The multiplexity of ecological communities

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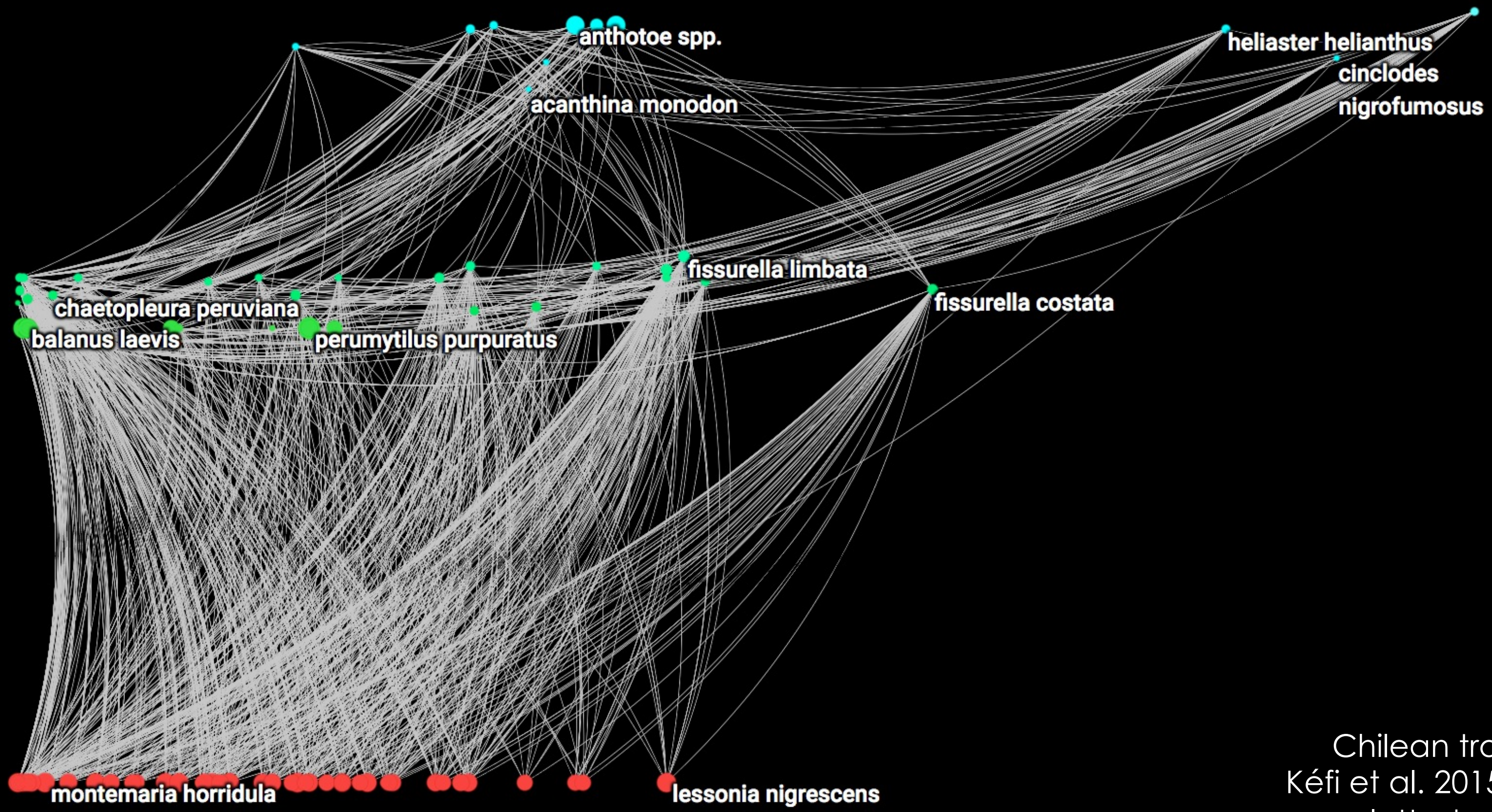
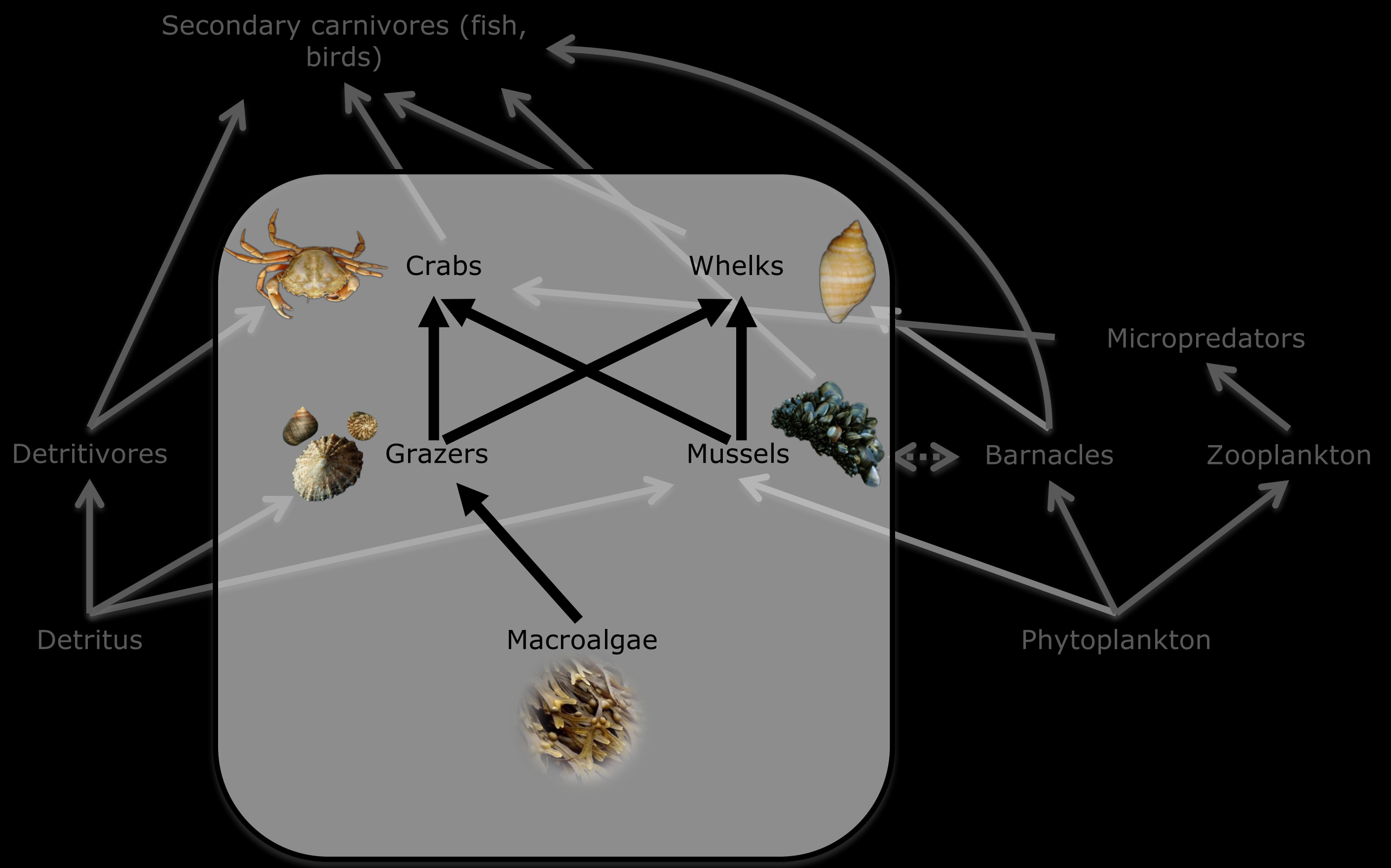
https://www.aao.org/eye-health/diseases/myopia-nearsightedness

