

# **Redes ecológicas ao longo dos níveis de organização**



**Paulo R. Guimarães Jr.**  
Universidade de São Paulo



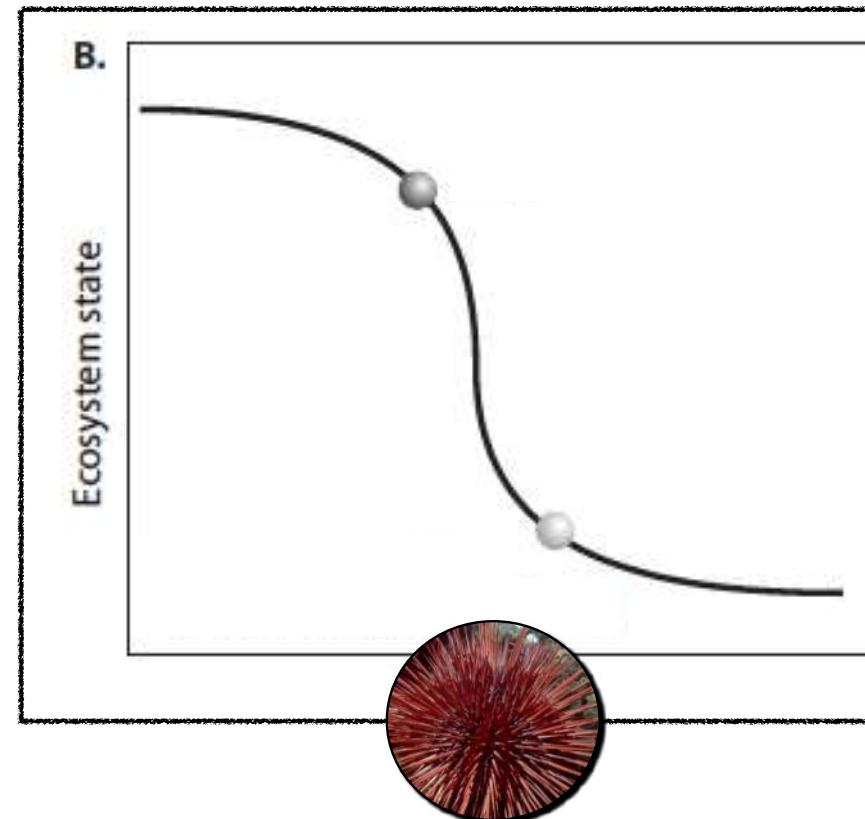






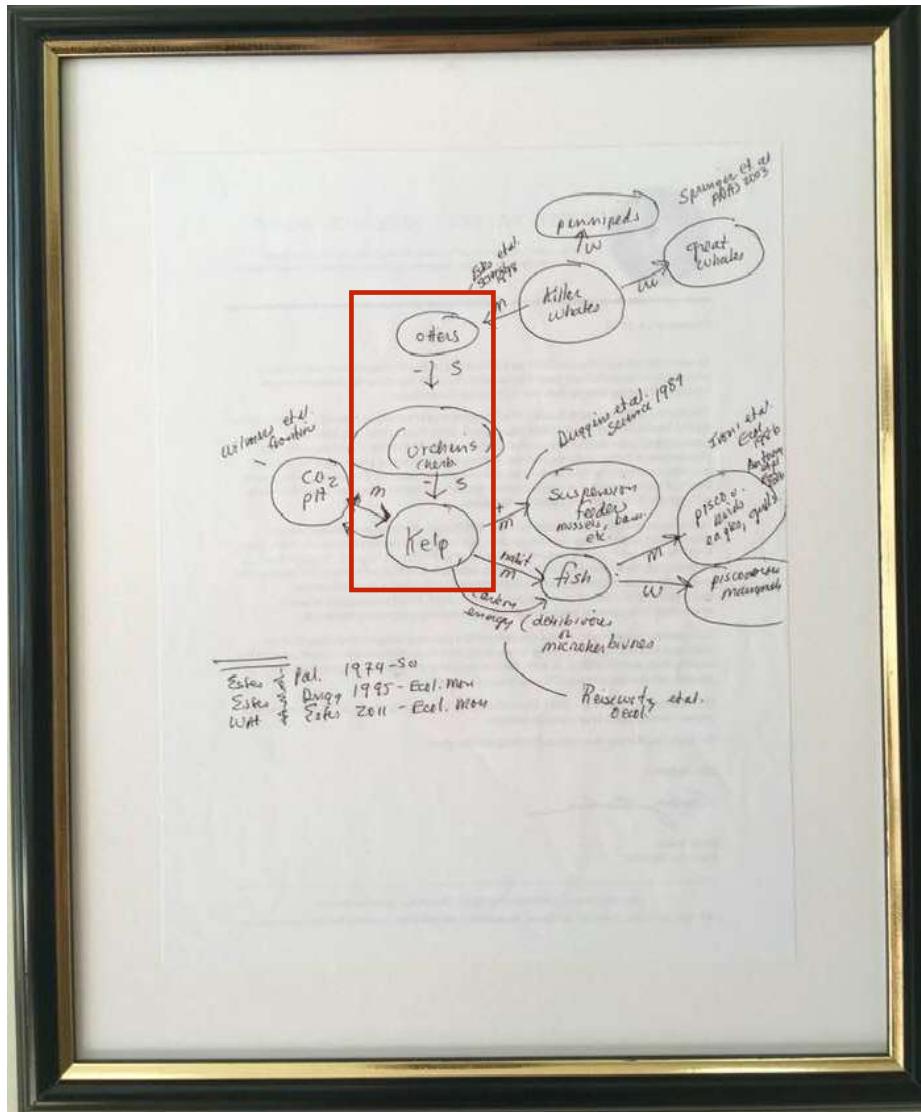
# O colapso de um ecossistema

Estados alternativos modulados por interações ecológicas



Kriegisch et al. 2016. PLoS ONE

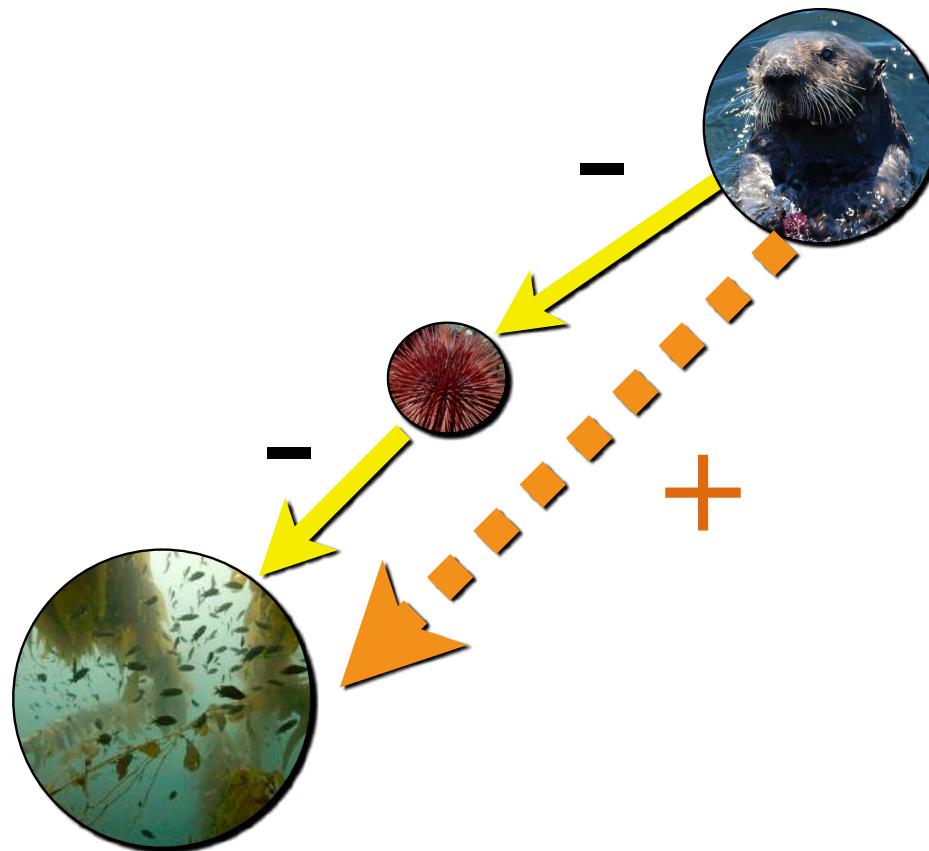




*James Estes*

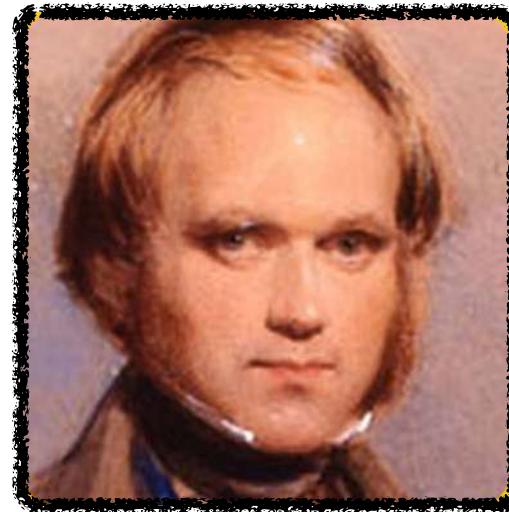
# O porquê das redes importarem: efeitos indiretos

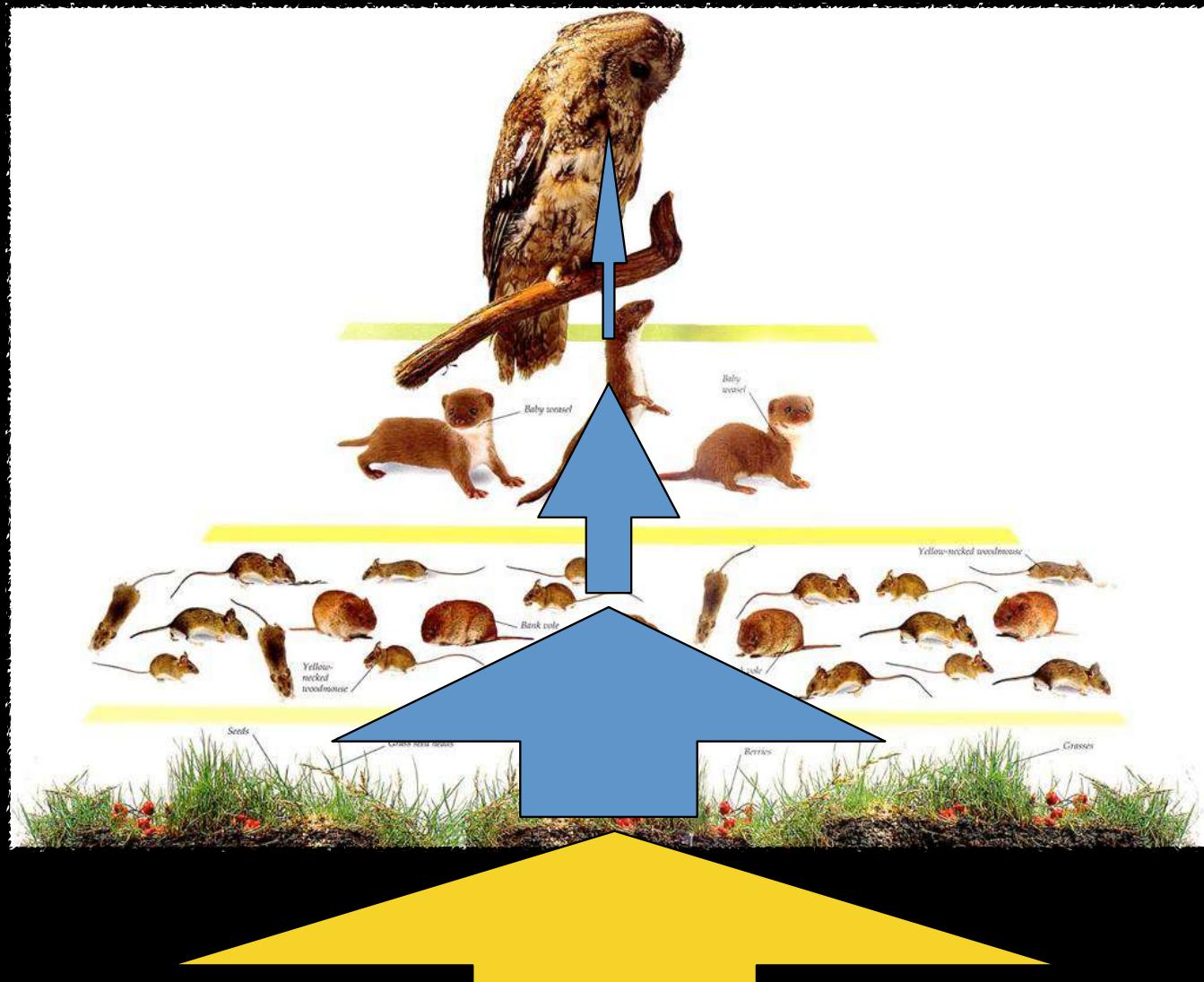
Um efeito ecológico ou evolutivo que ocorre por meio de uma cadeia de interações diretas

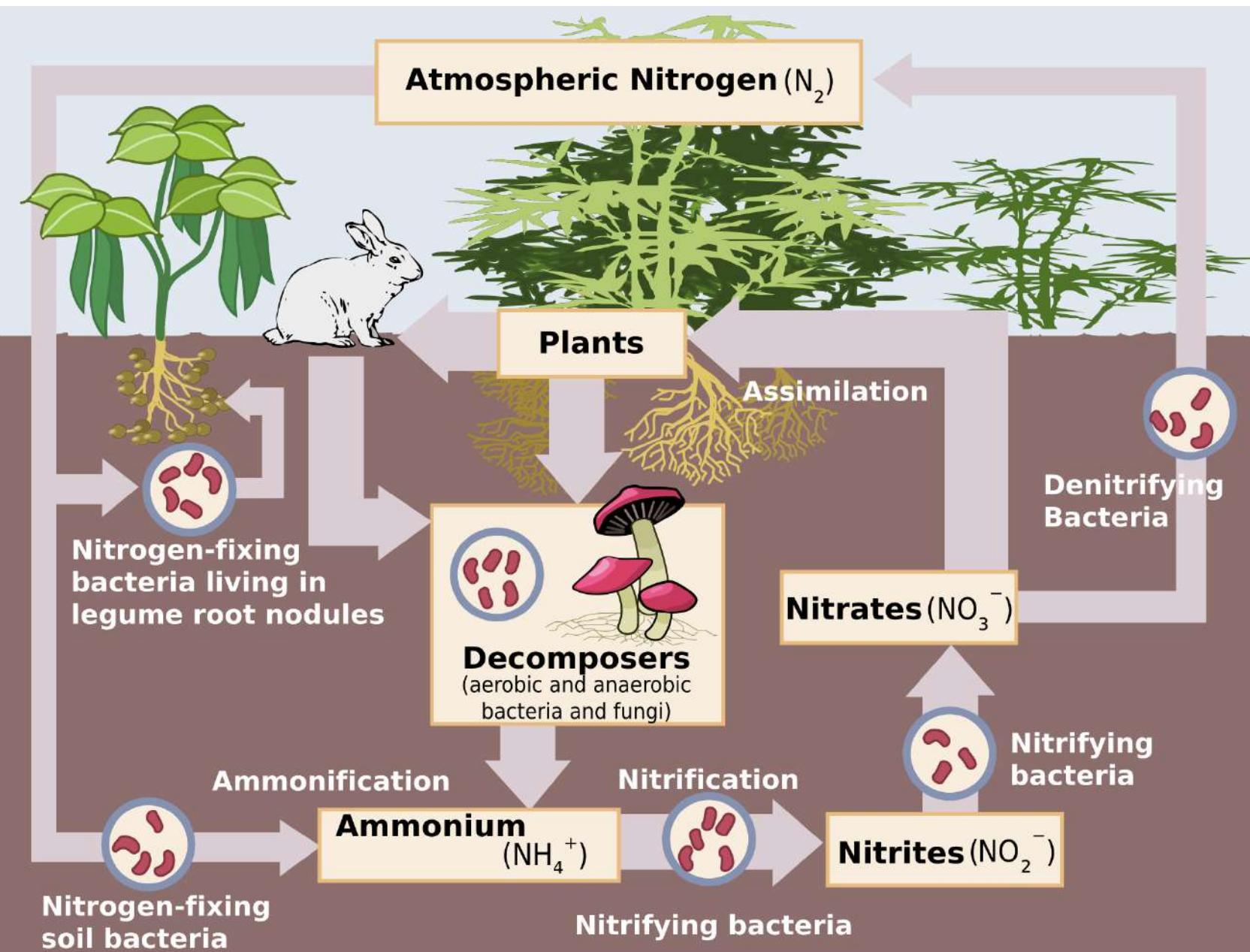


Estes & Palmisano 1974. Science

*I am tempted to give one more instance showing how plants and animals, most remote in the scale of nature, are bound together by a web of complex relations*





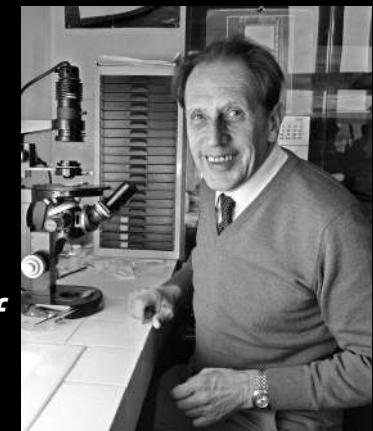




Memmott



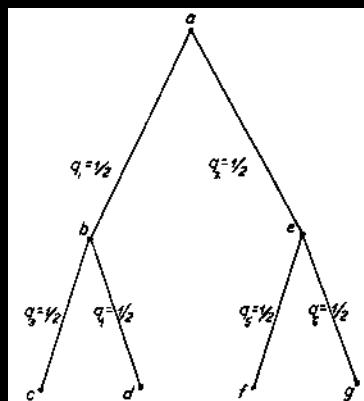
MacArthur



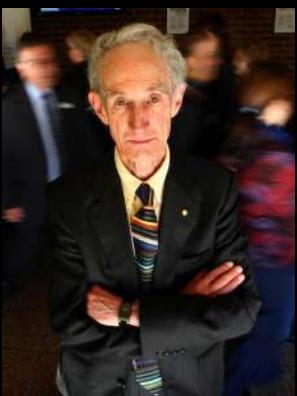
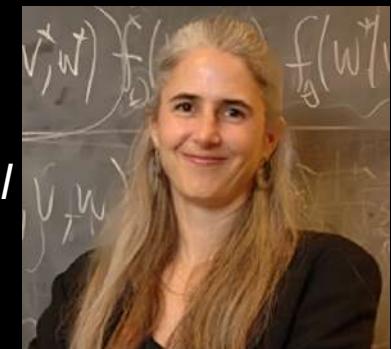
Margalef



