Structure et dynamique des communautés écologiques

(i)
Structure of interaction networks, indirect interactions and processes shaping networks

Colin Fontaine

Aussois 2021
By the side of many of these nests a small flying-fish was placed; which, I suppose, had been brought by the male bird for its partner...quickly a large and active crab (Craspus), which inhabits the crevices of the rock, stole the fish from the side of the nest, as soon as we had disturbed the birds. Not a single plant, not even a lichen, grows on this island; yet it is inhabited by several insects and spiders. The following list completes, I believe, the terrestrial fauna: a species of Feronia and an acarus, which must have come here as parasites on the birds; a small brown moth, belonging to a genus that feeds on feathers; a staphylinus (Quedius) and a woodlouse from beneath the dung; and lastly, numerous spiders, which I suppose prey on these small attendants on, and scavengers of the waterfowl.
From species list to interaction networks

- spiders
- fly
- acarus
- moth
- crab
- gannet
- terne
- fish
- rove bettle
- woodloose
- dung
From species list to interaction networks

- spiders
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- dung

= species
= trophic interaction
Diversity of ecological interactions

- Mutualism
- Commensalism
- Amensalism
- Competition
- Predation
- Neutralism
Interaction among species and species traits

Brose et al. (2006)
Interaction among species and species traits

Tradeoffs affecting pollinator attraction

(A) Wasp 1 (N. monticola)
(B) Wasp 2 (N. sp. aff. impatiens)
(C) Wasp 3 (N. sp. aff. reticulata)

Tradeoffs affecting pollinator morphological fit

(D) Bats
(E) Hummingbirds

Phillips et al. 2020
Networks of different interaction types

- 75% food webs
- 10% mutualistic webs
- 5% parasitic webs

Ings et al. 2009

Food web

Mutualistic web

Host-parasite web
(i) Structure of ecological networks

Food Web of Little Rock Lake, Wisconsin

997 feeding links among 92 taxa

Link color indicates type of feeding link
Node color indicates trophic level of taxa

Structure of trophic network and compartments

Trophic groups and modules: two levels of group detection in food webs
Benoit Gauzens1,2, Elisa Thébault1, Gérard Lacoux1,3 and Stéphane Legendre4
J. R. Soc. Interface 12: 20141176

Compartmentalization in food webs

Compartments revealed in food-web structure
Ann E. Krause, Kenneth A. Frank, Doran M. Mason, Robert E. Ulanowicz and William W. Taylor

Compartment and predation in an estuarine food web
DAVID RAFFAELLI and STEPHEN J. HALL*
Culterry Field Station, University of Aberdeen, Newburgh, Ellon, Aberdeen AB4 0AA, Scotland; and
*SOAFD Marine Laboratory, P.O. Box 101, Victoria Rd, Aberdeen AB9 5DB, Scotland

Origin of compartmentalization in food webs

LETTER
Compartments in a marine food web associated with phylogeny, body mass, and habitat structure

(a)
(b)
Different ways of making groups

Trophic groups

(a)

Compartment

(b)

Gauzens et al. 2015
Mutualistic networks and nestedness

- Continuum between specialist and generalist species
- Presence of a core of highly connected species
- Asymmetrical specialization

Bascompte et al. 2003
Mutualistic networks and nestedness
Network architecture and interaction type

Mutualistic

34 plant-pollinator webs

Antagonistic

24 plant-phytophagous insect webs
Network architecture and interaction type

**commensal**

**commensal/parasitic**

**parasitic**

Blick & Burns, 2011
and interaction intimacy?

mostly grasshoppers
mostly leaf-miners
and interaction intimacy?