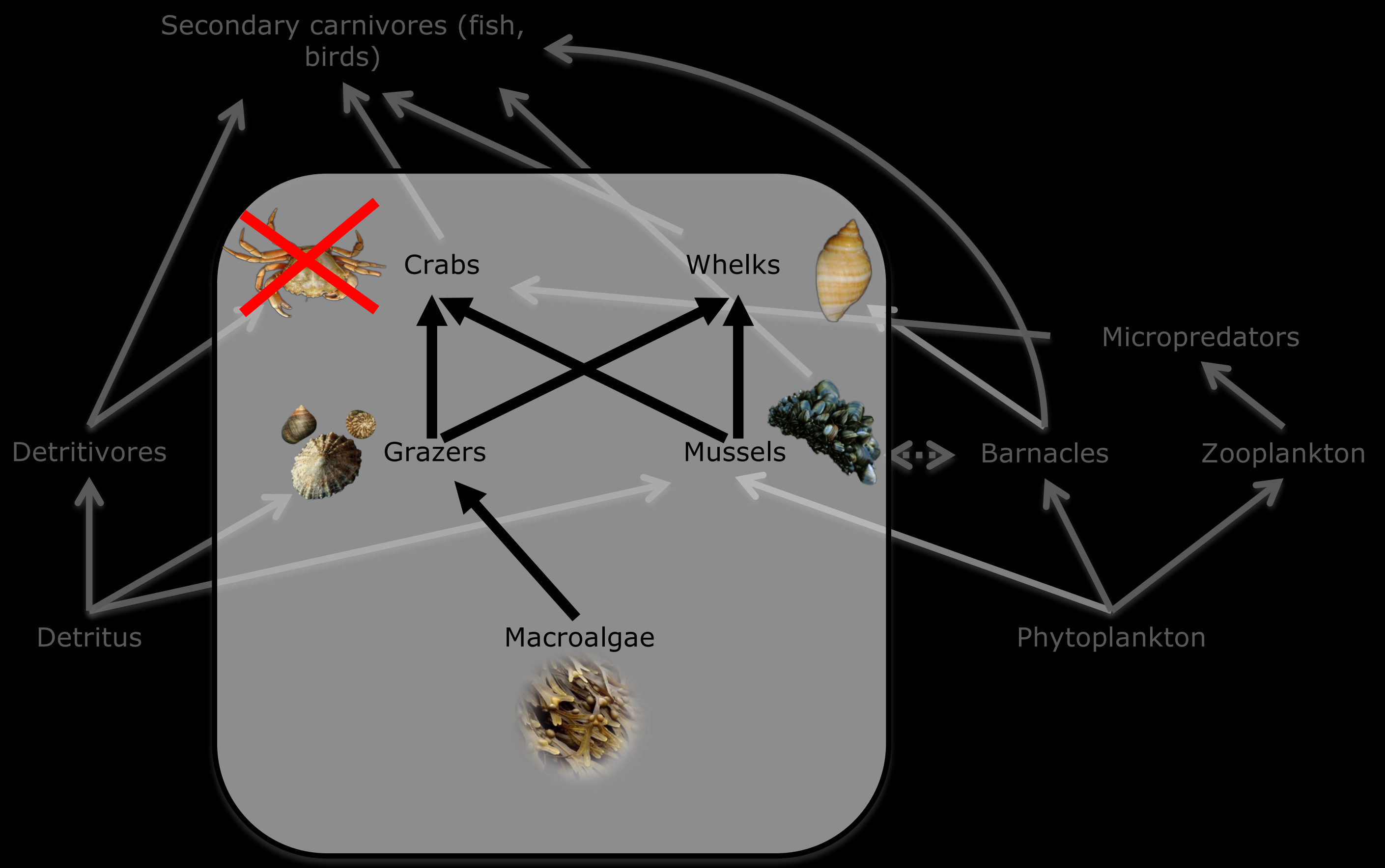


Chilean trophic web
Kéfi et al. 2015, Ecology
plotted with mappr

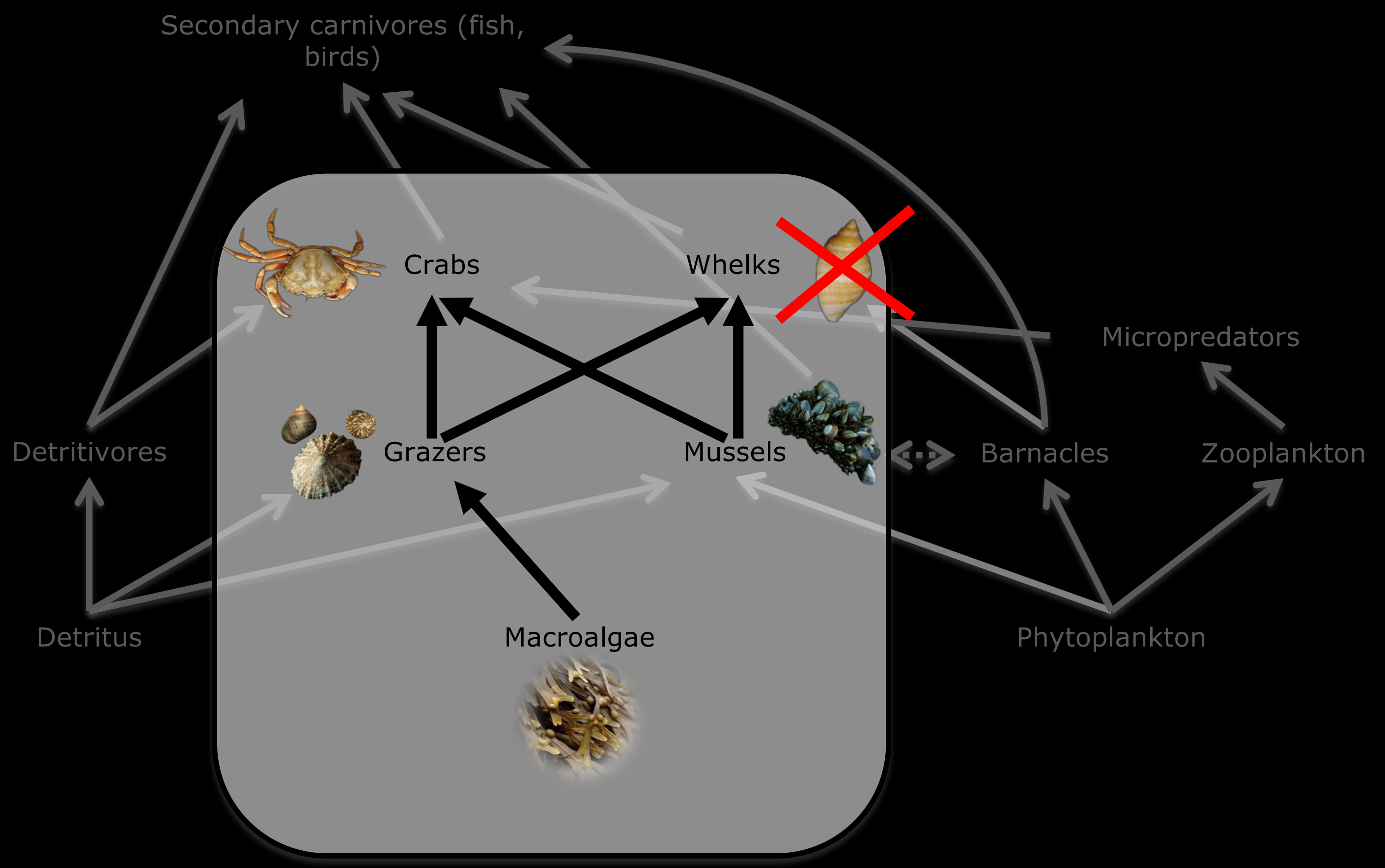
@Ian Donohue



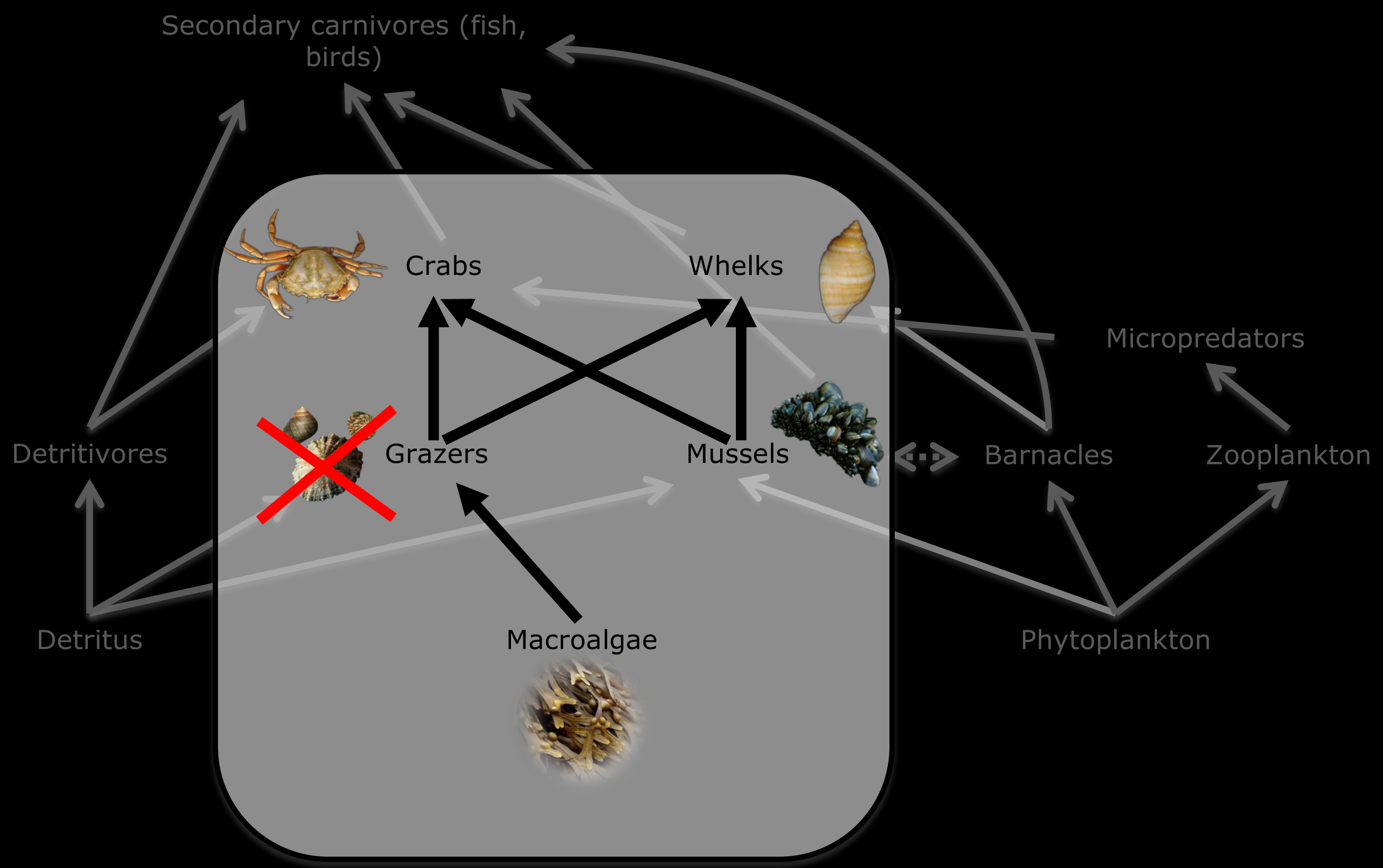
Donohue *et al.* 2017, GCB



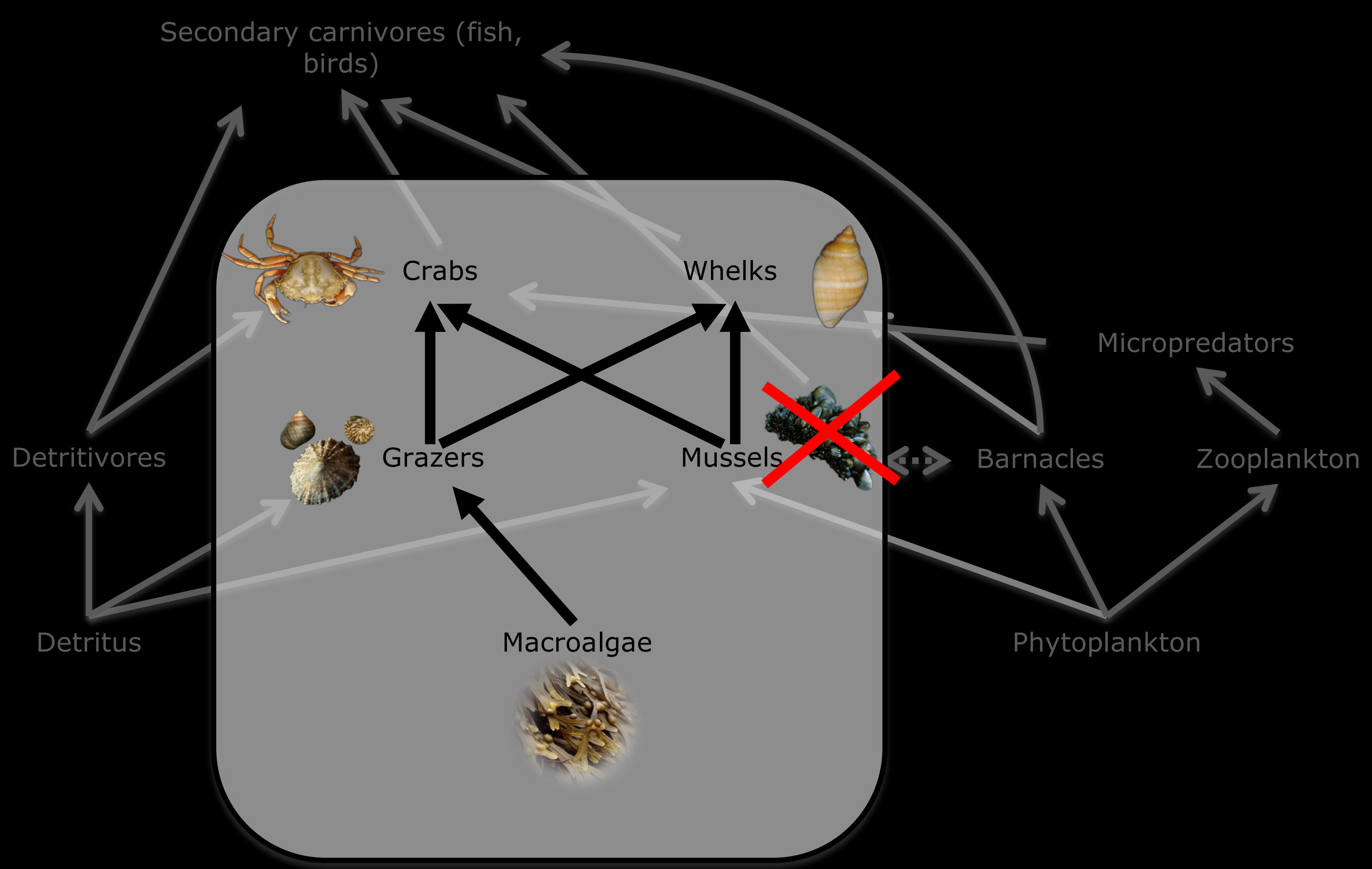
Donohue *et al.* 2017, GCB



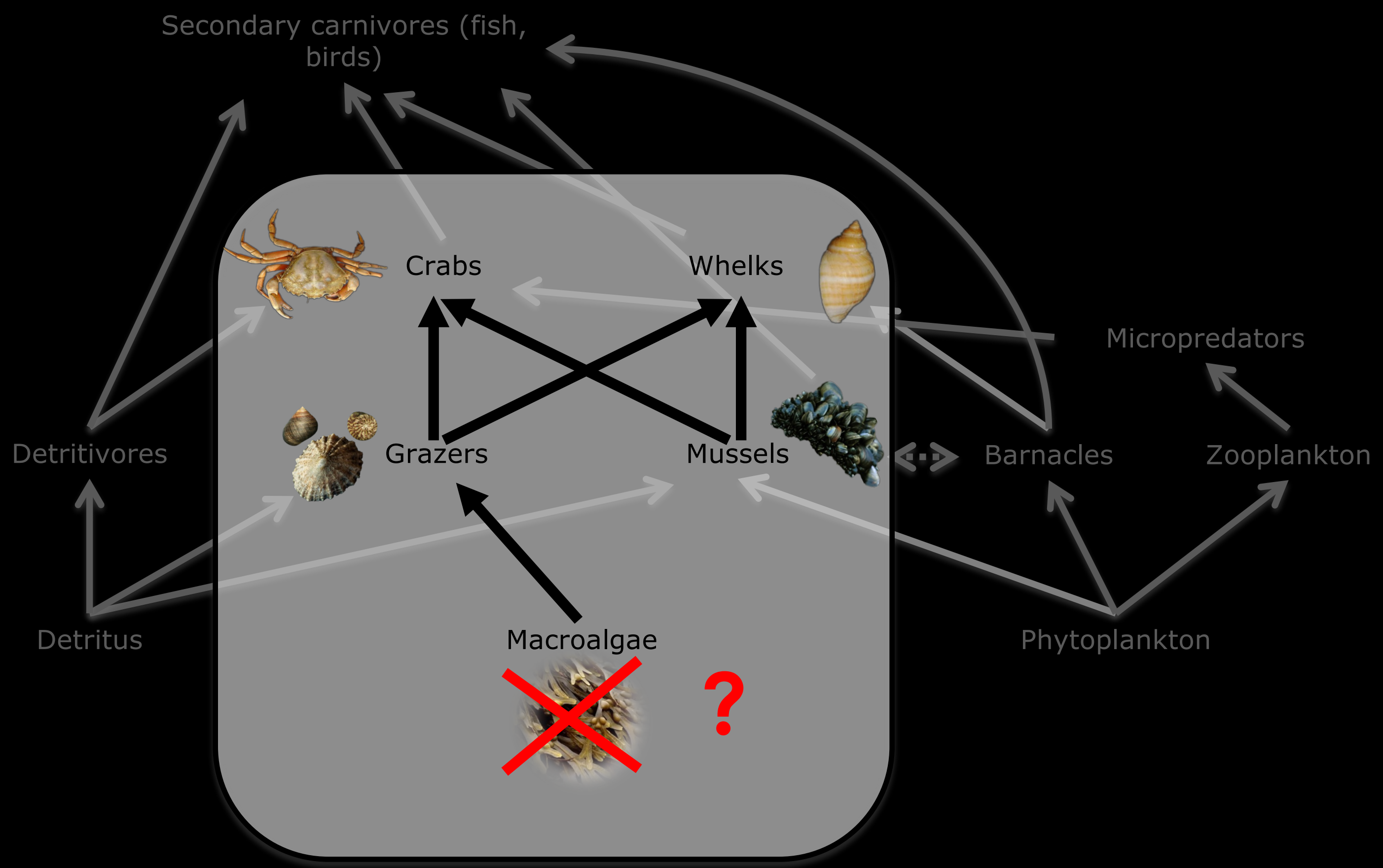
Donohue *et al.* 2017, GCB



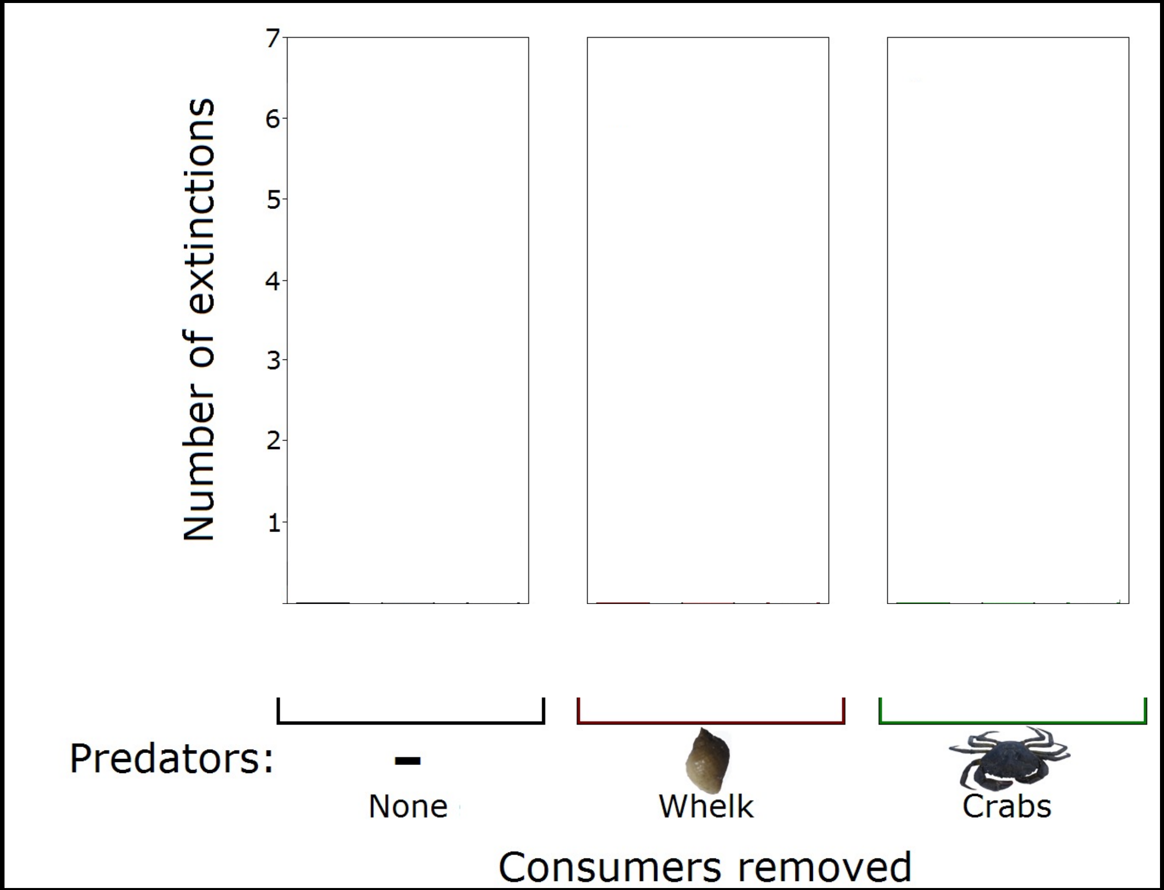
Donohue *et al.* 2017, GCB



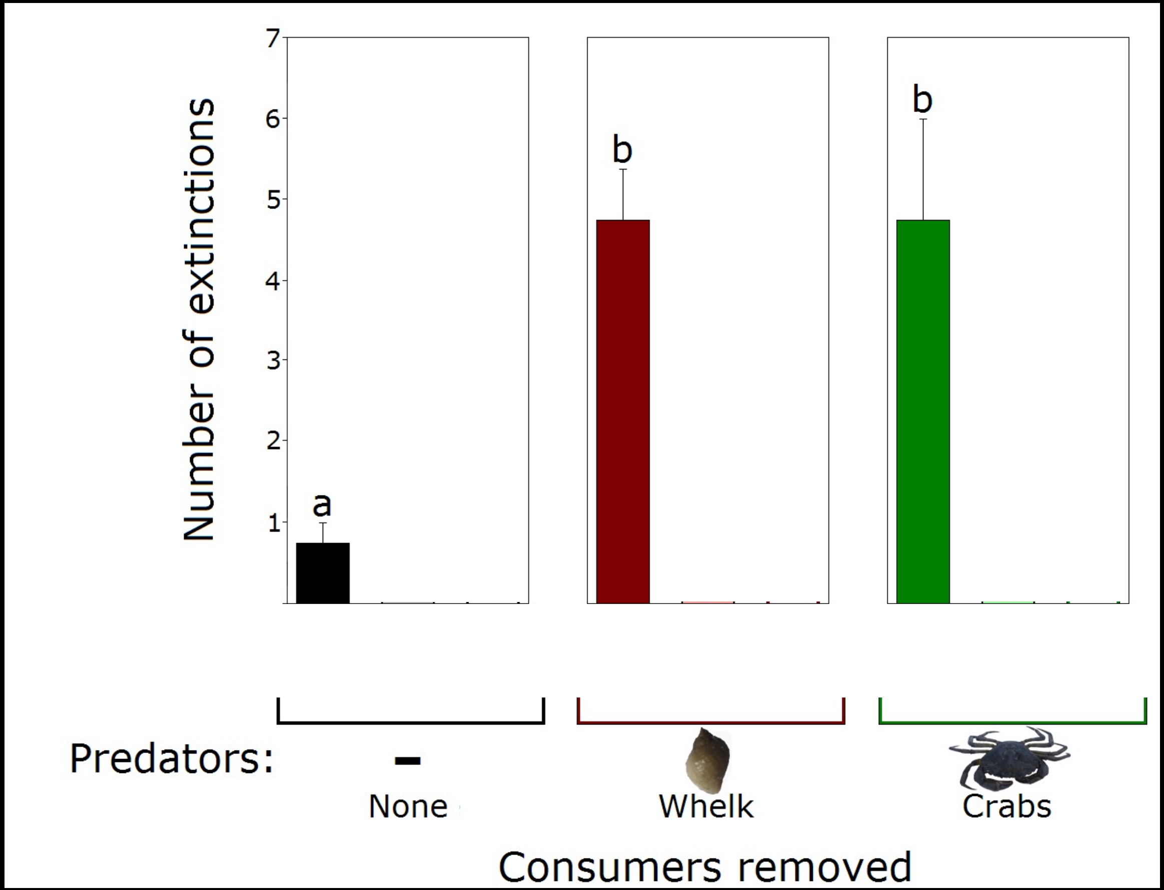
Donohue *et al.* 2017, GCB

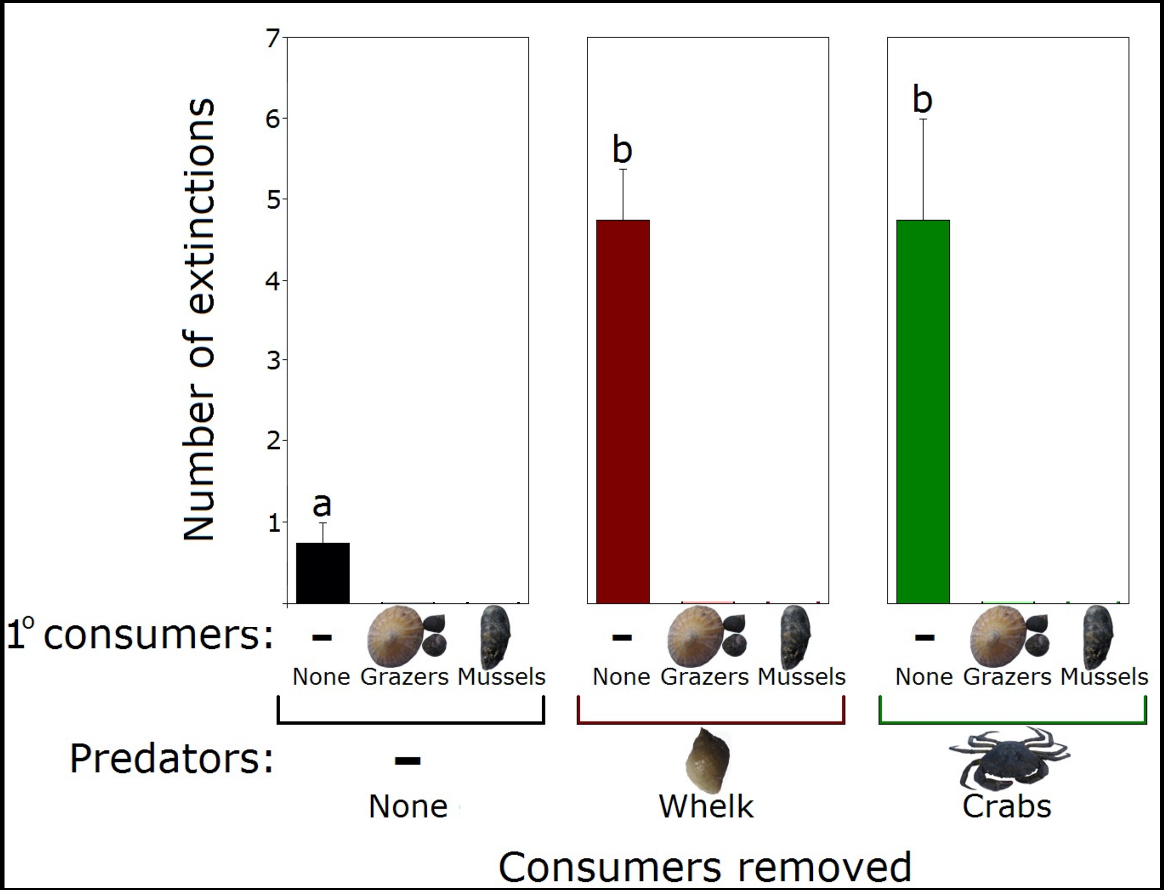


Donohue *et al.* 2017, GCB

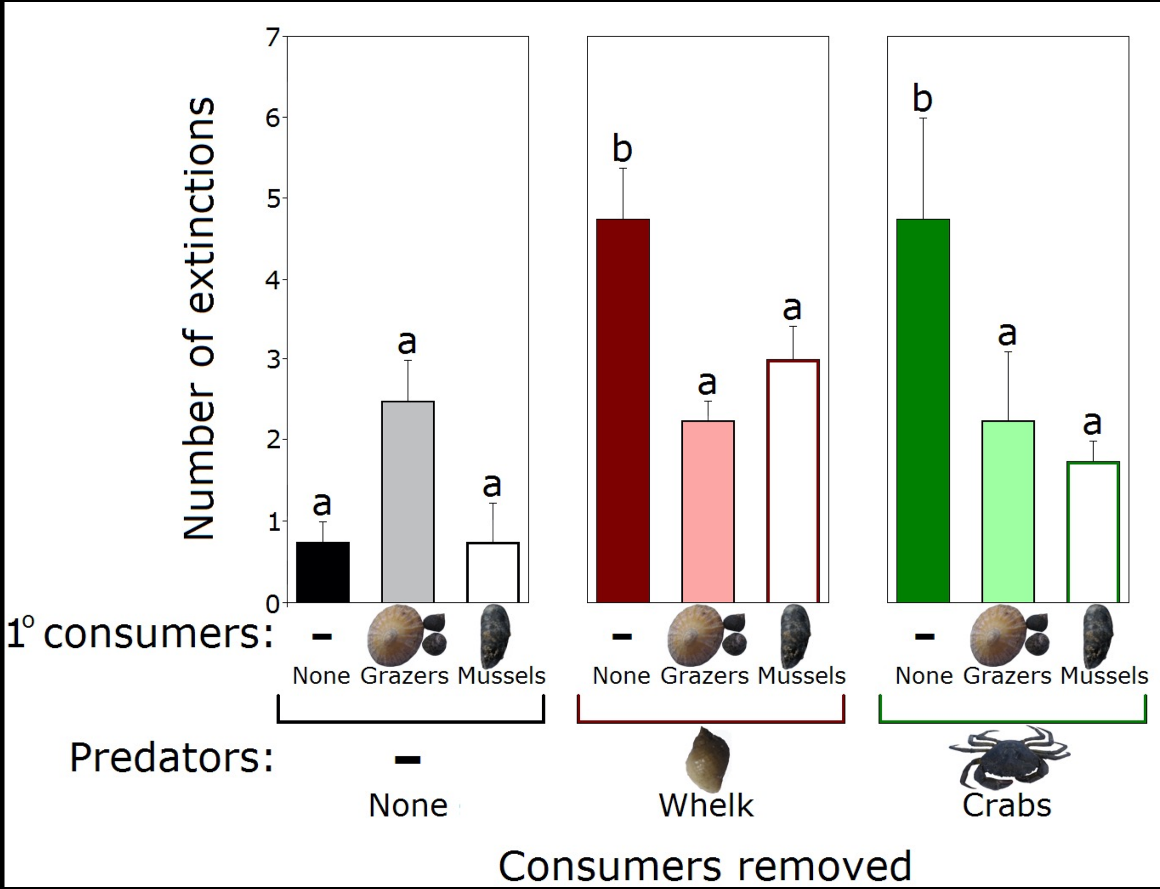


Number of extinctions
7
6
5
4
3
2
1
Predators:
None
Whelk
Crabs
Consumers removed


Number of extinctions
7
6
5
4
3
2
1
a
b
b
Predators:
None
Whelk
Crabs
Consumers removed



Number of extinctions
7
6
5
4
3
2
1
a
b
b
1° consumers:
None
Grazers
Mussels
None
Grazers
Mussels
None
Grazers
Mussels
Predators:
None
Whelk
Crabs
Consumers removed



Number of extinctions
7
6
5
4
3
2
1
0
a
a
a
b