Kondoh



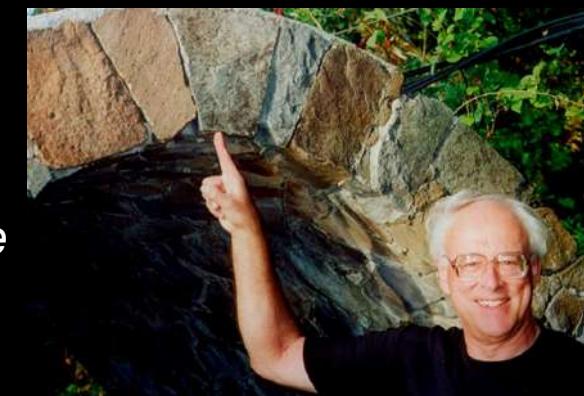
Pascual



May

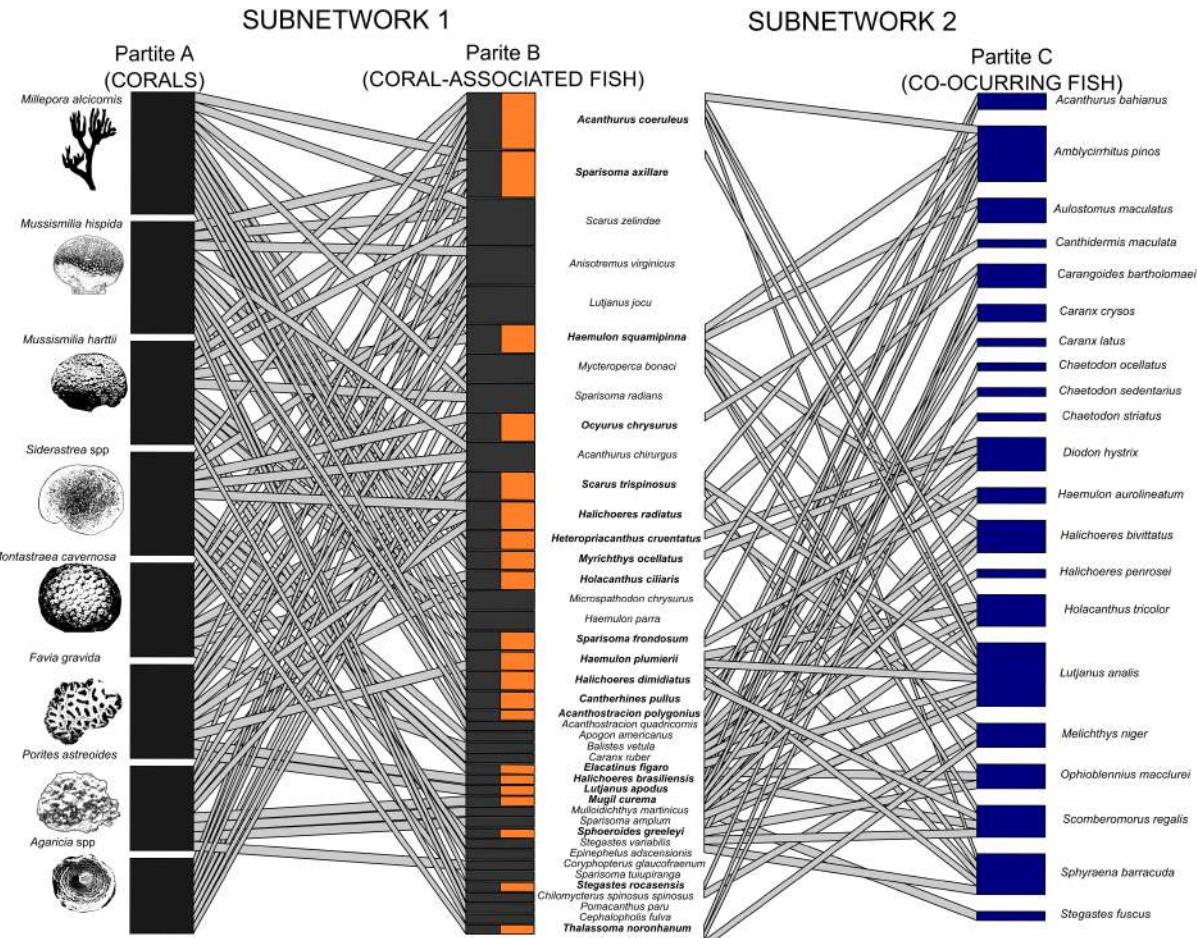


Bascompte



Paine

# Colapso por efeitos em cascata



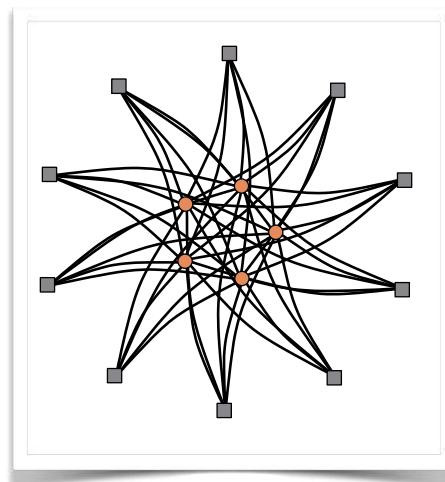
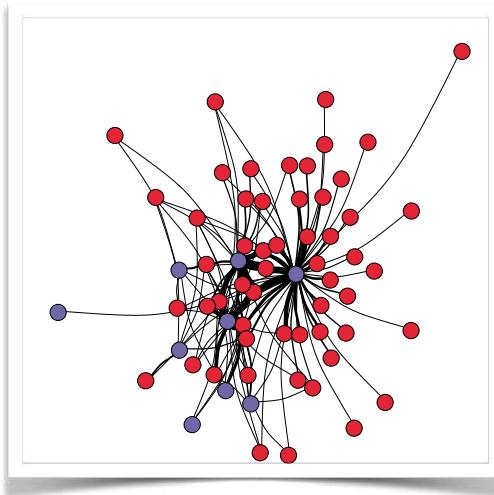
Mariana Bender

Luza et al. 2024. Global Change Biology



R. Albert

“... complex systems must display some organizing principles, which should be at some level encoded in their topology”

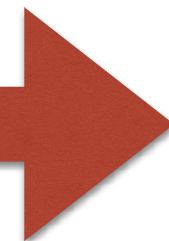
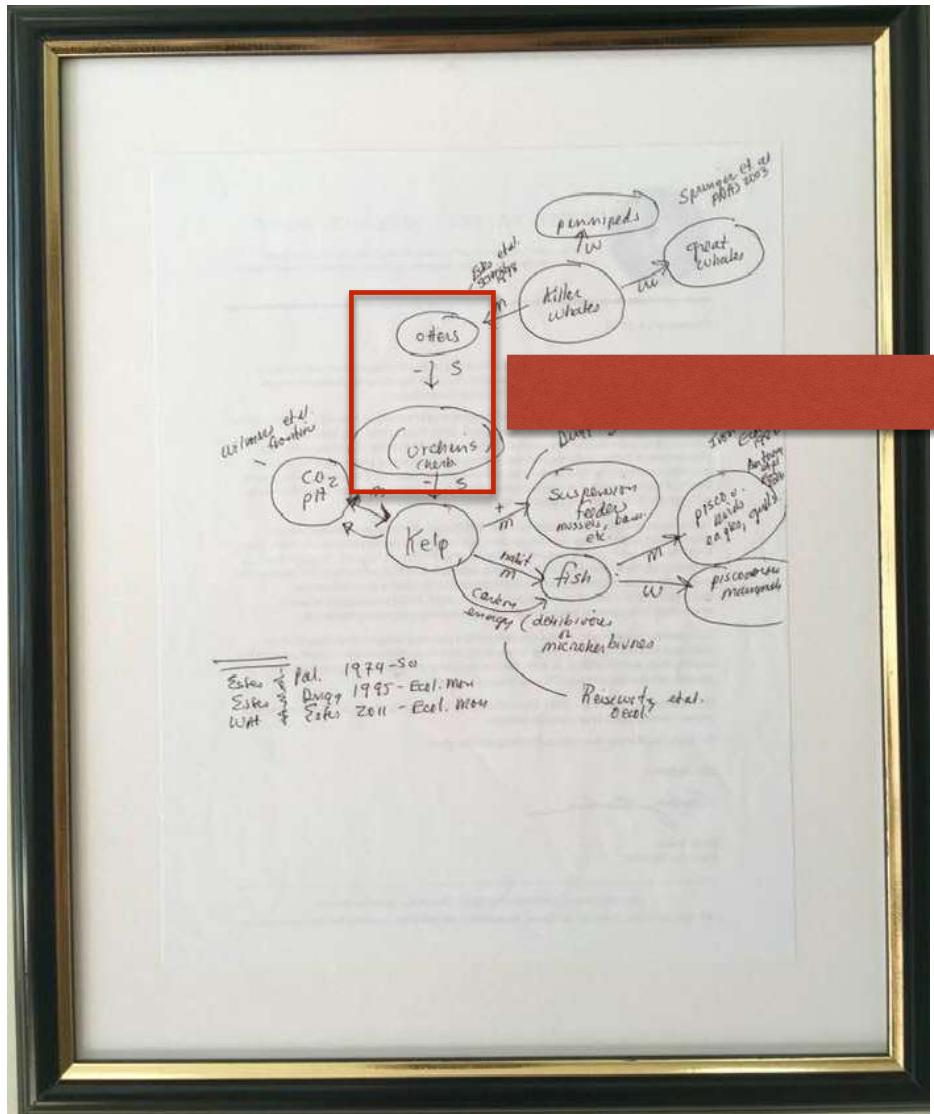


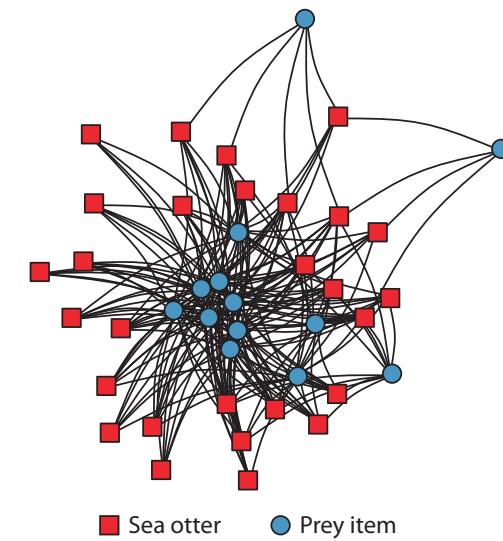
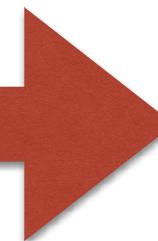
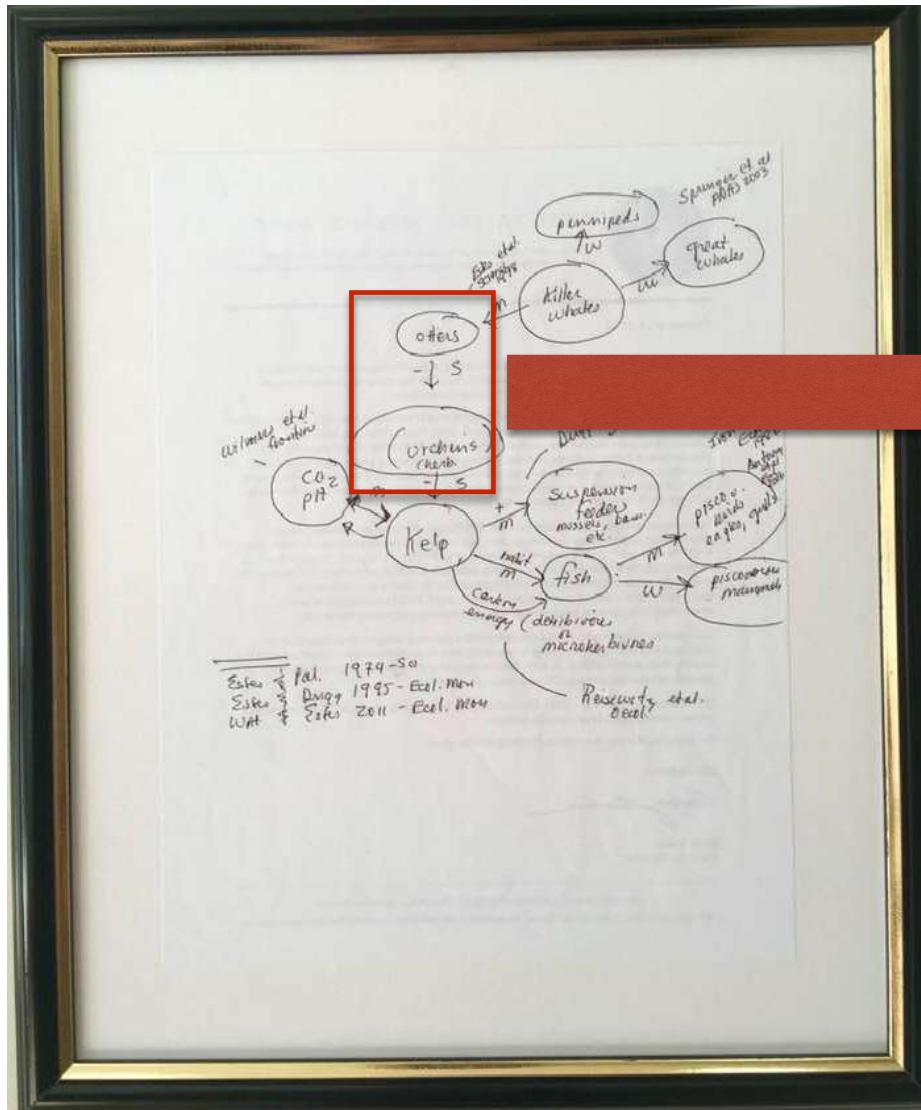
A. L. Barabási

Albert. 2002. Rev. Mod. Phys

# **Duas perguntas fundamentais**

- Como processos moldam a estrutura observada?
- Como a estrutura observada molda processos?

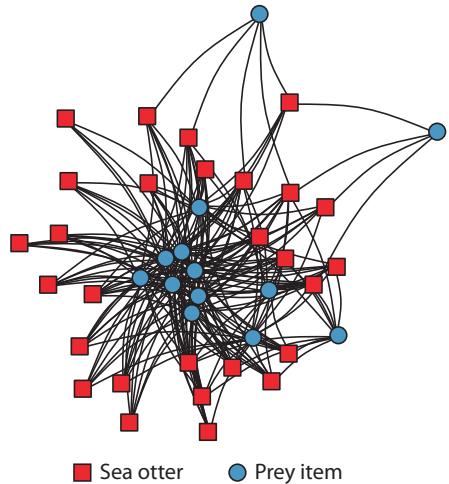




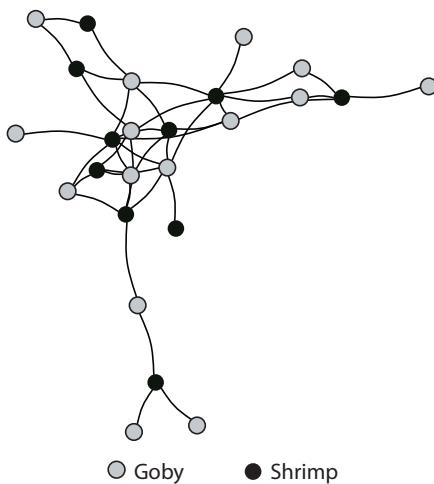
# Redes ecológicas: descrevendo padrões, inferindo processos

## Em diferentes níveis de organização

a An individual-based network



b A species-based network



# **Redes ecológicas ao longo dos níveis de organização**

- Redes baseadas em indivíduos e a estrutura do nicho populacional
- Redes baseadas em espécies: espécies super-conectadas e padrões arquitetônicos
- Efeitos indiretos em redes ecológicas
- Possíveis caminhos: integrando as redes biológicas

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# Uma observação trivial:

Não há variação intrapopulacional em uma população de especialistas extremos



*Utetheisa ornatrix* & *Crotalaria* spp.

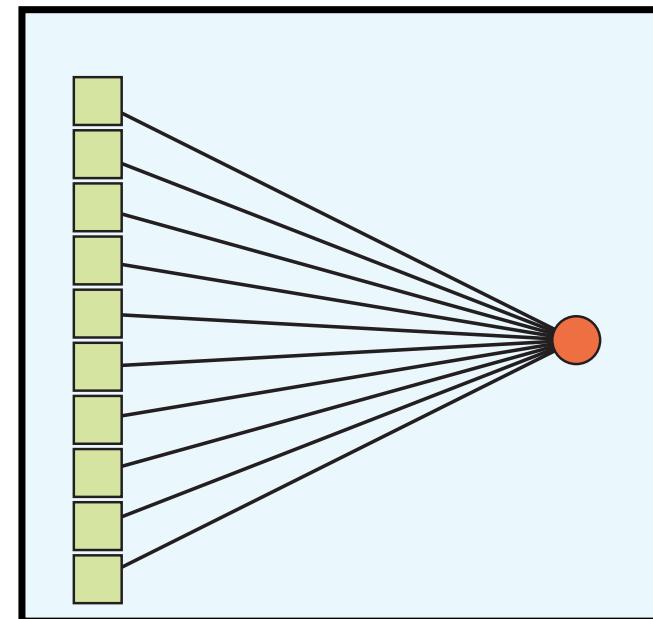


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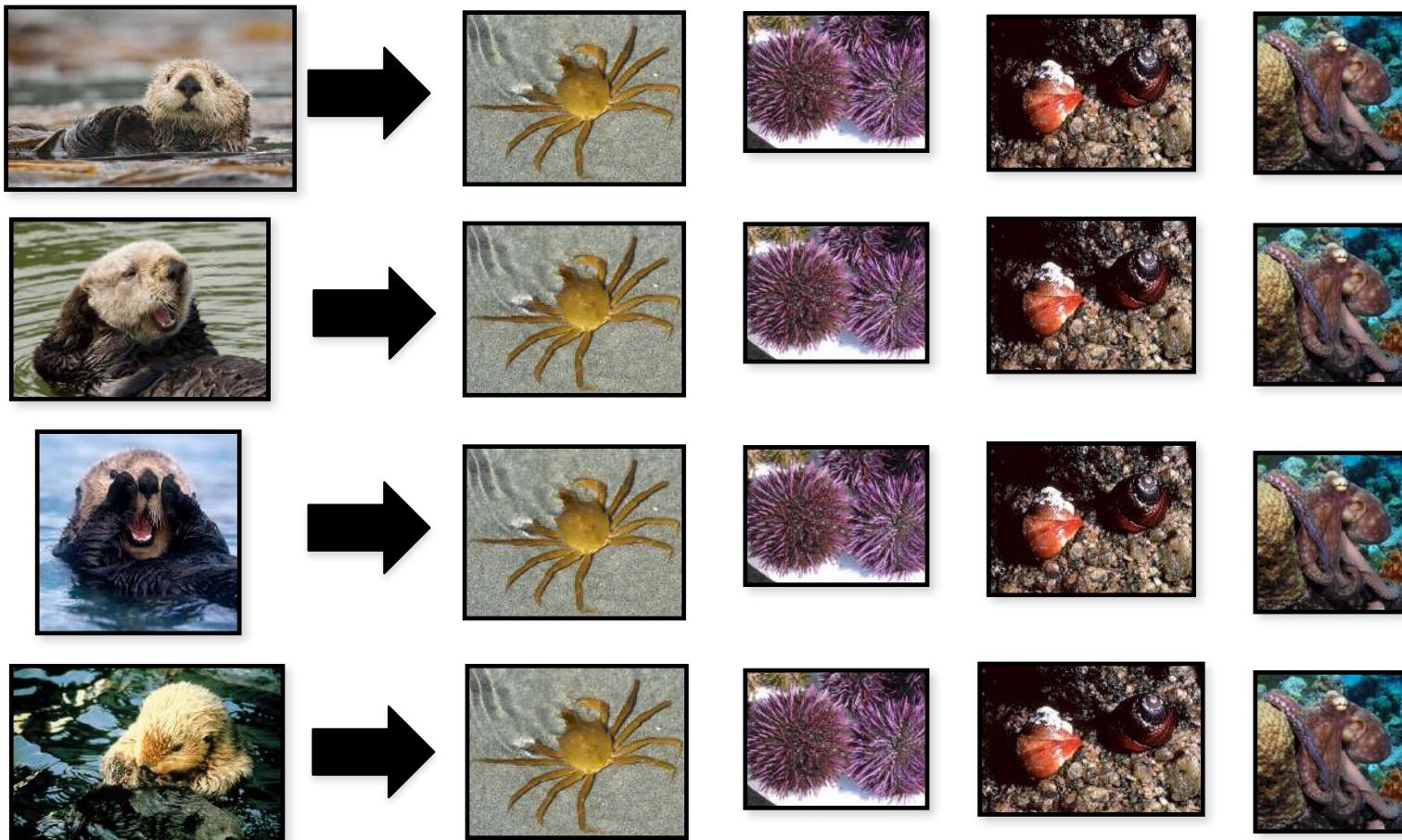


*Utetheisa ornatrix* & *Crotalaria* spp.



