# Introduction to the Study of Ecological Networks

Alyssa Cirtwill

Workshop NZES

# Community 1 – a food web

Sanak Island is one of the Aleutian Islands, off the coast of Alaska. Until 1828 the island was inhabited by the Aleut people but is currently uninhabited.

In the intertidal zone, crabs and small fishes forage on barnacles, mussels, and limpets. The barnacles are filter-feeders while the limpets graze on algae.   and detritus. Littorinid snails compete with the limpets for algae but are able to escape predation by emerging onto shore. Large crabs occasionally prey upon smaller ones, while the small fish are eaten by large fish. Take 10 minutes to draw a food web representing this system.

# Community 1 – Questions

1. How many species (nodes) are in your food web? How many interactions (links)?
2. What proportion of the possible links in the food web actually occur? What does this tell you about the community?
3. What's missing from this food web?

# Community 2 – a plant-pollinator network

Now consider a meadow that is heavily used by commercial honeybees as a foraging site. In this meadow are flowers including borage, clover, and viper's bugloss that are favorite forage species for the bees. Surrounding the meadow are several patches of manuka, which the bees also visit frequently. The bees also visit forget-me-nots, gorse, and thistles, but less frequently. A few native alpine flowers also grow in the meadow (including alpine daisies, eyebrights, and orchids), but these are usually pollinated by native flies rather than the introduced honeybees. Take 10 minutes to draw a network describing the role of honeybees in this meadow.

# Community 2 – Questions

1. This is an egocentric (or 'sink') web focused on the honeybees. What happens when you add non-honeybee pollinators?
2. How does this network differ from the Sanak Island food web?

# Nestedness

Camille Coux & Marilia P. Gaiarsa

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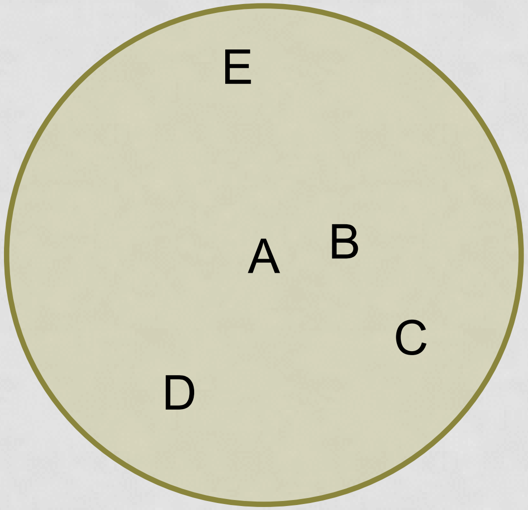
From island biogeography to explain spp occurrences in metacommunities.

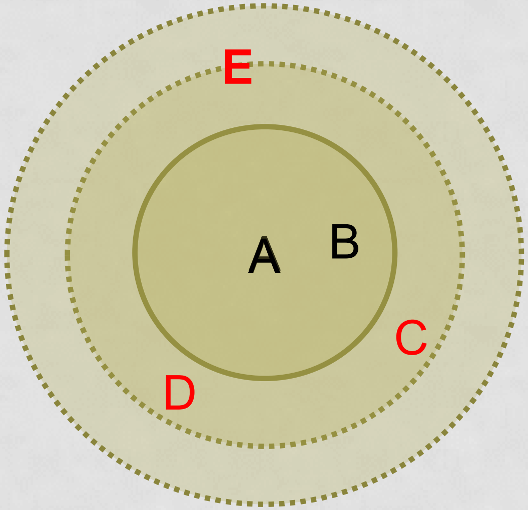


# From island biogeography to explain spp occurrences in metacommunities.

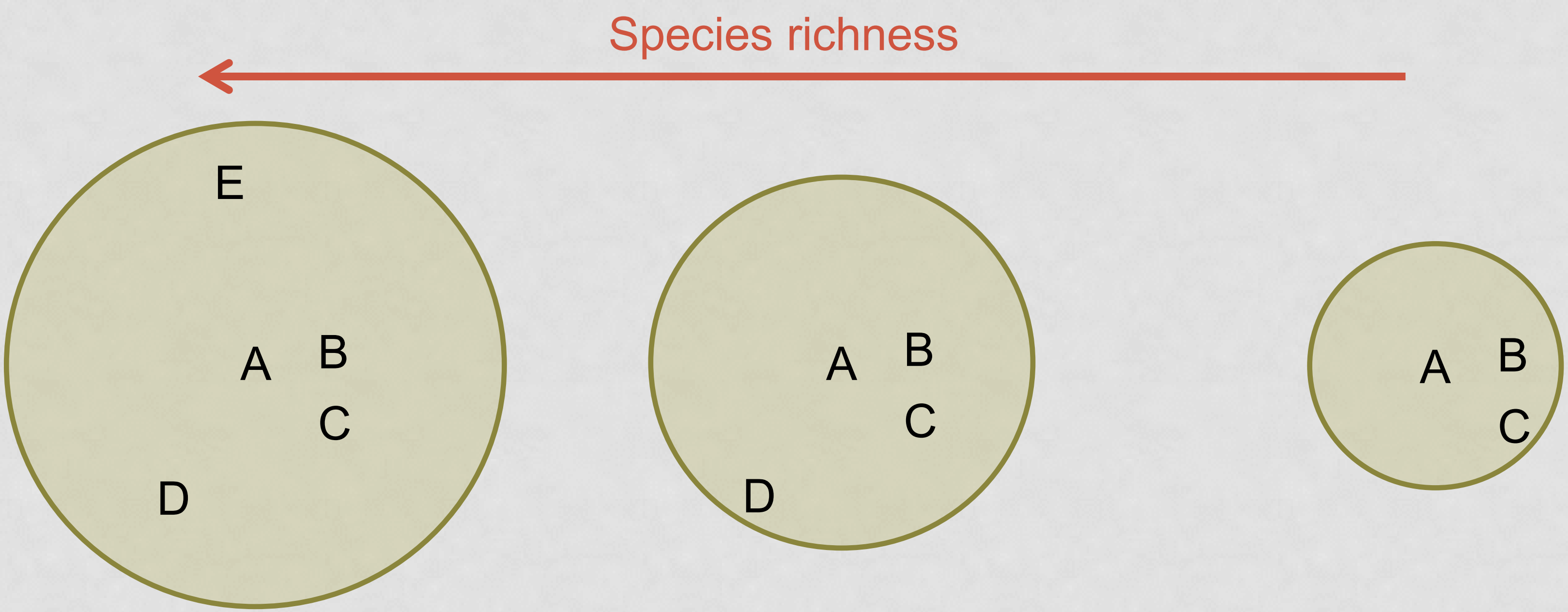
Large scale disturbance,

e.g. climate

→ Habitat reduction and fragmentation



- Archipelago of “islands”
- “Sp comprising a depauperate fauna should constitute a proper subset of those in richer fauna” (Darlington 1957)




**Nested series**

- Archipelago of “islands”
- “Sp comprising a depauperate fauna should constitute a proper subset of those in richer fauna” (Darlington 1957)

| Range | Montane mammal species* | Richness |
|---|---|---|
| 1 | A B C D E F G H I J K L M N O P Q R S T U V W X Y Z | 26 |
| 4 | A B C D E F G H I J K L M N O P Q R S T U V W X | 24 |
| 3 | A B C D E F G H I J K L M N O + Q R S T U V W X | 23 |
| 2 | A B C D E F G H I J K L M N O P Q R S T U + | 21 |
| 5 | A B C D E F G H I J K L M + O P Q R S T + | 19 |
| 8 | A B C D E + G H I J K + + N O P + | 13 |
| 9 | A B C D E + G + I J K + + N O + Q + V | 13 |
| 6 | A B C D E + + H I J K L + N O + + | 12 |
| 24 | A B C D E F G H + + K L + + P + | 11 |
| 10 | A B C D E F G + I J K + + + + + | 10 |
| 11 | A B C D E F G H I J + + + + + | 10 |
| 14 | A B C D E F G + + + + M + R | 9 |
| 23 | A B C D E F + H + + L + + P | 9 |
| 7 | A B C + E + I J + N | 7 |
| 13 | A B C D E F I + | 7 |
| 15 | A B C D E F + M | 7 |
| 17 | A B C D E + G + M | 7 |
| 22 | A B C D E F H + | 7 |
| 25 | A B C D E F H + | 7 |
| 12 | A B C D E F + | 6 |
| 21 | A B C D + F L | 6 |
| 16 | A B C D E + | 5 |
| 20 | A B C + + F L | 5 |
| 27 | A B + D E + | 4 |
| 26 | A B + F† | 3 |
| 28 | A B + | 2 |
| 18 | C | 1 |
| 19 | C | 1 |

Patterson & Atmar 1986

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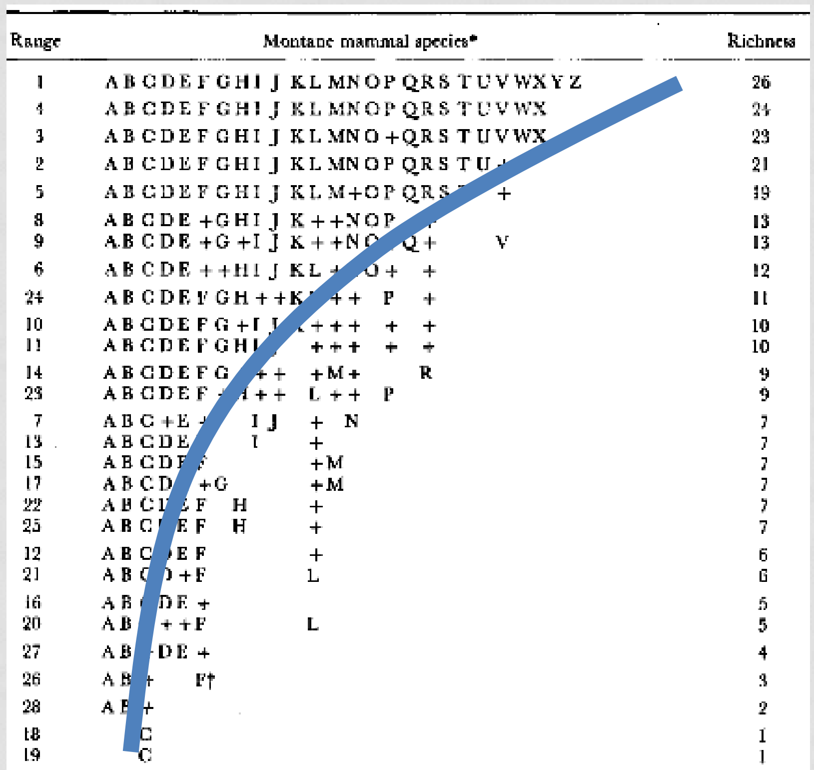

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| 5 | A B C D E F G H I J K L M + O P Q R S [illegible] + | 19 |
| 8 | A B C D E + G H I J K + + N O P [illegible] + | 13 |
| 9 | A B C D E + G + I J K + + N O [illegible] Q + V | 13 |
| 6 | A B C D E + + H I J K L + [illegible] O + + | 12 |
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| 10 | A B C D E F G + I J [illegible] + + + + + | 10 |
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| 23 | A B C D E F + [illegible] H + + L + + P | 9 |
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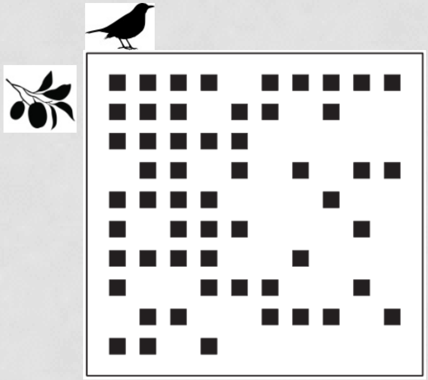
Patterson & Atmar 1986

# Nestedness of interactions:

Each sp interacts with subsets of sp interacting with more generalist species.