a
a
b
a
a
1° consumers:
None Grazers Mussels
None Grazers Mussels
None Grazers Mussels
Predators:
None
Whelk
Crabs
Consumers removed

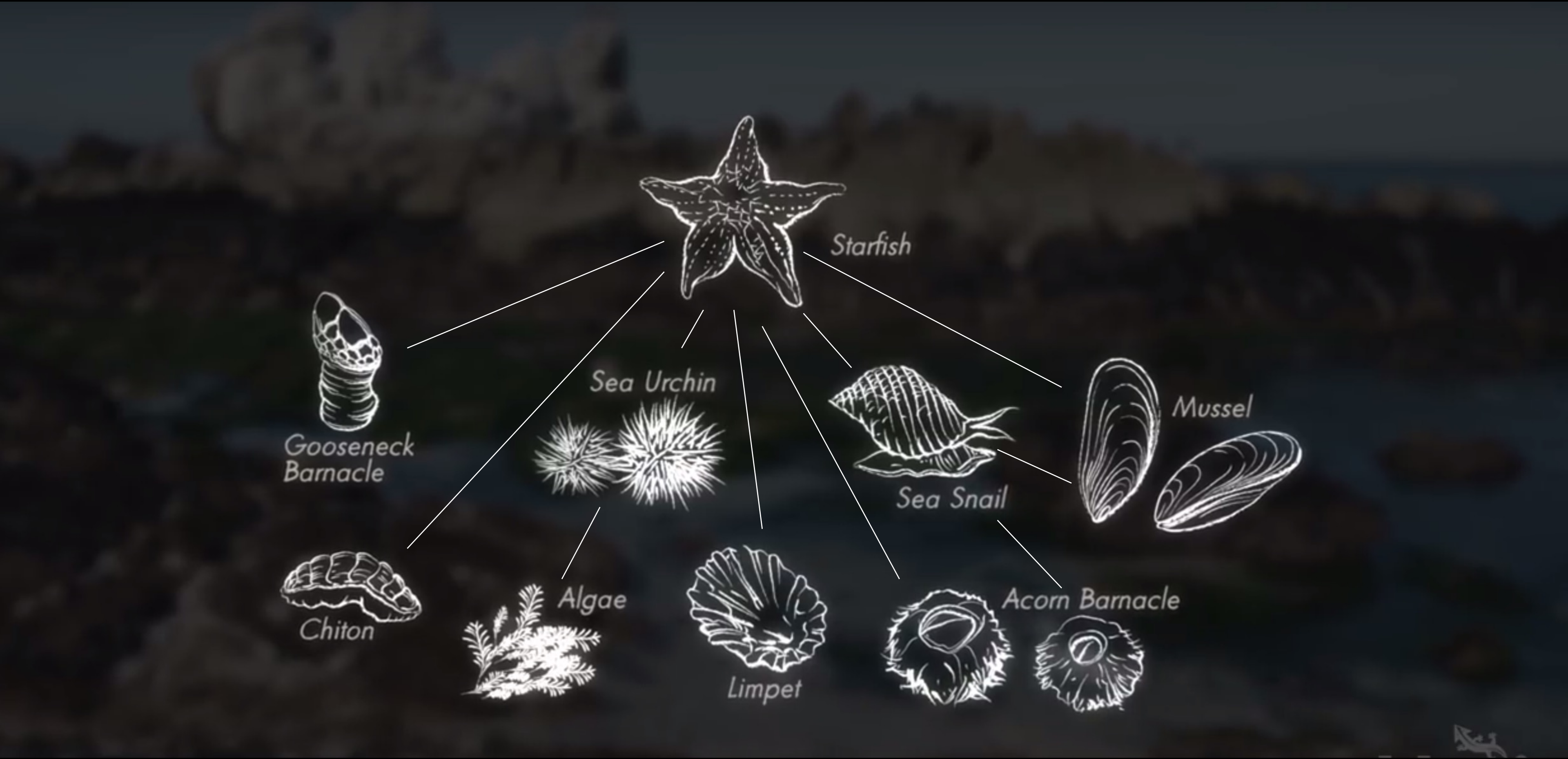
1/3 of the macroalgal taxa lost following the removal of either predator species

Donohue *et al.* 2017, GCB

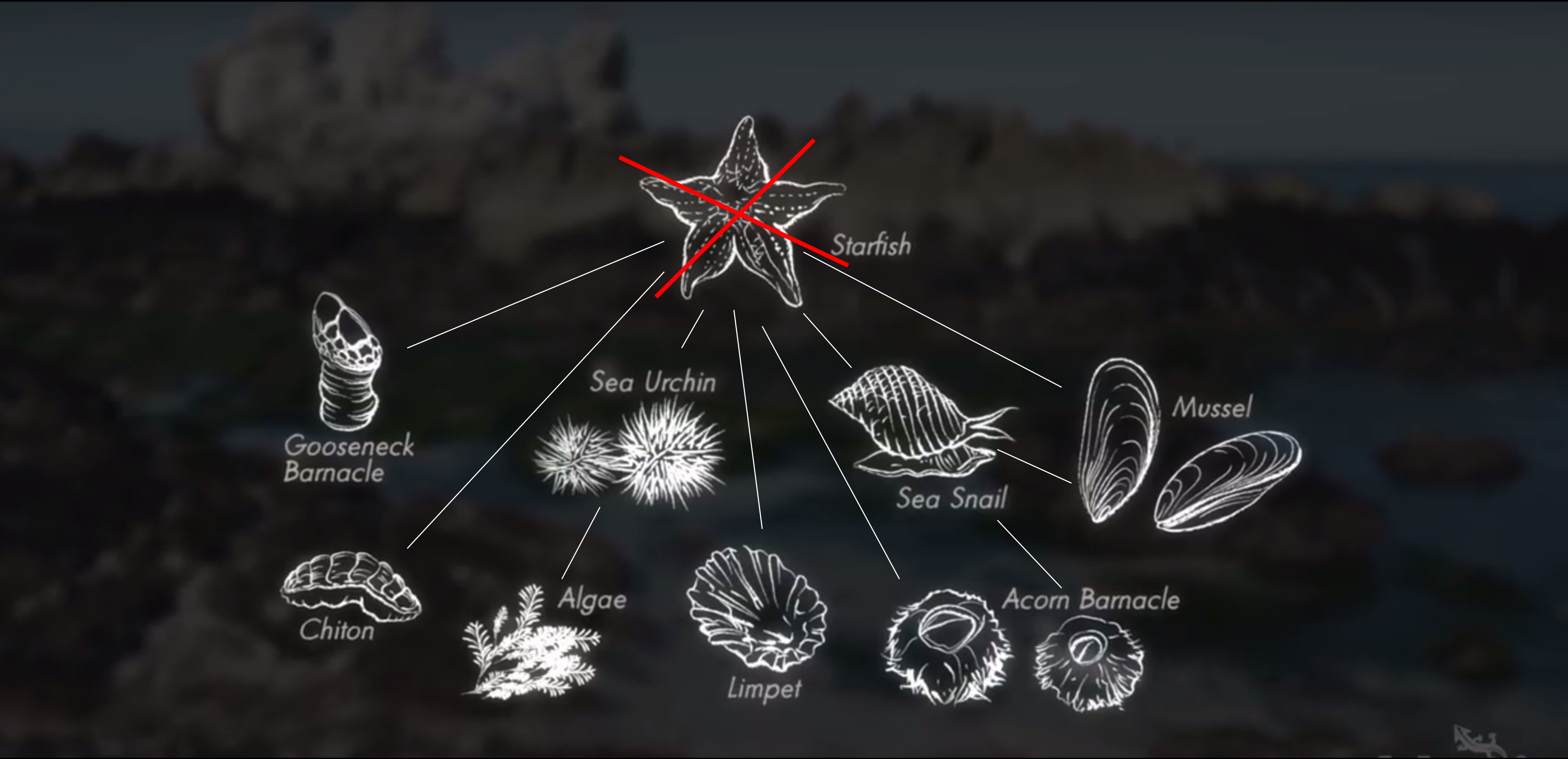
an order of magnitude greater than in models

e.g. Ebenman *et al.* 2006
Eklöf and Ebenman 2006
Quince *et al.* 2005
Petchey et al. 2008

Robert Paine
Credit: Alamy. Telegraph obituary

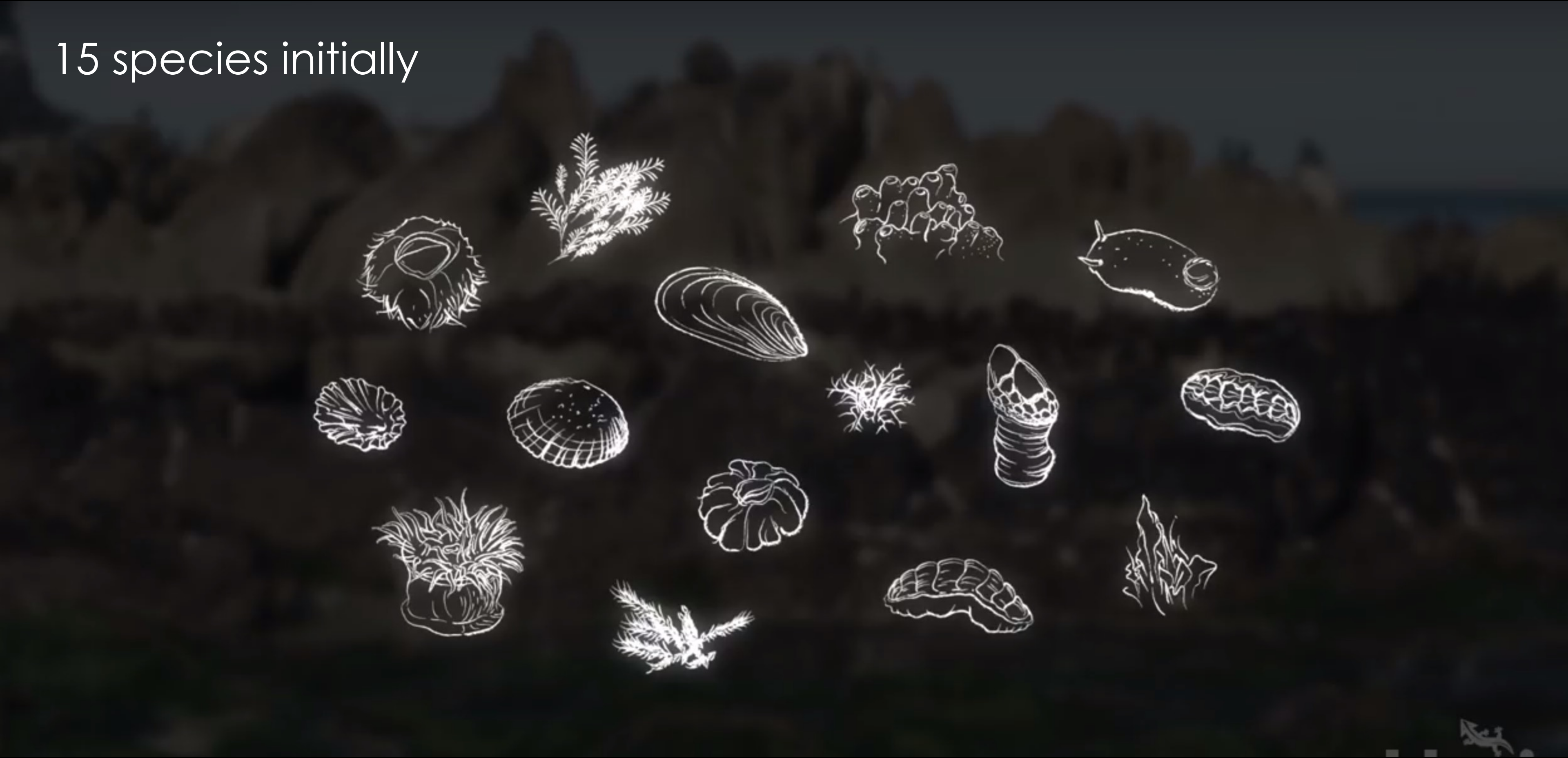


hhmi biointeractive
« Some Animals Are More Equal than Others: Keystone Species and Trophic Cascades »



hhmi biointeractive
« Some Animals Are More Equal than Others: Keystone Species and Trophic Cascades »

15 species initially



hhmi biointeractive
« Some Animals Are More Equal than Others: Keystone Species and Trophic Cascades »

7 species after 1,5 year

hhmi biointeractive
« Some Animals Are More Equal than Others: Keystone Species and Trophic Cascades »