# Ecologia clássica: indivíduos são equivalentes

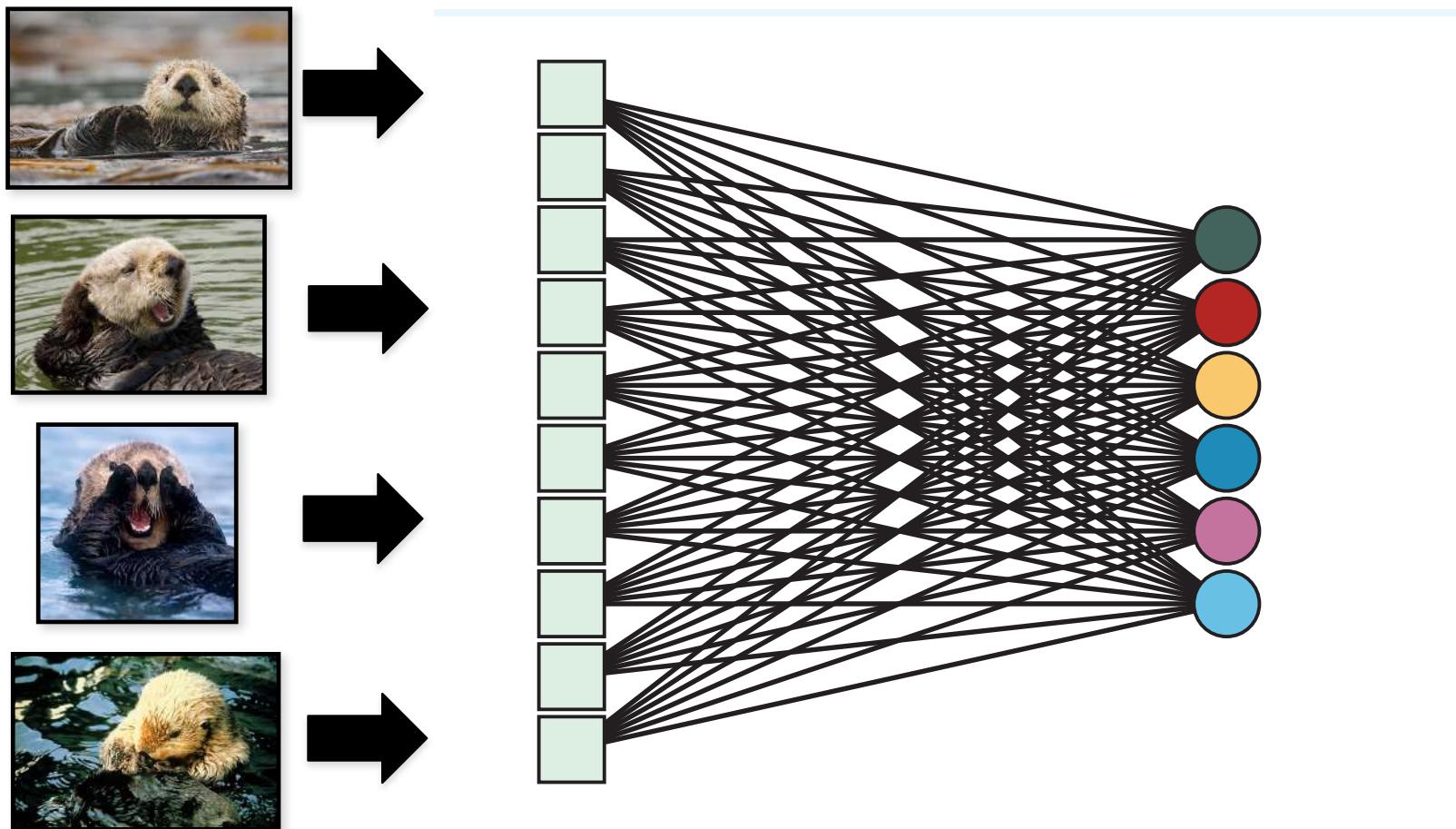
Campo médio: uma população generalista é formada por generalistas



Bolnick et al. 2003. American Naturalist, Estes et al 2003.J. Animal Ecology

# Ecologia clássica: indivíduos são equivalentes

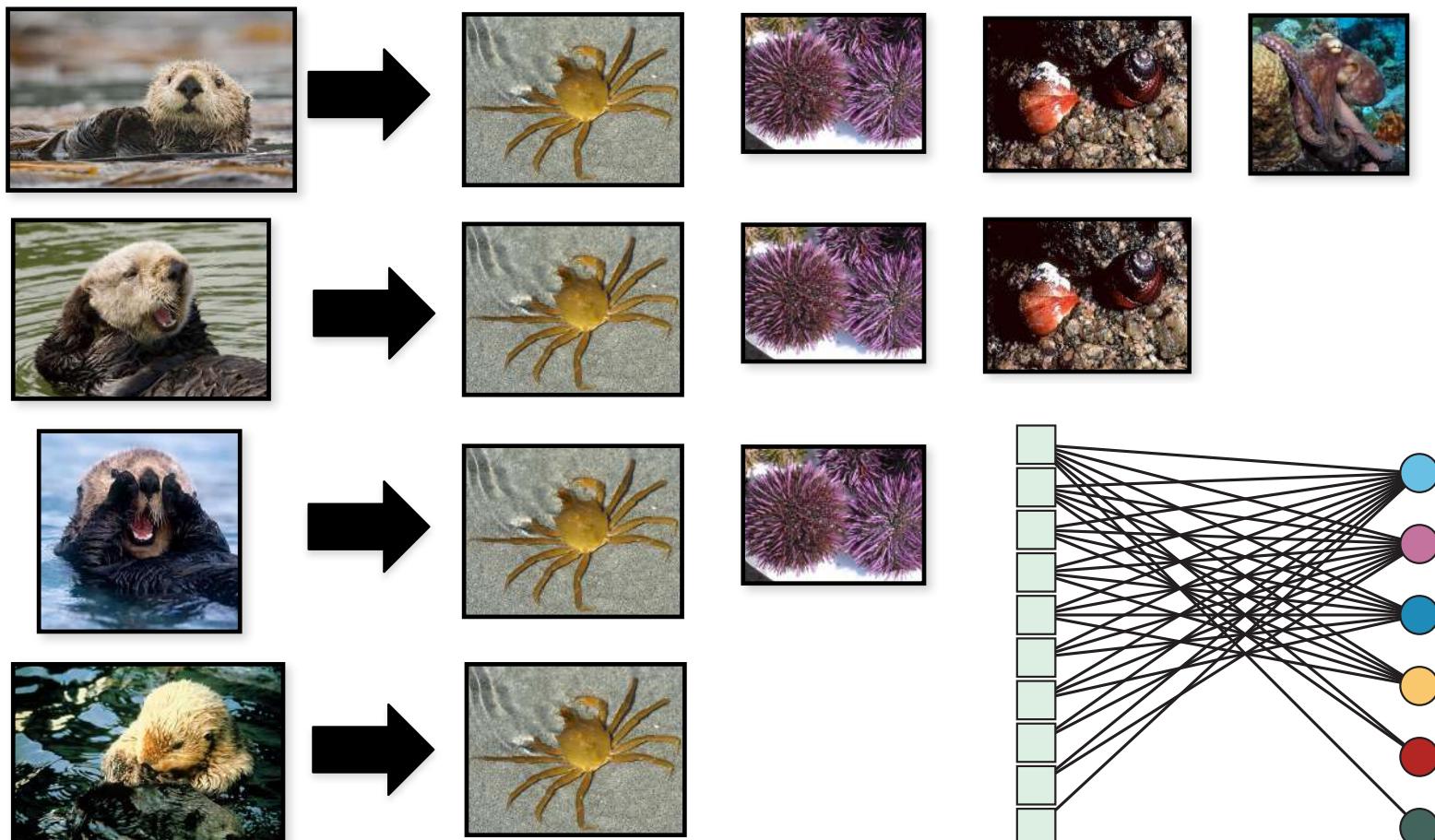
Campo médio: uma população generalista é formada por generalistas



Bolnick et al. 2003. American Naturalist, Estes et al 2003. J. Animal Ecology

# Há uma estrutura no uso do recurso

Descrições baseadas em redes revelam a estrutura do nicho populacional

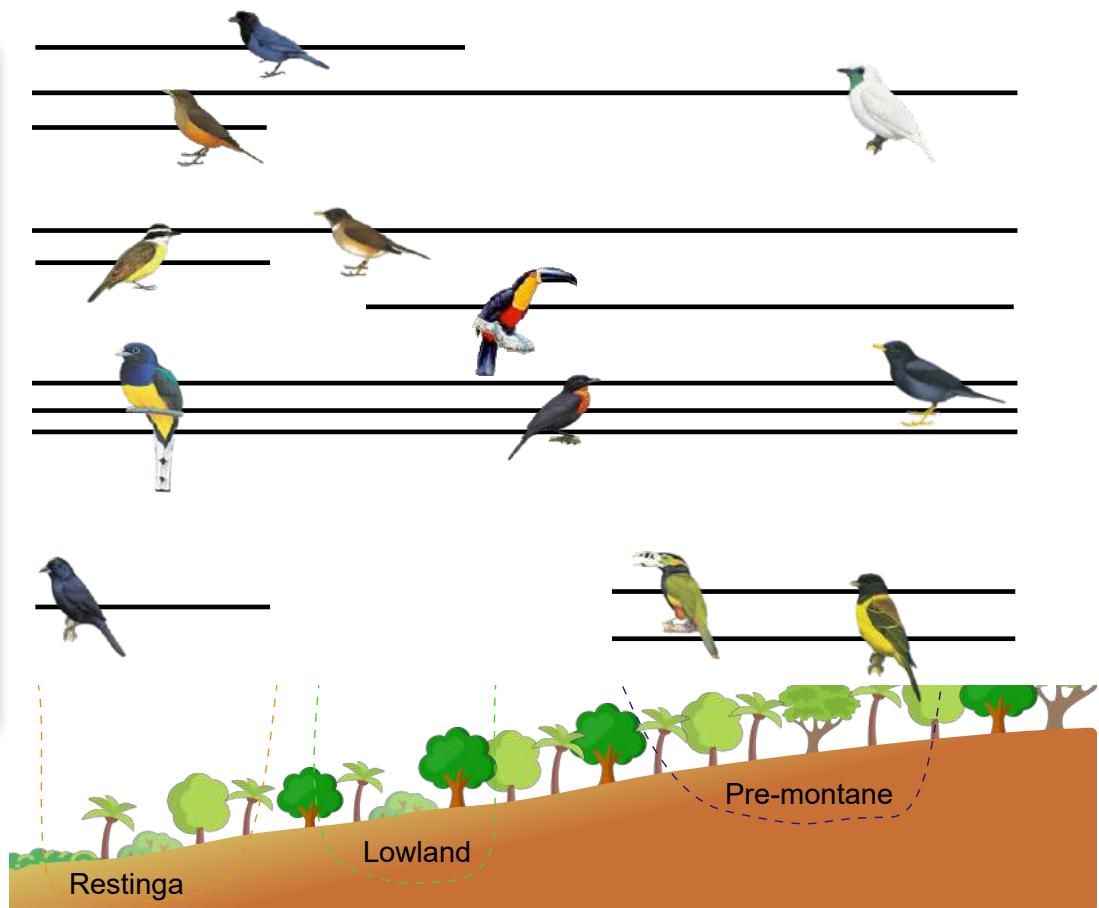


Tinker et al. 2012. Ecology Letters

# Espaço expandindo o nicho populacional



Pâmela Friedemann



Marina Côrtes

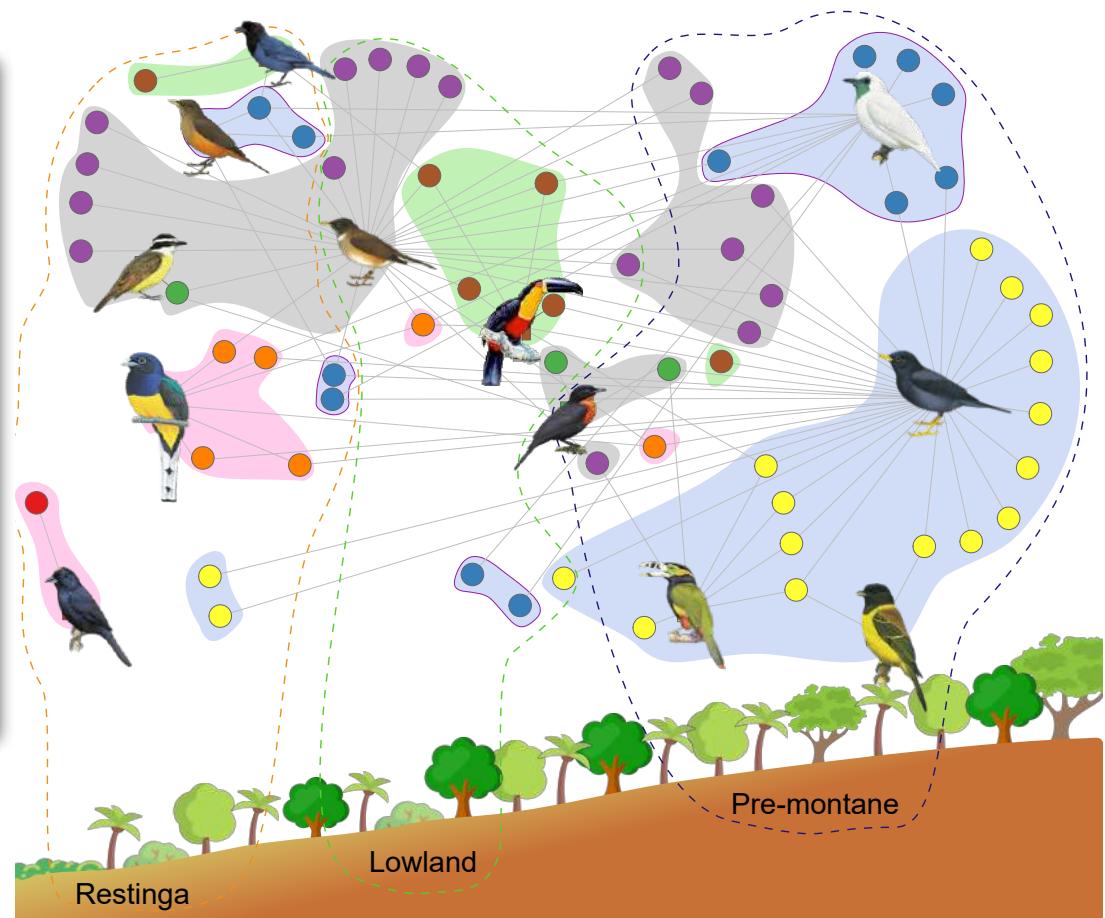
Friedemann et al. 2023. Oikos

# Espaço expandindo o nicho populacional

○ Palm individuals



Pâmela Friedemann



Marina Côrtes

Friedemann et al. 2023. Oikos

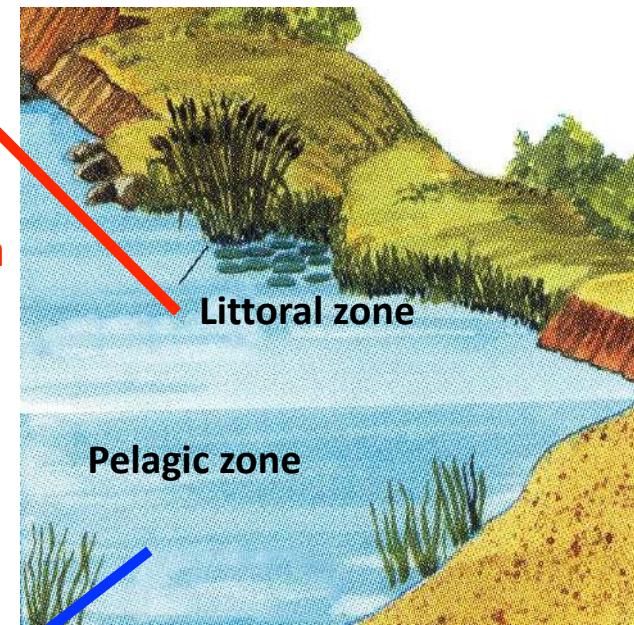
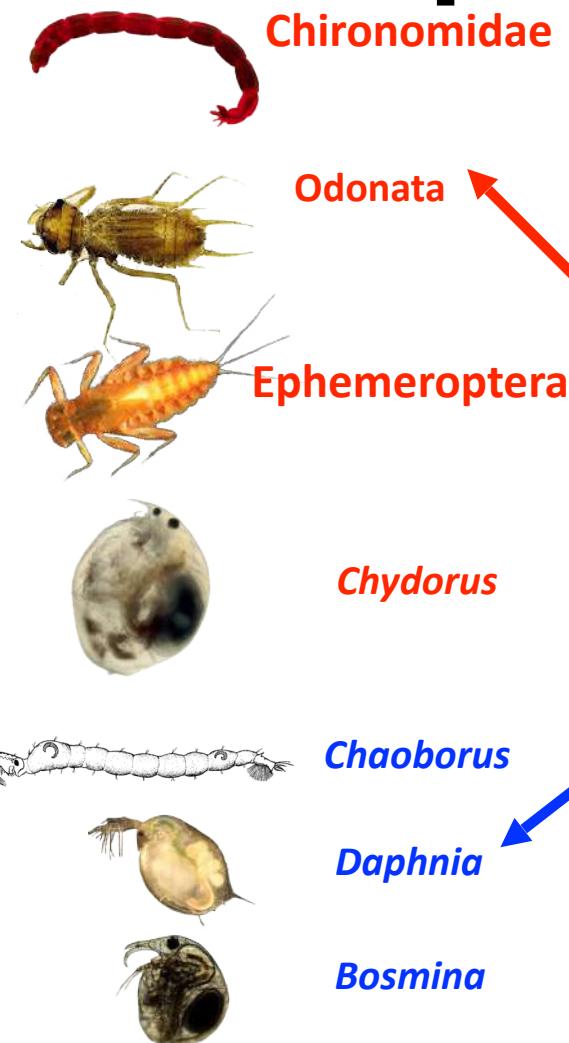
# Criando espécies super-conectadas



*Gasterosteus aculeatus*



Márcio Araújo



Littoral zone

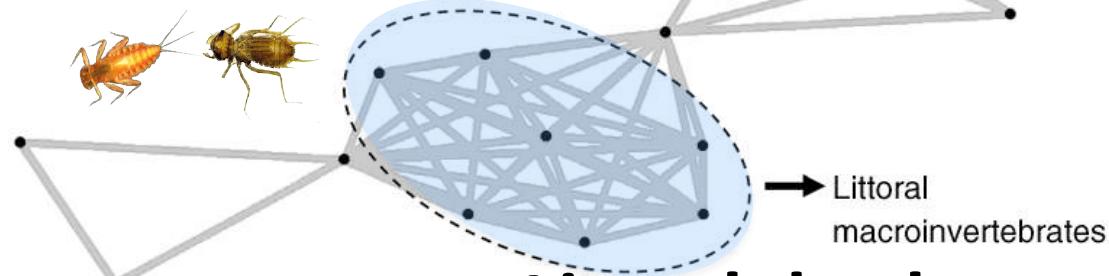
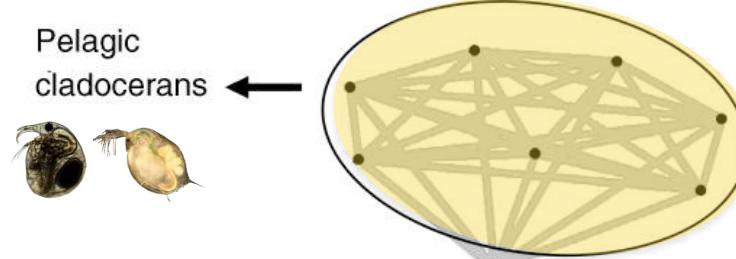
Pelagic zone

# Grupos alimentares estruturados no espaço



*Gasterosteus aculeatus*

## Zona pelágica dos lagos



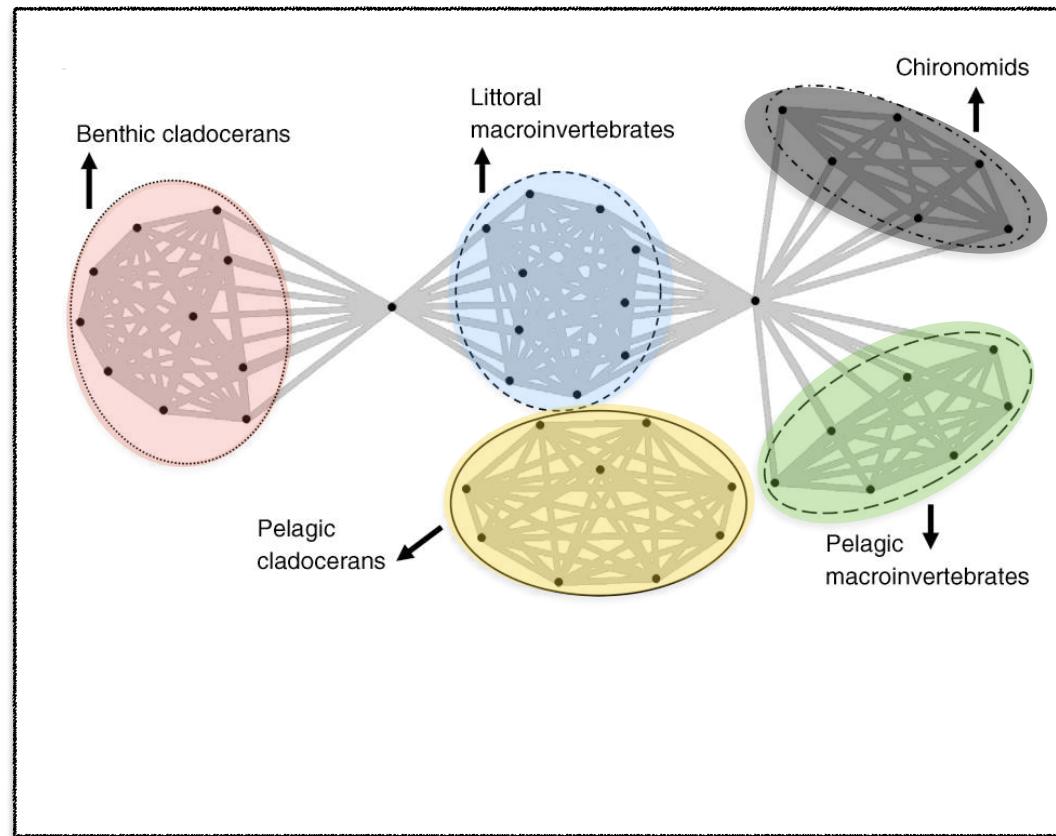
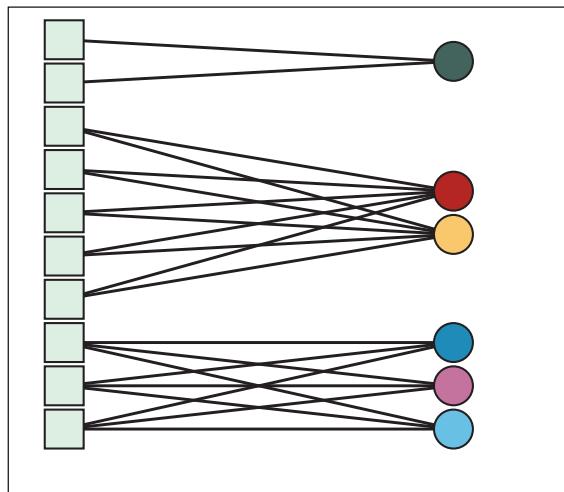
## Litoral dos lagos

