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
• Multiple definitions for **stability** and **complexity**

- Species richness
- Connectance
- Interaction strength

**Variability**

**Resilience**

**Resistance**
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.”
Conclusions:
“Additional empirical study of the structure and dynamics of hybrid communities composed of various types of interactions must be pursued”.

Fig. 1. (A to D) Relationships between the proportion of mutualistic links ($\rho_M$) 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 $N = 50$. 
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

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What does neutral mean?

Per capita ecological equivalence

- Birth
- Death
- Migration
- Speciation

All individuals of all species obey exactly the same rules but individuals and species are NOT the same
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

\[ J = 25 \text{ individuals} \]
\[ S = 7 \text{ species} \]
Ecological drift

$J = 25$ individuals
$S = 7$ species

Random death
Ecological drift and random migration

\[ J = 25 \text{ individuals} \]
\[ S = 7 \text{ species} \]

Random death

Replacement

Random migration
Ecological drift

\[ J = 25 \text{ individuals} \]
\[ S = 7 \text{ species} \]
Ecological drift

Species Abundance

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

Abundance vs. Time

Species

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

Time

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
Ecological drift leads to local extinction(s)

Community collapses to a single species
Two possible stable states for any given species

- Local extinction
- Local monodominance

\[ T \approx N_i (U - 1) [1 + \ln(U)] \]
Metacommunity

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

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

Assumption: constant metacommunity
Random speciation and the fundamental biodiversity number

\[ \theta = 2J_M \nu \]

- \( \theta \): Fundamental biodiversity number
- \( 2J_M \nu \): Speciation rate
- \( J_M \): Size of the metacommunity
Fundamental biodiversity number ($\theta$)

- Controls the SAD
- Equivalent to Fisher's $\alpha$ (and Simpson's diversity index)

Graph showing the equilibrium species abundance plotted against species rank in abundance for different values of $\theta$ (0.1, 1, 3, 10, infinite). Sample size is 64 individuals.
Fundamental biodiversity number

- $\theta \approx 0.22$
- $\theta \approx 6$
- $\theta \approx 24$
- $\theta \approx 180$

A. Boreal forest
B. Temperate deciduous forest
C. Tropical semideciduous forest
D. Tropical evergreen forest
Community assembly: Predicting which species will be present in a community

- Species richness
- Species abundances
- Species identity
Species differences and similarities

- **Conopophaga melanops**
- **Conopophaga lineata**
Darwin & the paradox of phenotypic similarity in closely related species

Similar traits

Adaptation to specific environment

Conopophaga lineata

Conopophaga melanops
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”
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

Species pool

- Time 0

- Species pool assembly

- Close to source

- Distant from source

- Isolation
Species pool assembly

- **Time 0**

- **Time 1**

Areas close to source populations fill more quickly by colonization.
Species pool assembly

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

Over time, colonists reach more isolated areas.
Species pool assembly

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

Isolation

Close to source  Distant from source

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
Species pool assembly

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).
Process of community assembly

Phylogeny of species in regional pool
Process of community assembly

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Emerson & Gillespie 2008 TREE
Process of community assembly
Process of community assembly
Process of community assembly

Emerson & Gillespie 2008 TREE
**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.
Family Euphorbiaceae; 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
Adding trait lability

Conserved evolution

Species interactions > habitat filtering

Local community exhibits:
- Phylogenetic overdispersion
- Phenotypic overdispersion
Adding trait lability

Labile traits

Species interactions > habitat filtering

Local community exhibits:

- Phylogenetic clustering
- Phenotypic overdispersion
Adding trait lability

Labile traits

Habitat filtering > species interactions

Local community exhibits:
  • Phylogenetic overdispersion
  • Phenotypic clustering
Summary

Island biogeography: species richness

Neutral theory: species richness and species-abundance distributions

Evolutionary theory: which species are present and why
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**