Bascompte et al., 2003

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Nestedness = nonrandom pattern beyond connectedness

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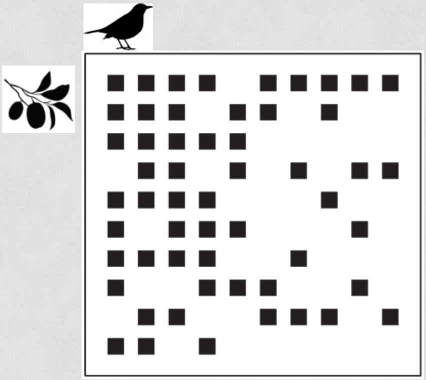

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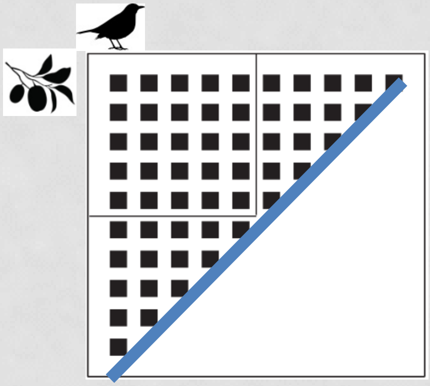

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Bascompte et al., 2003

Nestedness = nonrandom pattern beyond connectedness

# How is nestedness calculated?

Unweighted nestedness from Bastolloa et al., 2009:

*# of interactions common to both plants i and j*

$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between* $n_i$ *and* $n_j$

0 = random; 1=perfect nestedness

*# of interactions common to both plants i and j*

$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between $n_i$ and $n_j$*

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 |

$N = \underline{\hspace{5cm}}$

*# of interactions common to both plants i and j*

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| | | | |
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| 1 | 1 | 1 | 1 |
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$$N = \frac{3}{\quad}$$

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| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
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**4 < 3**

$$N = \frac{3}{3}$$

*# of interactions common to both plants i and j*

$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between $n_i$ and $n_j$*

| | | | |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 |

4 < 3

$$N = \frac{3+2+1+2+1+1}{3+2+1+2+1+1} = 1$$

*# of interactions common to both plants i and j*

$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between $n_i$ and $n_j$*

| | | | |
|---|---|---|---|
| 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 |

$$\frac{2+1+1+0+1+0}{2+2+1+2+1+1} = 0.55$$

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$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between $n_i$ and $n_j$*

| | | | |
|---|---|---|---|
| 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 |

3 < 2

$$\frac{2+1+1+0+1+0}{2+2+1+2+1+1} = 0.55$$

*# of interactions common to both plants i and j*

$$\eta = \frac{\sum_{i<j} n_{ij}}{\sum_{i<j} \min(n_i, n_j)}$$

*minimum # of interactions between $n_i$ and $n_j$*

| | | | |
|---|---|---|---|
| 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 3 | < | 2 | |

$$\frac{2+1+1+0+1+0}{2+2+1+2+1+1} = 0.55$$

# Many other calculations:

- Nestedness temperature : deviation from isocline (Atmar & Patterson 1993)

  0=cold, i.e. perfect N, 100=hot, i.e.chaos

- NODF: Node Overlap and Decreasing Fill (Almeida-Neto et al. 2008)

  high values = high nestedness

- Weighted version of NODF

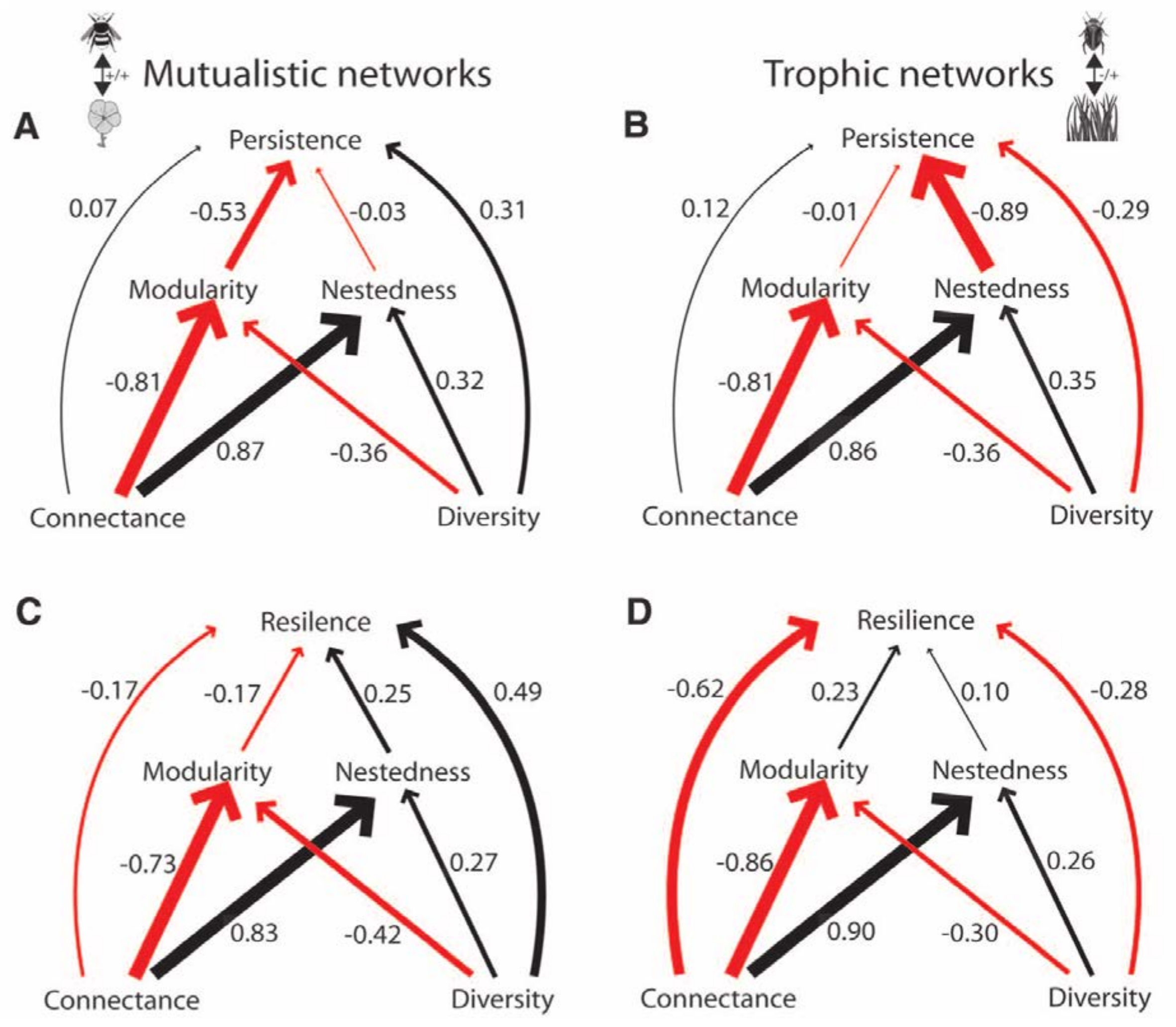
(Almeida-Neto et al. 2010)

# Implications: consequences for stability

- Generalist core with rest of the community attached to it

- Asymmetric specialisation: specialists interact with generalists, not with other specialists

# Implications: consequences for stability




Thebault & Fontaine 2010

# Implications: consequences for (co)evolution

- In mutualistic networks, cohesive core of generalist species hypothesised to act as a “coevolutionary vortex” (Bascompte et al. 2003; Thompson 2005; Guimaraes et al. 2007)

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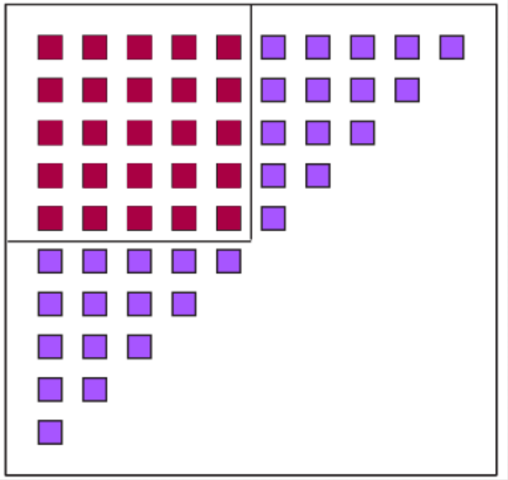

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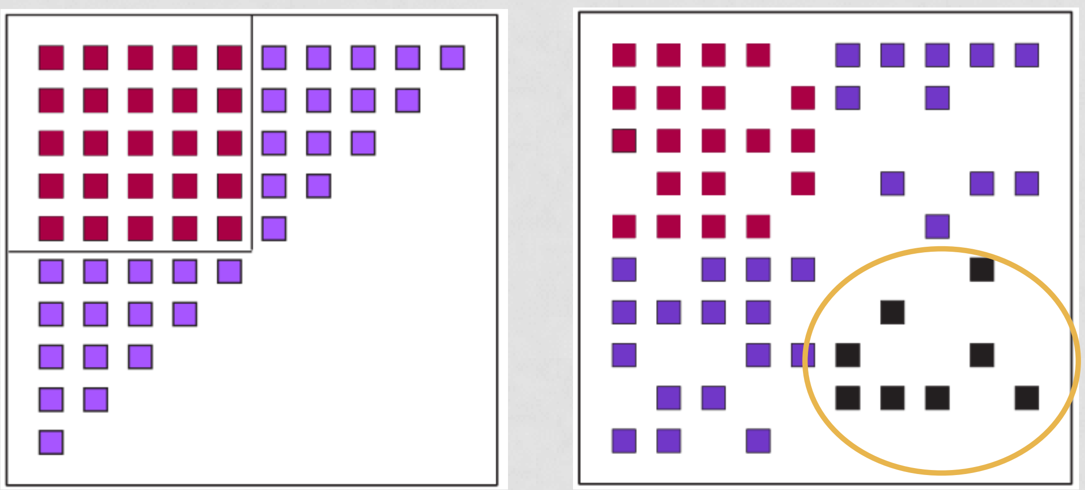