Araújo et al 2008. Ecology

# E por competição ....



*Gasterosteus aculeatus*

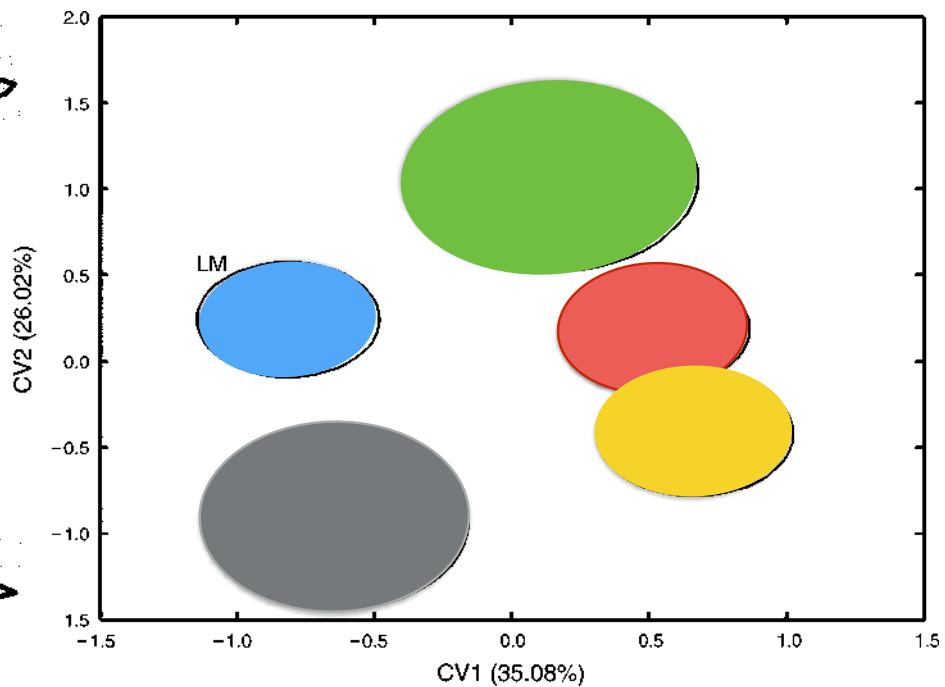
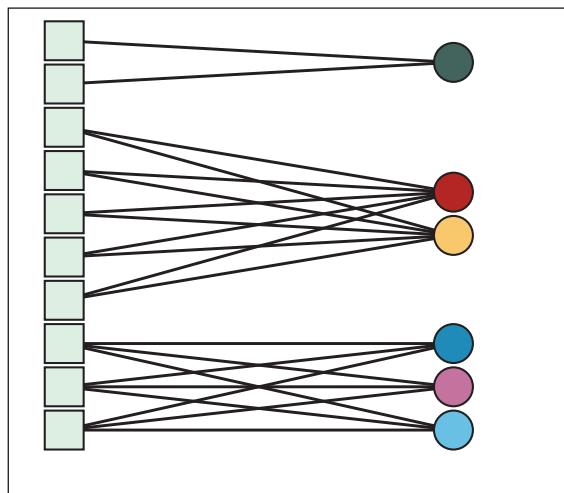


Araújo et al 2008. Ecology

# E por traços fenotípicos ....



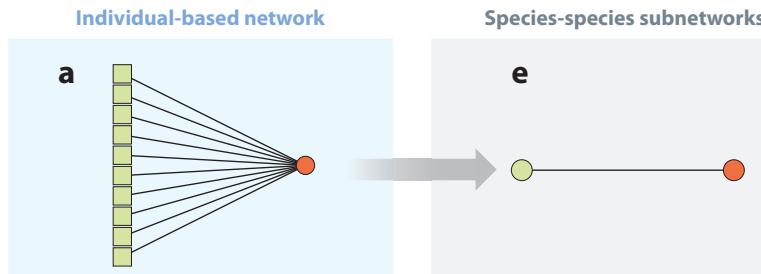
*Gasterosteus aculeatus*



Araújo et al 2008. Ecology

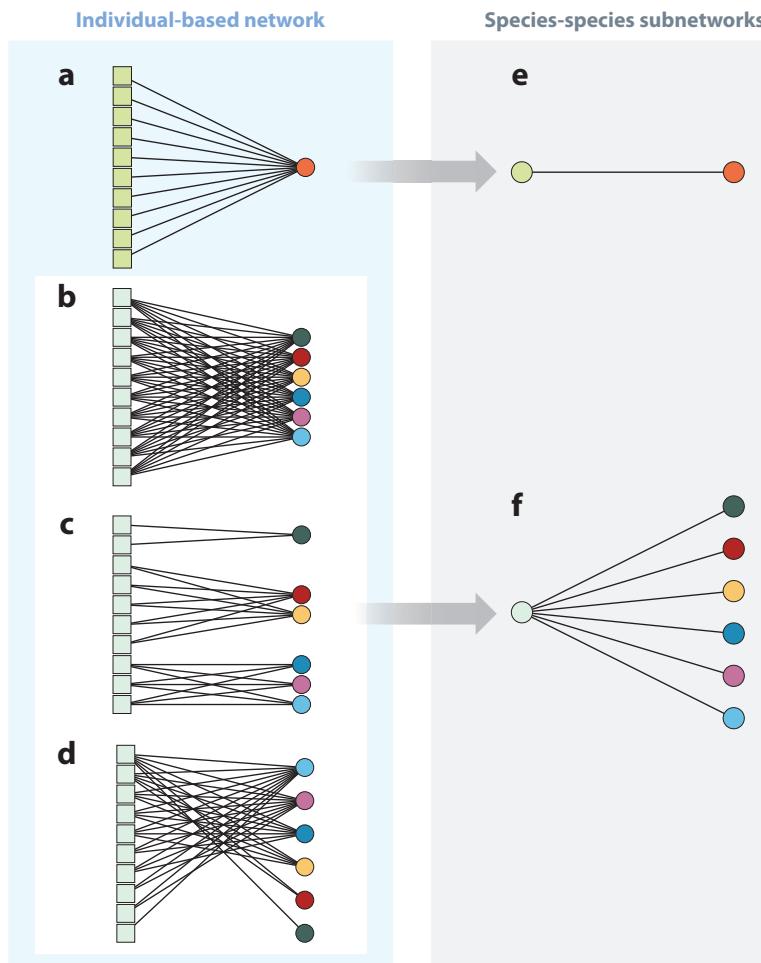
# Criando redes baseadas em espécies

Um efeito ecológico ou evolutivo que ocorre por meio de uma cadeia de interações diretas



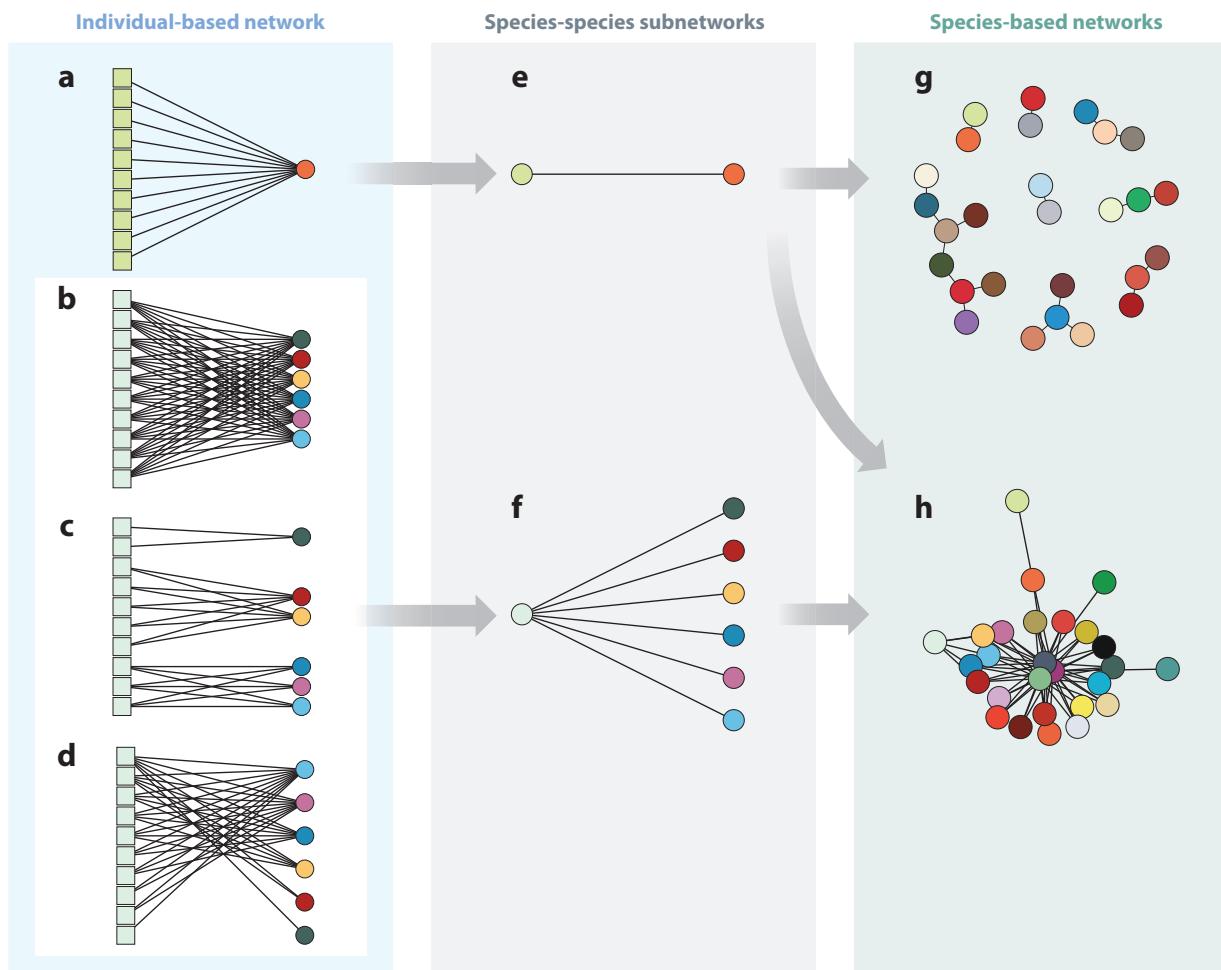
# Criando redes baseadas em espécies

Todos os especialistas se parecem, cada generalista é generalista à sua maneira



# Criando redes baseadas em espécies

## Combinando subredes



Guimarães 2020. AREES

# Redes ecológicas ao longo dos níveis de organização

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# Padrões estruturais

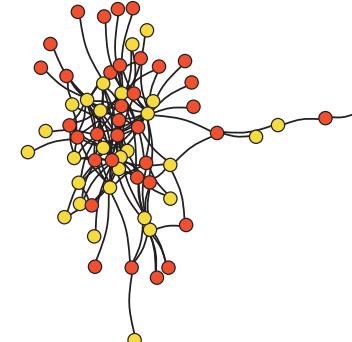
Possibilidades infinitas



JP Krajewski

31 espécies de plantas

21 espécies de vertebrados



Plants and frugivores

Guimarães 2020. AREES

# Padrões estruturais

Possibilidades infinitas

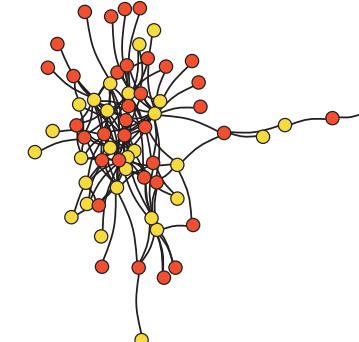


JP Krajewski

31 espécies de plantas

21 espécies de vertebrados

$2^{651} = 10^{196}$  possíveis interações



Plants and frugivores

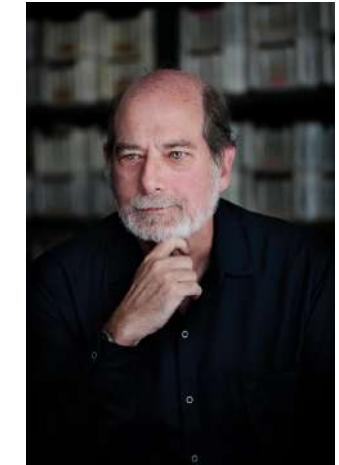
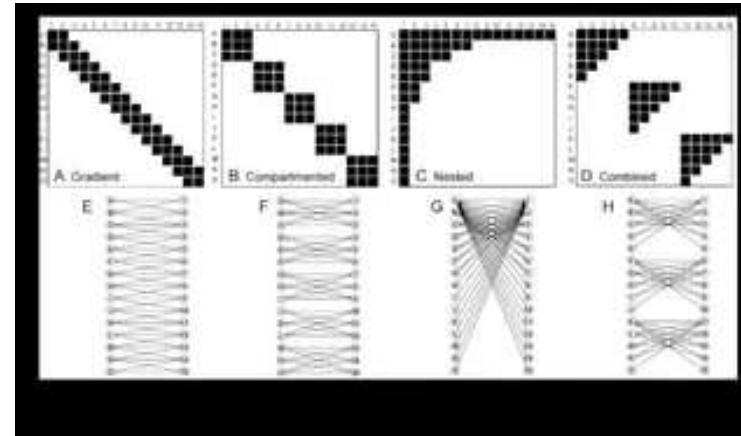
Guimarães 2020. AREES

$10^{196}$  interações possíveis >>>  $10^{79}$  elétrons no universo



# A estrutura das redes ecológicas

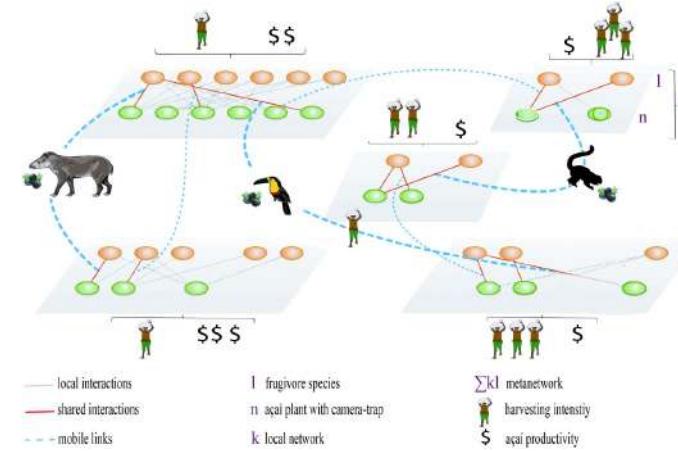
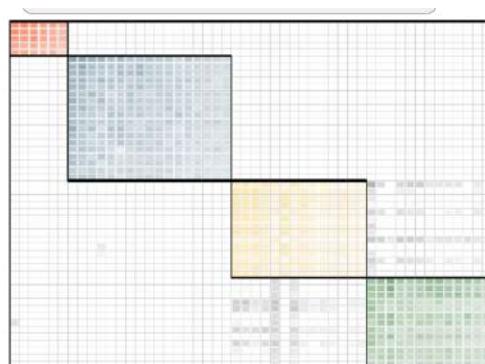
## Padrões estruturais complexos



**Thomas Lewinsohn**



**Marco A. Mello**

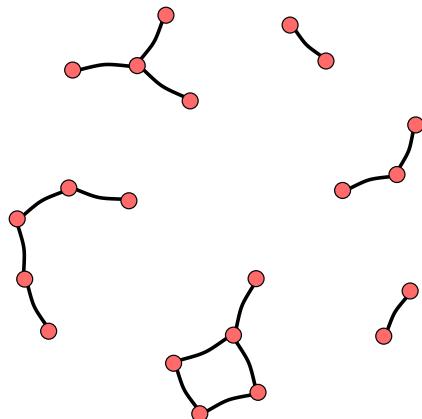


**Carine Emer**

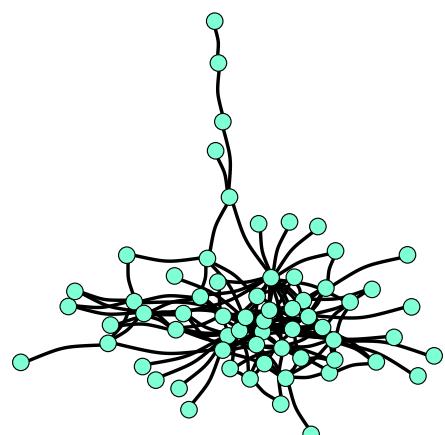
Lewinsohn et al. 2006. Oikos, Emer et al. 2018. Ecology Letters, Pinheiro et al. 2019. Ecology

# Um aspecto muito simples da estrutura

Duas formas de ser uma rede ecológica



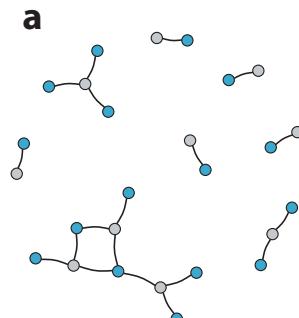
**Redes desconectadas  
(componentes múltiplos)**



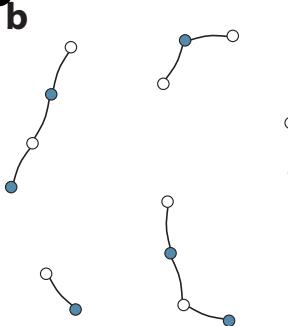
**Redes conectadas  
(a componente gigante)**

# Um aspecto muito simples da estrutura

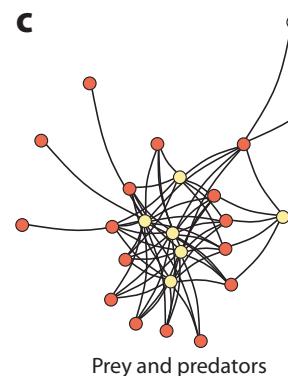
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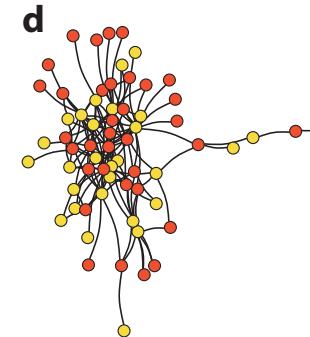
Plants and galling insects



