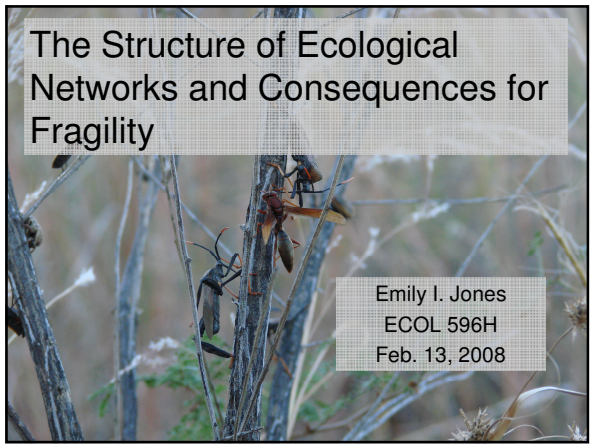


Characteristics of ecological networks

- closely connected
  - not many links separate species
- clustered
  - many species have direct links to a focal species
- compartmentalized
  - the network contains mostly independent sub-networks
- nested
  - species with few links have a sub-set of the links of other species (instead of a different set of links)

Why ecological network structure matters

- Complex ecological networks are sometimes thought to be vulnerable to disturbance, species loss, or species invasion
- Are they actually fragile and how is fragility related to network structure?

Outline

I. What are ecological networks?

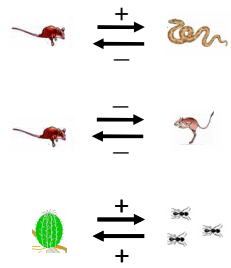
II. What makes ecological networks structurally different from other networks?

III. How does the network structure affect 'fragility' (cascading extinction of species)?

Part I: Basics of ecological networks

1. Types of interactions between species
2. Types of ecological networks
3. What network patterns (connectedness, clustering, compartmentalization, nestedness) look like in ecological networks

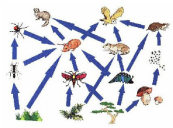
Types of interactions



- Predator-prey
  - (also herbivory and parasitism)
- Competition
- Mutualism

Types of ecological networks

- Food webs
  - Describe who eats who (flow of energy through the ecosystem)
- Mutualistic networks
  - Show links between two guilds (e.g. plants and pollinators)



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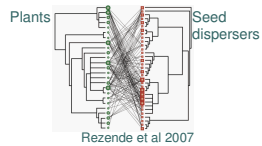
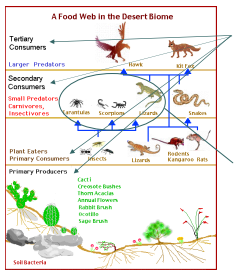


Rezende et al 2007

Types of ecological networks

- Actual ecological networks have both predator-prey and mutualistic interactions
- Furthermore, competition between species can limit the number of links they have in common

Characteristics of ecological networks



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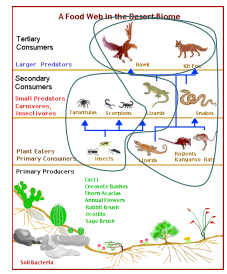
- Trophic level – position in hierarchy of predator-prey interactions
  - only a few links between top and bottom of food web = high *connectedness*
- Guild – group of species with similar connections

Characteristics of ecological networks



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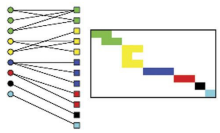
- *Compartments* – parts of the network that are mostly separate
- Omnivory – connections across multiple trophic levels
  - Can lead to *clustering*

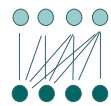
Characteristics of ecological networks



Guimaraes et al., 2007

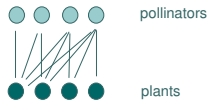
- *Compartments* – in a mutualistic network, compartments may be completely separate

Characteristics of ecological networks



- Specialists –
  - interact with one or a few species
- Generalists –
  - interact with many other species
- *Nestedness* –
  - specialists interact with a subset of those species that generalists interact with
  - often found within guilds

Characteristics of ecological networks



- Nestedness of interacting species can be very different
- Interaction strength can be asymmetrical
  - most important link for a rare species may be relatively unimportant for the linked species

Part II: The special features of ecological networks

- Properties of nodes and connections
- Network formation

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- Patterns in ecological networks

Properties of nodes and connections

- Nodes represent species or groups of species (guilds)
- Species vary in:
  - interaction type / trophic level
  - specialization vs. generalization
  - abundance
- These variables lead to a distribution in the direction, strength, and number of connections between species

Network formation

- Energy is lost between trophic levels, which constrains network structure
  - There cannot be many links between the top and the bottom of a food web → high *connectedness*
  - There are fewer species (and individuals) at higher trophic levels and these may be omnivores → *clustering*

Network formation

- More abundant species have more connections → may result in a redundancy and *nestedness* of similar connections
- Species with many connections (relative to abundance) may also have weak connections → parts of network weakly linked and *compartmentalized*

Network formation

- Phylogenetic history and coevolution can influence network structure
  - related species are likely to have more similar connections than random
  - The strength of interactions can affect specialization of species
    - Stronger interactions → compartmentalization
    - Weaker interactions → nestedness

Part III: Network structure and fragility

- Structural characteristics of fragile vs. robust networks
- Which characteristics do real ecological networks have?

Connectedness vs. compartmentalization

- When species are closely connected, effects of species loss can cascade through the network
- In contrast, compartmentalization of networks may prevent disturbances from spreading through the entire network

Keystone species

- Ecological networks should be fragile when there is dependence on 'keystone' species
  - Loss of focal species from within a cluster of species could collapse the network
  - Networks composed of many weak connections are more robust

Primary producers as 'keystone' species

- Ecological networks should be more vulnerable to the loss of primary producers
  - Loss of producers limits energy in the food web, causing secondary extinctions
  - If there are multiple, well connected primary producers, there is less risk

Nested structure

- Nested ecological networks should be more robust, as long as less connected species are the most likely to go extinct
  - More connected species should be more abundant (and less susceptible to extinction)
  - Nestedness creates redundancy in interactions

Robustness of ecological networks

- Close connectedness and clustering around 'keystone' species could allow a cascade of secondary extinctions
- However, nestedness, compartmentalization, and in general, a high proportion of weak links can limit cascading effects even when the network has high connectedness and clustering

Robustness of ecological networks

- Even if ecological networks are robust to ‘normal’ levels of disturbance, will they continue to be robust with the current increased rate of disturbance?
- An understanding of the structures of real networks can help identify which species are important to conserve