Not influenced by the core

# Modularity

Marilia P. Gaiarsa & Camille Coux

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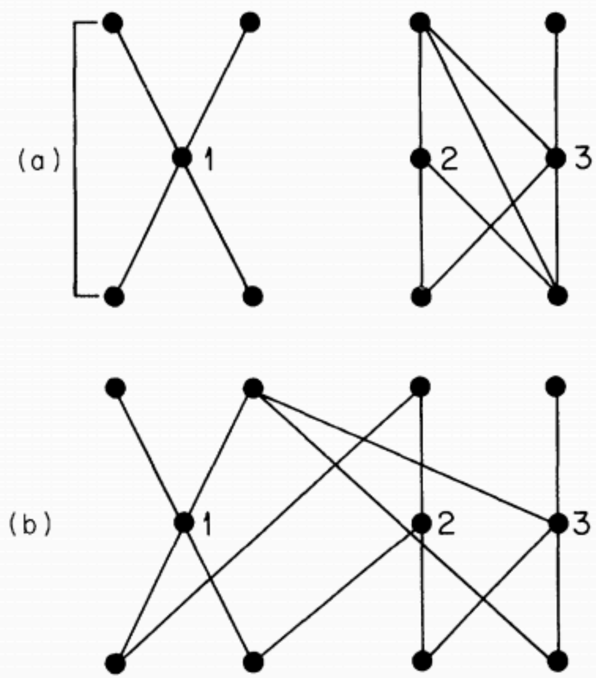
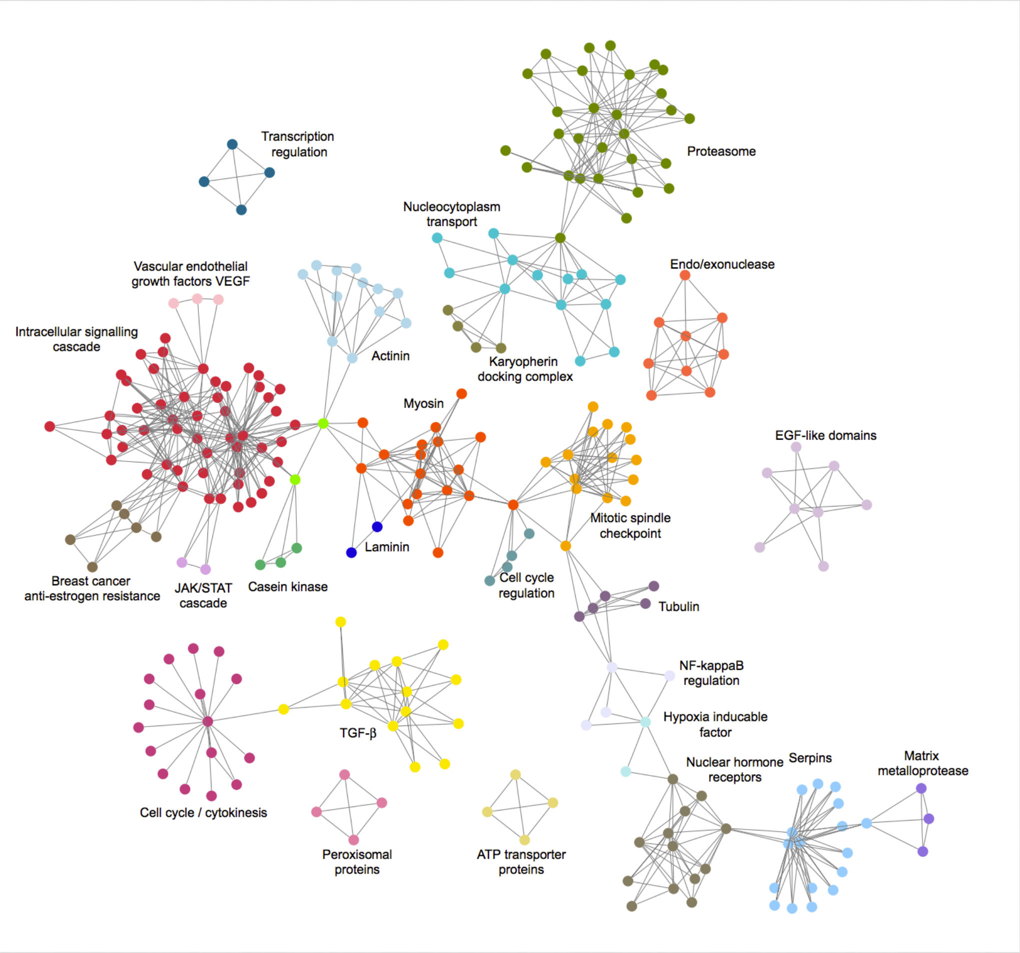
*Journal of Animal Ecology* (1980), **49,** 879–898