Myrmecophytes and ants



Prey and predators



Plants and frugivores

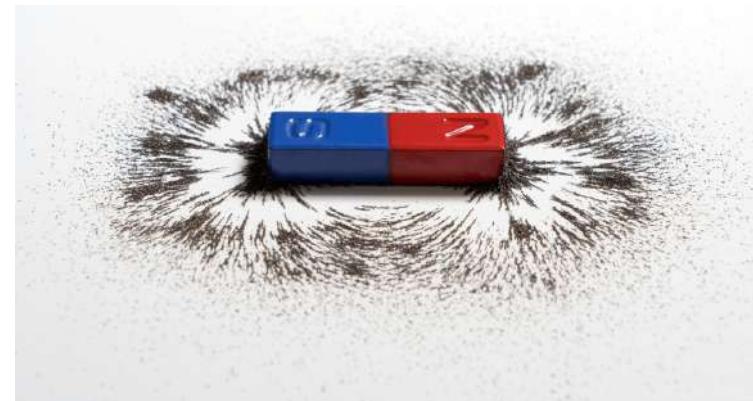


Foto: Motta Jr

Fontaine et al. 2011. Ecology letters, Pires & Guimarães 2013. Interface

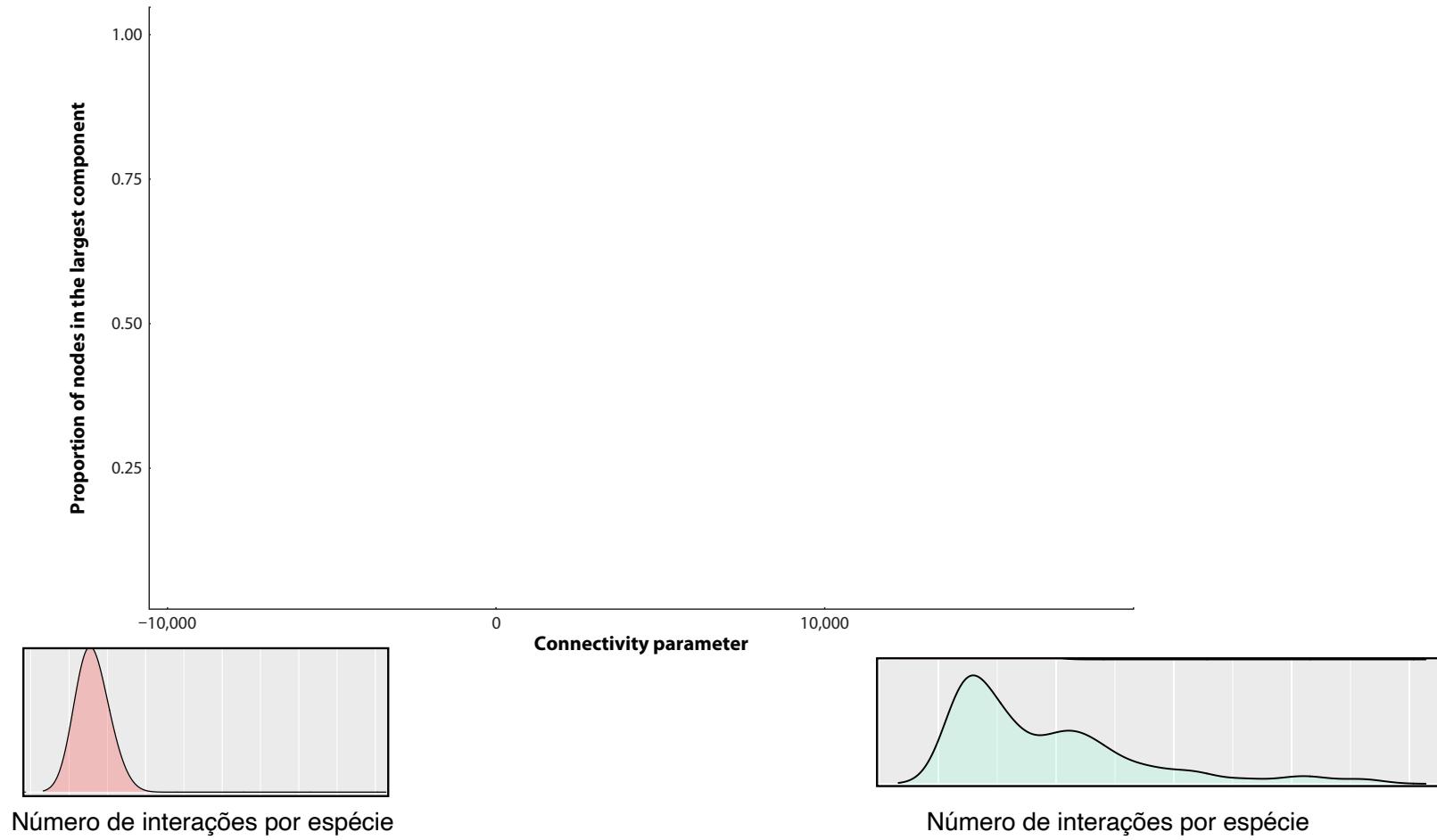
# A emergência da componente gigante

## Uma transição de fase em redes



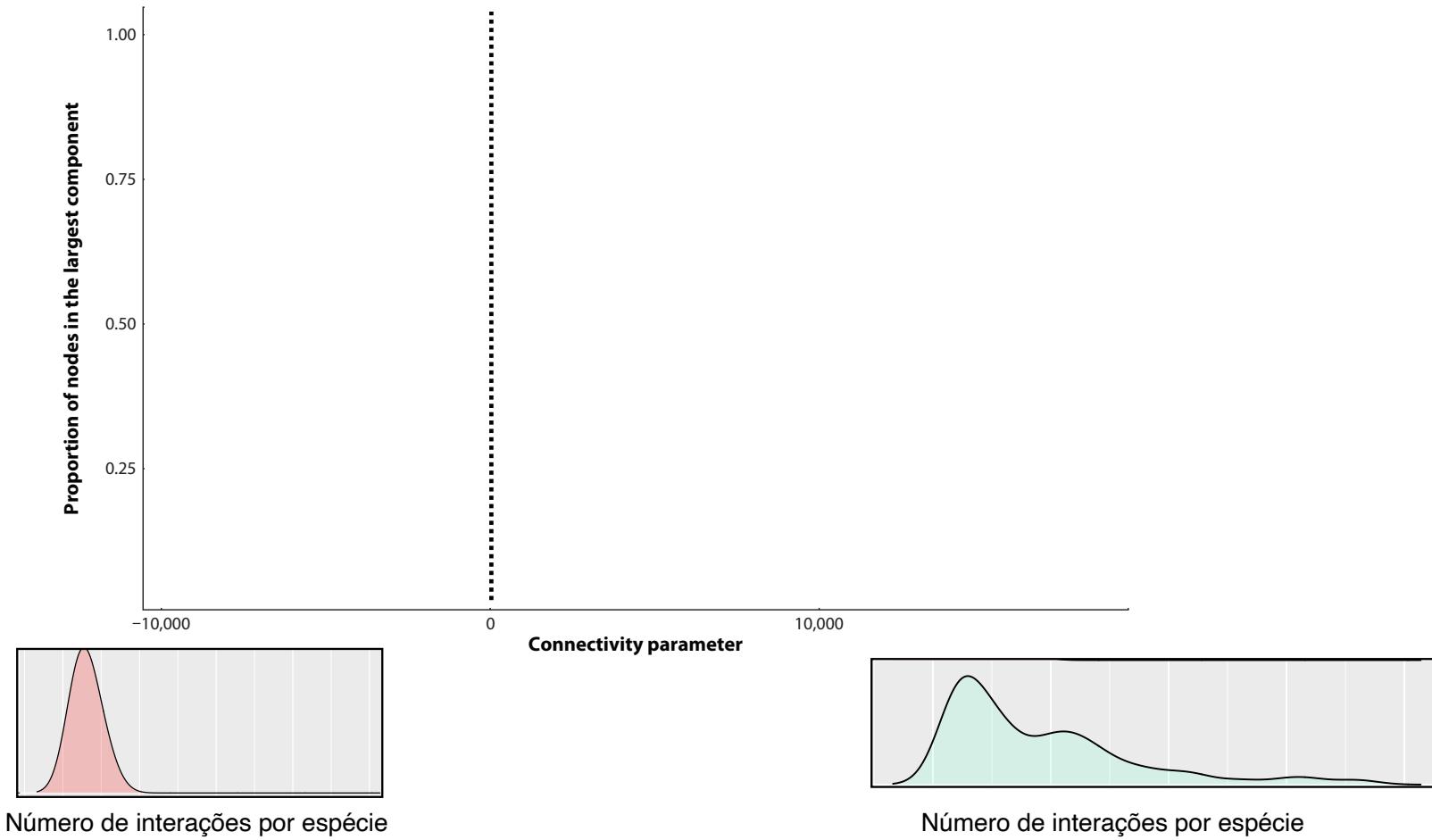
# Transição crítica em redes ecológicas

Um primeiro padrão arquitetônico: a emergência da componente gigante



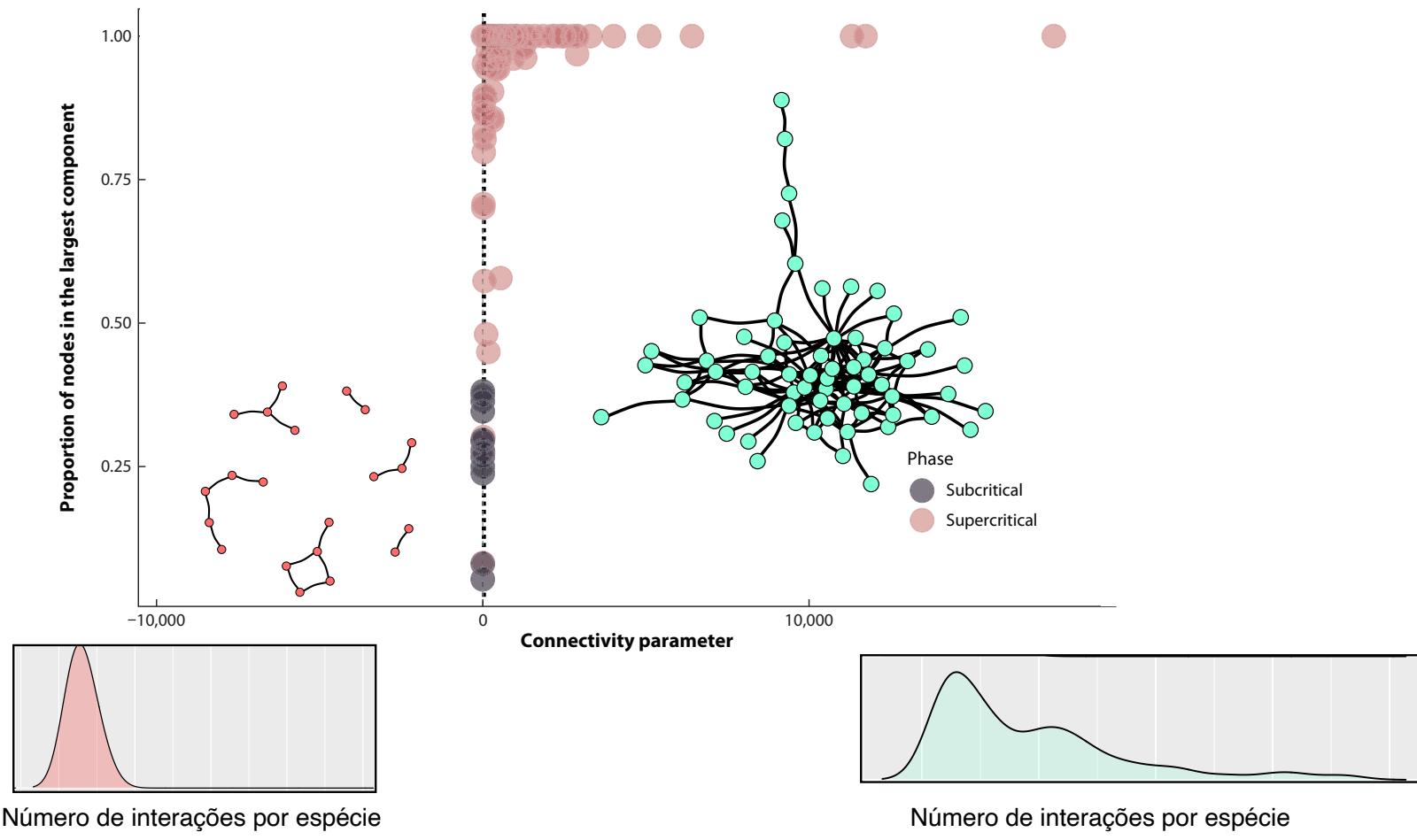
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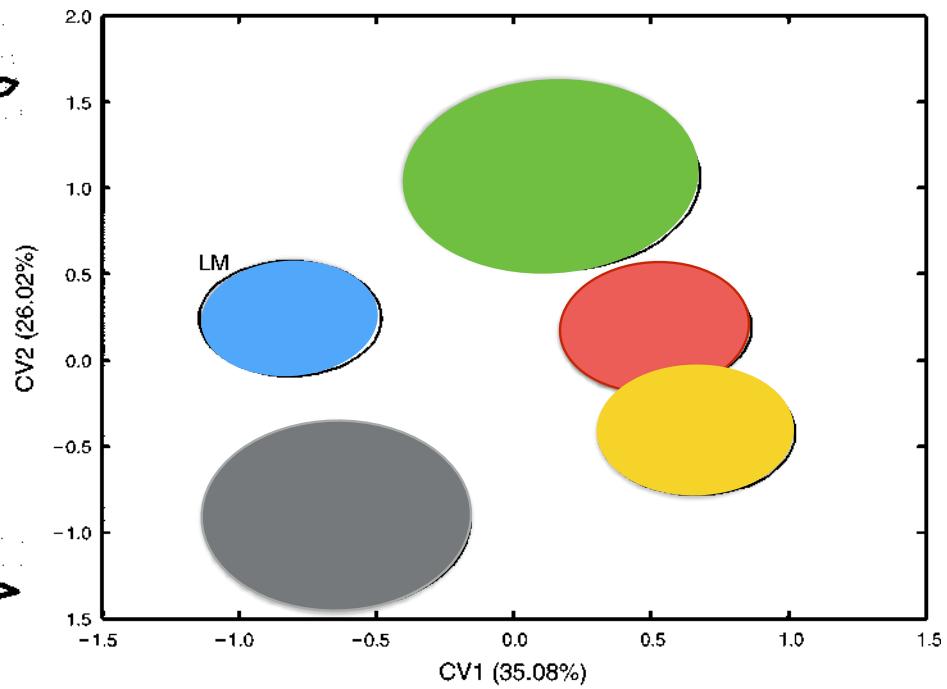
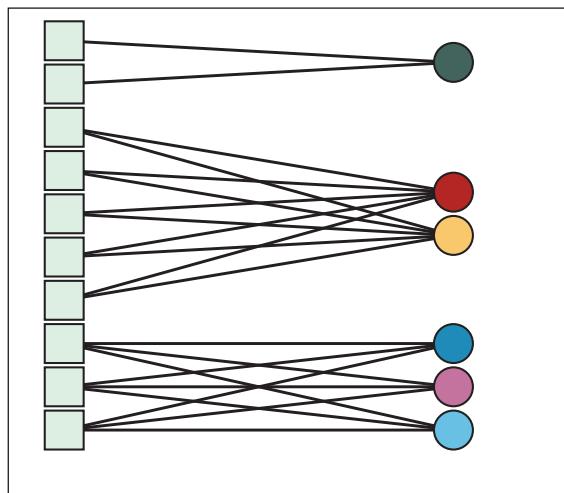
Um primeiro padrão arquitetônico: a emergência da componente gigante



# Gerando superconectadas: variação intra-específica



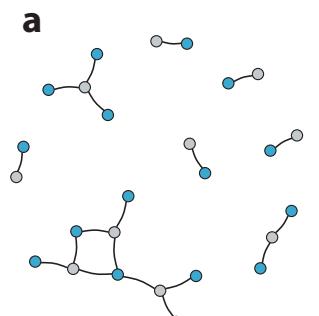
*Gasterosteus aculeatus*



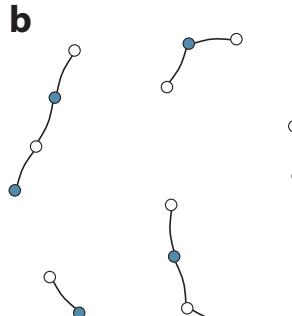
Araújo et al 2008. Ecology

# Traços modulam as interações

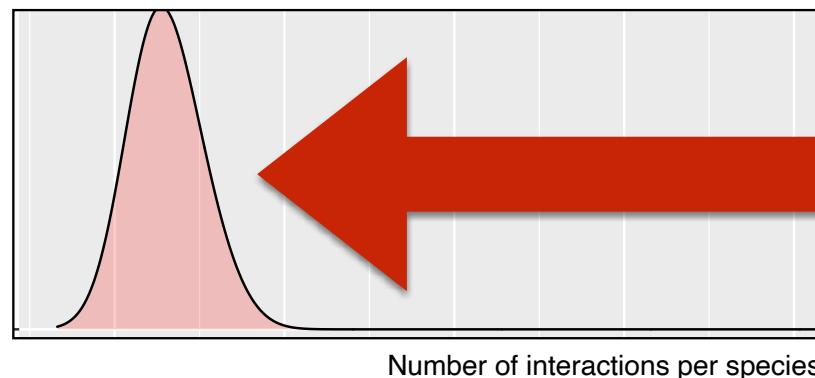
## Seleção natural favorecendo especialistas



## Plants and galling insects



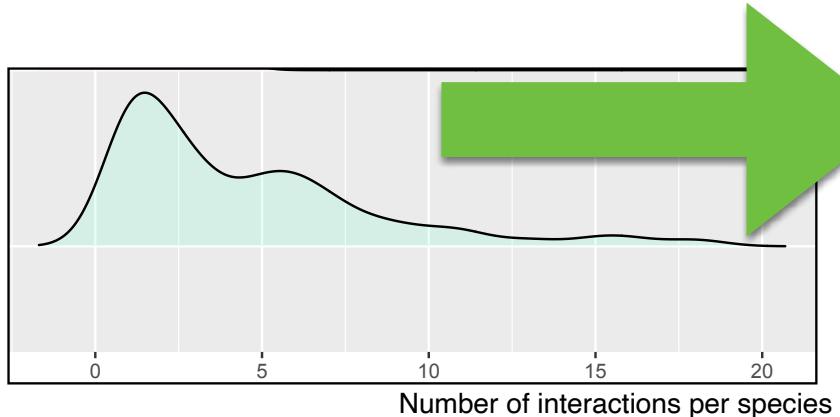
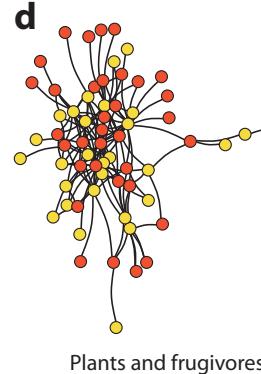
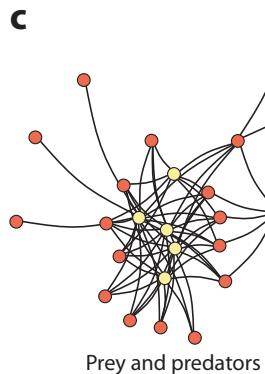
## Myrmecophytes and ants



## Seleção contra generalismo

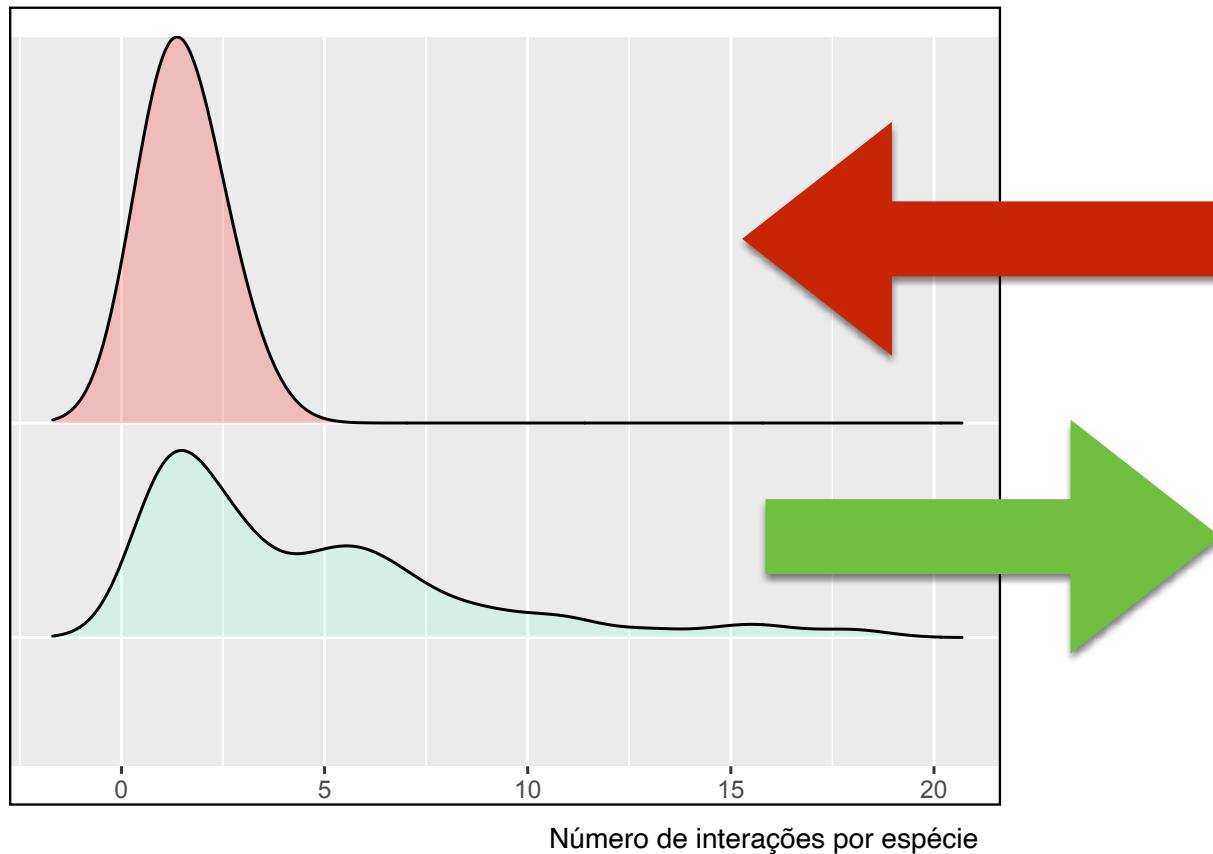
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## Seleção natural favorecendo generalistas



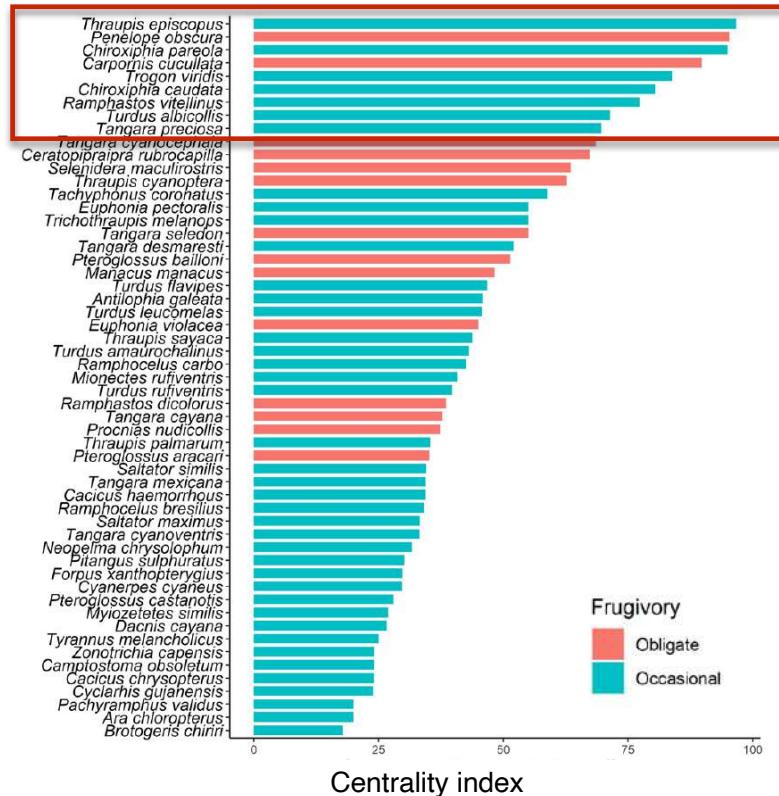
Seleção favorecendo alguns modos de vida  
Superconectados

# Seleção natural & especialização



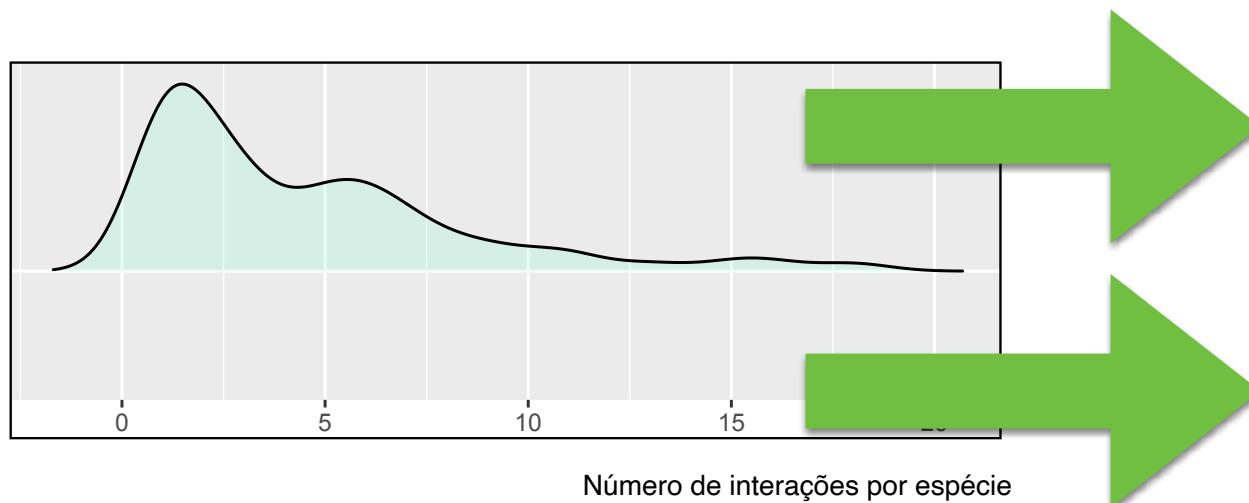


## Espécies super-conectadas



Bonfim et al. 2022. Oikos

# Dois tipos de espécies super-conectadas



Guimarães 2020. AREES, Guimarães, in prep.

