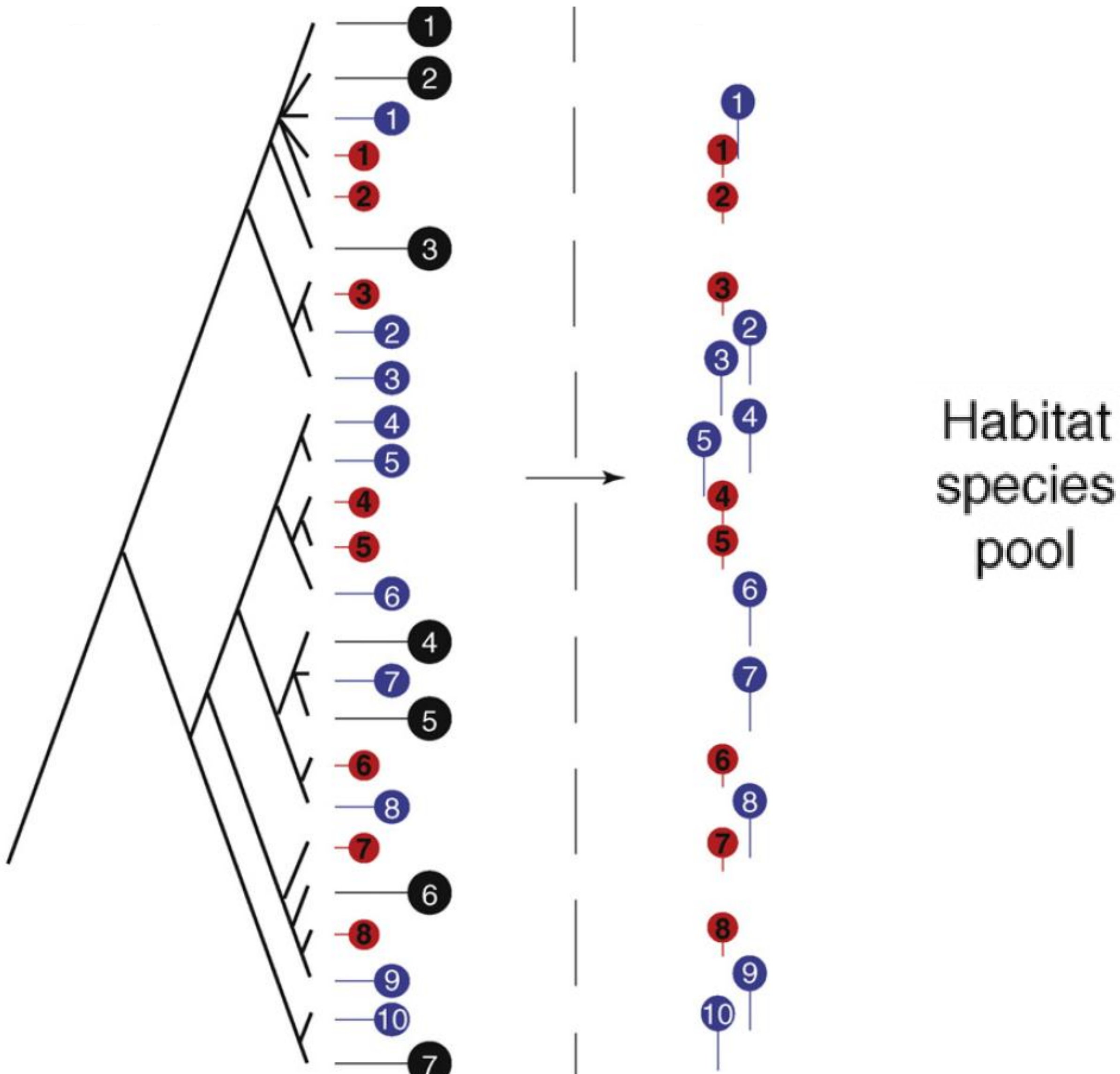
Emerson & Gillespie 2008 TREE

Process of community assembly



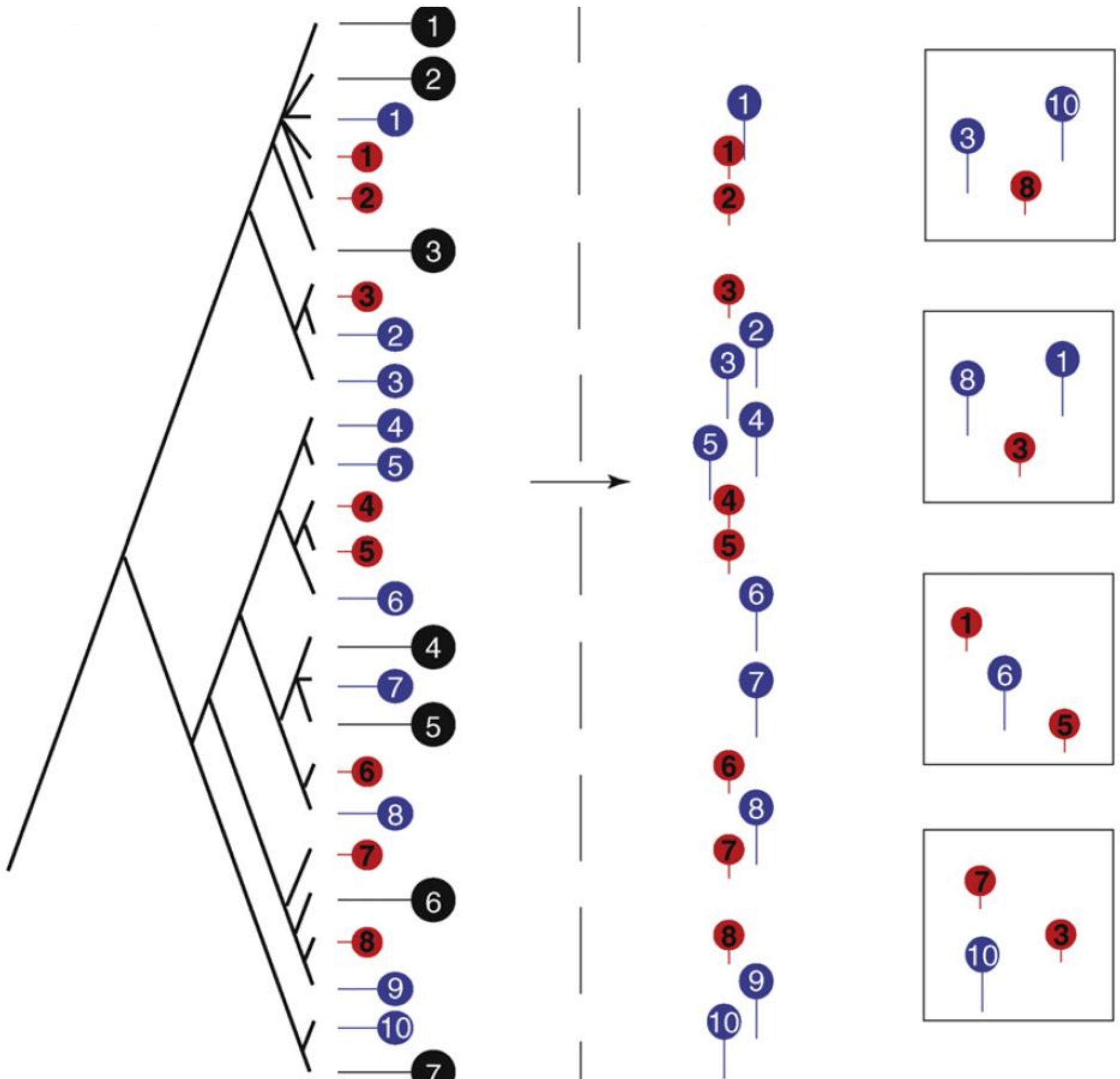
Emerson & Gillespie 2008 TREE

Process of community assembly

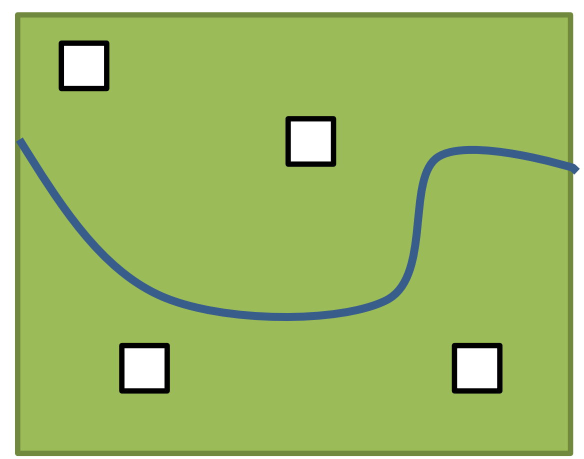


Emerson & Gillespie 2008 TREE