1 species after 7 years

hhmi biointeractive
« Some Animals Are More Equal than Others: Keystone Species and Trophic Cascades »

→ puzzling discrepancy between observations and the prediction of most theoretical models

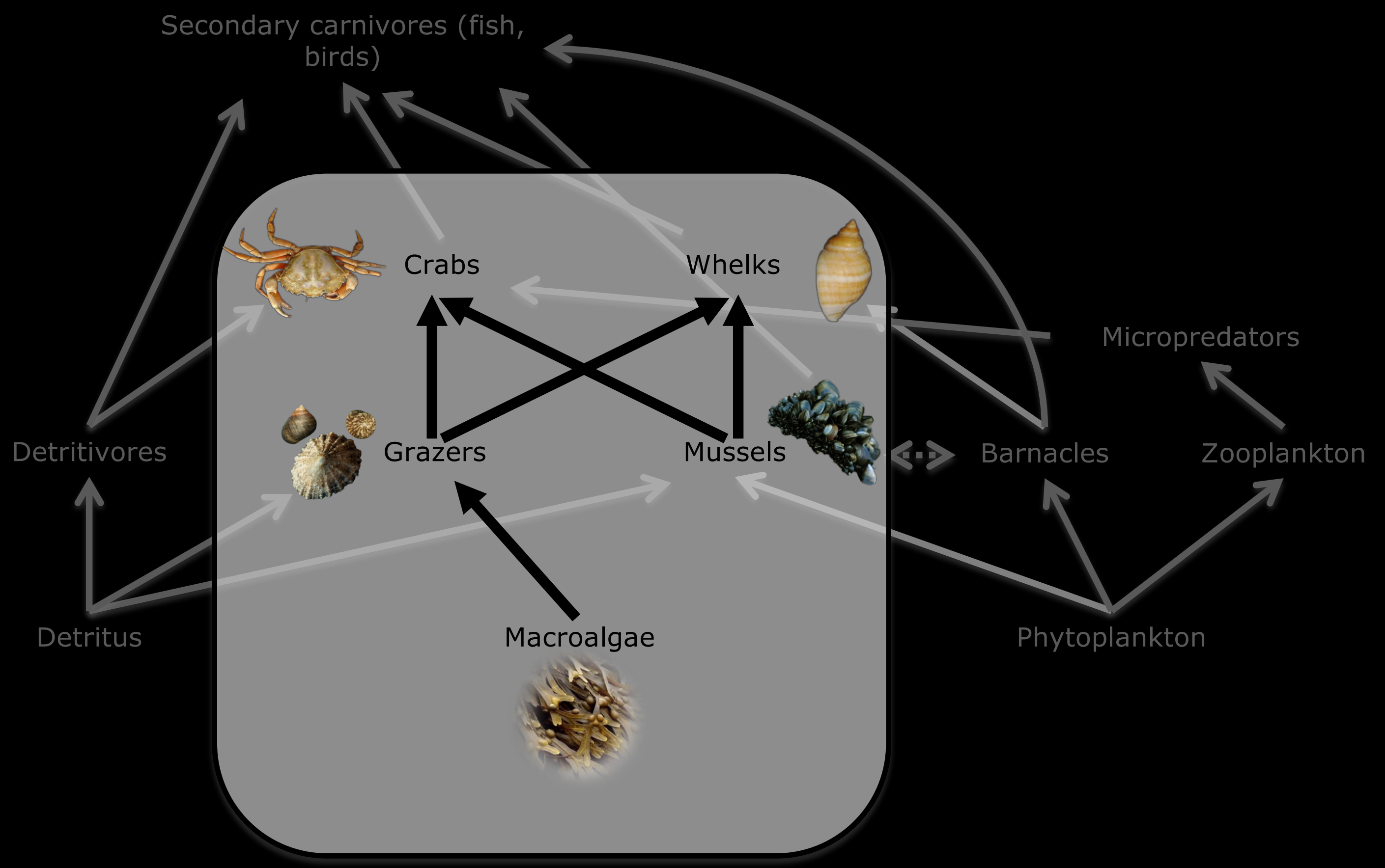
feeding interactions

@Evie Wieters

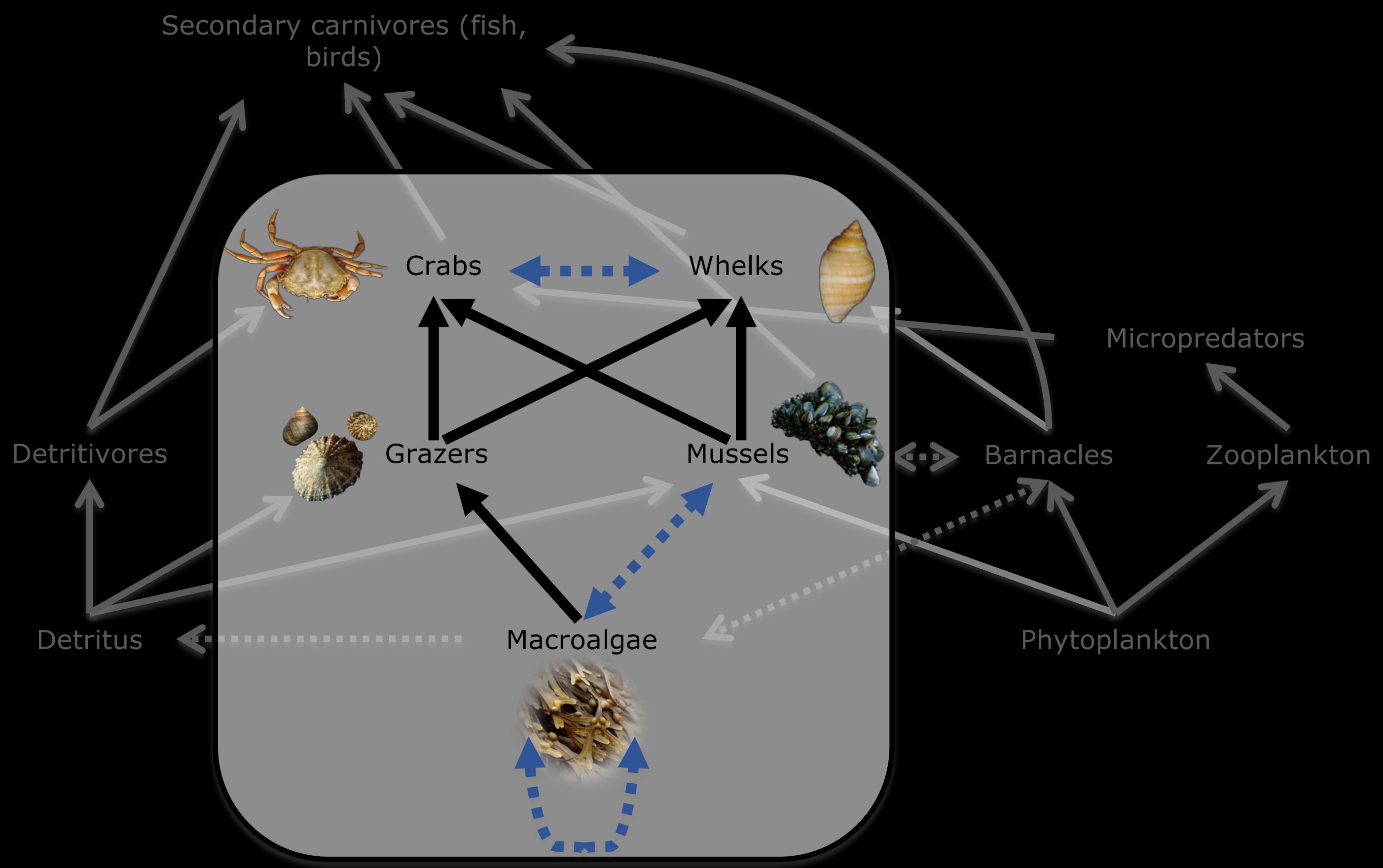
@Evie Wieters


@Evie Wieters

@Evie Wieters



Donohue *et al.* 2017, GCB



Donohue *et al.* 2017, GCB

dynamical model

[bioenergetic consumer-resource model]

$$\frac{\mathrm{d}B_i}{\mathrm{dt}} = r_i\left(1 - \frac{B_i}{K_i}\right)B_i + eB_i\sum_j F_{ij} - \sum_k F_{ki}B_k - x_iB_i$$

Yodzis and Innes 1992
Brose et al. 2005, 2006
Stouffer et al. 2011

$$\frac{\mathrm{d}B_i}{\mathrm{d}t} = r_i\left(1 - \frac{B_i}{K_i}\right)B_i + eB_i\sum_j F_{ij} - \sum_k F_{ki}B_k - x_iB_i$$

primary producers: $r_i\left(1 - \frac{B_i}{K_i}\right)B_i$ — growth

non-primary producers: $eB_i\sum_j F_{ij}$ — consumption (eats)

$\sum_k F_{ki}B_k$ — consumption (is eaten)

x_iB_i — metabolism

Yodzis and Innes 1992
Brose et al. 2005, 2006
Stouffer et al. 2011

$$\frac{dB_i}{dt} = r_i\left(1 - \frac{B_i}{K_i}\right)B_i + eB_i\sum_j F_{ij} - \sum_k F_{ki}B_k - x_iB_i$$

growth

consumption (eats)

consumption (is eaten)

metabolism

$$F_{ij} = \frac{w_i b_{ij} B_j^{1+q}}{1 + w_i h_i \sum_k b_{ik} B_k^{1+q}}$$

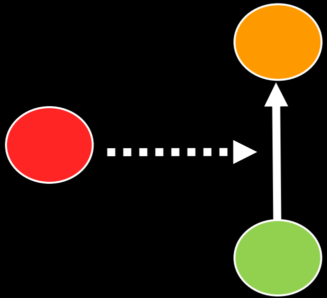
Yodzis and Innes 1992
Brose *et al.* 2005, 2006
Stouffer *et al.* 2011

+ non-trophic interactions

Kéfi *et al.* 2012 Eco. Lett.

How to integrate the great diversity of non-trophic interactions in current food web models?

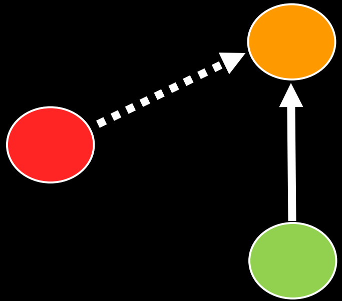
Kéfi *et al.* 2012 Eco. Lett.



Modification of
trophic interactions

Handling time
Capture efficiency

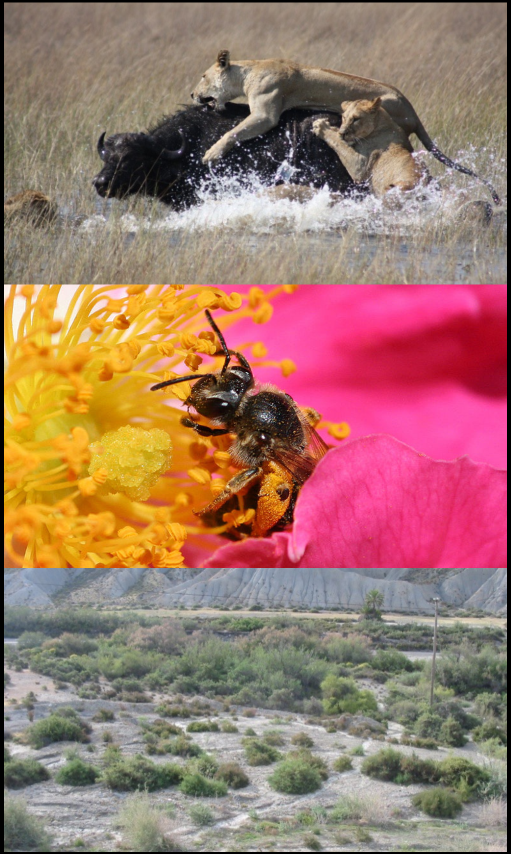
Kéfi *et al.* 2012 Eco. Lett.

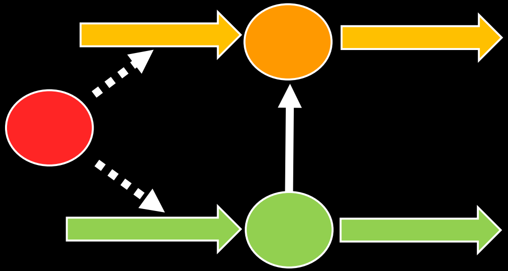


Modification of node attributes

Mortality
Establishment
Growth rate
Reproduction

Kéfi *et al.* 2012 Eco. Lett.





Input/output of matter (open systems)

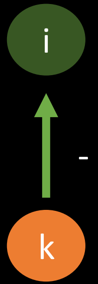
Immigration/Emigration
Incoming/outcoming flow of a resource

Kéfi *et al.* 2012 Eco. Lett.

The relevant model parameters become functions of the source species

Kéfi *et al.* 2012 Eco. Lett.

Example: competition for space

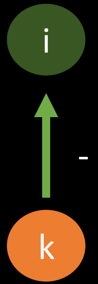


$$\frac{\mathrm{d}B_i}{\mathrm{dt}} = g_i\left[r_i\left(1-\frac{B_i}{K_i}\right)B_i + eB_i\sum_j F_{ij} - x_iB_i\right] - \sum_k F_{ki}B_k$$

grows | eats | dies | is eaten

Example: competition for space

$$g_i = 1 - \sum_k c_{ik} B_k$$



$$\frac{\mathrm{d}B_i}{\mathrm{dt}} = g_i \left[r_i \left(1 - \frac{B_i}{K_i}\right) B_i + e B_i \sum_j F_{ij} - x_i B_i \right] - \sum_k F_{ki} B_k$$

grows · eats · dies · is eaten

dynamical model

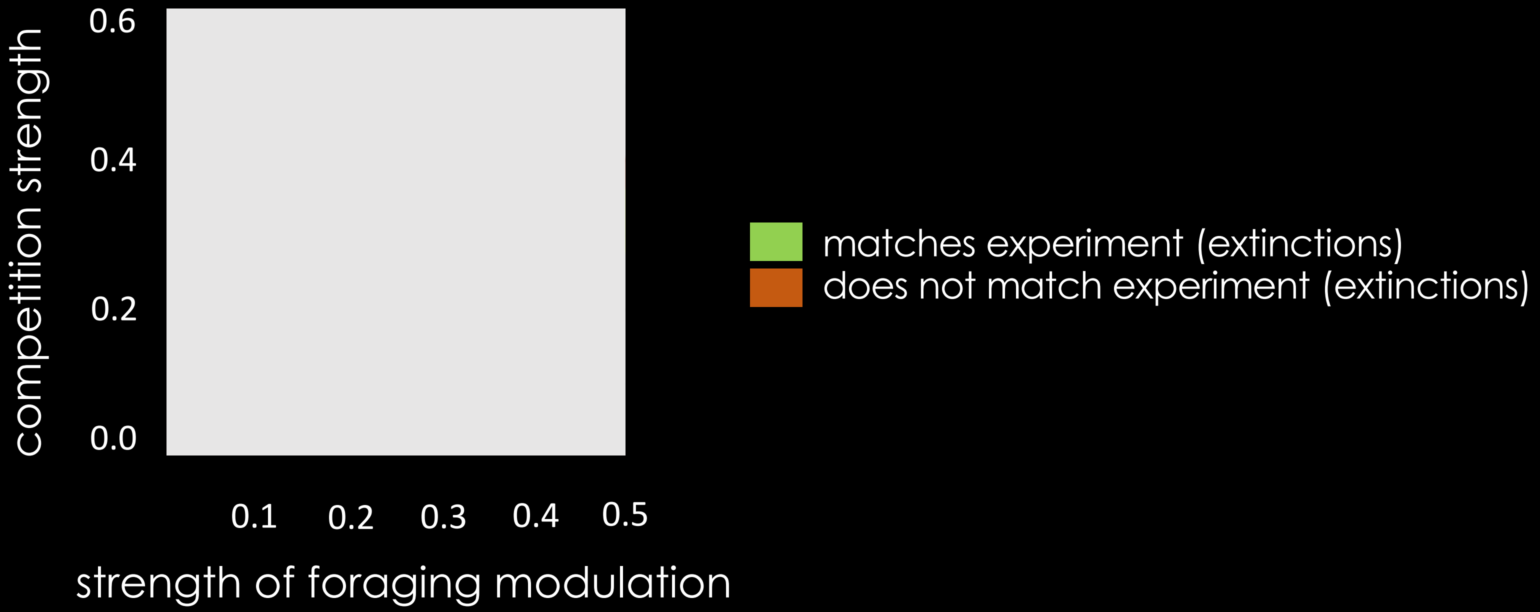
[bioenergetic consumer-resource model]