# Super-generalistas: especialistas em redes



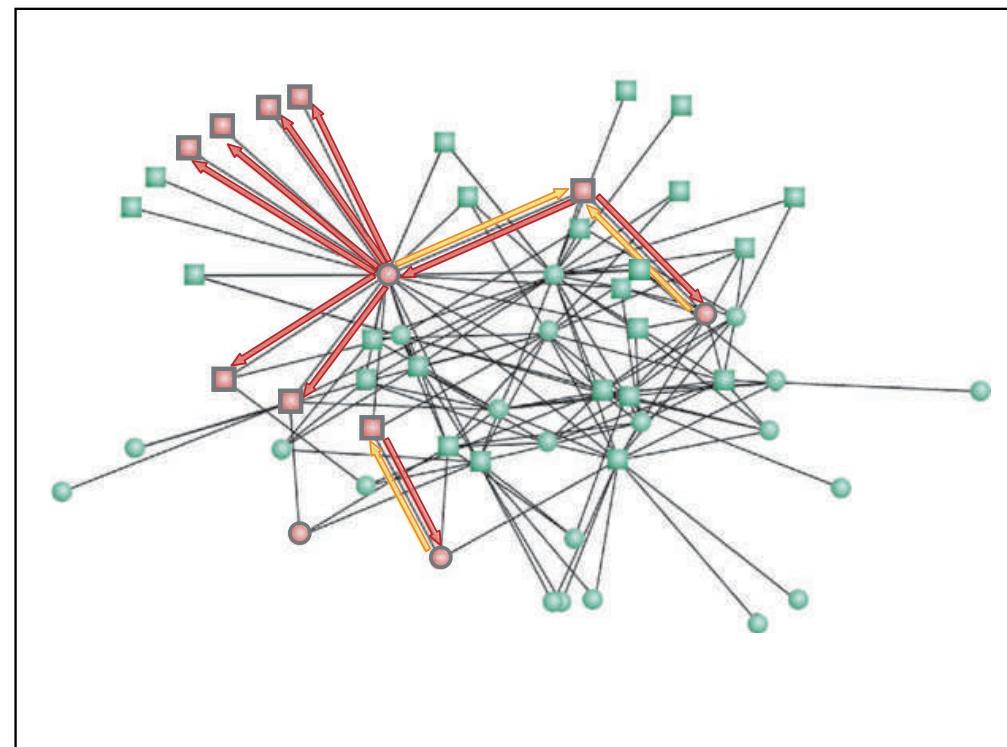
Jordano et al. 2003. Ecology Letters, Thompson 2005

# **As espécies super-conectadas criam a rede**

## **Segundo padrão arquitetônico: mundo pequeno**

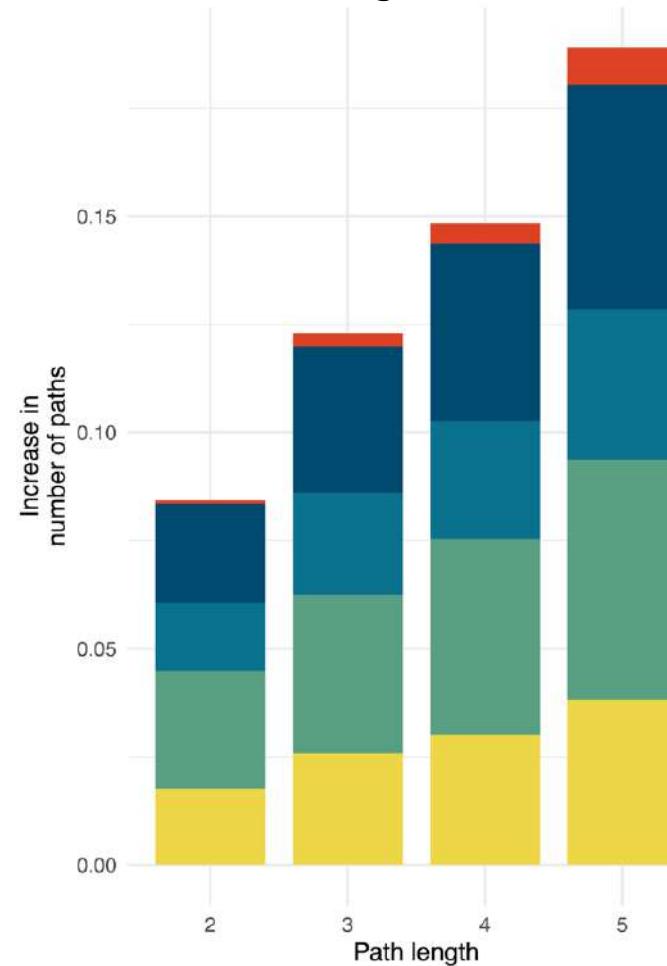
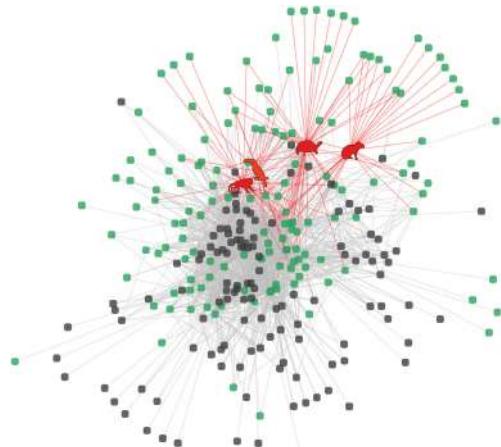
### **Mundo pequeno**

- Uma propriedade básica das redes
- Amplificado pelas espécies super-conectadas



# As espécies super-conectadas criam a rede

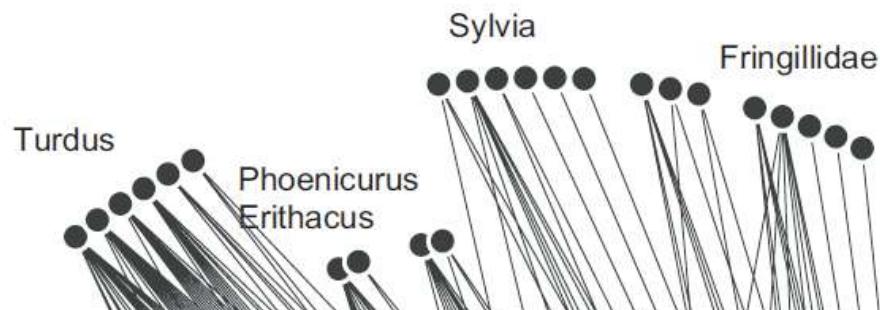
## Terceira padrão arquitetônico: proliferação de rotas



Mittelman et al. 2022, Oikos

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- Redes baseadas em espécies: espécies super-conectadas e padrões arquitetônicos
- **Efeitos indiretos em redes ecológicas**
- Possíveis caminhos: integrando as redes biológicas



## Um exemplo: a dinâmica coevolutiva em redes ecológicas

**1. Dados ecológicos**

**2. Modelos (gradientes de seleção e acoplamento fenotípico)**

**3. Ferramentas da mecânica estatística**



**“Nothing is less real than realism.  
Details are confusing. It is only by  
selection, by elimination, by  
emphasis, that we get at the real  
meaning of things.”**

**Georgia O'Keeffe**



Jordi Bascompte



Pedro Jordano



Ana Paula Assis



John N. Thompson



Marcus Aguiar



Cecilia Andreazzi



Mathias Pires



Flavia Marquitti



Carlos Melián



Paula Lemos-Costa



Magne Friberg



Pam Santana



Rafael Raimundo



Irina Barros



Kate Maia



Lucas Camacho



Lucas Medeiros



Lucas Nascimento

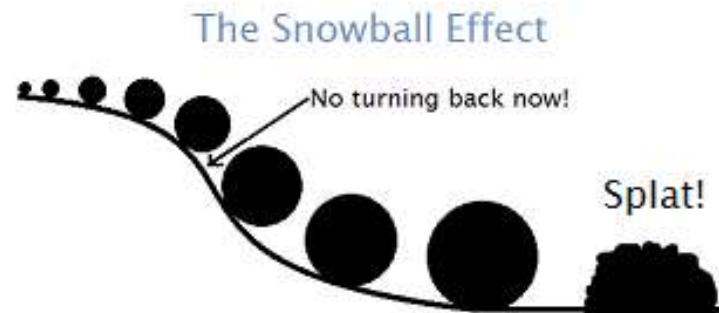
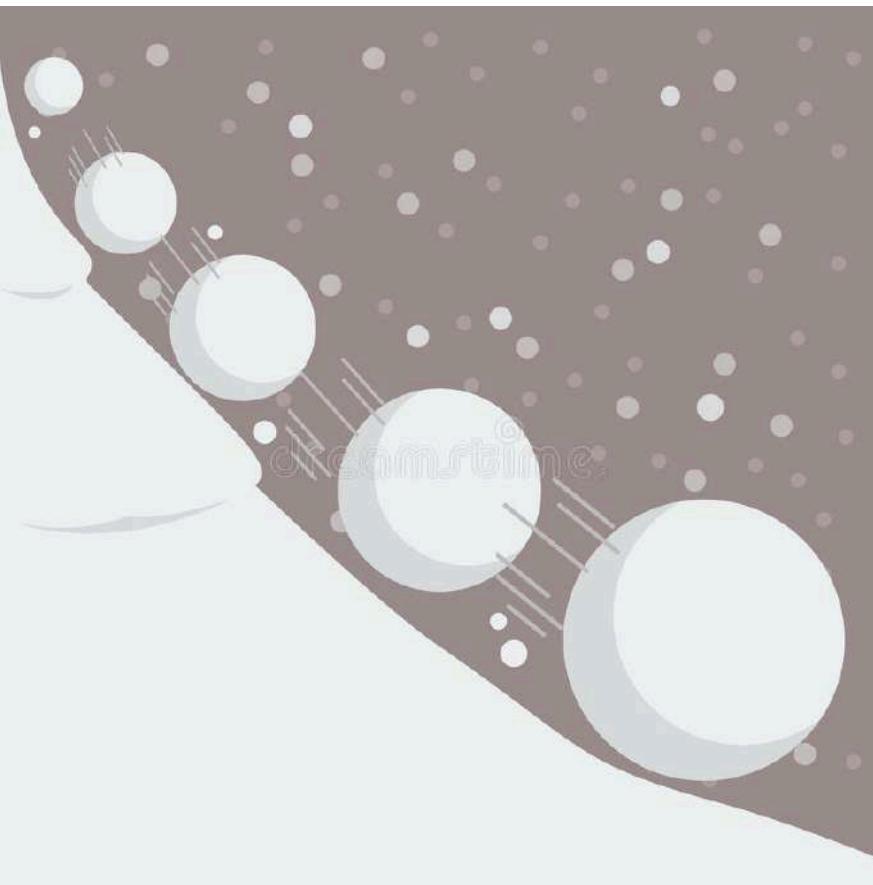


Leandro Cosmo



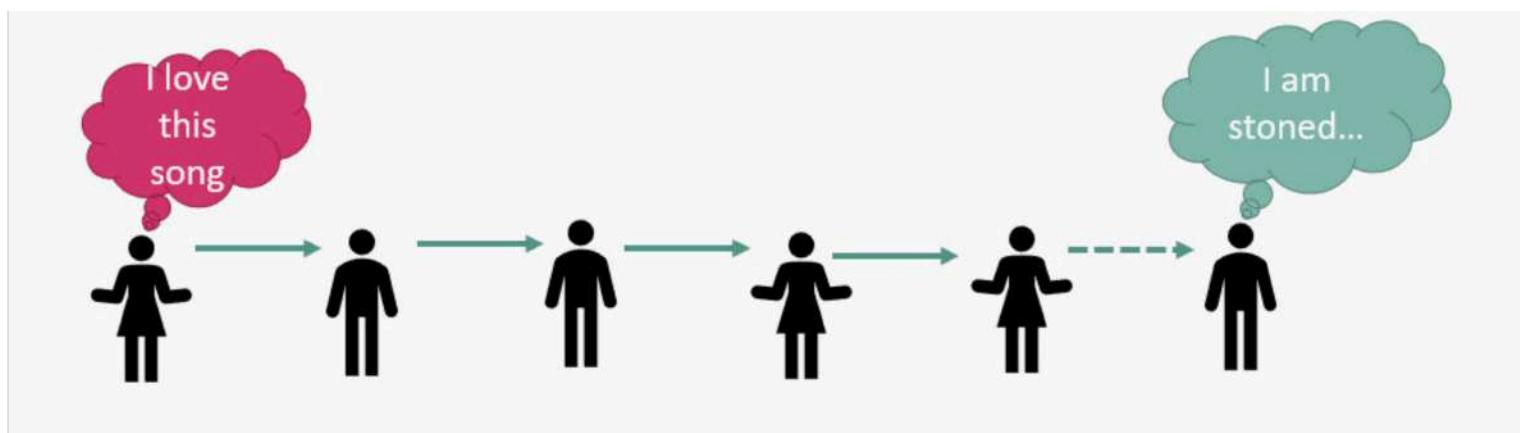
Vinícius Bastazini

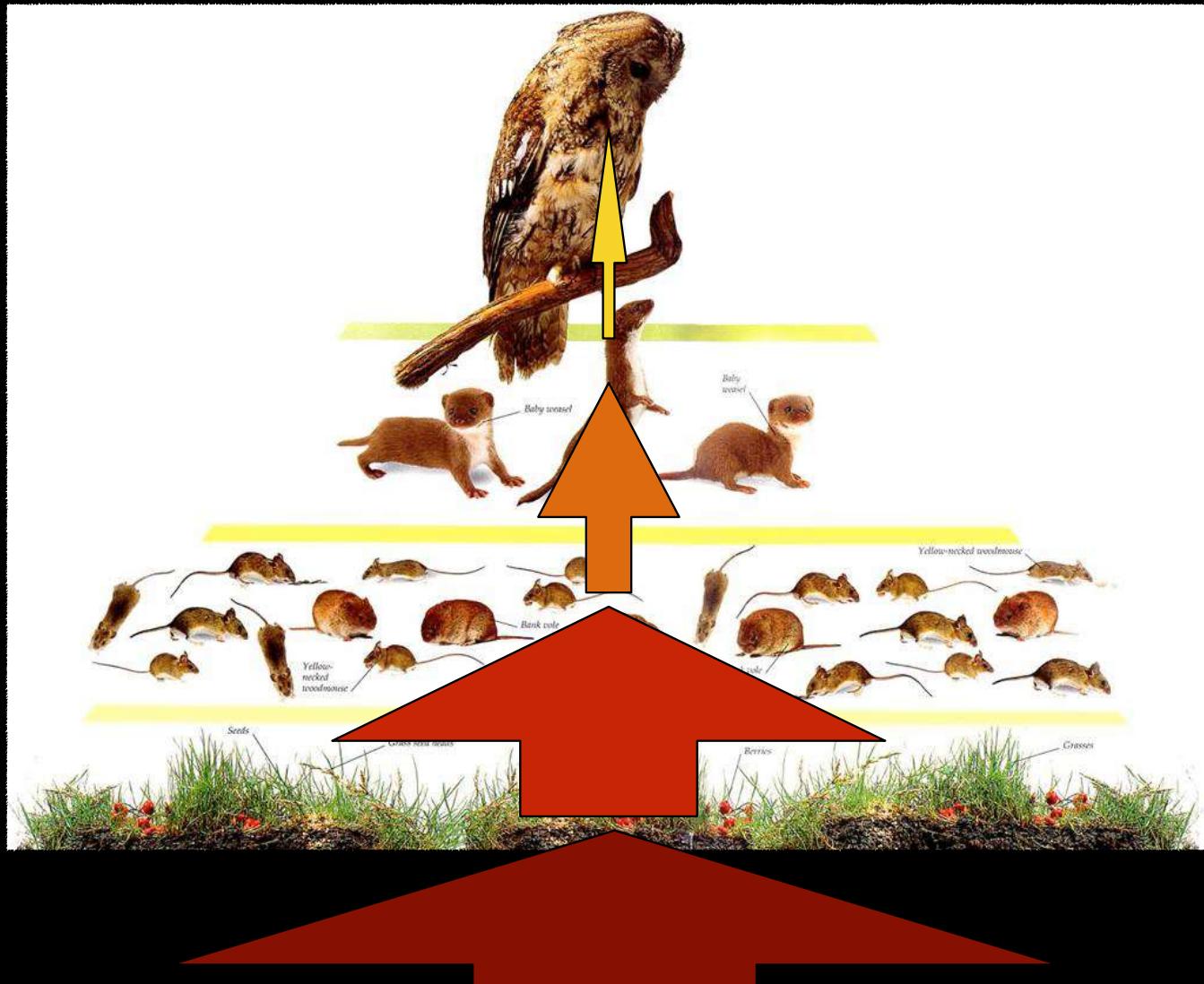
# Efeito bola-de-neve



# Efeitos telefone-sem-fio

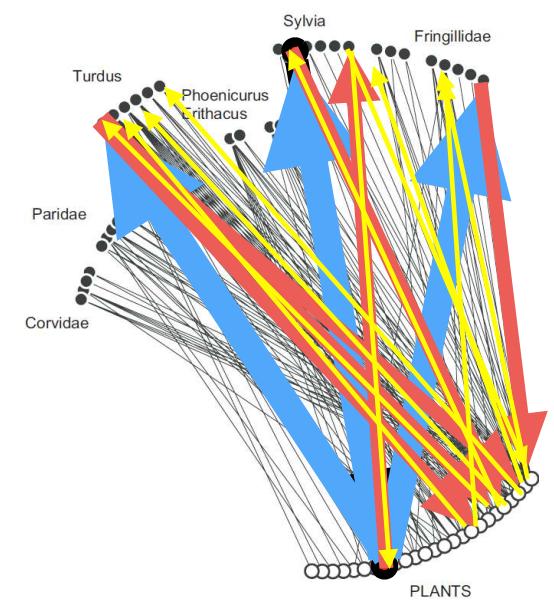
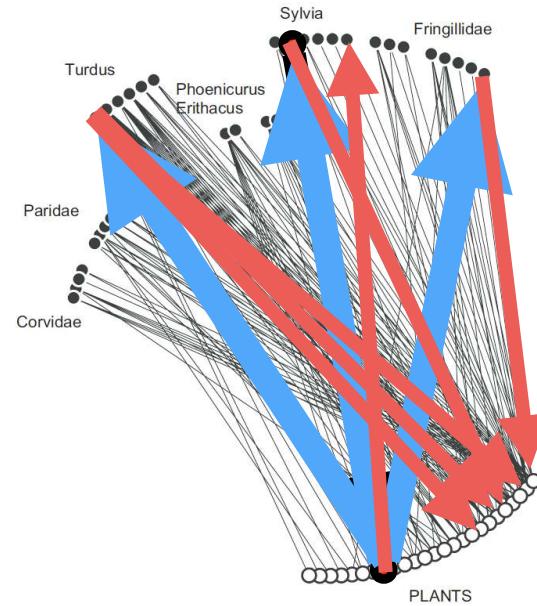
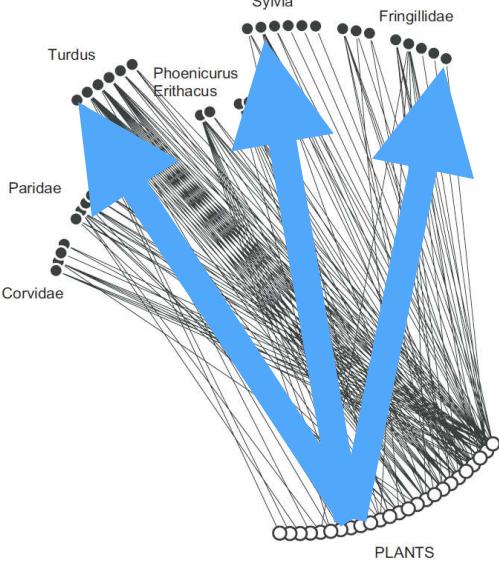
- Sistemas dissipativos