Process of community assembly



Communities structured by species interactions



Emerson & Gillespie 2008 TREE

Adding trait lability

Trait lability: the probability of evolutionary change in a trait. Traits associated with niche that have high lability confer a high probability of adaptive change into a new niche. Traits associated with niche that have low lability confer a low probability of adaptive change into a new niche.

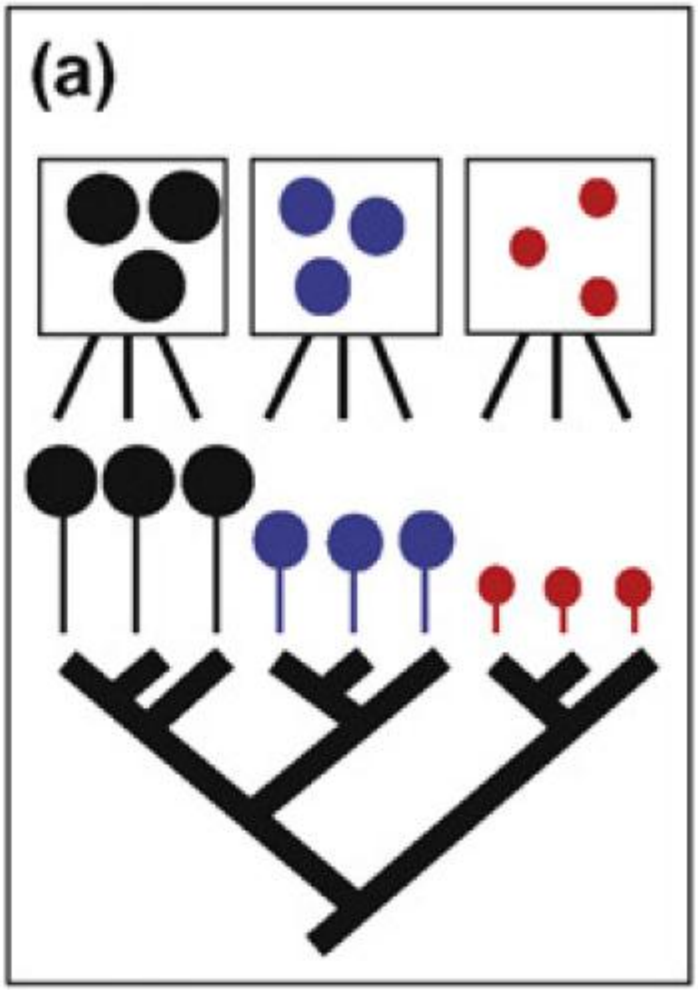
Emerson & Gillespie 2008 TREE

(credit: Johannes Burge)