+ non-trophic interactions

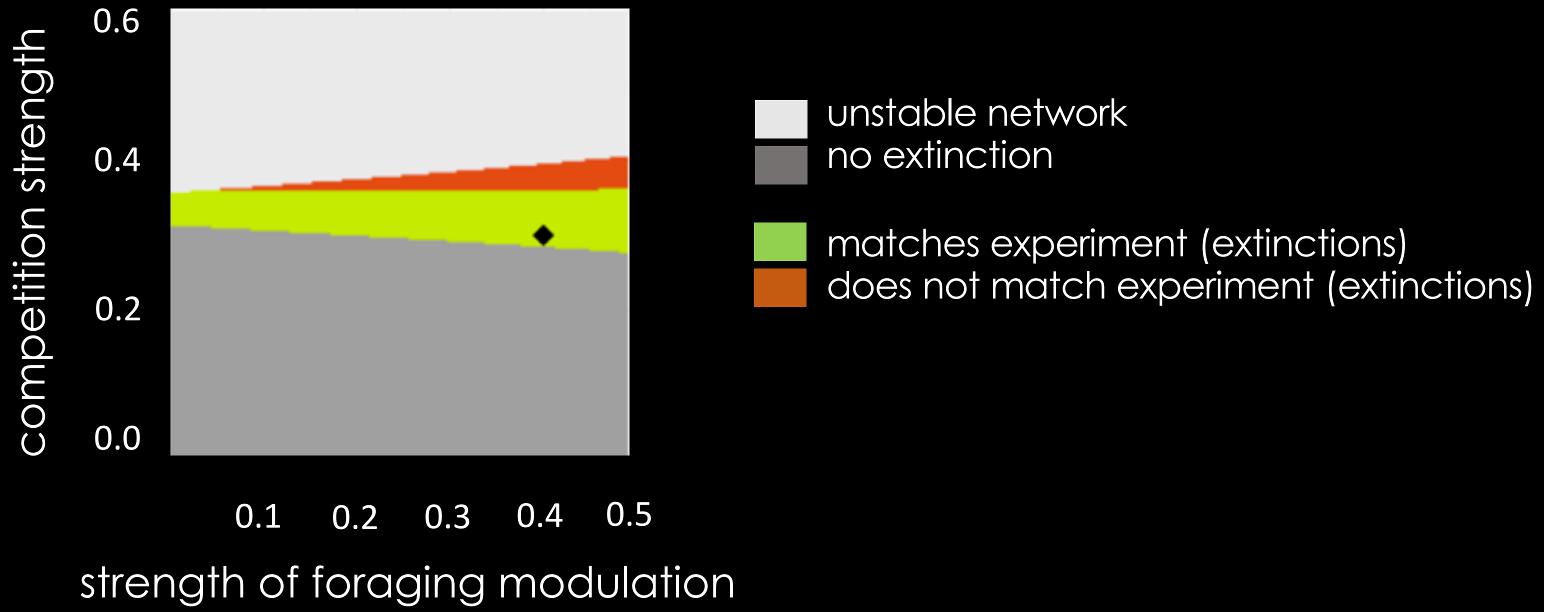
competition for space

foraging modulation

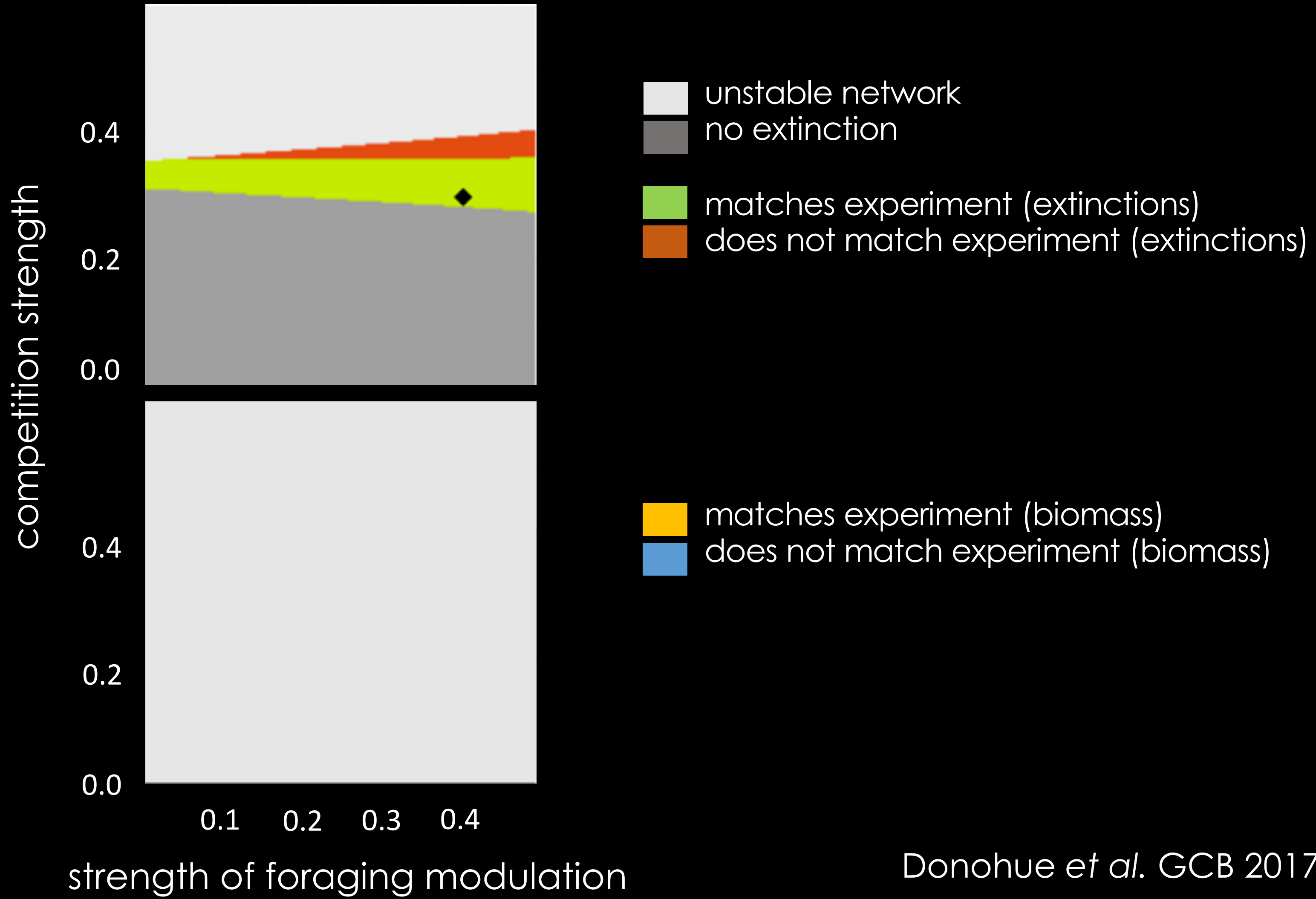
Kéfi *et al.* 2012 Eco. Lett.



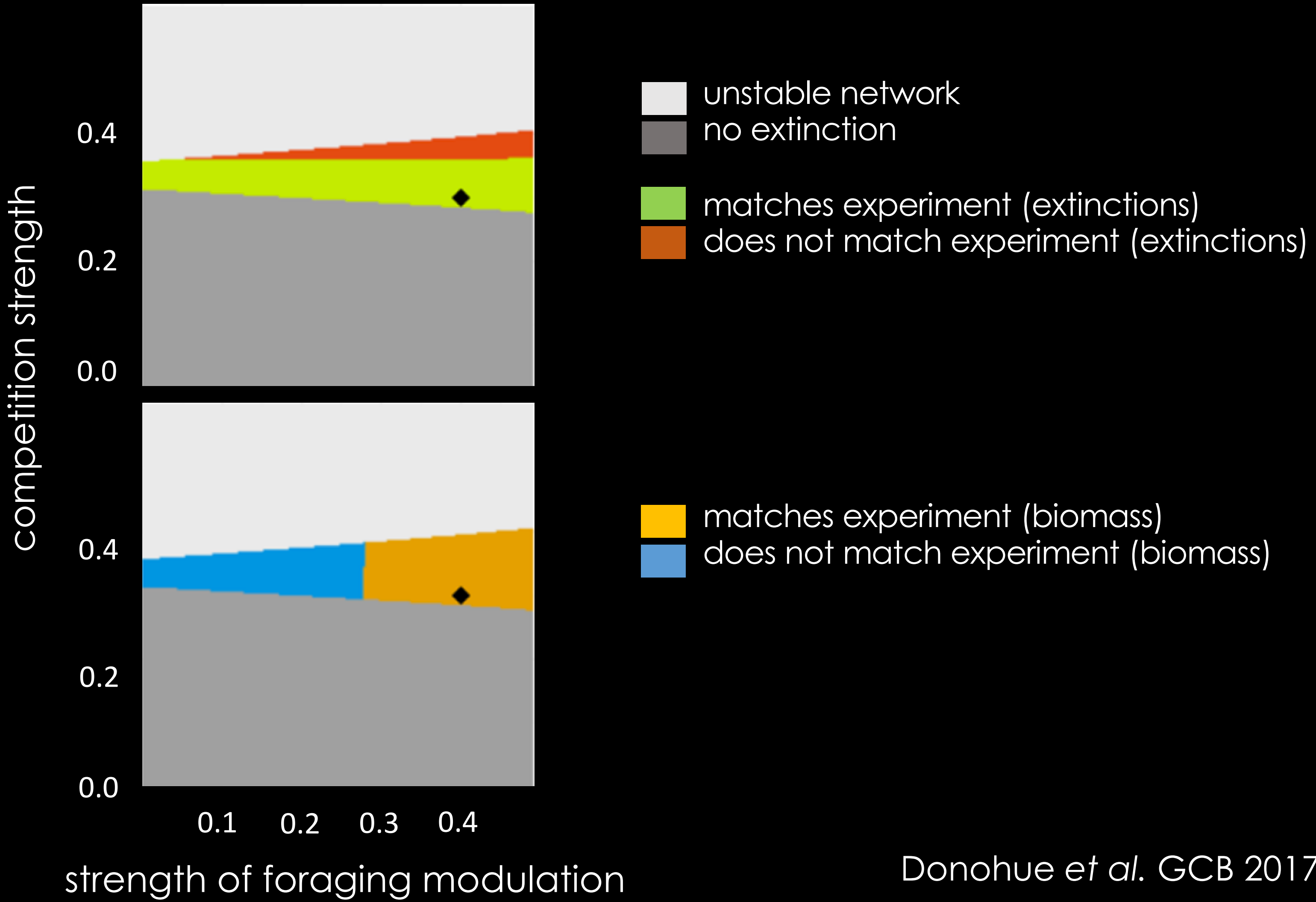
Donohue *et al.* GCB 2017



Donohue *et al.* GCB 2017



Donohue *et al.* GCB 2017



Donohue *et al.* GCB 2017

The diversity of interaction types is needed to reproduce the results of the experiments

How does the diversity of interaction types affect functioning?

dynamical model

[bioenergetic consumer-resource model]

dynamical model

[bioenergetic consumer-resource model]

+ non-trophic interactions

Competition for space

Predator interference

Recruitment facilitation

Refuge provisioning

Positive and negative effects on survival

Kéfi *et al.* 2012 Eco. Lett.

Simulations

Niche model for food web skeleton, 100 species incl. 20 plants

Miele *et al.* 2019

Simulations

Niche model for food web skeleton, 100 species incl. 20 plants
Plug NTI 'links randomly'

Miele *et al.* 2019

Simulations

Niche model for food web skeleton, 100 species incl. 20 plants
Plug NTI 'links randomly'
Run dynamics with and without NTI

Miele *et al.* 2019

Simulations

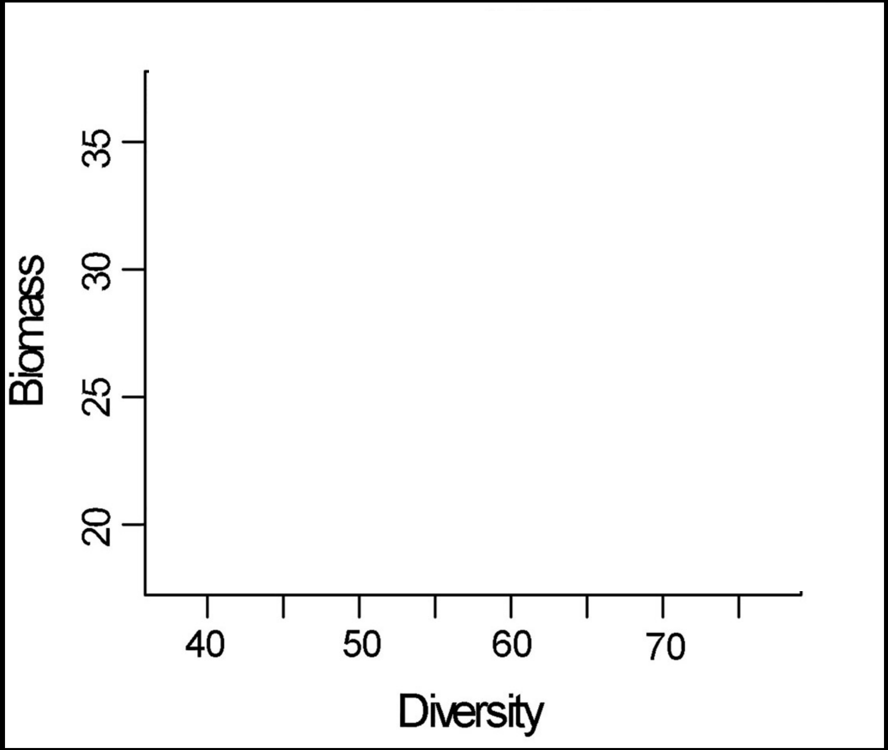
Niche model for food web skeleton, 100 species incl. 20 plants
Plug NTI 'links randomly'
Run dynamics with and without NTI

⬇

Calculate species diversity and total biomass

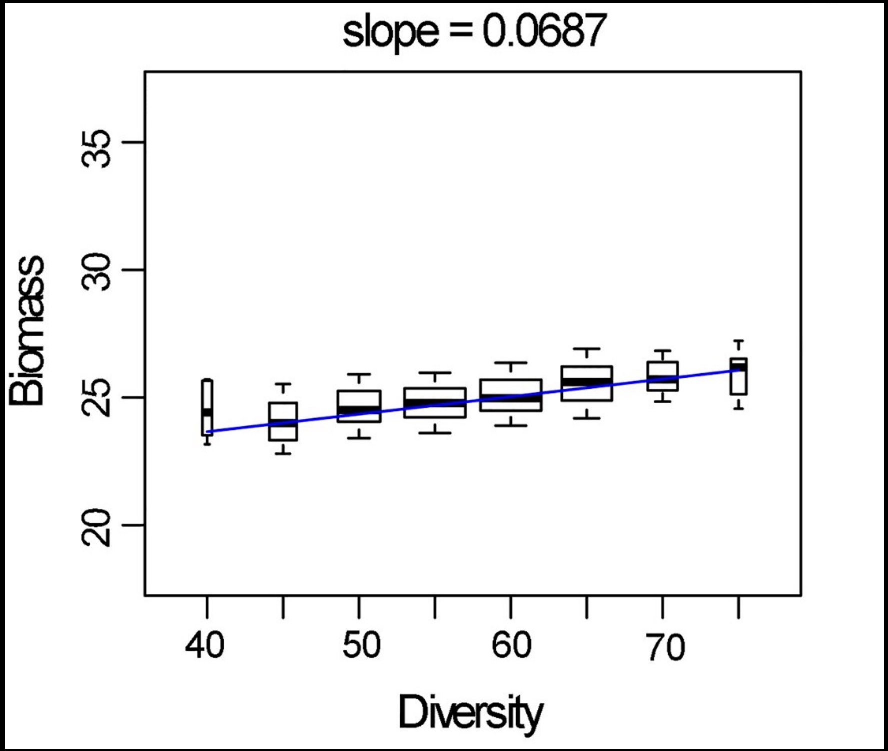
Miele *et al.* 2019

One interaction type (trophic)



Miele *et al.* 2019

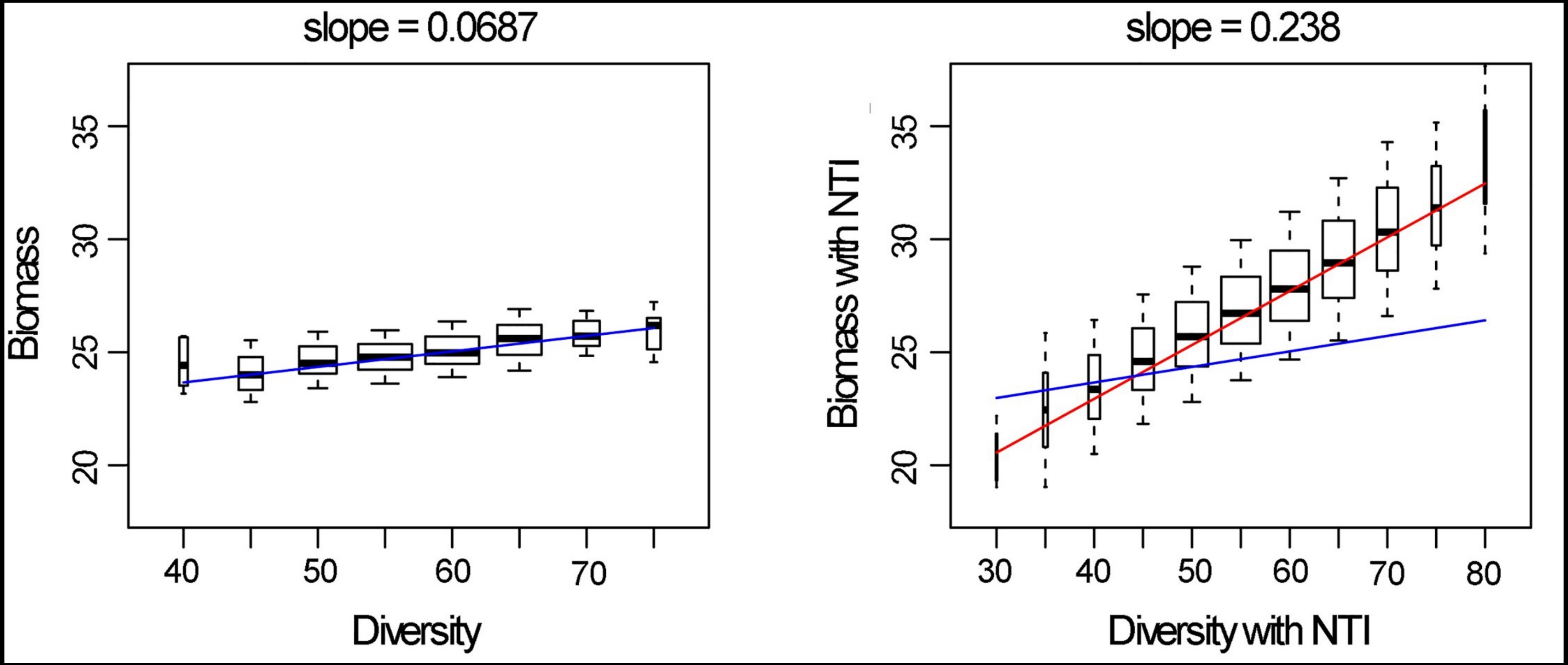
One interaction type (trophic)