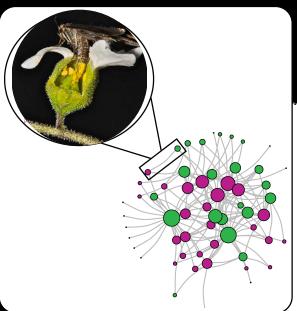




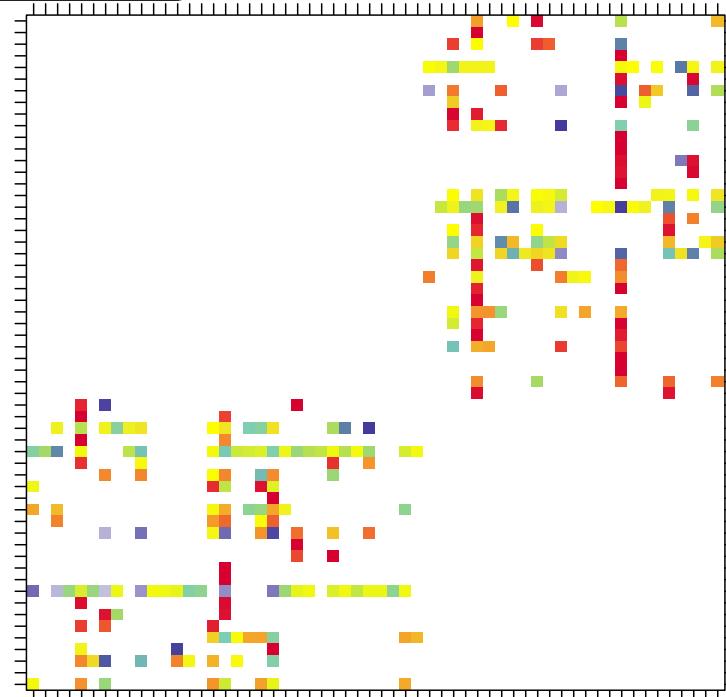
# Estimando efeitos indiretos

- Sistemas dissipativos
- Proliferação de rotas

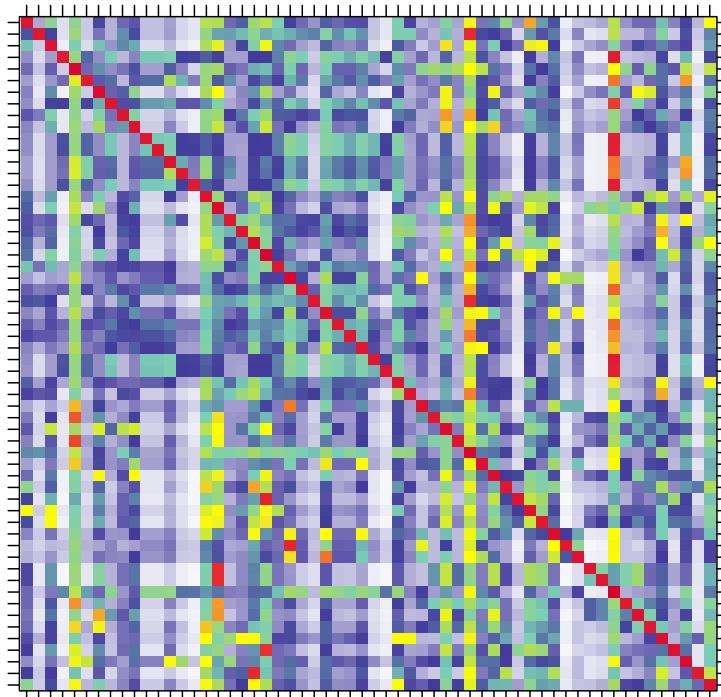




$Q$



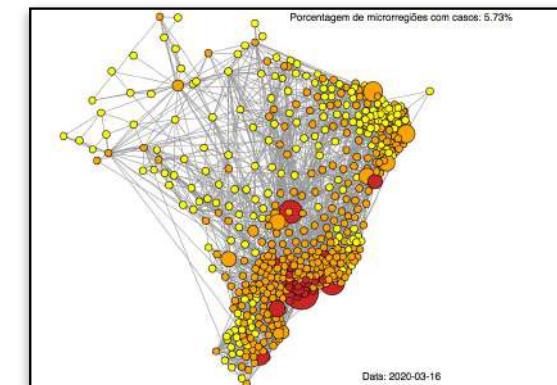
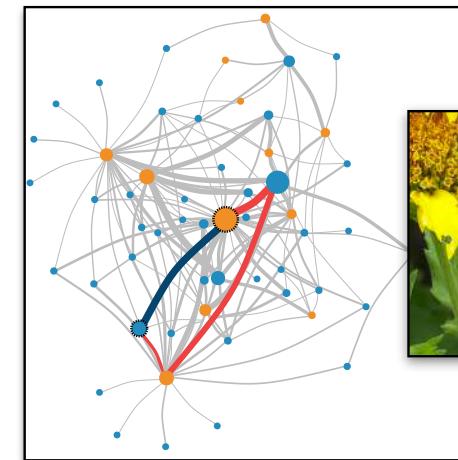
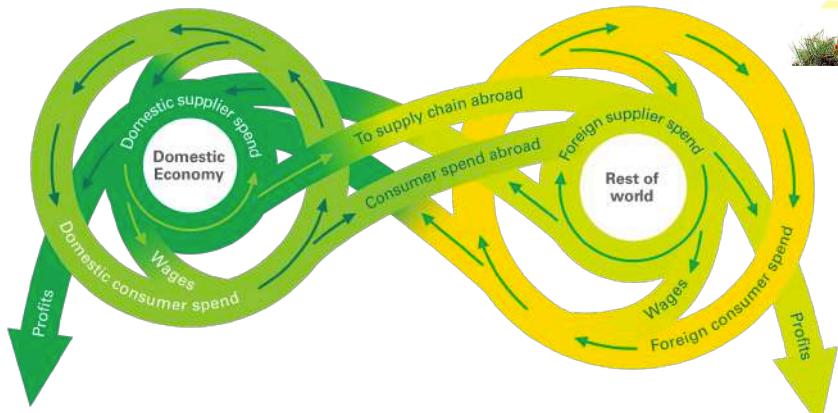
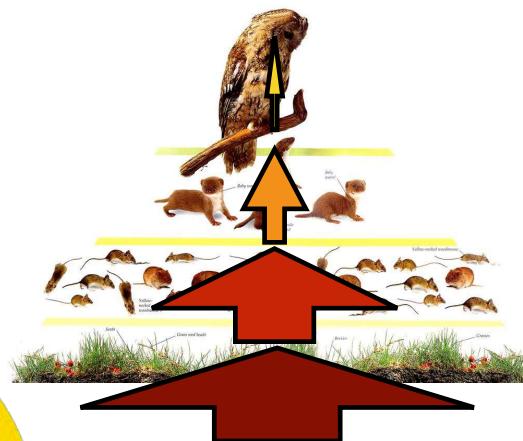
$$T = (I - Q)^{-1}$$



# Esse resultado é geral para sistemas dissipativos



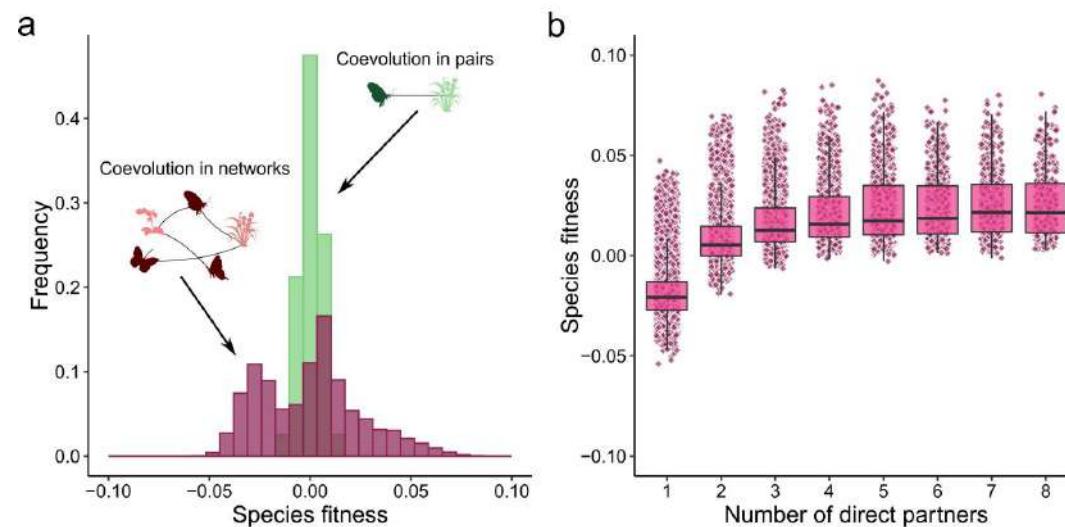
$$(I - Q)^{-1}$$



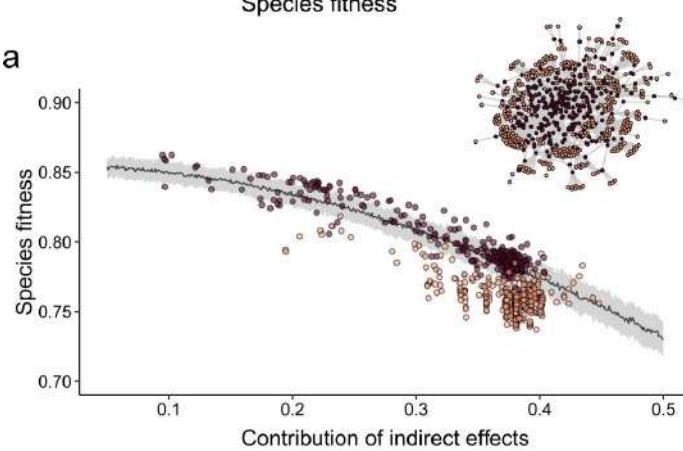
OBSERVATÓRIO  
COVID-19 BR



# Essas rotas podem influenciar a aptidão



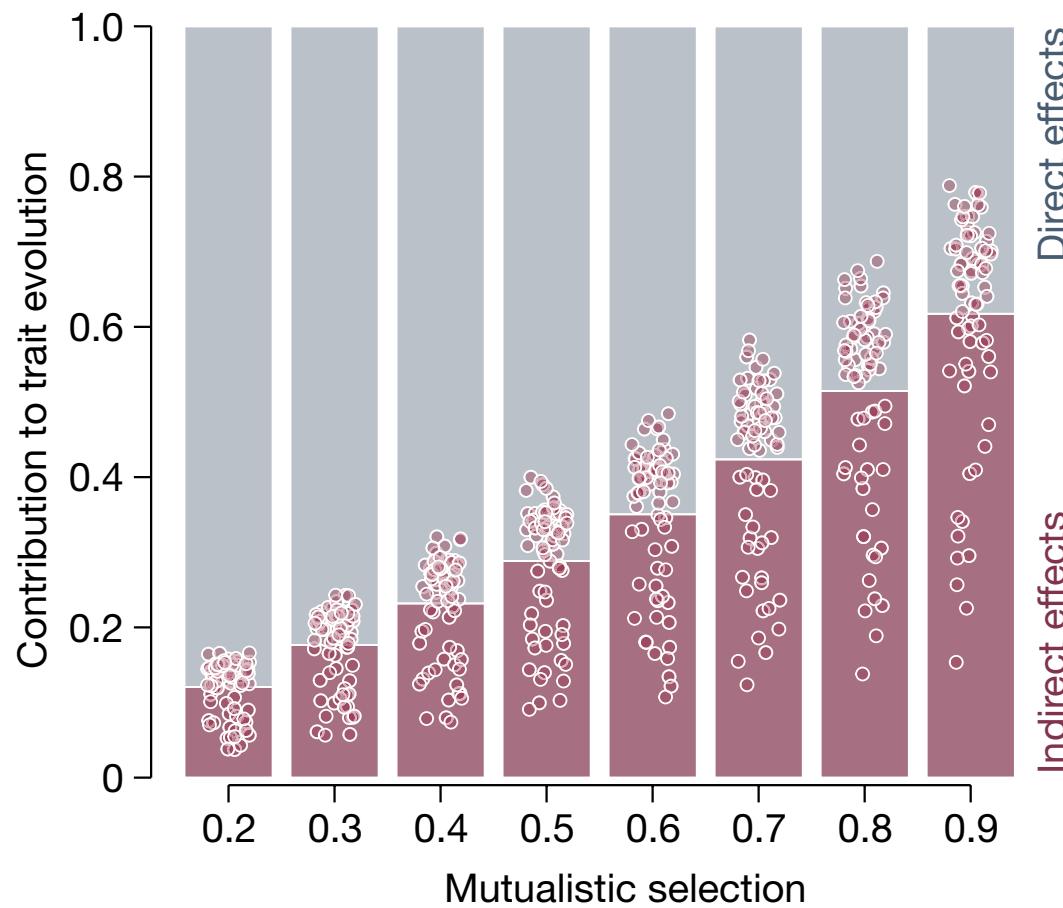
Leandro Cosmo



Cosmo et al. 2023. Nature

# Teoria como um mapa e uma prova de conceito

Efeitos indiretos ocorrem na natureza?

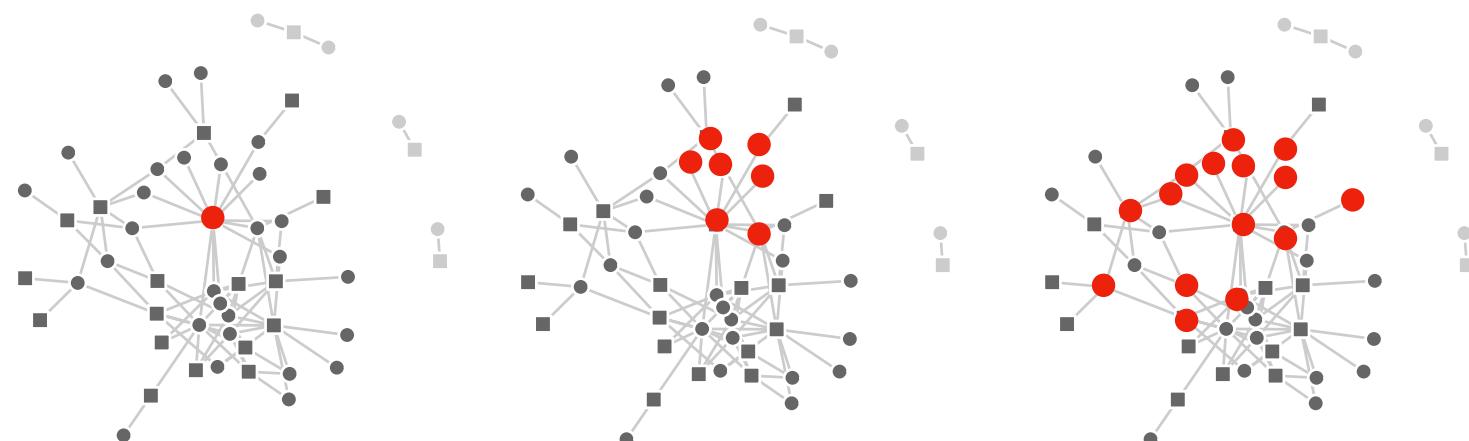


Guimarães et al. 2017. Nature

# Seleção direta forte implica efeitos indiretos



Kate Maia



Maia & Guimarães 2024. Ecology Letters

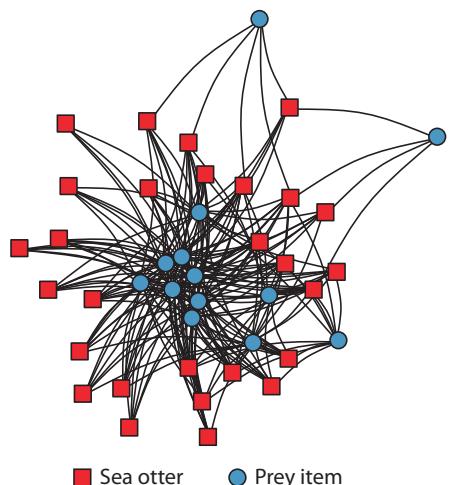
# **Redes ecológicas ao longo dos níveis de organização**

- Redes baseadas em indivíduos e a estrutura do nicho populacional
- Redes baseadas em espécies: espécies super-conectadas e padrões arquitetônicos
- Efeitos indiretos em redes ecológicas
- **Possíveis caminhos: integrando as redes biológicas**

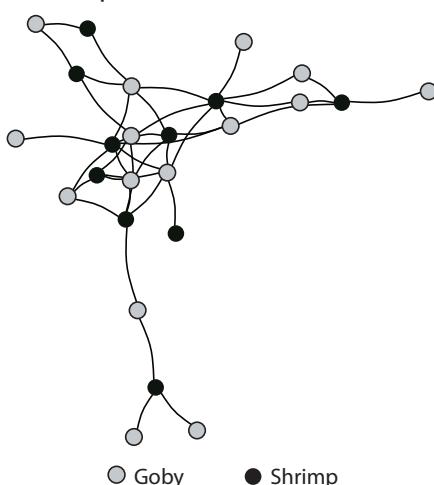
# Redes ecológicas: descrevendo padrões, inferindo processos

## Em diferentes níveis de organização

a An individual-based network



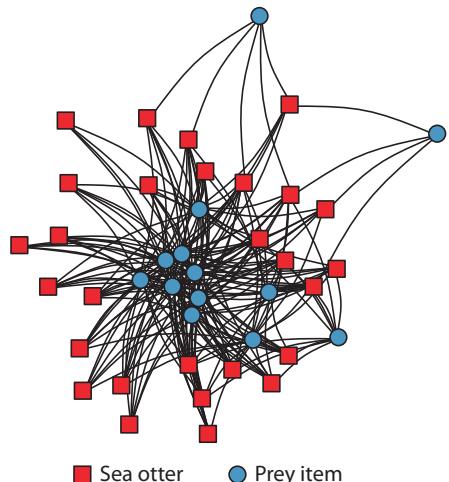
b A species-based network



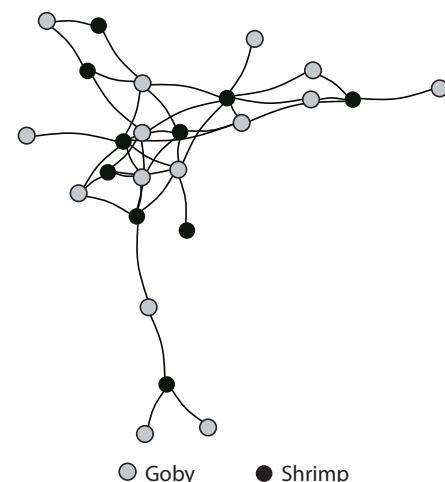
# Redes ecológicas: descrevendo padrões, inferindo processos