Mutualistic interactions

Antagonistic interactions

Guimaraes et al. 2007

van Veen et al. 2008
Interaction type and interaction intimacy

Interaction type: mutualistic, antagonistic
Intimacy: low, high

A

B

Stronger effect of interaction intimacy on mutualistic web

Fontaine et al., 2011
On the importance of sampling effects when analysing numerous networks from various origins

A database of 295 pollination networks

Looking for effects of:

- Anthropogenic disturbances
- Climate
- Sampling effort and protocol

on network richness and species generalism

Doré et al. (2020)
Networks combining multiple interaction types

Pocock et al. (2012)

Need for new sampling methods as well as metrics accounting for

Sauve et al. (2016)

e.g. correlation in plant generalism degree between pollination and herbivory

A farm food web

Sauve et al. (2016)
Networks combining multiple interaction types

- 106 species
- 1362 trophic links
- 3089 interference/competition for space links
- 172 habitat/refuge provisioning links
Pairwise interactions are governed by species traits

The structure of ecological networks varies depending on the type of interaction (mutualistic vs antagonistic; intimate vs non-intimate)

Comparing the structure among networks needs to account for sampling heterogeneity

Integrating several interaction types within networks is in its infancy and require new datasets and metrics
(ii)
Indirect interactions and community dynamic
Foodwebs, network motifs and indirect interactions
Foodwebs, trophic chains and trophic cascades

Otter extinction

See urchin explosion

Over-consumption of kelp

Extinction of species inhabiting kelp forests

Estes & Palmisano 1974
Foodwebs, trophic chains and trophic cascades
If an equilibrium exist with three species, then:

- \( \frac{dR}{dt} = R(r(1 - R/K) - a_{NR}N) \)
- \( \frac{dN}{dt} = N(e_{NR}a_{NR}R - d_N - a_{PN}P) \)
- \( \frac{dP}{dt} = P(e_{PN}a_{PN}N - d_P) \)

- \( R^* = K\left(1 - \frac{a_{NR}}{r}N^* \right) \)
- \( N^* = \frac{d_p}{e_{PN}a_{PN}} \)
- \( P^* = \frac{1}{a_{PN}}(e_{NR}a_{NR}R^* - d_N) \)

- \( r \) = intrinsic growth rate of \( R \)
- \( K \) = carrying capacity of \( R \)
- \( a_{NR} \) et \( a_{PN} \) are attack rates
- \( e_{NR} \) et \( e_{PN} \) are conversion efficacies
- \( d_N \) et \( d_P \) are mortality rates

Oksanen 1981
Foodwebs, trophic chains and trophic cascades

Wootton & Power, 1993
Trophic chains: bottom-up and top-down effects

- Trophic chain with four levels:

\[
P_2^* = \frac{1}{a_{P2P}}(e_{PN}a_{PN}N^* - d_P)
\]

\[
p^* = \frac{d_{P2}}{e_{P2P}a_{P2P}}
\]

\[
N^* = \frac{1}{a_{NR}} \left(1 - \frac{R^*}{K}\right)
\]

\[
R^* = \frac{d_N + a_{PN}P^*}{e_{NR}a_{NR}}
\]
Trophic chains: bottom-up and top-down effects

Alternation of control by predators and resources in a trophic chain depending on the number of trophic levels

Hairston et al. 1960
Foodwebs, sharing of predator and apparent competition

Bonsall & Hassell, 1997
Foodwebs, sharing of predator and apparent competition

Morris et al., 2004
Foodwebs, interference and coexistence

A. ervi

A. pisum  M. viciae

V. faba

van Veen & al. Ecology, 2005
Foodwebs, interference and coexistence

Lotka-Volterra competition model

\[ \frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2) \]
\[ \frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{21} N_1 - \alpha_{22} N_1) \]

Lotka-Volterra predator-prey model

\[ \frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1) - N_1 \frac{\alpha_{1p} P}{1 + b N_1} \]
\[ \frac{dP}{dt} = N_1 \frac{\alpha_{1p} P}{1 + b N_1 + c P} - \mu P \]