Miele et al. 2019

One interaction type (trophic)

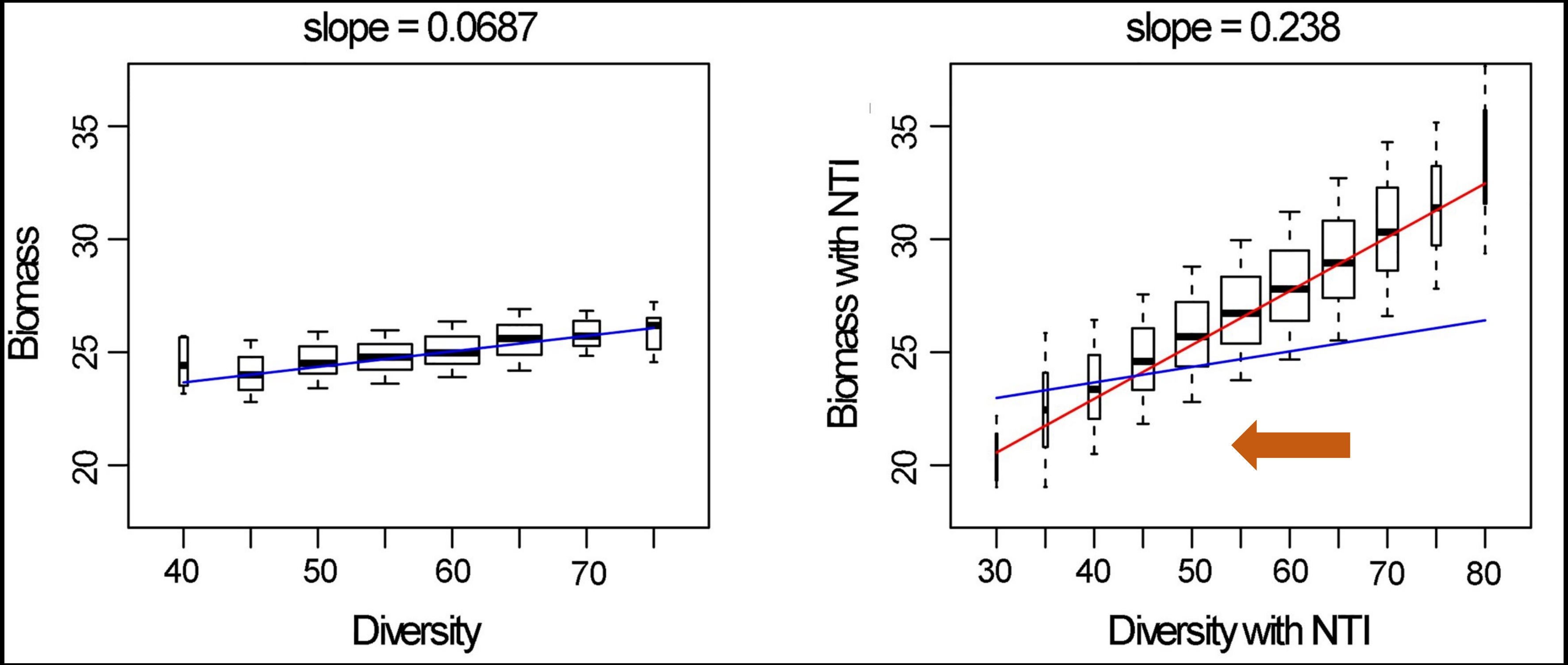
Diverse interactions types (multiplex)



Miele *et al.* 2019

One interaction type (trophic)

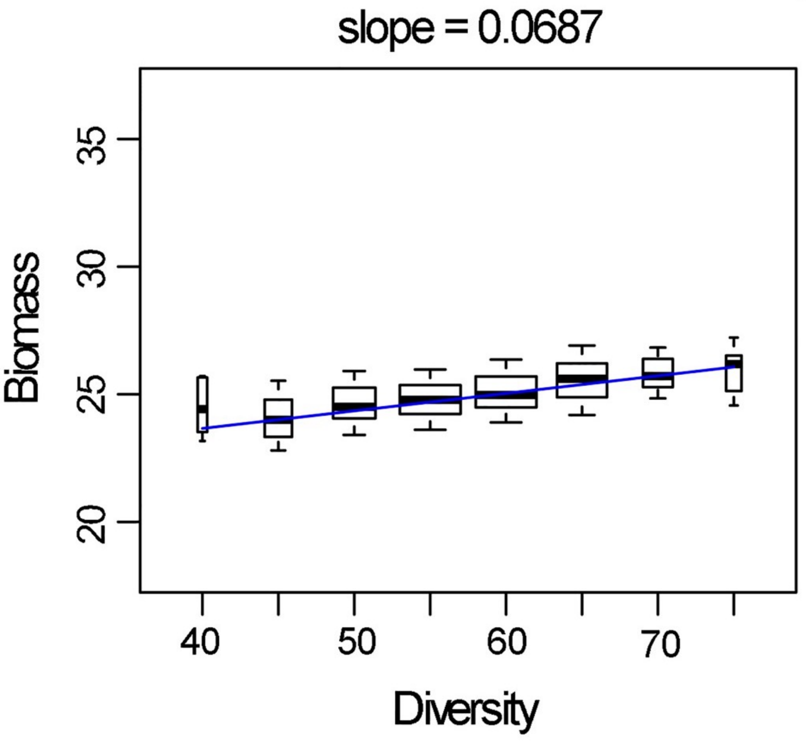
Diverse interactions types (multiplex)

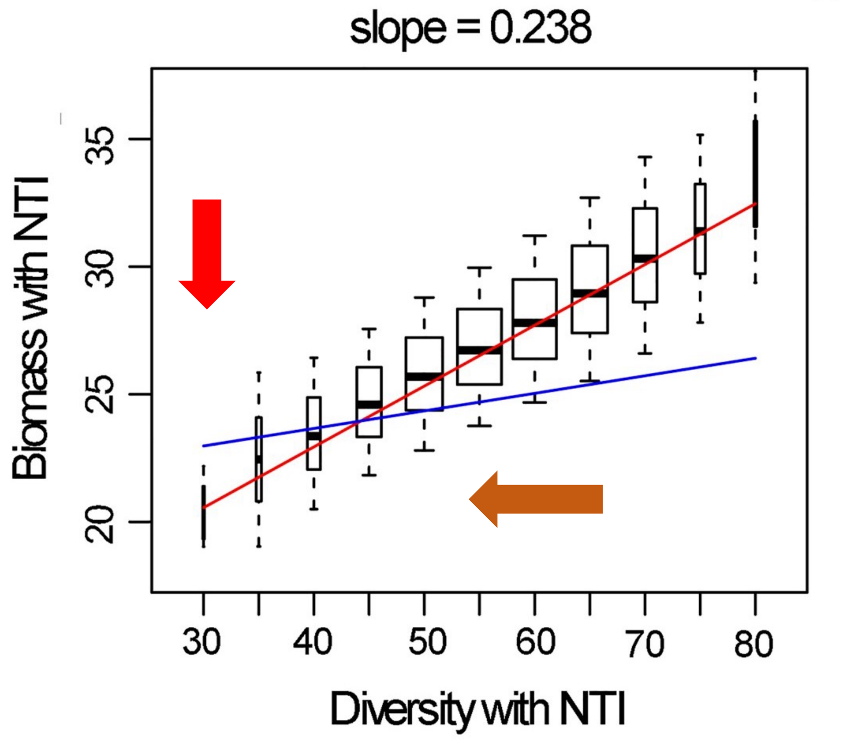


Miele *et al.* 2019

One interaction type (trophic)

Diverse interactions types (multiplex)



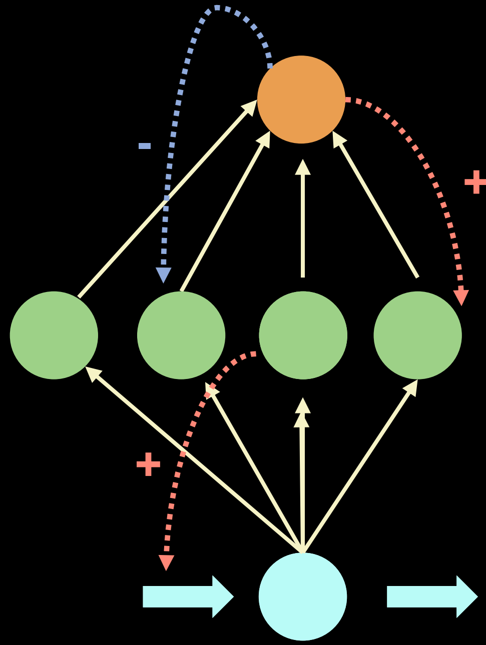


Miele *et al.* 2019

NTIs affect species diversity, community functioning and their relationship

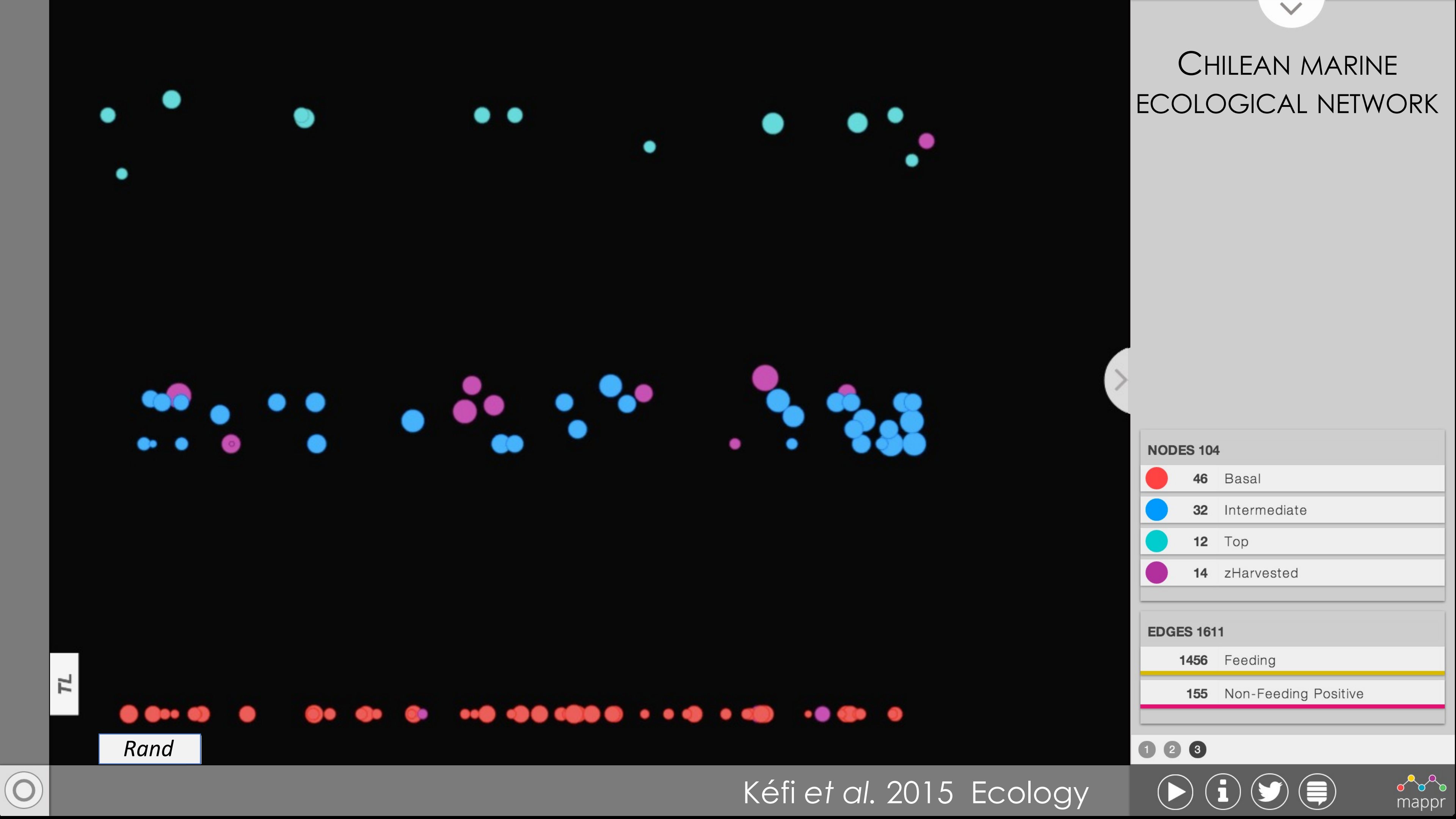
Miele *et al.* 2019

How do different interaction types map onto each other?

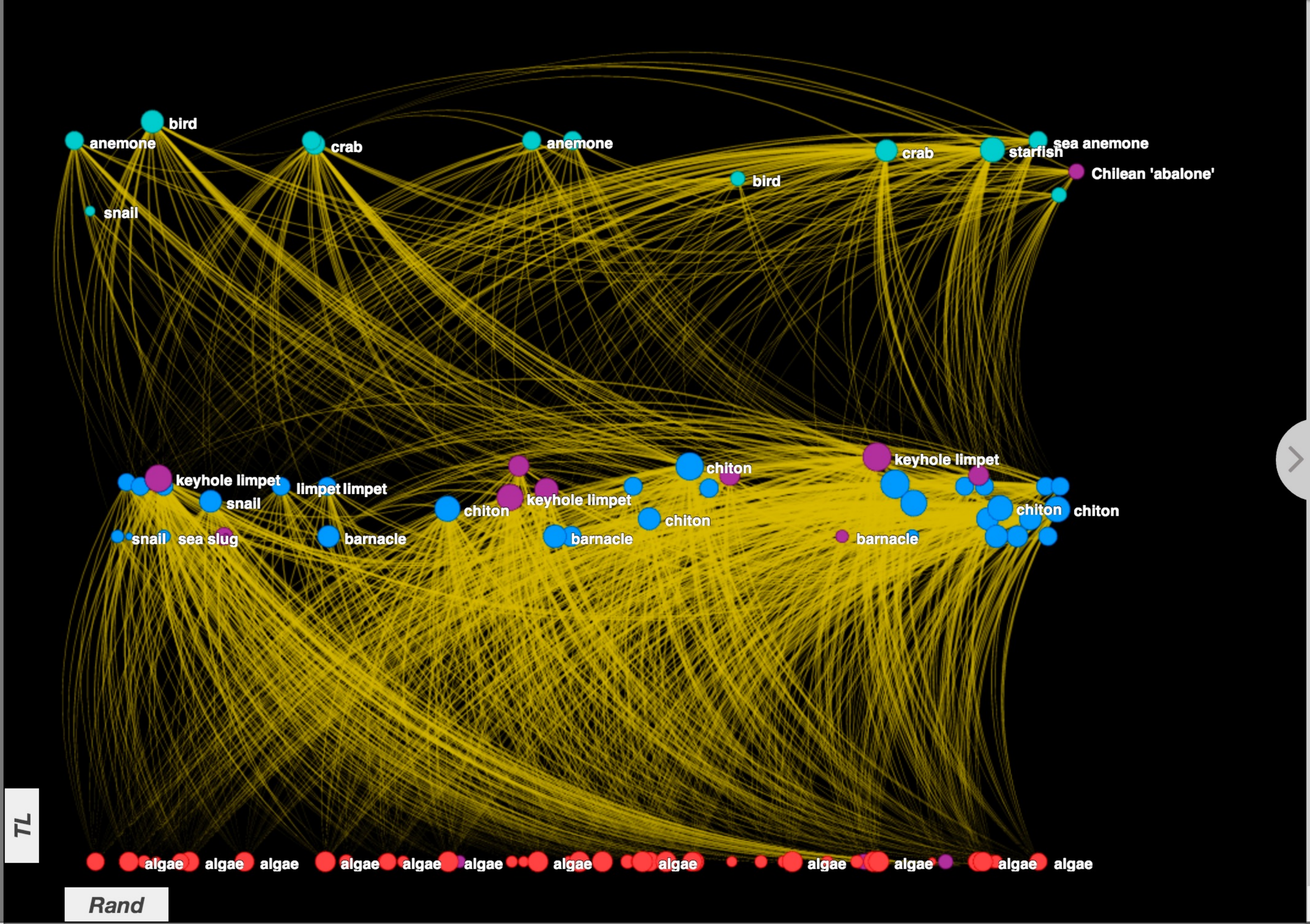


multiplex ecological network


Sergio Navarrete,
Evie Wieters
Kéfi *et al.* 2015


CHILEAN MARINE ECOLOGICAL NETWORK
TL
Rand
NODES 104
46 Basal
32 Intermediate
12 Top
14 zHarvested
EDGES 1611
1456 Feeding
155 Non-Feeding Positive
1 2 3
Kéfi et al. 2015 Ecology
mappr