# ARE FOOD WEBS DIVIDED INTO COMPARTMENTS?*

By STUART L. PIMM† and JOHN H. LAWTON

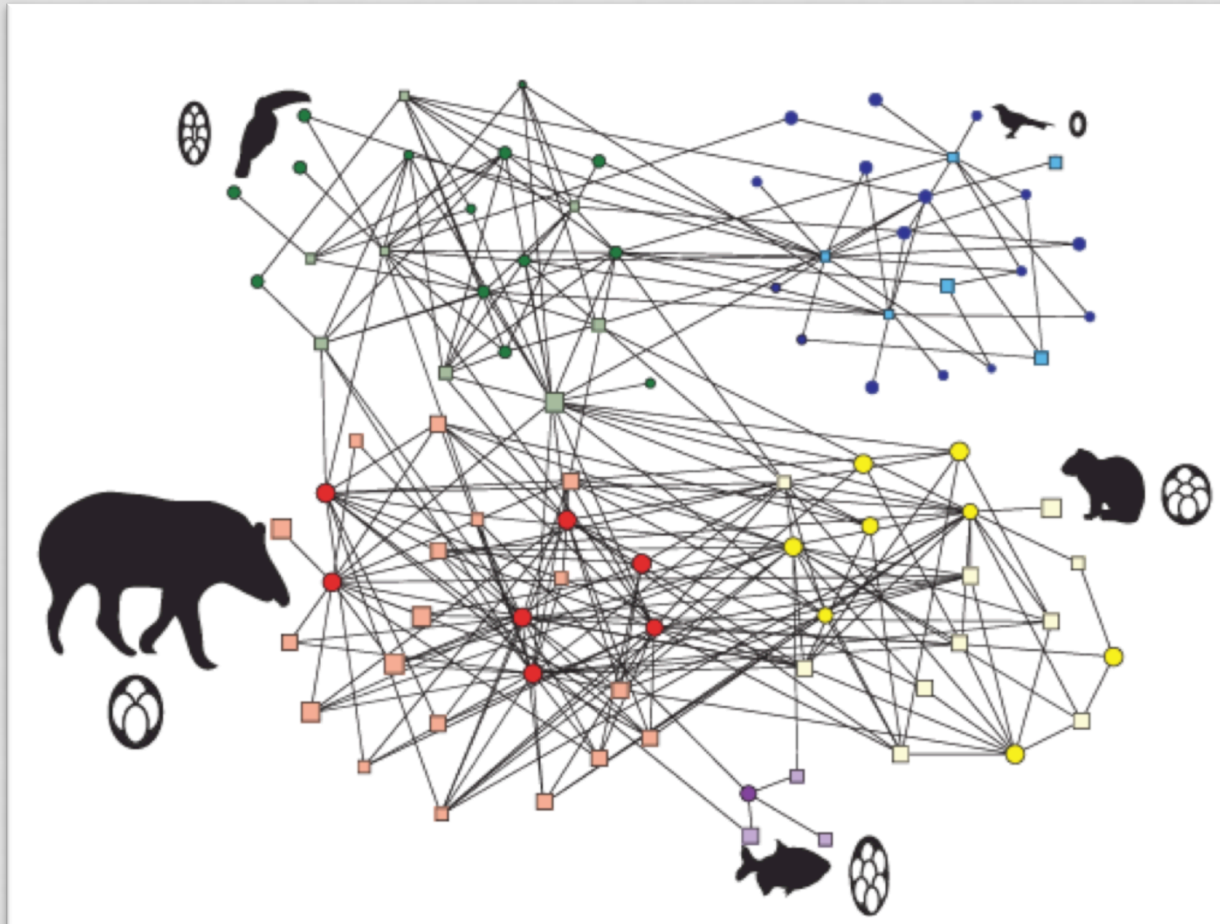
*Are food webs compartmented?*



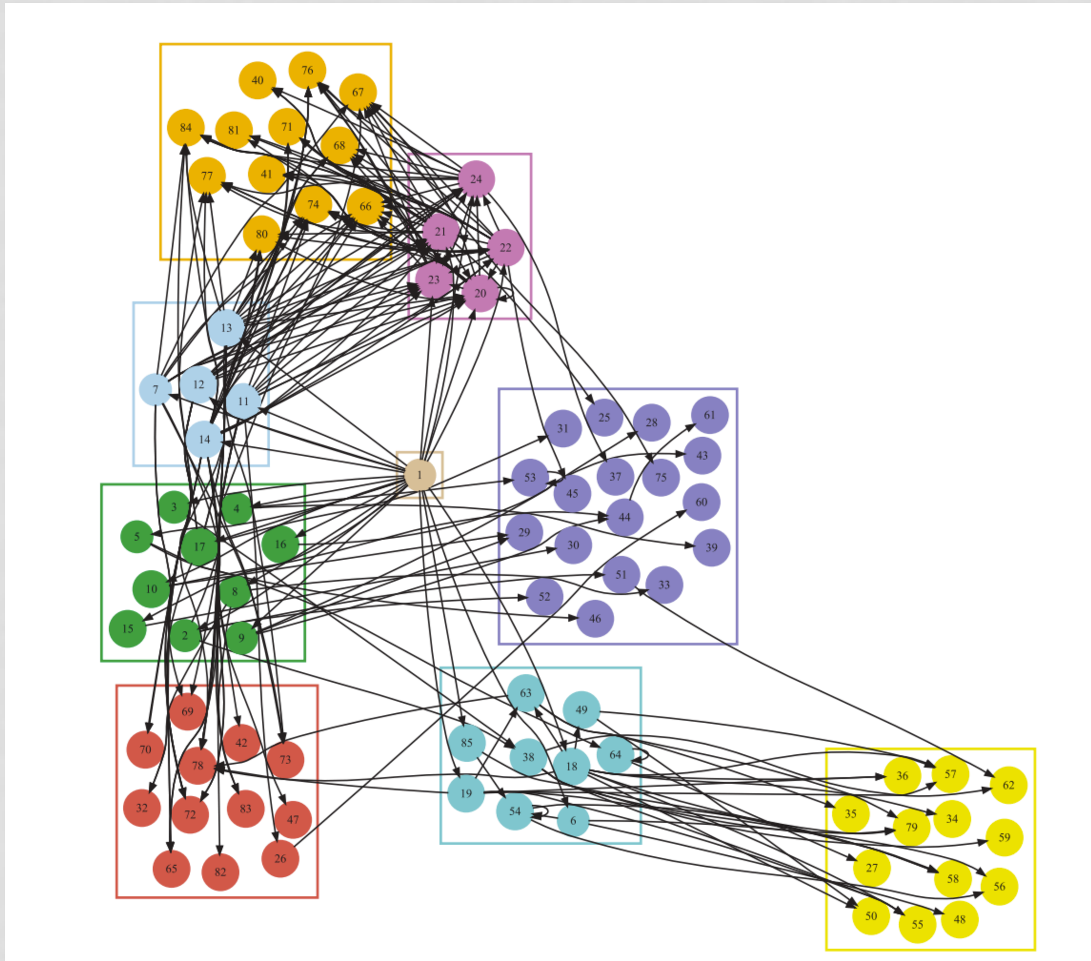



Jonsson et al. 2006, Fortunato 2010

# Modularity



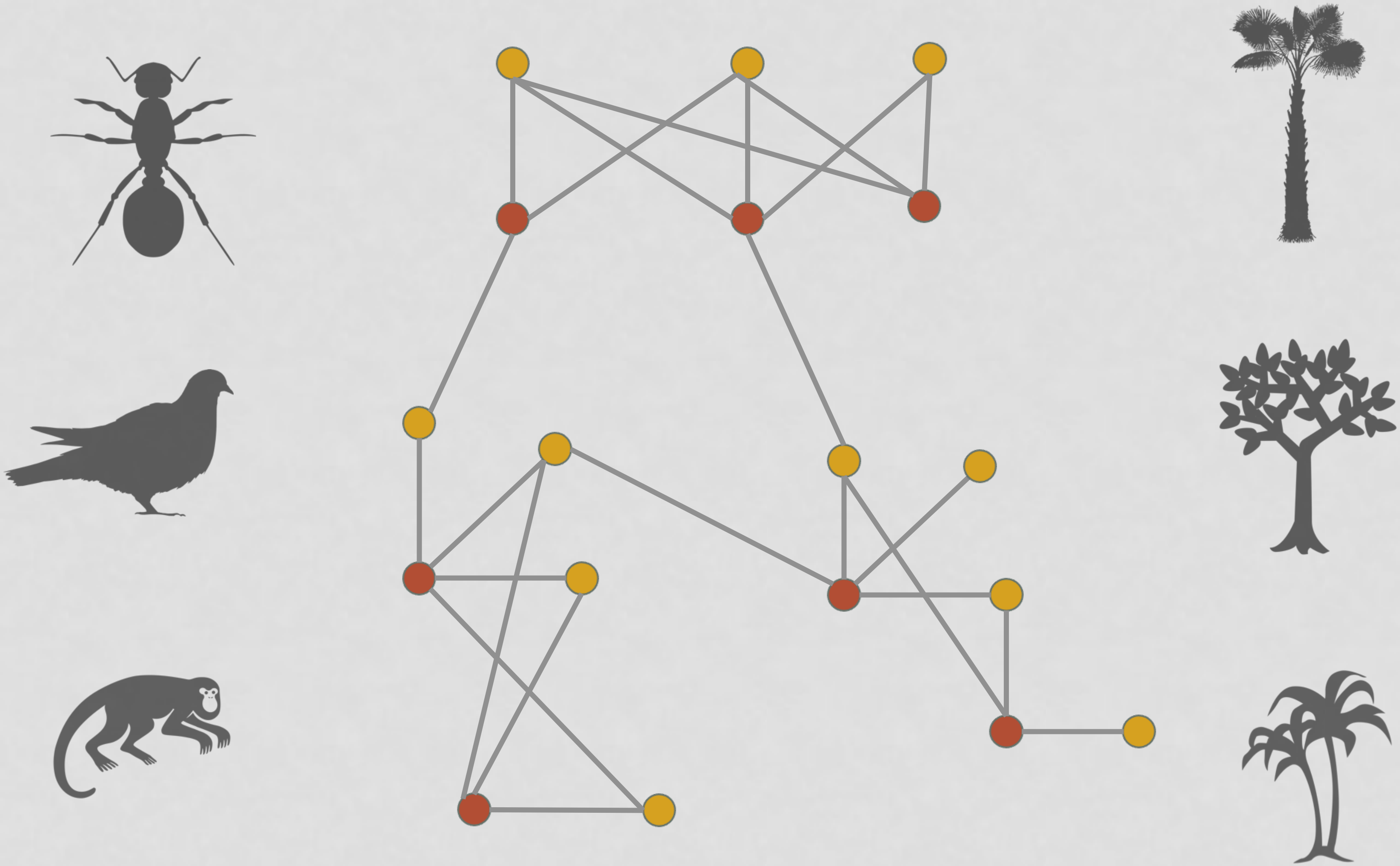
Donatti et al. 2011




Allesina & Pascual 2009

"Modularity is the tendency where species within a module tend to interact with a much higher frequency among them than they do with species from other modules" (Bascompte & Jordano 2014)

# Modularity



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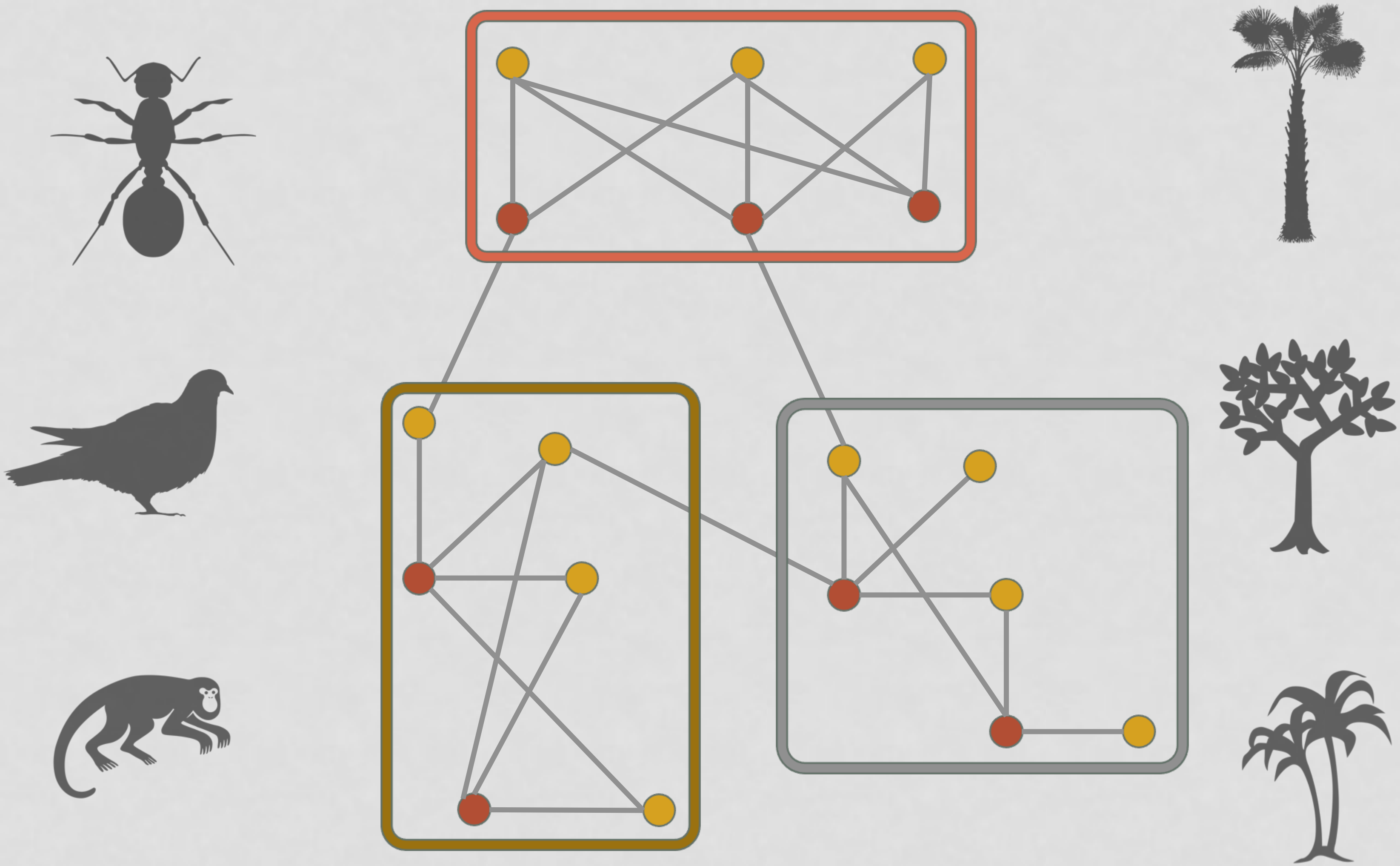

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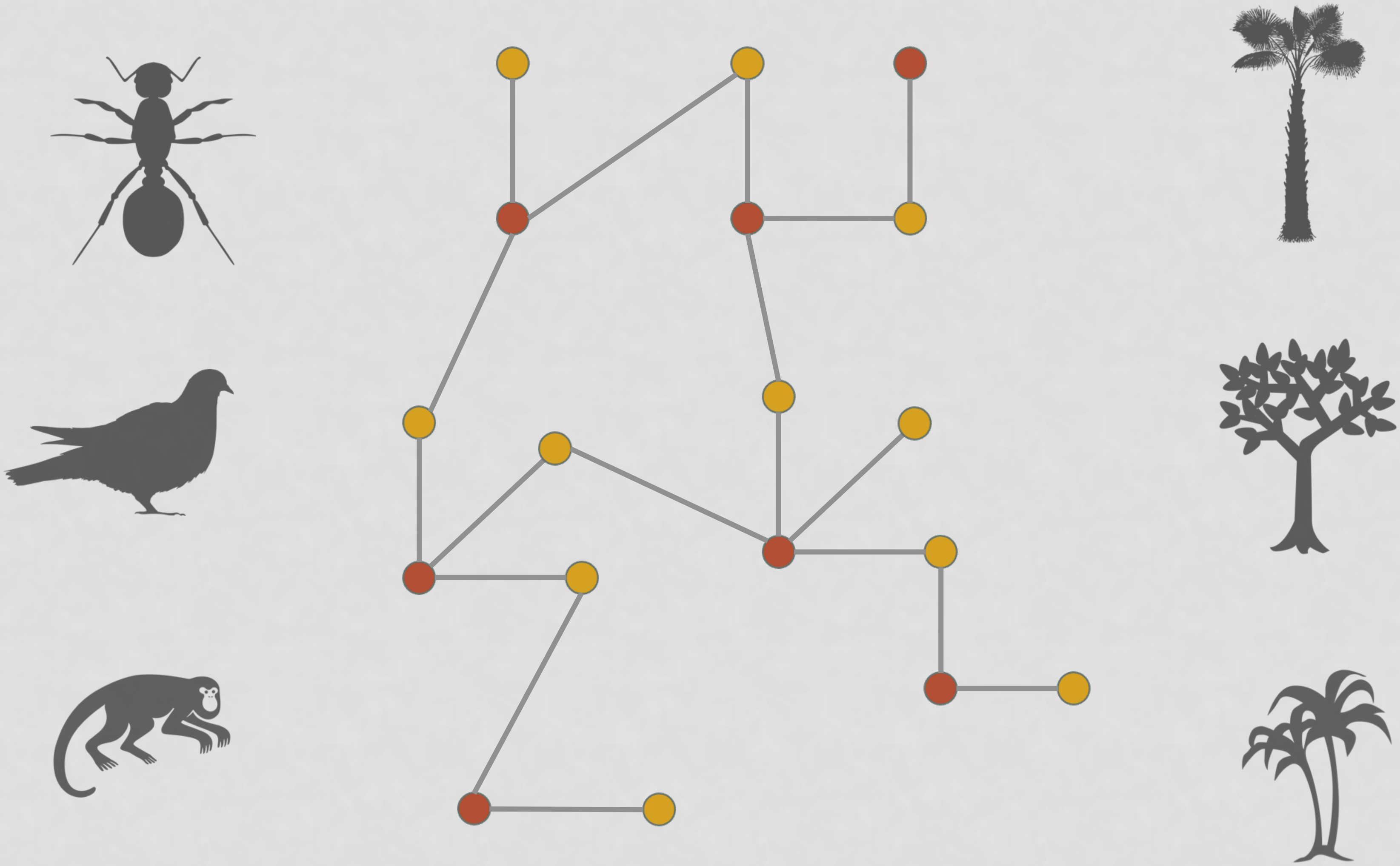
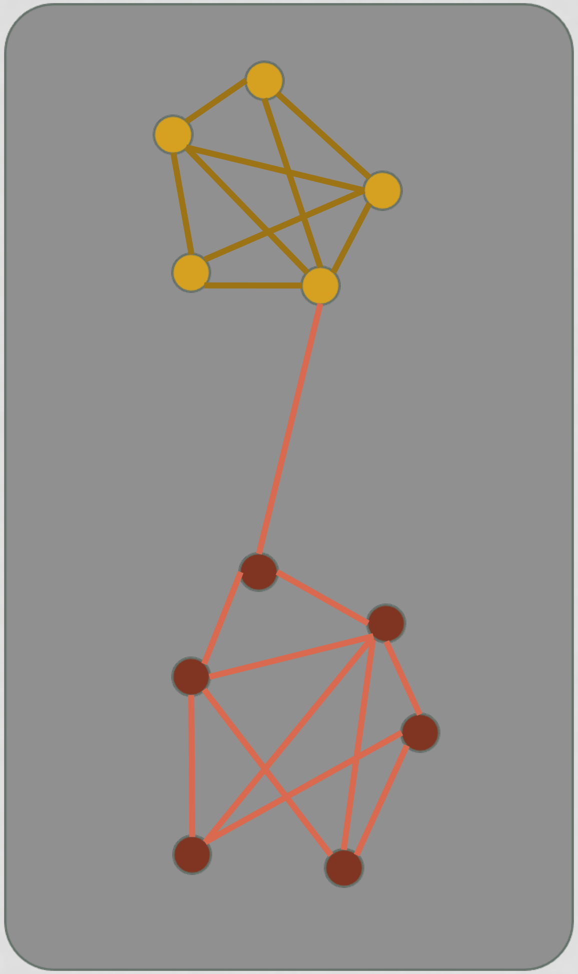