Family Euphorbiacea; Genus ***Macaranga***
South-east Asia

Family Urticaceae; Genus ***Cecropia***
South America

Adding trait lability



Conserved evolution

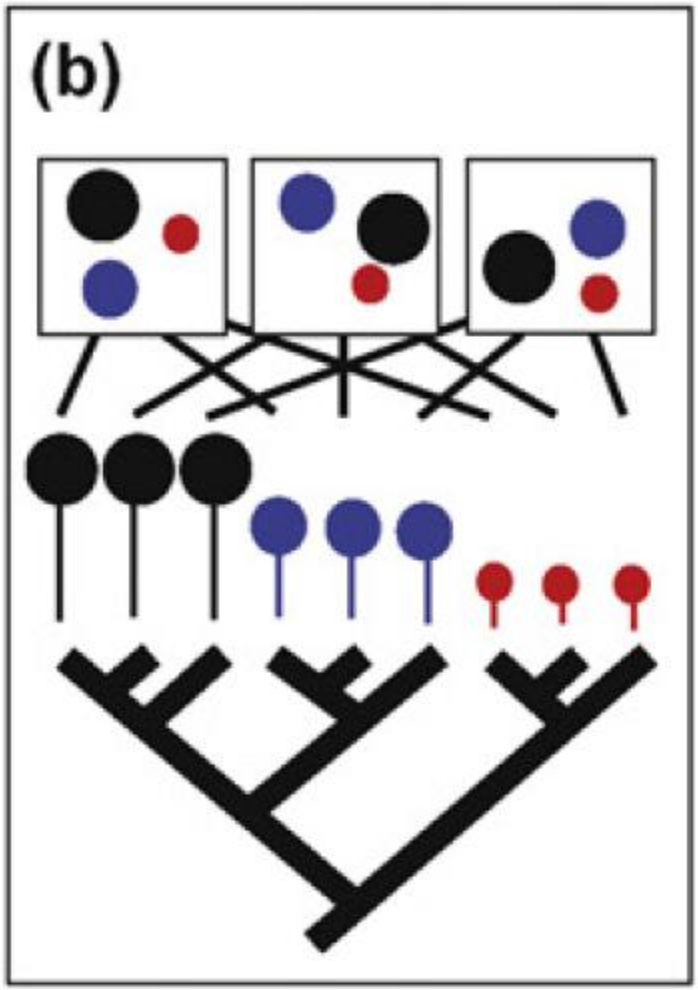
Habitat filtering > species interactions

Local community exhibits:

- Phylogenetic clustering
- Phenotypic clustering

Emerson & Gillespie 2008 TREE

Adding trait lability



Conserved evolution

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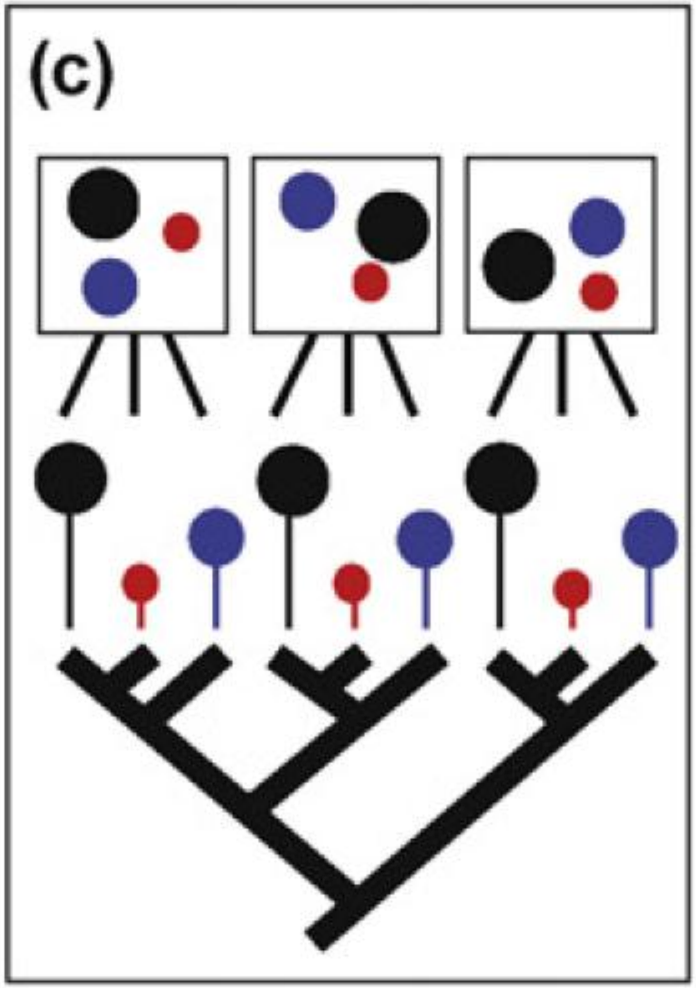
Local community exhibits:

- Phylogenetic overdispersion
- Phenotypic overdispersion

Emerson & Gillespie 2008 TREE

Adding trait lability



Labile traits

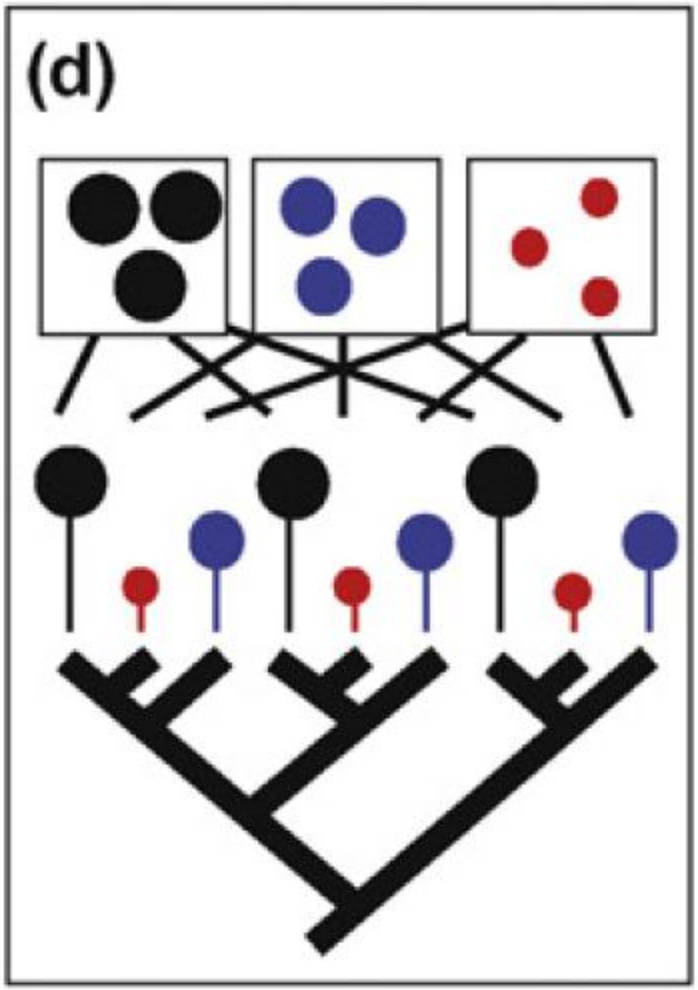
Species interactions > habitat filtering

Local community exhibits:

- Phylogenetic clustering
- Phenotypic overdispersion

Emerson & Gillespie 2008 TREE

Adding trait lability



Labile traits

Habitat filtering > species interactions

Local community exhibits:

- Phylogenetic overdispersion
- Phenotypic clustering

Emerson & Gillespie 2008 TREE

Summary

Island biogeography: species richness

Neutral theory: species richness and species-abundance distributions

Evolutionary theory: which species are present and why

Imperial College London

Why physicists and mathematicians should collaborate with and community ecologists

- A **community is** an assemblage of species that occur together in space and time. **Sum of properties of individuals and species plus their interactions**.

- **Complex systems**: “complex systems is a new approach to science that studies how relationships between parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its environment” (wikipedia)

- Communities present tendencies to change in deterministic ways but are extremely sensitive to **initial conditions**

- **Chaos theory**