CHILEAN MARINE FOOD WEB



NODES 104

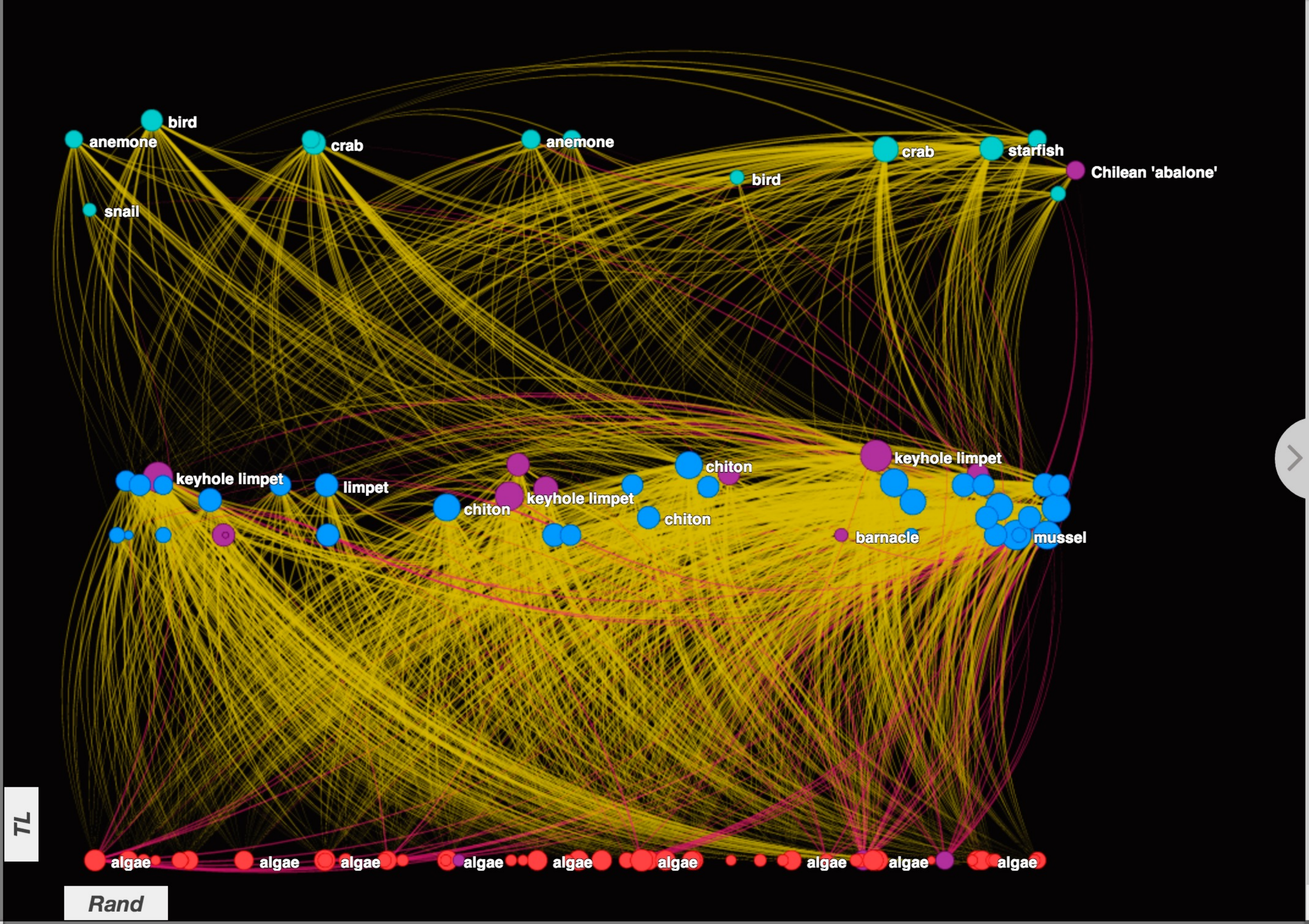
●	46	Basal
●	32	Intermediate
●	12	Top
●	14	zHarvested

1 2

Kéfi *et al.* 2015 Ecology

mappr

Chilean Marine Ecological Network



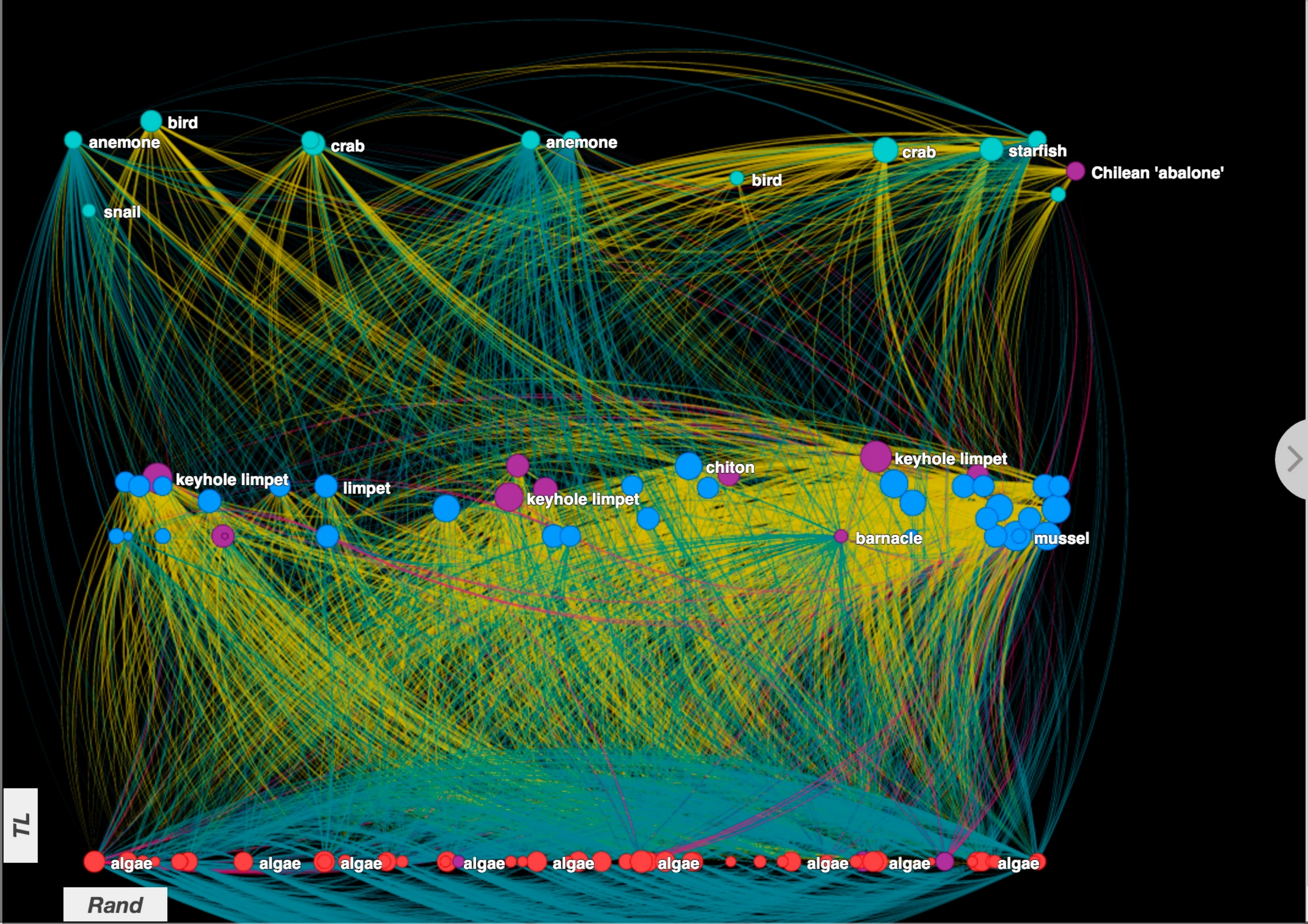
NODES 104		
	46	Basal
	32	Intermediate
	12	Top
	14	zHarvested

EDGES 1611	
1456	Feeding
155	Non-Feeding Positive

1 2 3

Kéfi *et al.* 2015 Ecology

Chilean Marine Ecological Network



NODES 104

46	Basal
32	Intermediate
12	Top
14	zHarvested

EDGES 4720

1424	Feeding
3141	Non-Feeding Negative
155	Non-Feeding Positive

1 2 3

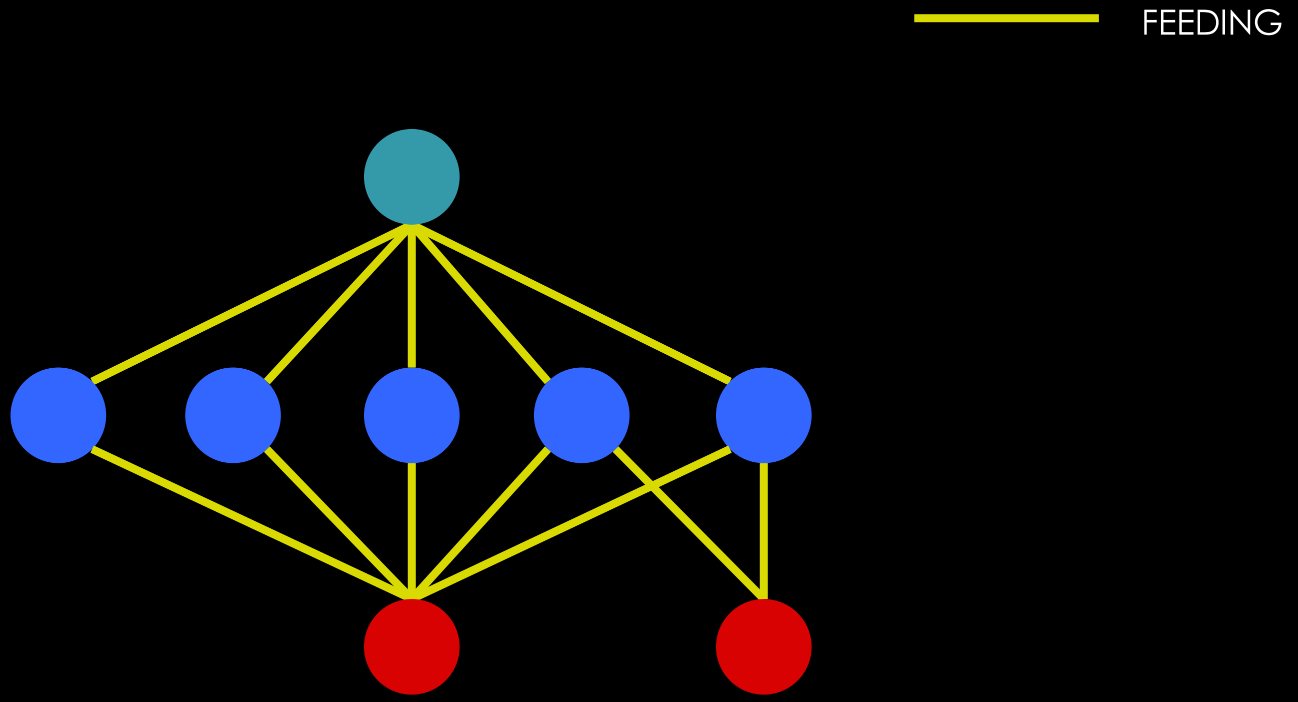
Kéfi *et al.* 2015 Ecology

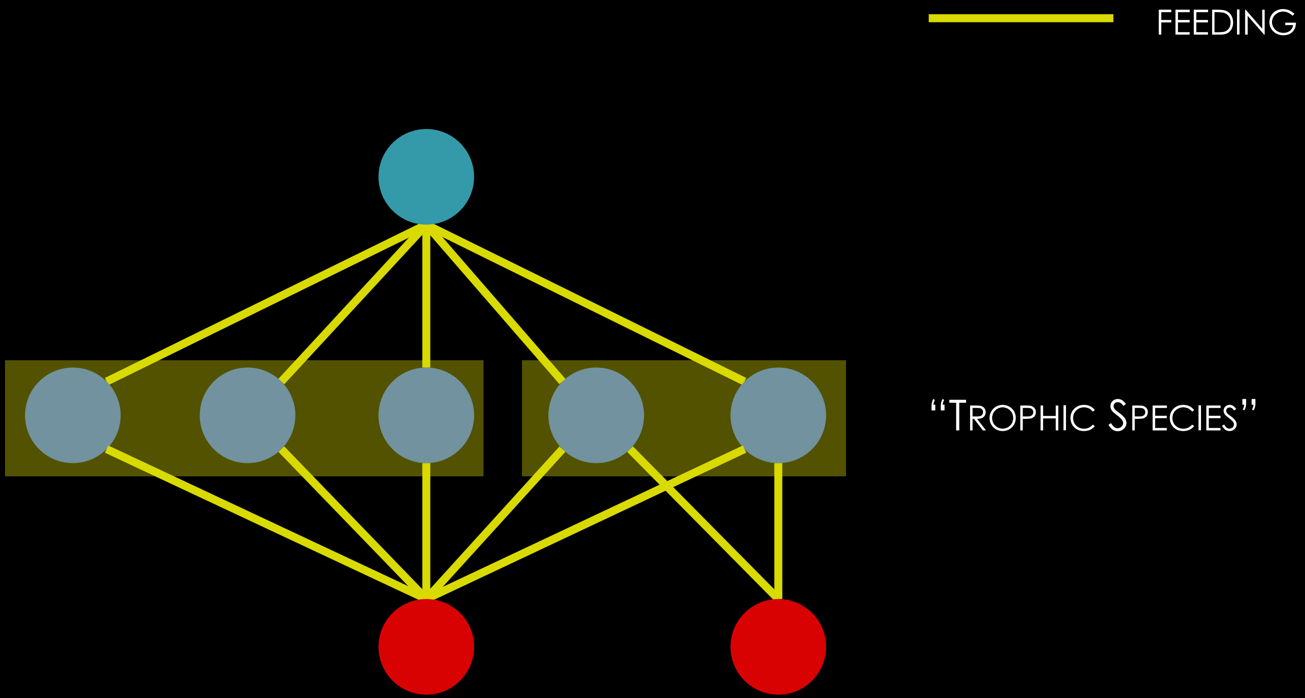
mappr

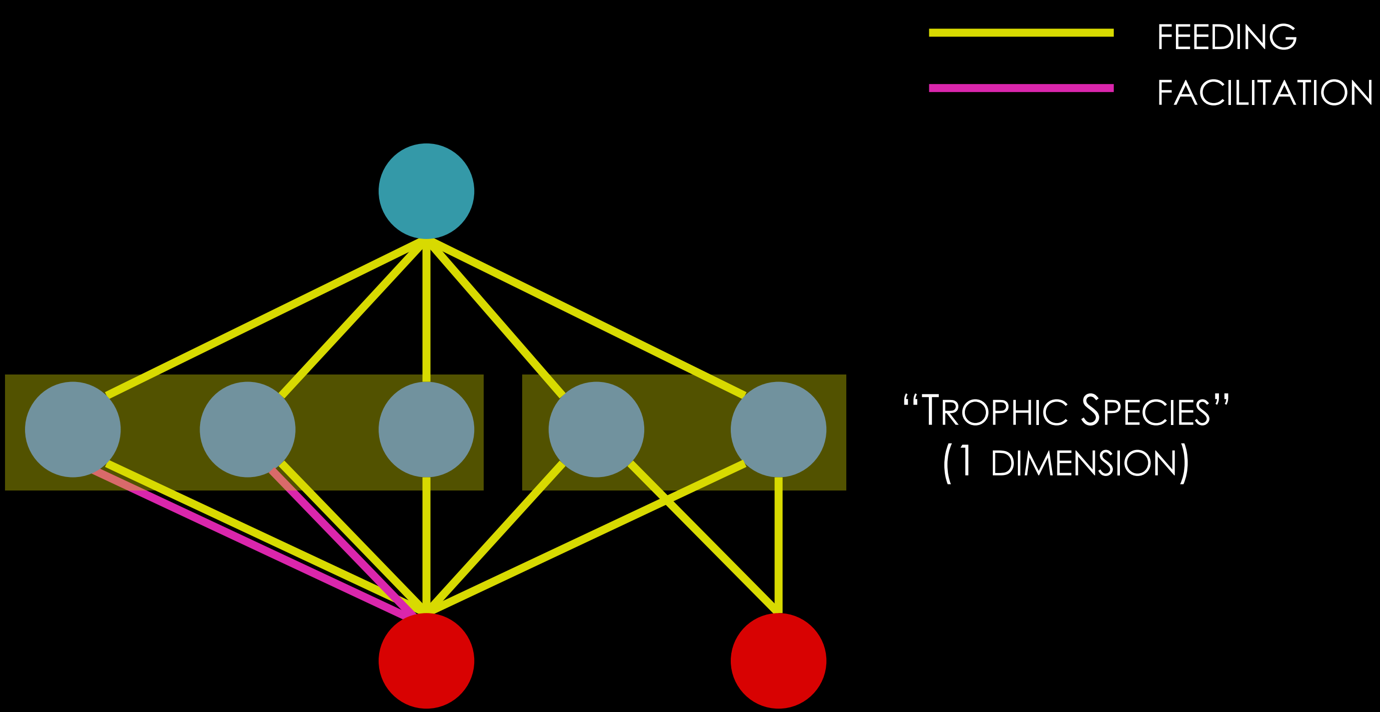
Do species collapse into a smaller set of multiplex clusters?