# How to characterize groups of interactions?

The metric M

$$M = \sum_{\text{all modules s}} \left( \frac{l_s}{L} - \frac{d_s^P}{L} \frac{d_s^A}{L} \right)$$

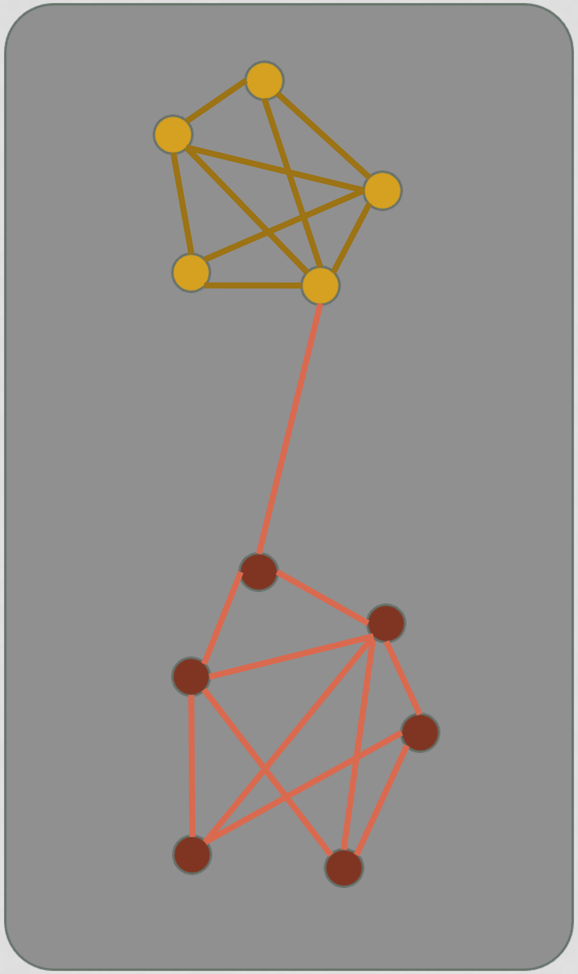
Barber 2007, Guimerà et al. 2007



# of interactions inside module s

$$M = \sum_{\text{all modules s}} \left( \frac{l_s}{L} - \frac{d_s^P}{L} \frac{d_s^A}{L} \right)$$

# of interactions in the whole network



*Sum of the plants' degree inside module s*

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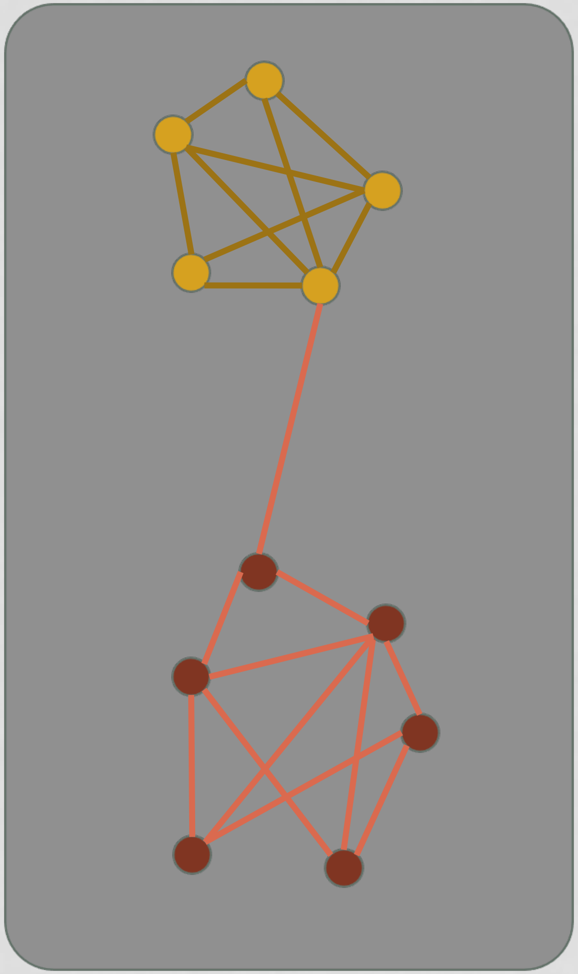

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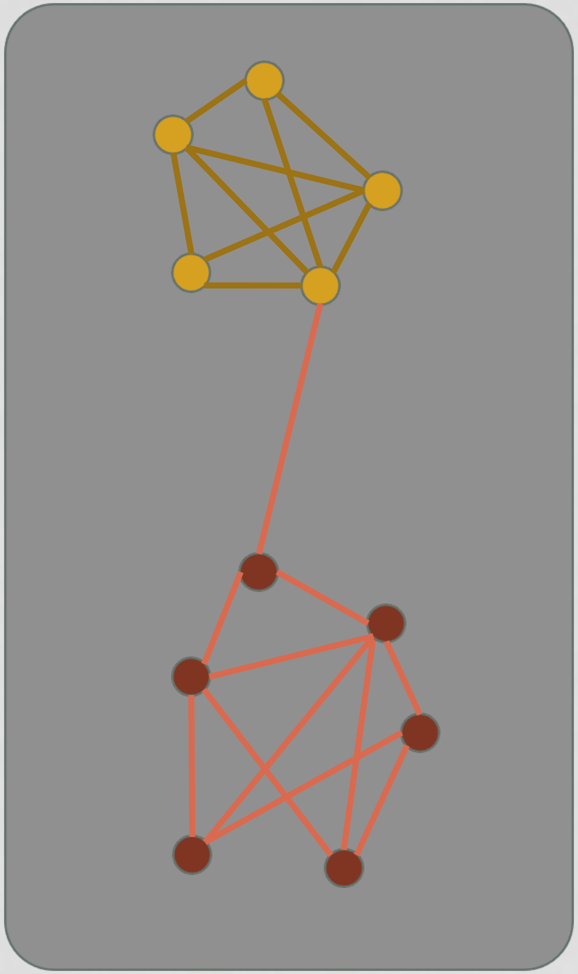
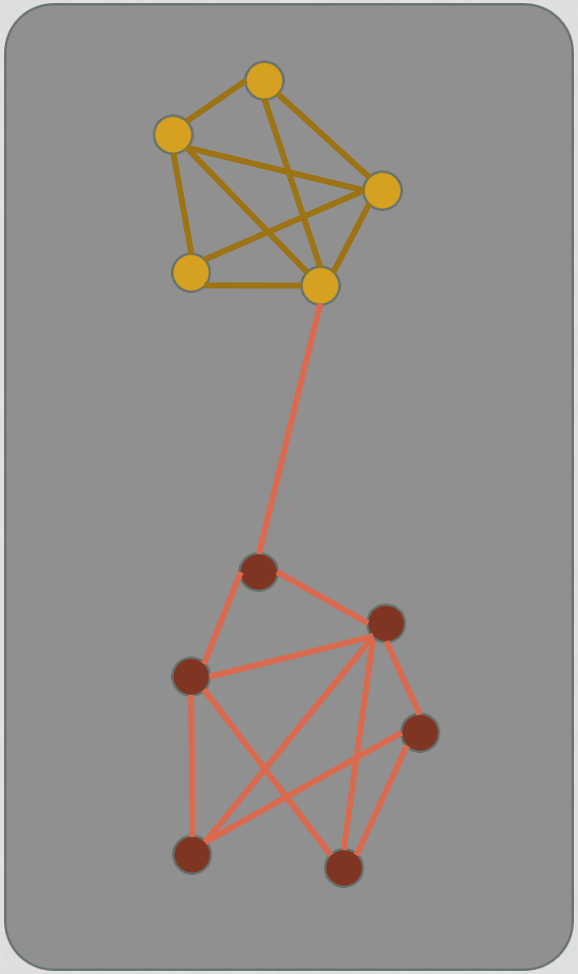


## The metric M

$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

Newman & Girvan 2004



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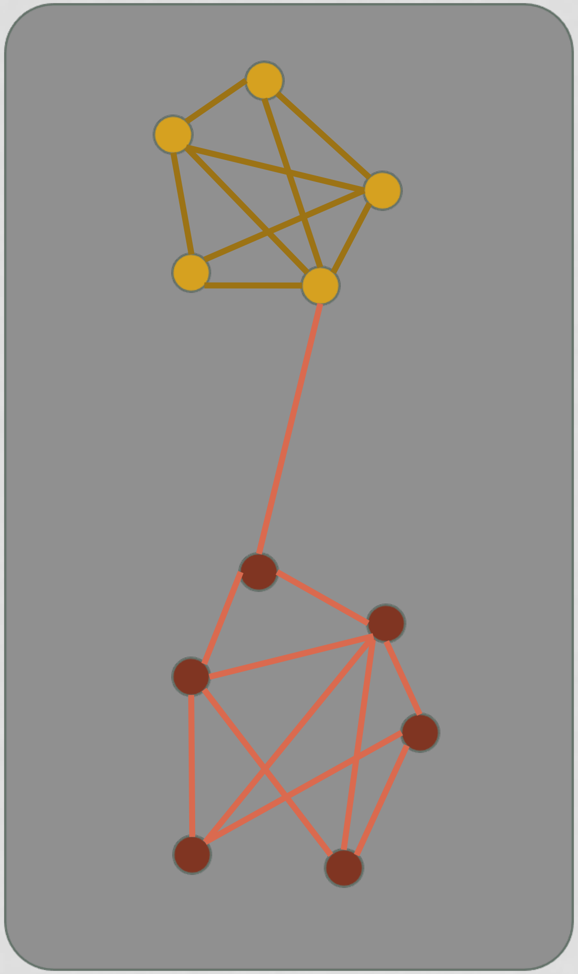
# of interactions in the whole network