(i) Intra and interspecific competition for hosts
(ii) hyperbolic (Type II) functional response
(iii) density dependent parasitoid recruitment

van Veen & al. Ecology, 2005
Foodwebs, interference and coexistence

\[ \frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2) - N_1 \frac{\alpha_{1P} P}{1 + bN_1} \]

\[ \frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{22} N_2 - \alpha_{21} N_1) \]

\[ \frac{dP}{dt} = N_1 \frac{\alpha_{1P} P}{1 + bN_1 + cP} - \mu P \]

\[ \frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2) - N_1 \frac{\alpha_{1P} P}{1 + bN_1 + \omega N_2} \]

\[ \frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{22} N_2 - \alpha_{21} N_1) \]

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Trait mediated indirect effect: Interference of M. viciae with searching behaviour of the parasitoid.

van Veen & al. Ecology, 2005
Indirect interactions have strong effects on species abundances and coexistence.

Network approaches allow understanding cascading effects within communities which are pervasive.
(iii)
Processes shaping the network architecture of a multilevel antagonistic network

From Rezende et al. 2007
What are the processes shaping network architecture?

Phylogenetic constraints

Indirect interactions

From the consumer side: exploitative competition

From the resource side: apparent competition

Closely related species should interact with the same species

Species should interact with different partner to minimise competition

From Rezende et al., *Nature* 2007
The Rush Meadow dataset

Sampling along transects every fortnight between 1994 and 2003

For each date:
- Nb of plant units/m²
- Nb of aphids and mummies
- Mummies reared in the lab for identification

The number of individuals of each species per m²
Who eats whom in what numbers
Phylogenetic signal estimated as the correlation between ecological and phylogenetic distances

The Rush Meadow dataset
Phylogenetic signal and anti-signal within a network

Elias & al., 2014
Phylogenetic signal and anti-signal within a network

Strong **phylogenetic signal** for prey levels

**Phylogenetic anti-signal** for predator levels

Vulnerability traits are **phylogenetically constrained**

Foraging traits are phylogenetically labile and **ecologically constrained**

Elias & al., 2014
Variation of signal strength with trophic levels

Lower phylogenetic signal with increasing trophic level for resource species

Stronger phylogenetic anti-signal with increasing trophic level for consumer species
Interaction as resources are phylogenetically constrained ➔ evolutionary history of species
Interaction as consumer are not ➔ exploitative competition

Phylogenetic signal varies within network

<table>
<thead>
<tr>
<th>Interactions as consumer</th>
<th>Interaction as resource</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>r (S.E.)</td>
<td>P</td>
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<tr>
<td></td>
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<tr>
<td>Chesapeake Bay</td>
<td>0.231 (0.057)</td>
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<tr>
<td>Coachella*</td>
<td>0.159 (0.057)</td>
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<td>Skipwith Pond*</td>
<td>0.101 (0.050)</td>
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<td>St-Martin Island</td>
<td>0.270 (0.067)</td>
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<td>Ythan estuary*</td>
<td>0.099 (0.027)</td>
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<td>0.330 (0.092)</td>
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<td>0.131 (0.073)</td>
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<td>0.206 (0.035)</td>
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Bersier & Kehrly, Ecol. Complex. 2008
What are the processes shaping network architecture?

Closely related species should interact with the same species

From Rezende et al., Nature 2007

70% of the 116 genus analysed present conserved interactions

Presence of a phylogenetic signal
Absence of a phylogenetic signal
Missing data

Gomez, Verdu & Perfectti, Nature 2010
Indirect interactions and effect spread through antagonistic and mutualistic interactions

Knight et al. 2005
Trophic chains: bottom-up and top-down effects

- Trophic chain with four levels:

\[ P_2^* = \frac{1}{a_{P2P}} (e_{PN} a_{PN} N^* - d_P) \]

\[ p^* = \frac{d_{P2}}{e_{P2P} a_{P2P}} \]

\[ N^* = \frac{1}{a_{NR}} \left( 1 - \frac{R^*}{K} \right) \]

\[ R^* = \frac{d_N + a_{PN} P^*}{e_{NR} a_{NR}} \]
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Hairston et al. 1960