## Em diferentes níveis de organização

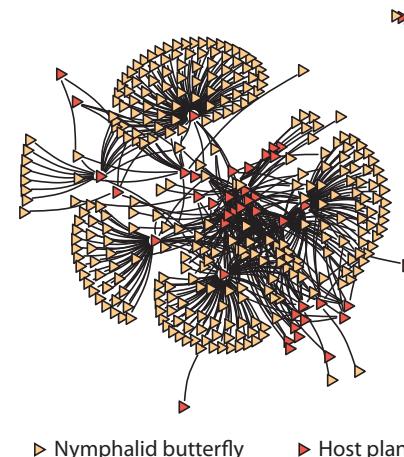
a An individual-based network

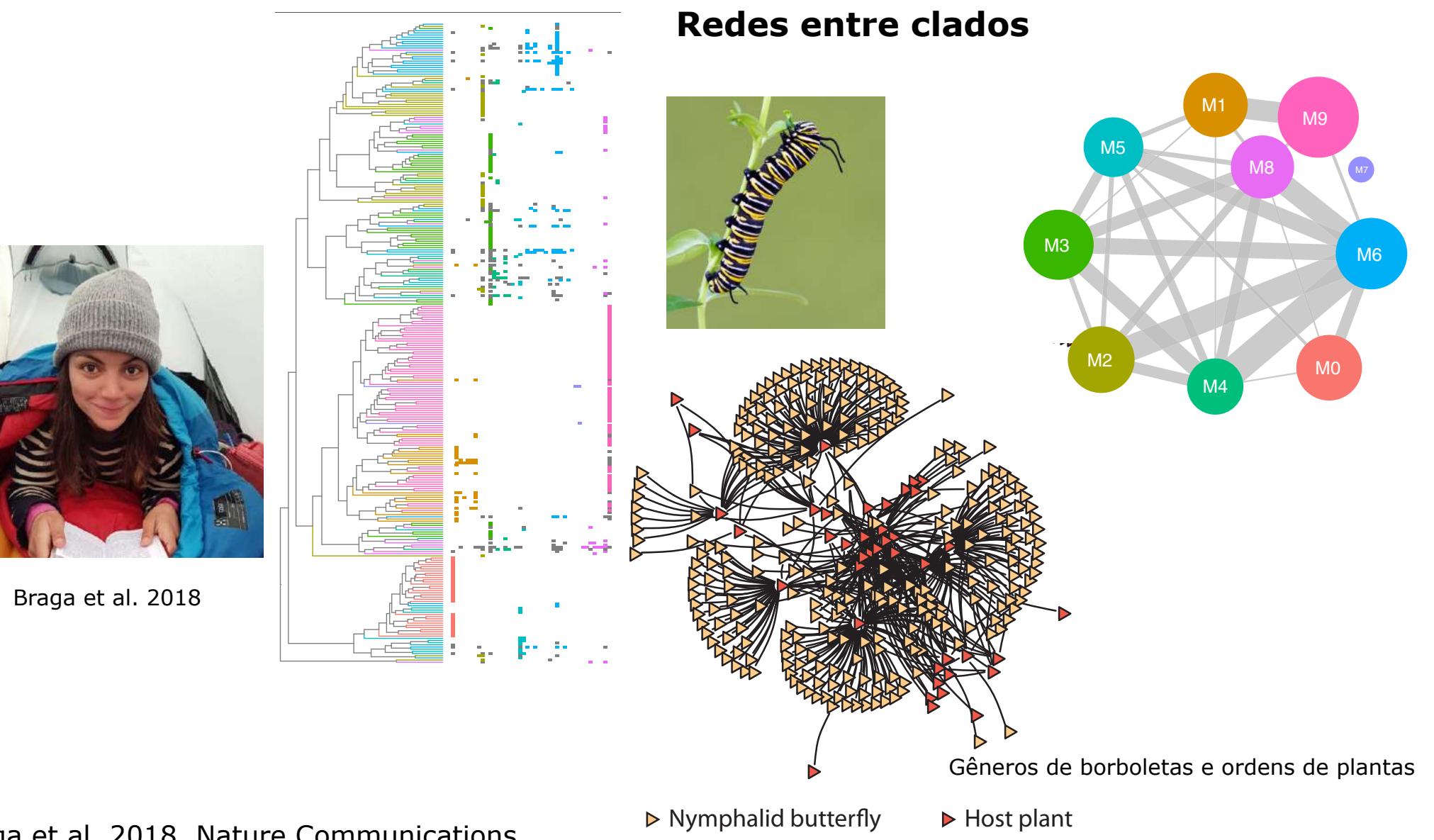


b A species-based network



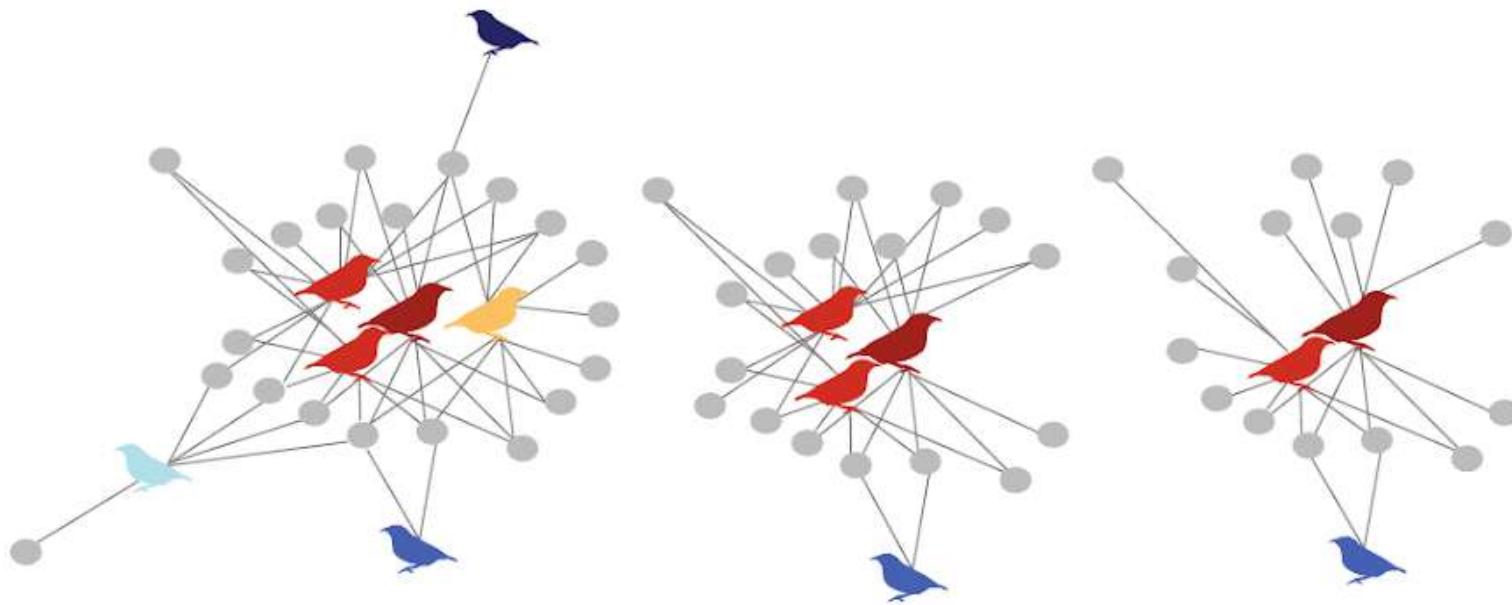
c A clade-based network





# Processos evolutivos e espécies super-conectadas

Network evolves over time



Gustavo Burin



Tiago Quental

# Processos evolutivos e espécies super-conectadas

1. Baixas taxas de extinção



Gustavo Burin

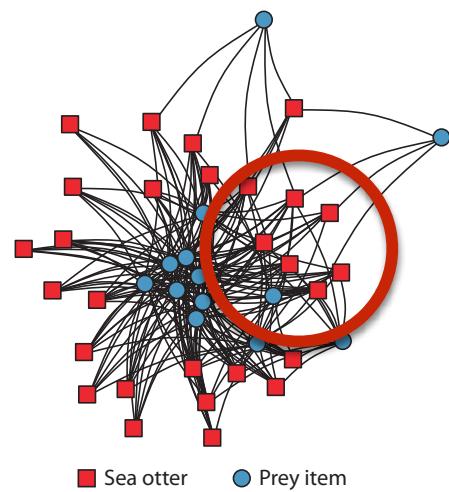
2. Altas taxas de diversificação



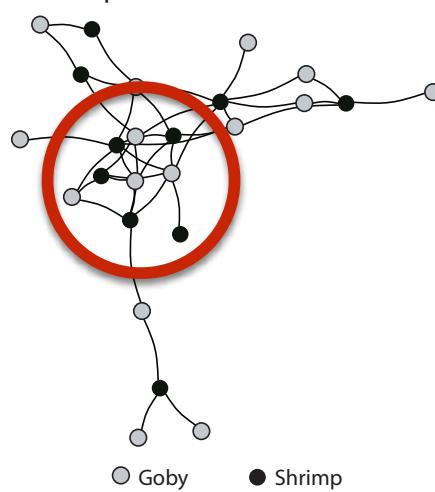
Tiago Quental

# Uma visão hierárquica das interações ecológicas: Redes "de fato" surgem das presença de unidades super-conectadas

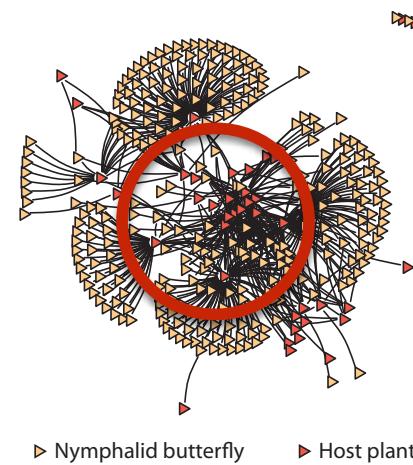
a An individual-based network



b A species-based network

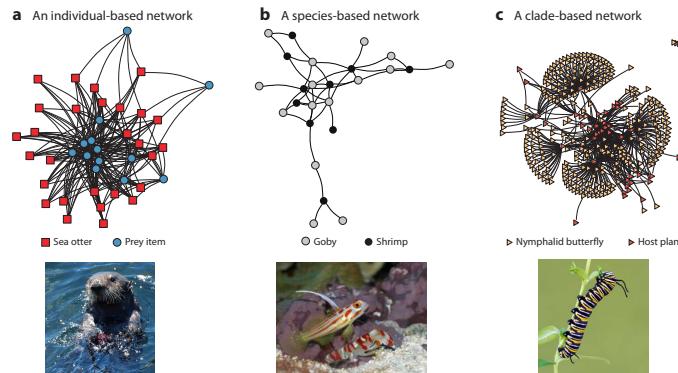


c A clade-based network



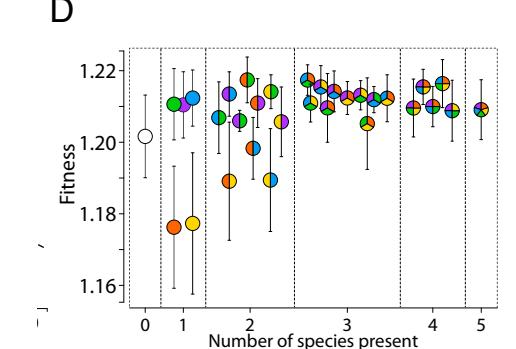
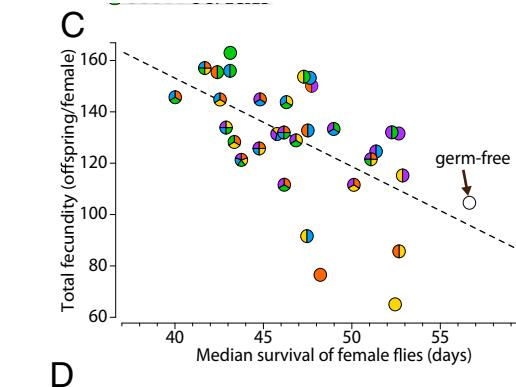
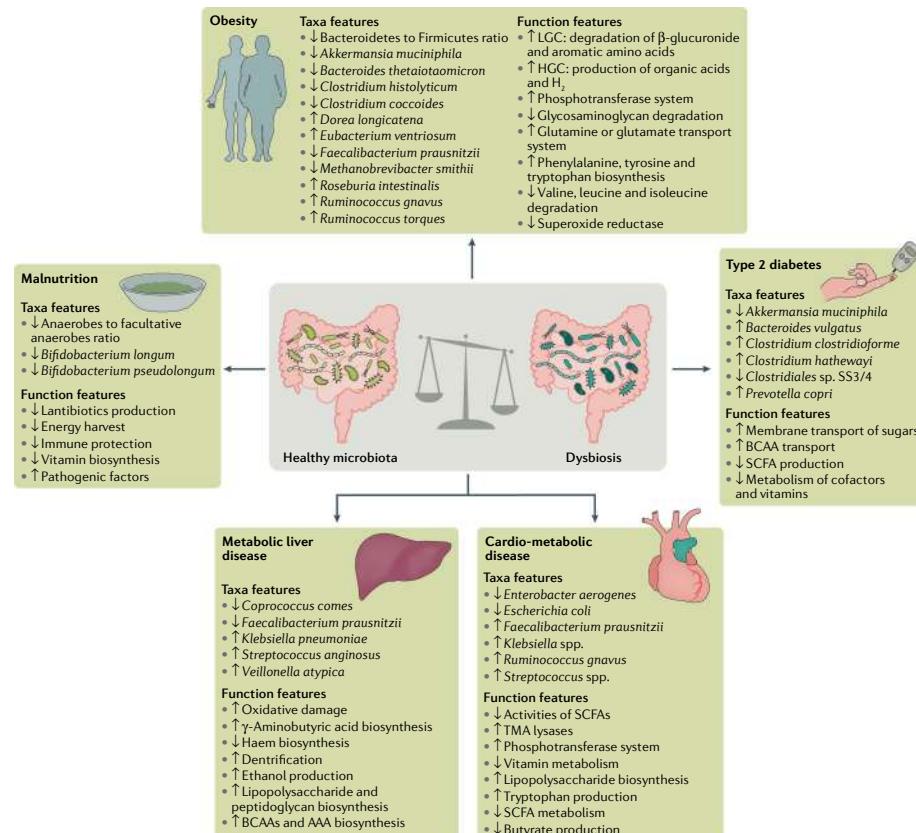
# Integrando redes biológicas

## Conectando redes ao longo dos níveis de organização



# Integrando redes biológicas

## Conectando biologia molecular, ecologia e evolução



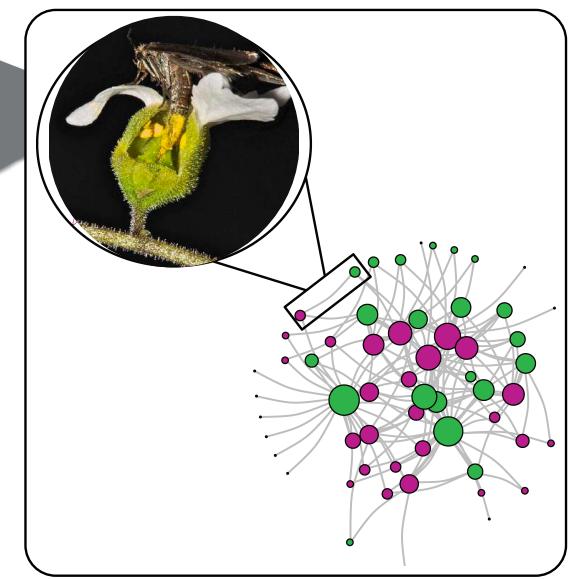
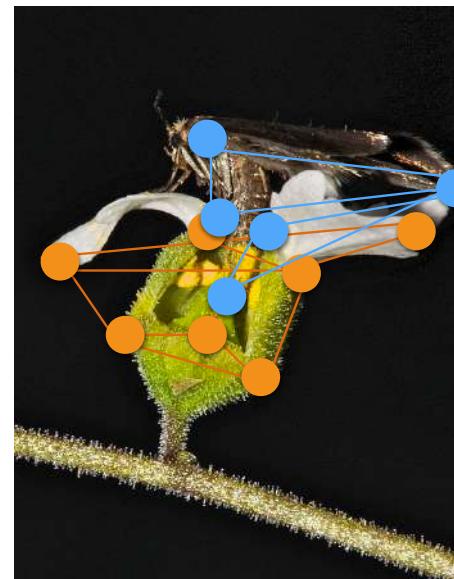
● *Lactobacillus plantarum* ● *Acetobacter tropicalis* ● *Acetobacter orientalis*

# Integrando redes biológicas

## Conectando biologia molecular, ecologia e evolução



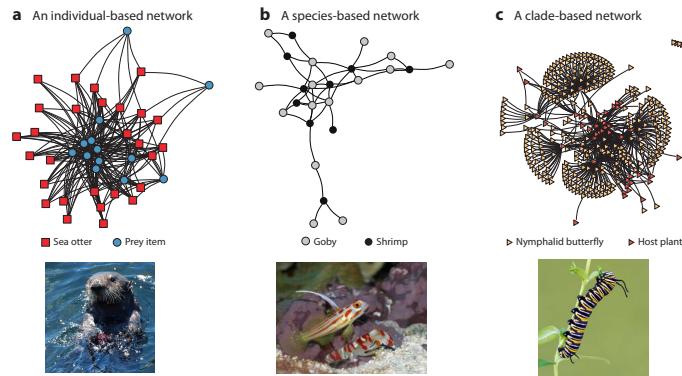
**Ana P. A. Assis**



Assis et al. 2020. Ecology Letters

# Integrando redes biológicas

## Conectando redes ao longo dos níveis de organização



# **As redes globais estão mudando**



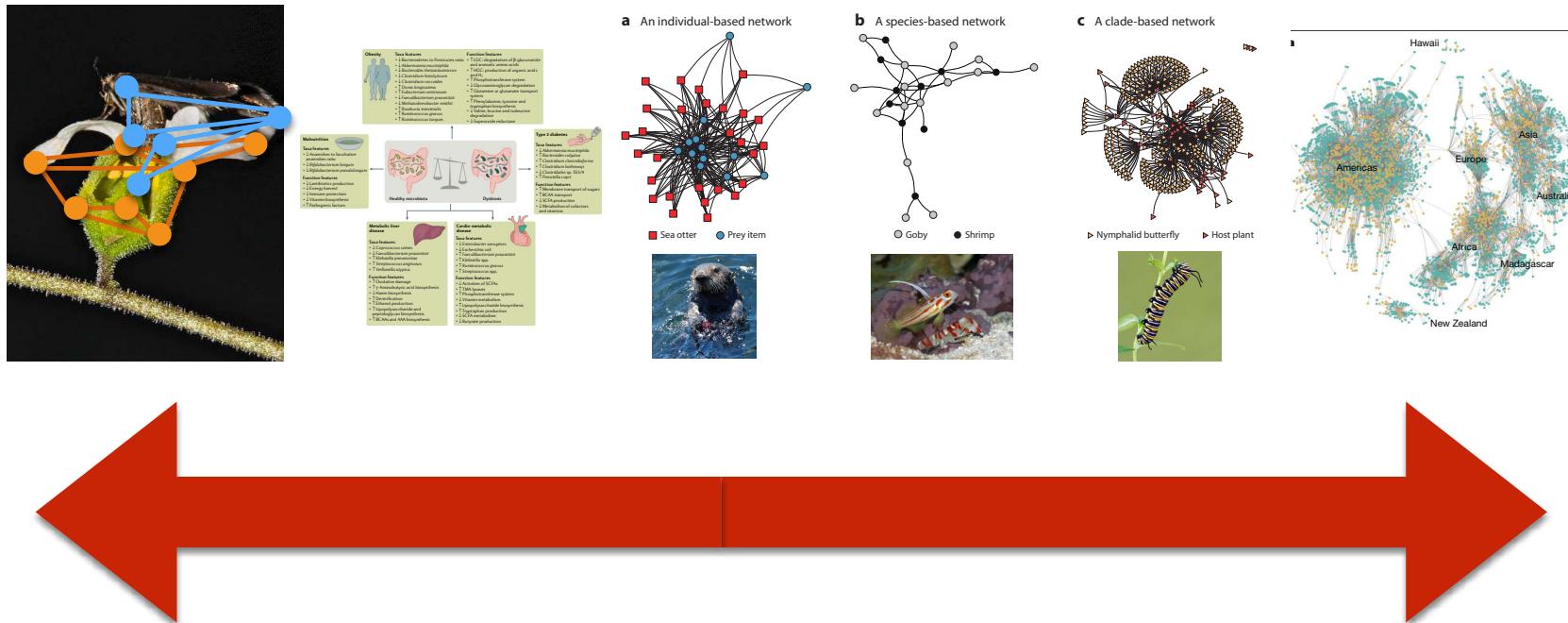
Foto: Motta Jr

## Networks at the global level are changing



Fricke & Svenning 2020. Nature

# Integrando redes biológicas ao longo dos níveis de organização

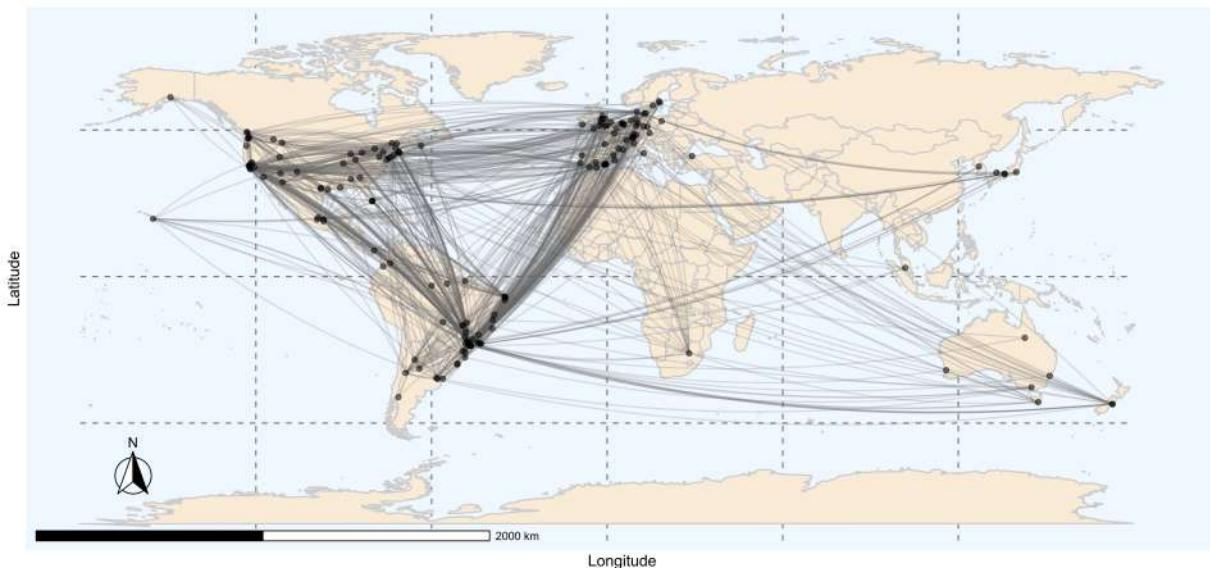


Guimarães 2020. AREES

## Lab

Caroline Draxler  
Solimary Garcia  
Andrés Rojas  
Lily Ulvee  
Augusto Carvalho  
Bruno Melati

E toda(o)s os ex-participantes



## Colaboradores

John Thompson  
Mauro Galetti  
Sérgio F. dos Reis  
Pedro Jordano  
Jordi Bascompte  
José R. Trigo  
Marcus Aguiar  
  
Mathias Pires  
Marina Côrtes  
Cecília Andreazzi  
Alexandra Pires  
Eliana Cazetta  
Darren Evans  
Flavia Marquitti  
Glauco Machado  
Jim Estes  
Justin Yeakel  
Mariano Devoto  
Marília Gaiarsa  
Márcio Araújo  
Tim Tinker  
Patricia Morellato  
Paulo I. Prado  
Rodolfo Dirzo  
Rodrigo Cogni  
Tiago Quental  
Carlos Melián



**info @ [www.guimaraes.bio.br](http://www.guimaraes.bio.br)**



**"Pour connaître la rose,  
quelqu'un emploie  
la géométrie  
et un autre emploie  
le papillon."**

**Paul Claudel**  
Extrait de "L'oiseau noir dans le soleil levant"