*Sum of the species' degree inside module s*

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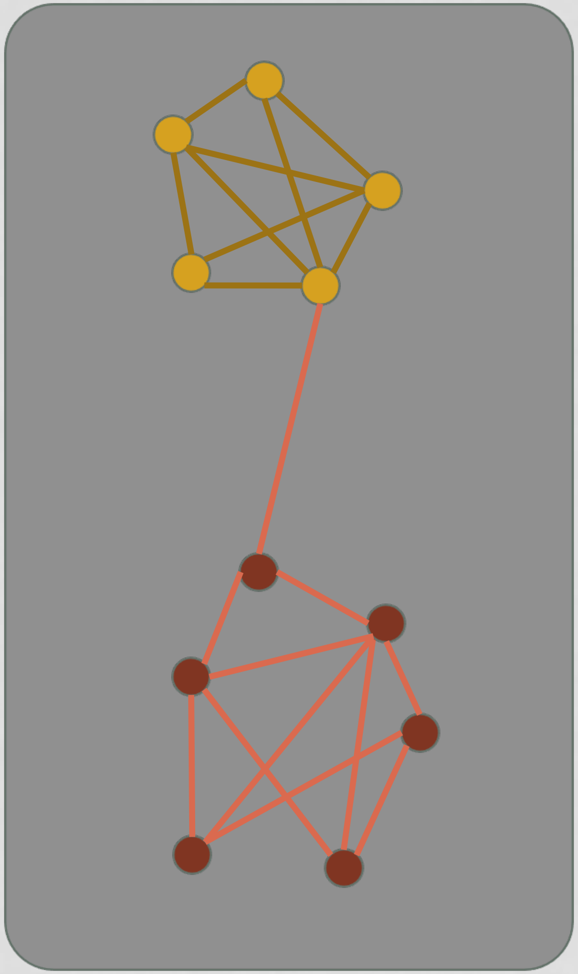
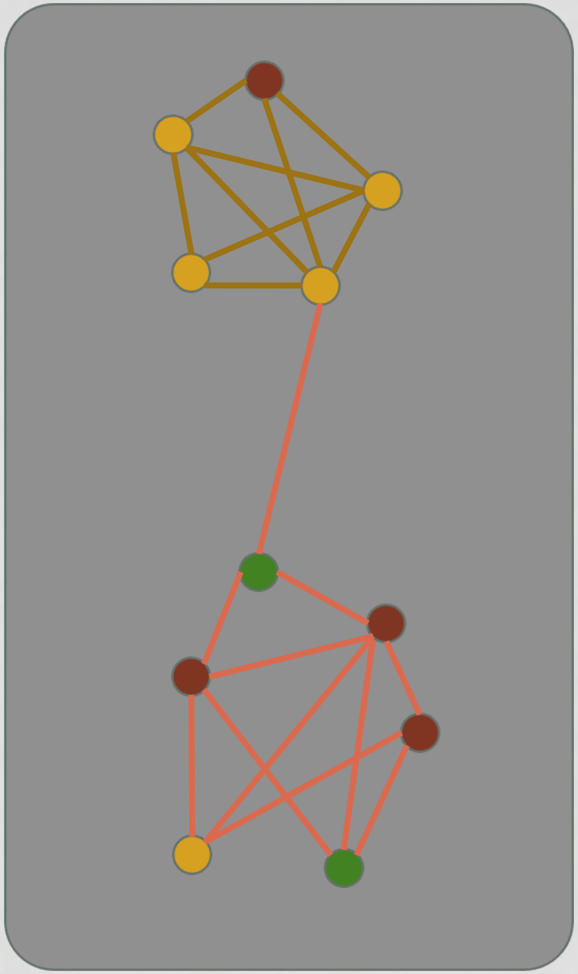


How to find the modules?

$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$



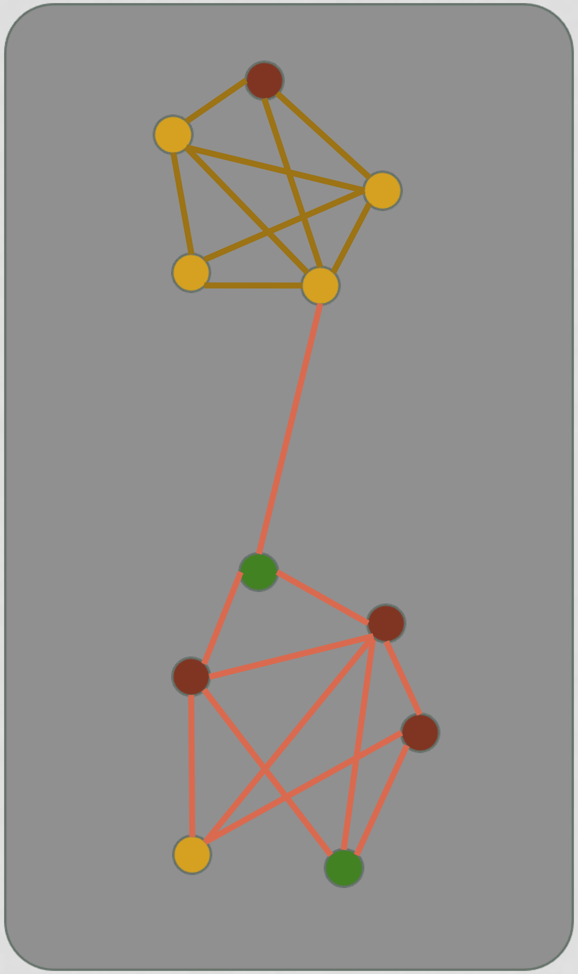
How to find the modules?

$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

$(2/20) - (15/40)^2$

$(6/20) - (18/40)^2$

$(0/20) - (6/40)^2$



How to find the modules?

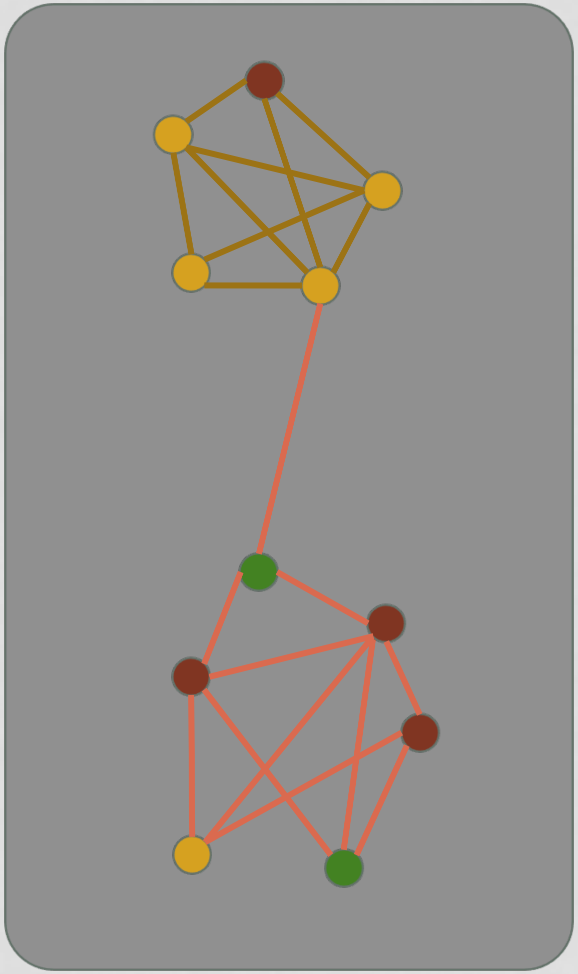
$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

- 0.04

0.10

- 0.02

M = 0.04



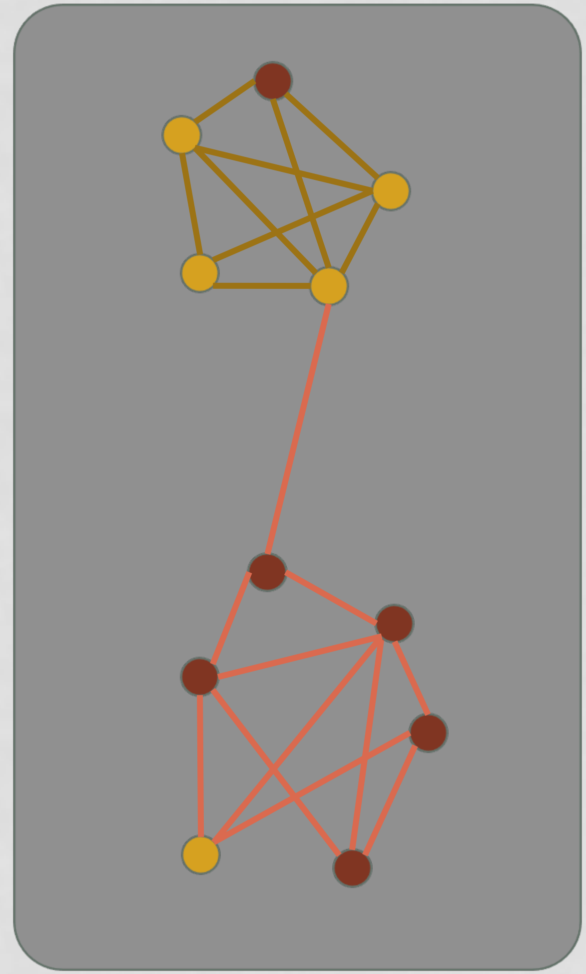
## How to find the modules?

$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

0.01

0.15

M = 0.16



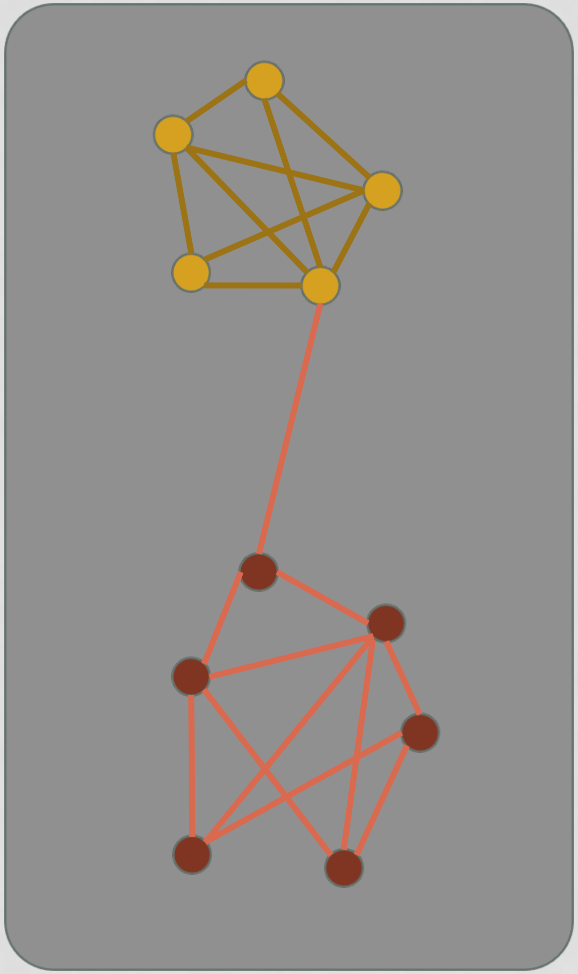
How to find the modules?

$$M = \sum_{\text{all modules s}} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

0.22

0.25

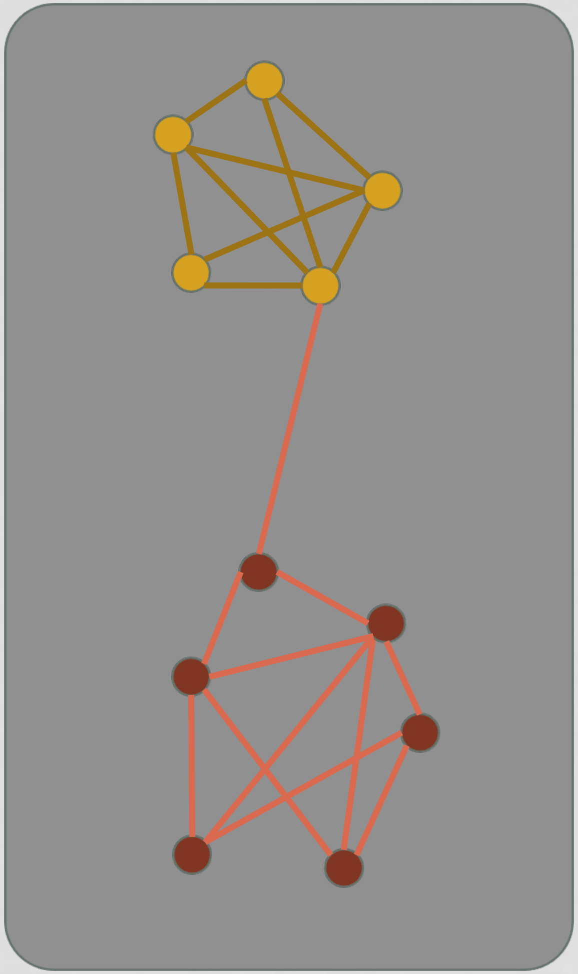
M = 0.47



11 species: 1 – 11 modules;

Different sizes;

How to optimize?



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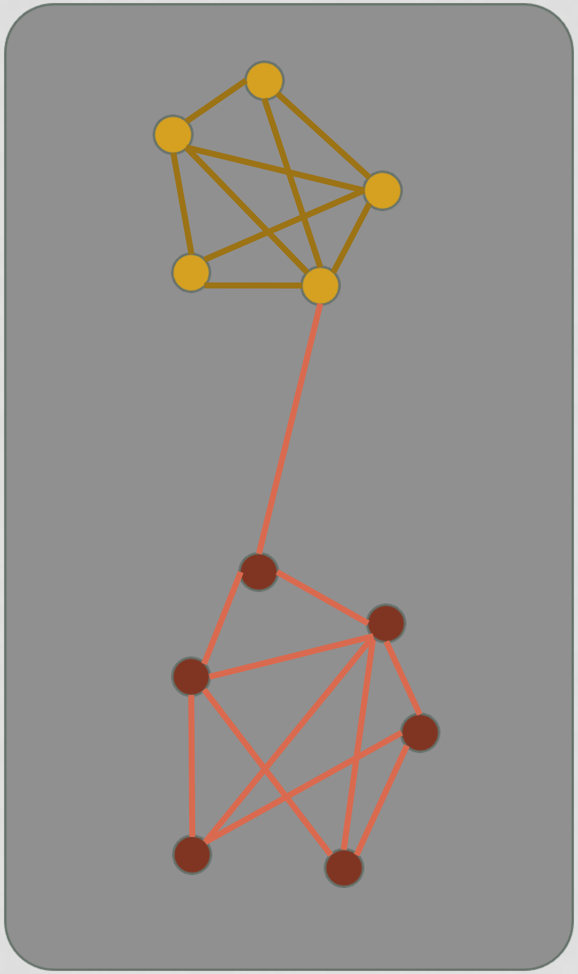
**Simulated annealing**



11 species: 1 – 11 modules;

Different sizes;

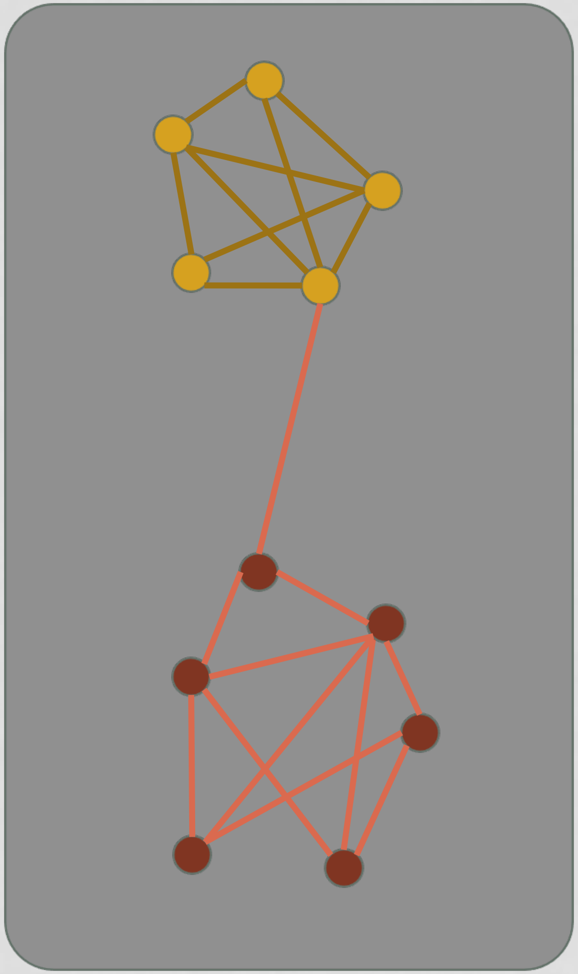
How to optimize?

Simulated annealing

**Netcarto** (Guimera & Amaral)

**Rnetcarto** (Doulcier)

**Modular** (Marquitti et al.)



Software notes

**Ecography 37: 221–224, 2014**
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# MODULAR: software for the autonomous computation of modularity in large network sets

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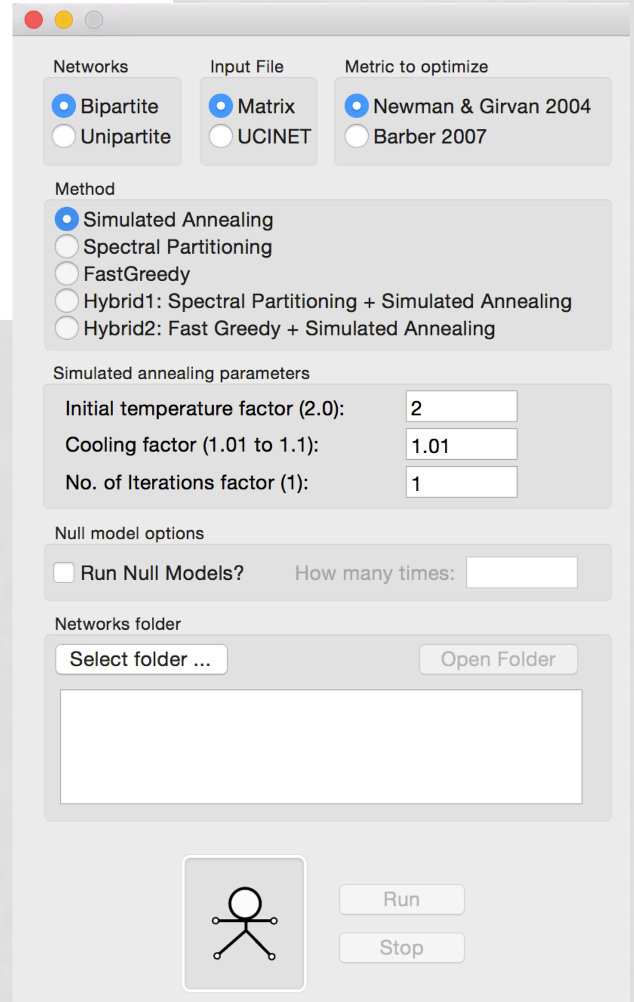


| File | N.modules | Modularity |
|---|---|---|
| q_modelo 1 1 40 .txt | 2 | 0.500000 |
| q_modelo 1 10 50 .txt | 4 | 0.533504 |
| q_modelo 1 100 42 .txt | 2 | 0.500000 |
| q_modelo 1 11 38 .txt | 4 | 0.645329 |
| q_modelo 1 12 38 .txt | 4 | 0.530181 |
| q_modelo 1 13 47 .txt | 2 | 0.500000 |
| q_modelo 1 14 55 .txt | 4 | 0.595577 |
| q_modelo 1 15 40 .txt | 4 | 0.548201 |
| q_modelo 1 16 23 .txt | 2 | 0.500000 |
| q_modelo 1 17 44 .txt | 3 | 0.501417 |
| q_modelo 1 18 39 .txt | 4 | 0.627704 |
| q_modelo 1 19 35 .txt | 4 | 0.509849 |
| q_modelo 1 2 50 .txt | 2 | 0.500000 |
| q_modelo 1 20 44 .txt | 4 | 0.607114 |
| q_modelo 1 21 40 .txt | 4 | 0.672936 |
| q_modelo 1 22 48 .txt | 4 | 0.523752 |
| q_modelo 1 23 41 .txt | 2 | 0.500000 |
| q_modelo 1 24 27 .txt | 4 | 0.506483 |
| q_modelo 1 25 27 .txt | 4 | 0.514467 |
| q_modelo 1 26 46 .txt | 4 | 0.524399 |
| q_modelo 1 27 44 .txt | 2 | 0.500000 |
| q_modelo 1 28 43 .txt | 4 | 0.540542 |
| q_modelo 1 29 54 .txt | 2 | 0.500000 |
| q_modelo 1 3 27 .txt | 4 | 0.526535 |
| q_modelo 1 30 41 .txt | 2 | 0.500000 |
| q_modelo 1 31 48 .txt | 3 | 0.501357 |
| q_modelo 1 32 45 .txt | 4 | 0.588084 |
| q_modelo 1 33 40 .txt | 4 | 0.555611 |
| q_modelo 1 34 40 .txt | 2 | 0.500000 |

| Node | Module |
|---|---|
| R1 | 2 |
| C1 | 5 |
| C5 | 0 |
| C7 | 1 |
| C8 | 4 |
| C13 | 4 |
| C16 | 2 |
| C17 | 2 |
| C19 | 2 |
| C22 | 0 |
| C23 | 2 |
| C24 | 0 |
| C25 | 2 |
| C28 | 1 |
| C29 | 0 |
| C33 | 0 |
| C39 | 5 |
| C44 | 5 |
| C46 | 2 |
| C47 | 2 |
| R2 | 0 |
| C18 | 0 |
| C26 | 0 |
| R3 | 2 |
| C9 | 3 |
| C12 | 1 |
| C30 | 2 |
| C31 | 4 |

# Package ‘rnetcarto’

November 12, 2015

**Type** Package

**Title** Fast Network Modularity and Roles Computation by Simulated Annealing (Rgraph C Library Wrapper for R)

**Version** 0.2.4

**Date** 2015-11-11

**Maintainer** Guilhem Doulcier <guilhem.doulcier@ens.fr>

**Description** It provides functions to compute the modularity and modularity-related roles in networks. It is a wrapper around the rgraph library (Guimera & Amaral, 2005, doi:10.1038/nature03288).

# Package 'rnetcarto'

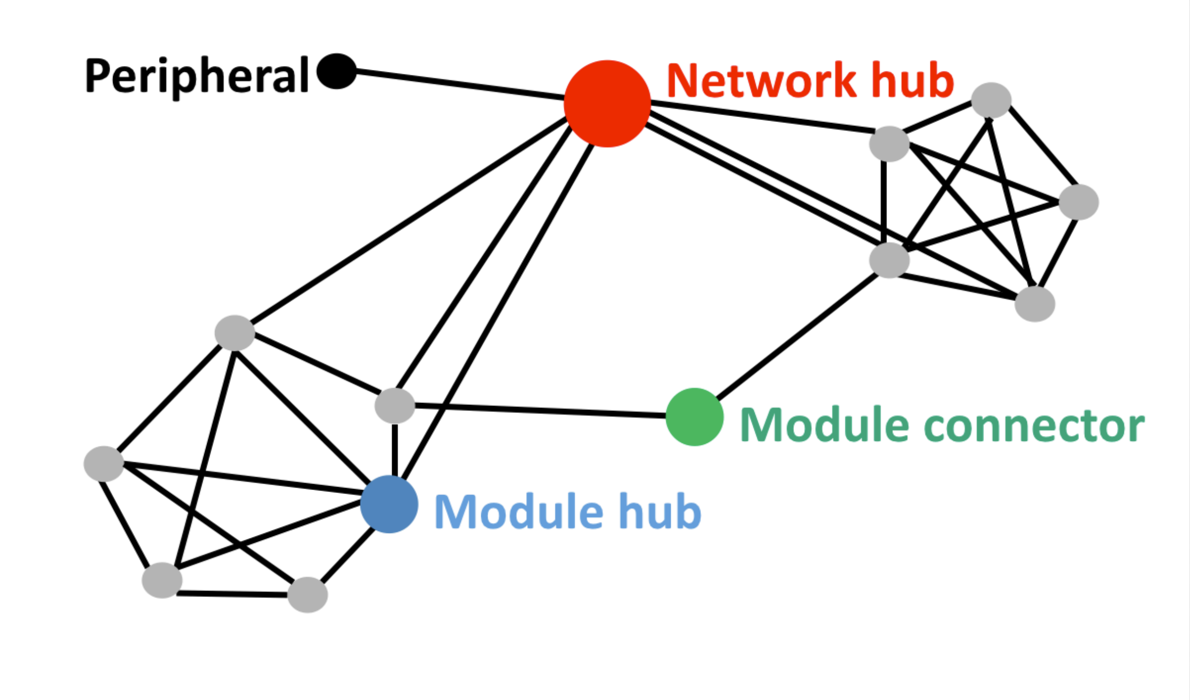
```
## [[1]]
##   name module connectivity participation              role
## 8    h      0   -1.4142136     0.0000000 Ultra peripheral
## 5    d      0    0.7071068     0.0000000 Ultra peripheral
## 4    c      0    0.7071068     0.6400000        Connector
## 2    b      1   -0.7071068     0.5000000       Peripheral
## 6    f      1   -0.7071068     0.6666667        Connector
## 9    i      1    1.4142136     0.0000000 Ultra peripheral
## 1    a      2   -0.7071068     0.0000000 Ultra peripheral
## 7    g      2   -0.7071068     0.5000000       Peripheral
## 3    b      2    1.4142136     0.4444444       Peripheral
##
## [[2]]
## [1] 0.2024793
```

**Functional cartography of complex metabolic networks**

**Roger Guimerà** and **Luís A. Nunes Amaral**
*NICO and Department of Chemical and Biological Engineering, Northwestern University, Evanston, Illinois 60208, USA*

**The modularity of pollination networks**

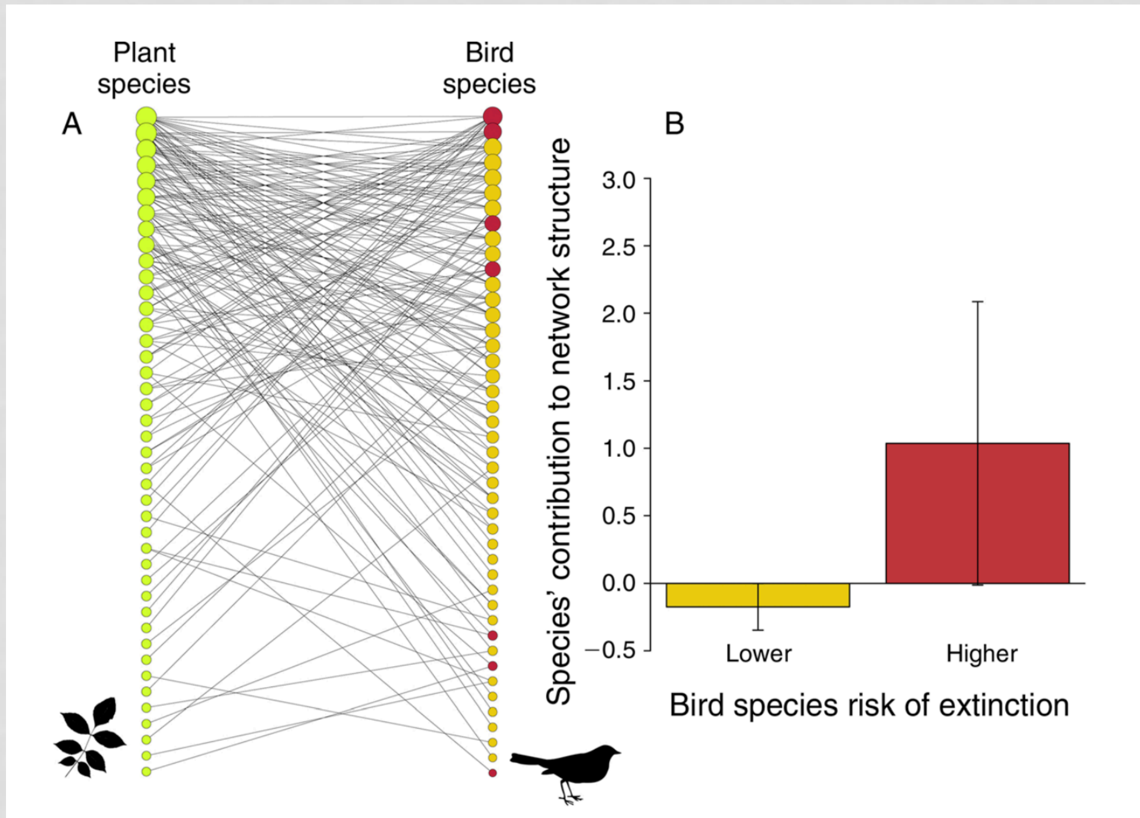
**Jens M. Olesen*†, Jordi Bascompte‡, Yoko L. Dupont*, and Pedro Jordano‡**



*Ecology*, 95(12), 2014, pp. 3440–3447


# Frugivores at higher risk of extinction are the key elements of a mutualistic network

Mariana M. Vidal,[1] Erica Hasui,[2] Marco A. Pizo,[3] Jorge Y. Tamashiro,[4] Wesley R. Silva,[5] and Paulo R. Guimarães, Jr.[1,6]

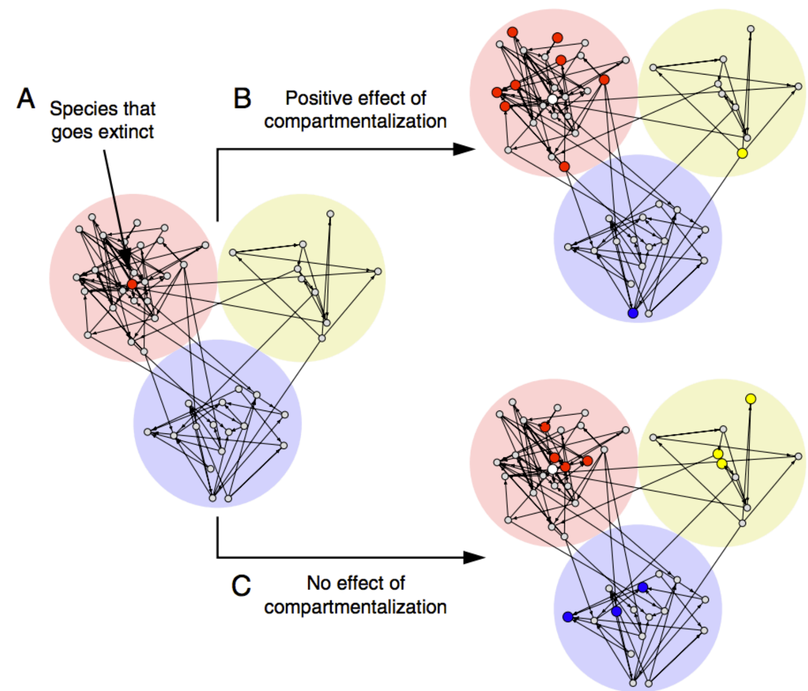


# Strong contributors to network persistence are the most vulnerable to extinction

Serguei Saavedra[1,2,3]*, Daniel B. Stouffer[4,5]*, Brian Uzzi[1,2] & Jordi Bascompte[4]

# Compartmentalization increases food-web persistence

Daniel B. Stouffer[1] and Jordi Bascompte

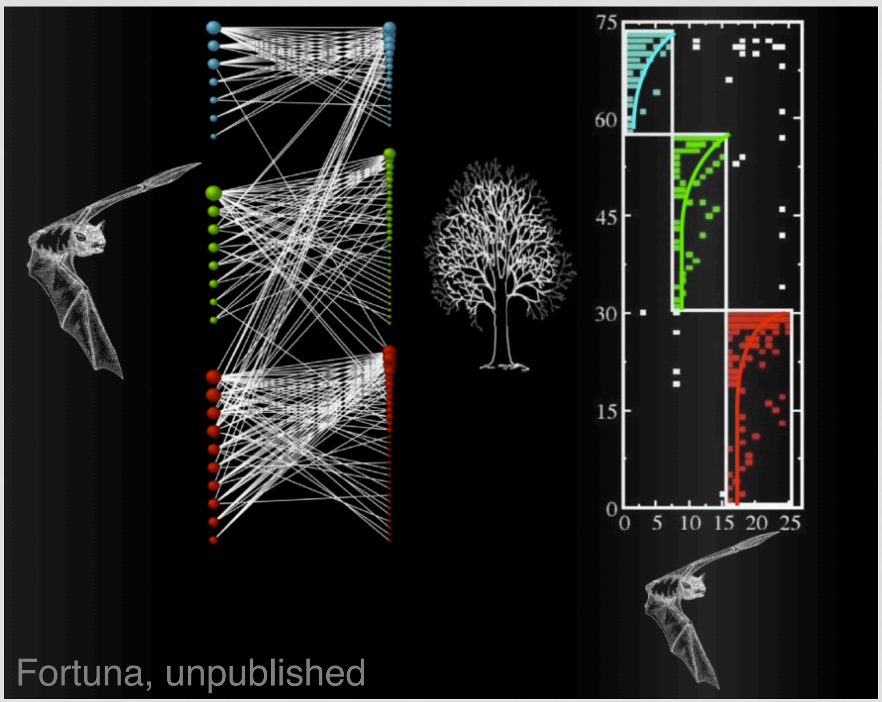


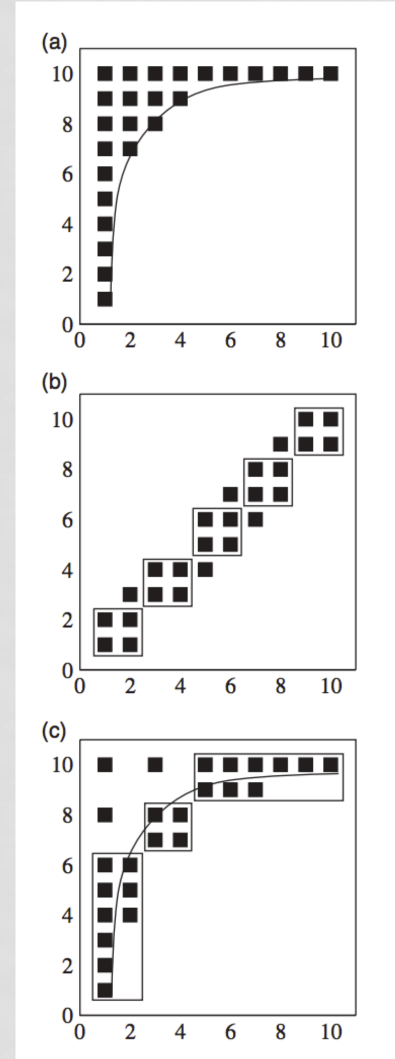
Journal of Animal Ecology

*Journal of Animal Ecology* 2010, **79**, 811–817 doi: 10.1111/j.1365-2656.2010.01688.x

# Nestedness versus modularity in ecological networks: two sides of the same coin?

**Miguel A. Fortuna[1]*, Daniel B. Stouffer[1], Jens M. Olesen[2], Pedro Jordano[1], David Mouillot[3], Boris R. Krasnov[4], Robert Poulin[5] and Jordi Bascompte[1]**



## Plant-Seed Disperser

| Network | Size | Connectance | Nestedness | Modularity |
|---|---|---|---|---|
| 1 | 28 | 0.085 | * 0.763 | 0.311 |
| 2 | 58 | 0.106 | ** 0.944 | 0.312 |
| 3 | 78 | 0.026 | ** 0.842 | 0.308 |
| 4 | 26 | 0.264 | * 0.847 | 0.121 |

## Plant-Pollinator

| Network | Size | Connectance | Nestedness | Modularity |
|---|---|---|---|---|
| 23 | 61 | 0.090 | ** 0.925 * | 0.591 ** |
| 24 | 185 | 0.043 | ** 0.960 | 0.516 ** |
| 25 | 107 | 0.071 | ** 0.907 | 0.519 ** |
| 26 | 90 | 0.098 | ** 0.811 * | ** 0.569 ** |

## Host-Parasite

| Network | Size | Connectance | Nestedness | Modularity |
|---|---|---|---|---|
| 57 | 35 | 0.247 | ** 0.819 | ** 0.516 ** |
| 58 | 36 | 0.384 | ** 0.662 | 0.268 |
| 59 | 45 | 0.217 | ** 0.783 | ** 0.437 ** |
| 60 | 46 | 0.191 | ** 0.749 | 0.312 |

Fortuna et al. 2010