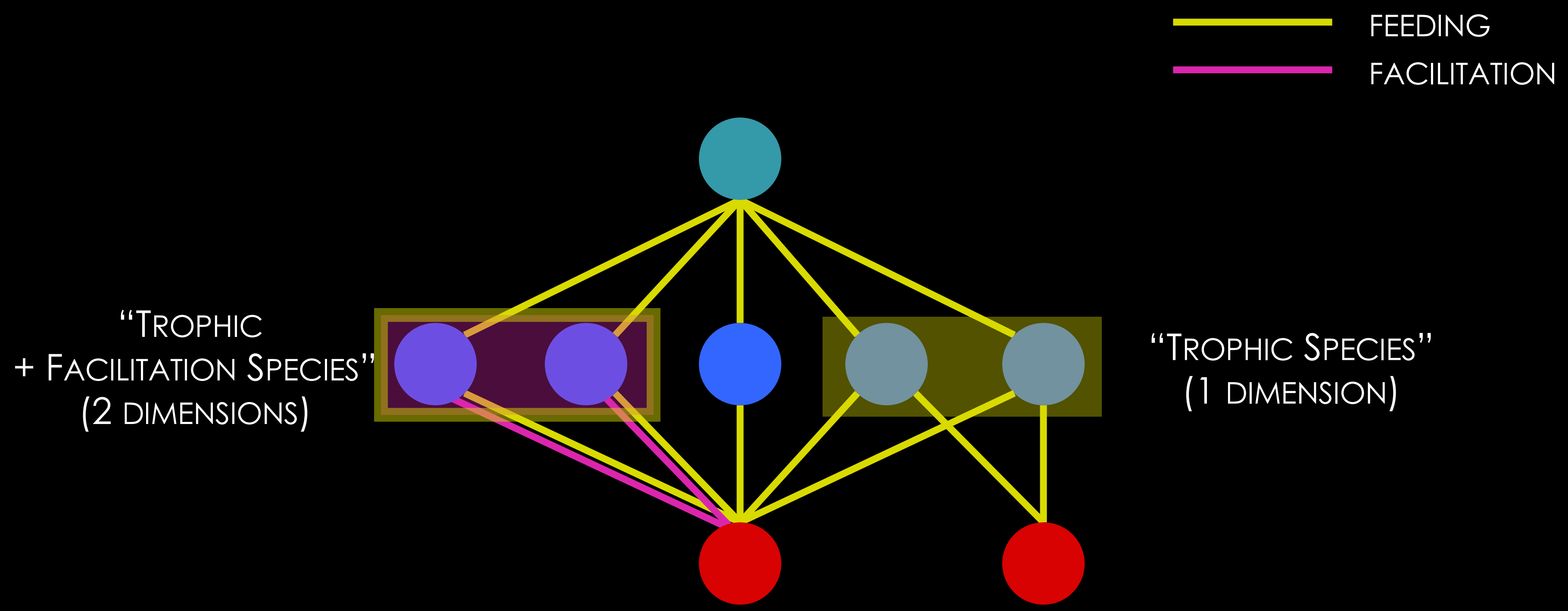
stochastic block model

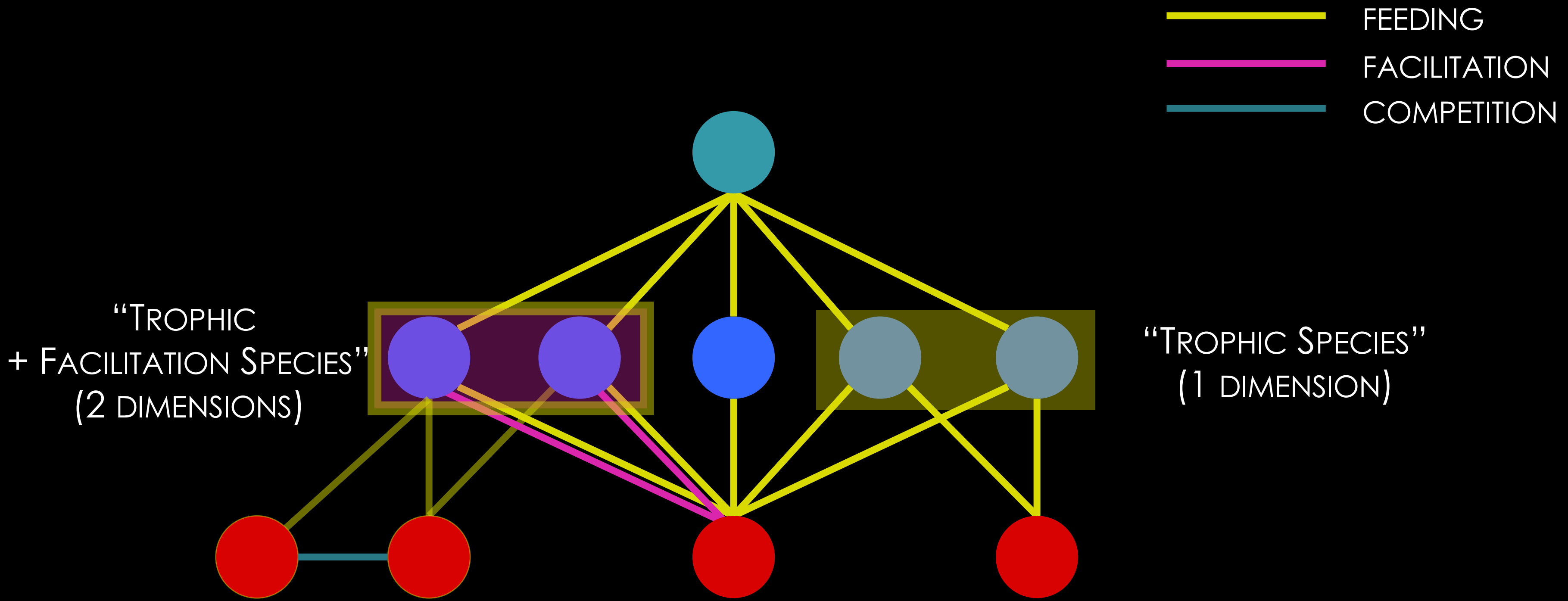
Newman and Leicht 2007
Daudin *et al.* 2008
Miele *et al.* 2014


FEEDING

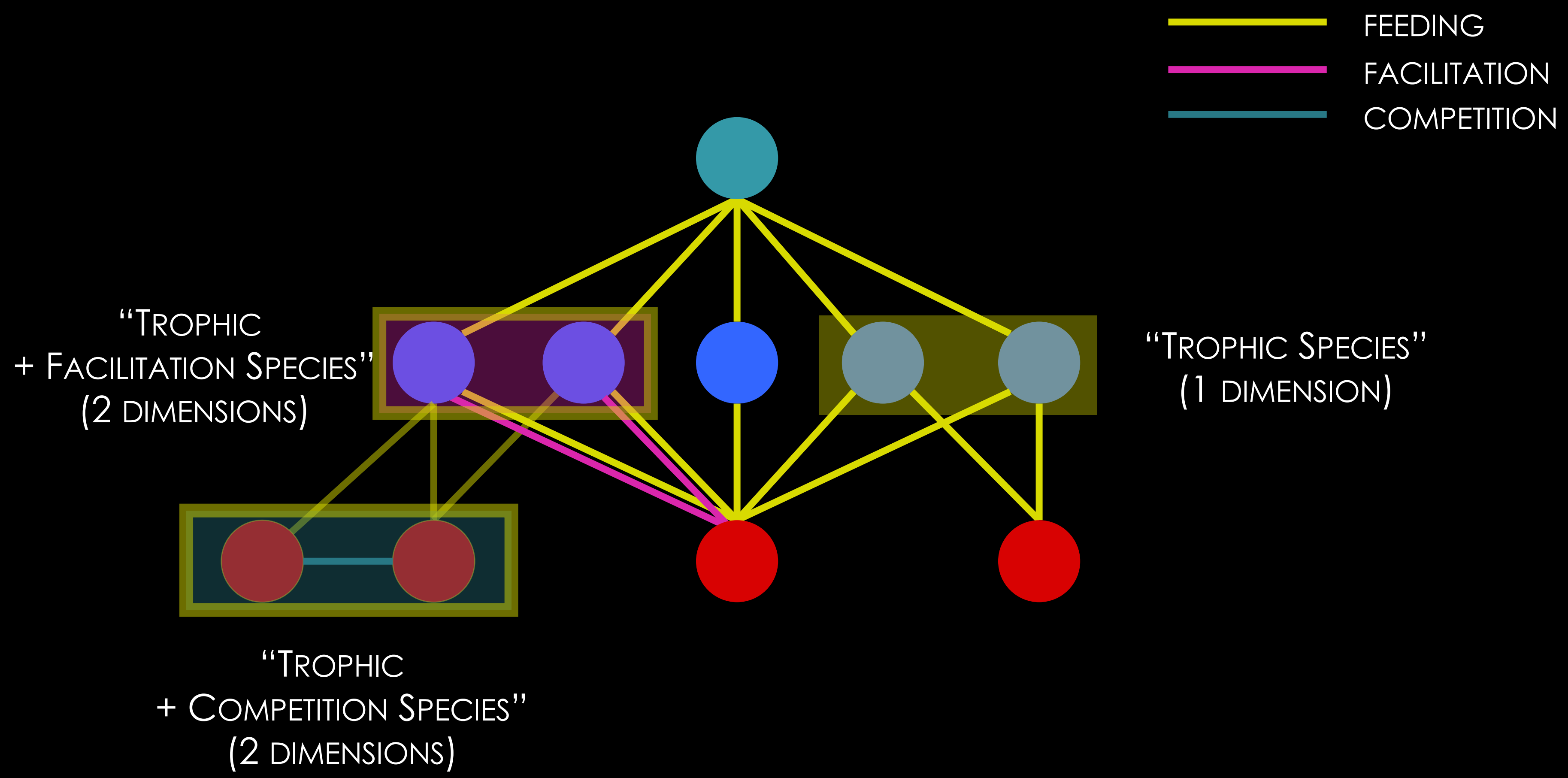

FEEDING
"TROPHIC SPECIES"

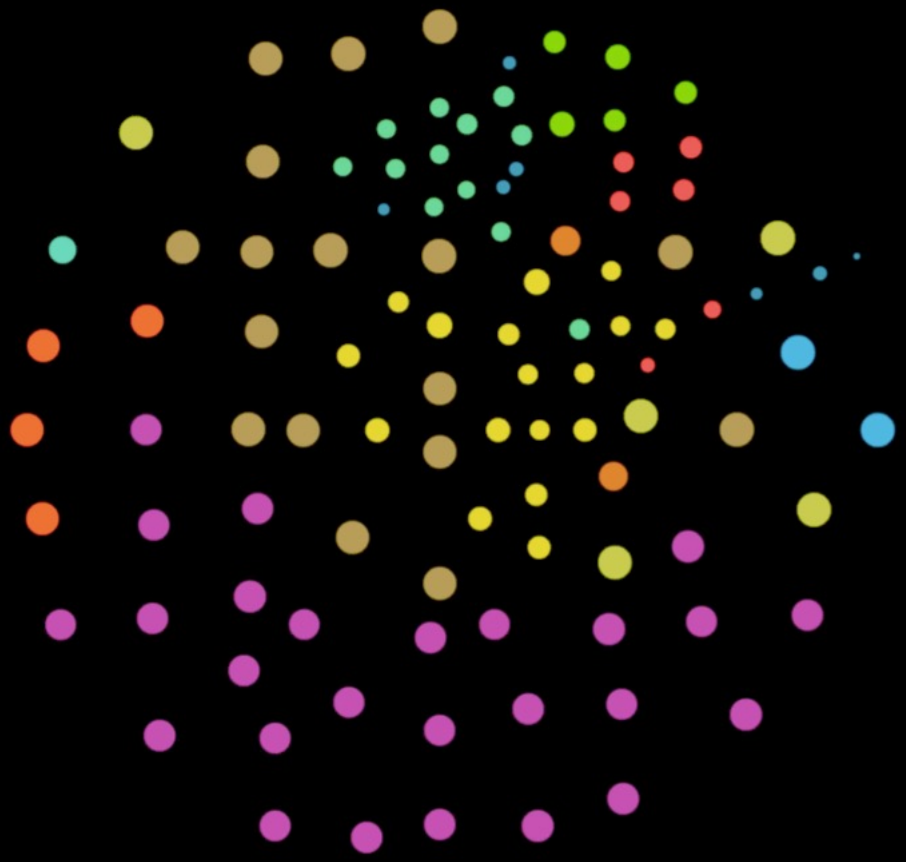

FEEDING
FACILITATION
"TROPHIC SPECIES"
(1 DIMENSION)


FEEDING
FACILITATION
"Trophic + Facilitation Species" (2 dimensions)
"Trophic Species" (1 dimension)



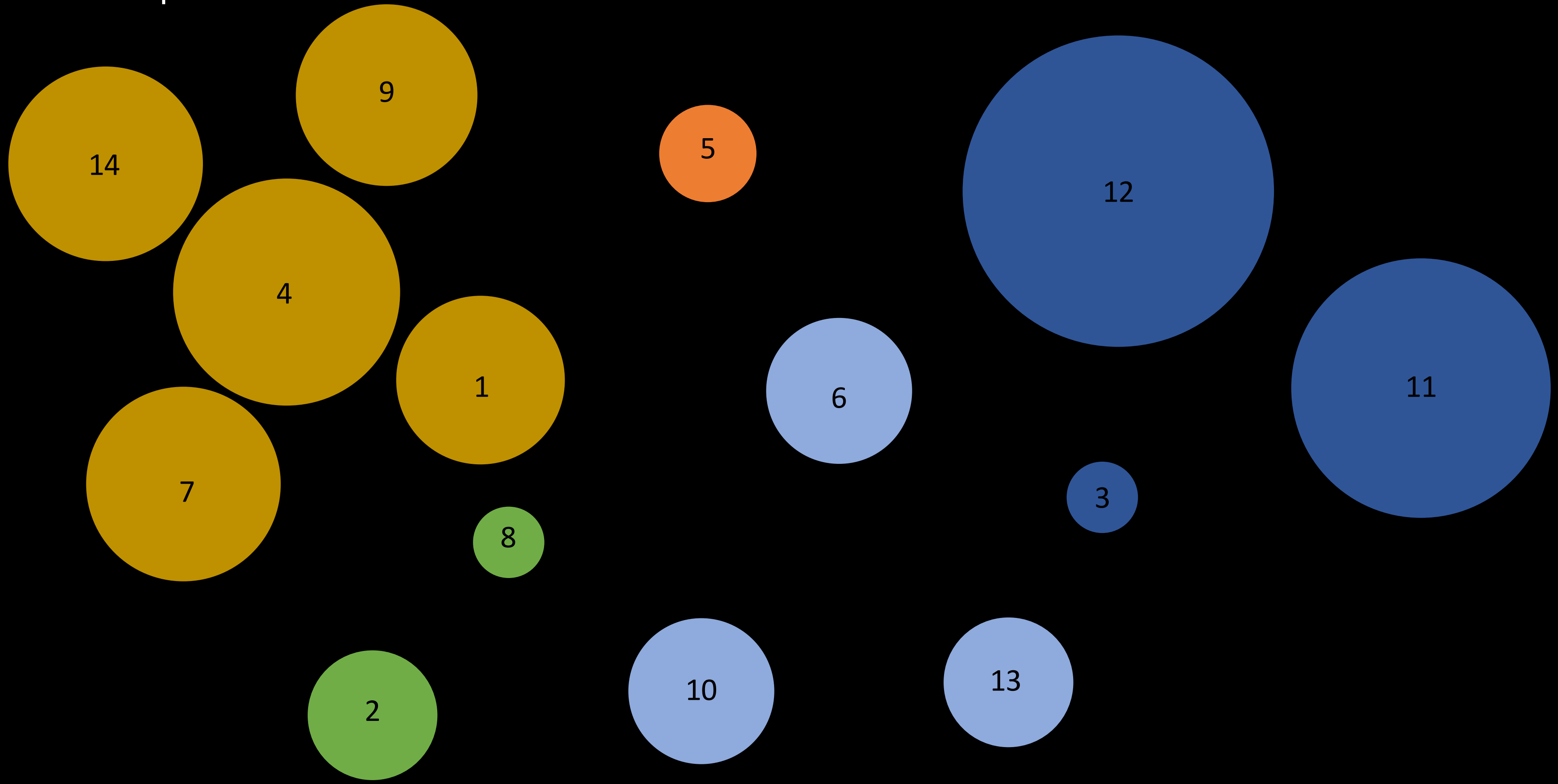
FEEDING
FACILITATION
COMPETITION
"TROPHIC + FACILITATION SPECIES" (2 DIMENSIONS)
"TROPHIC SPECIES" (1 DIMENSION)


FEEDING
FACILITATION
COMPETITION
"TROPHIC
+ FACILITATION SPECIES"
(2 DIMENSIONS)
"TROPHIC SPECIES"
(1 DIMENSION)
"TROPHIC
+ COMPETITION SPECIES"
(2 DIMENSIONS)



Kéfi, Miele *et al.* 2016 PLOS Biol.

14 multiplex clusters



Kéfi, Miele *et al.* 2016 PLOS Biol.

Species collapse into a small set of multiplex clusters

What are the functional consequences of the 3-dimensional connectivity pattern?

dynamical model

[bioenergetic consumer-resource model]

dynamical model

[bioenergetic consumer-resource model]

+ non-trophic interactions

Competition for space
Predator interference
Recruitment facilitation
Refuge provisioning
Positive and negative effects on survival

Kéfi *et al.* 2012 Eco. Lett

Simulations

14 nodes
('typical' species of
the cluster)

Kéfi, Miele *et al.* 2016 PLOS Biol.

Simulations

14 nodes
('typical' species of the cluster)

→ (i) Connectivity of the Chilean web

Kéfi, Miele *et al*. 2016 PLOS Biol.

Simulations

14 nodes
('typical' species of the cluster)

→ (i) Connectivity of the Chilean web

→ (ii) 500 random networks (keep degree sequence)

Kéfi, Miele *et al.* 2016 PLOS Biol.

Simulations

14 nodes
('typical' species of the cluster)

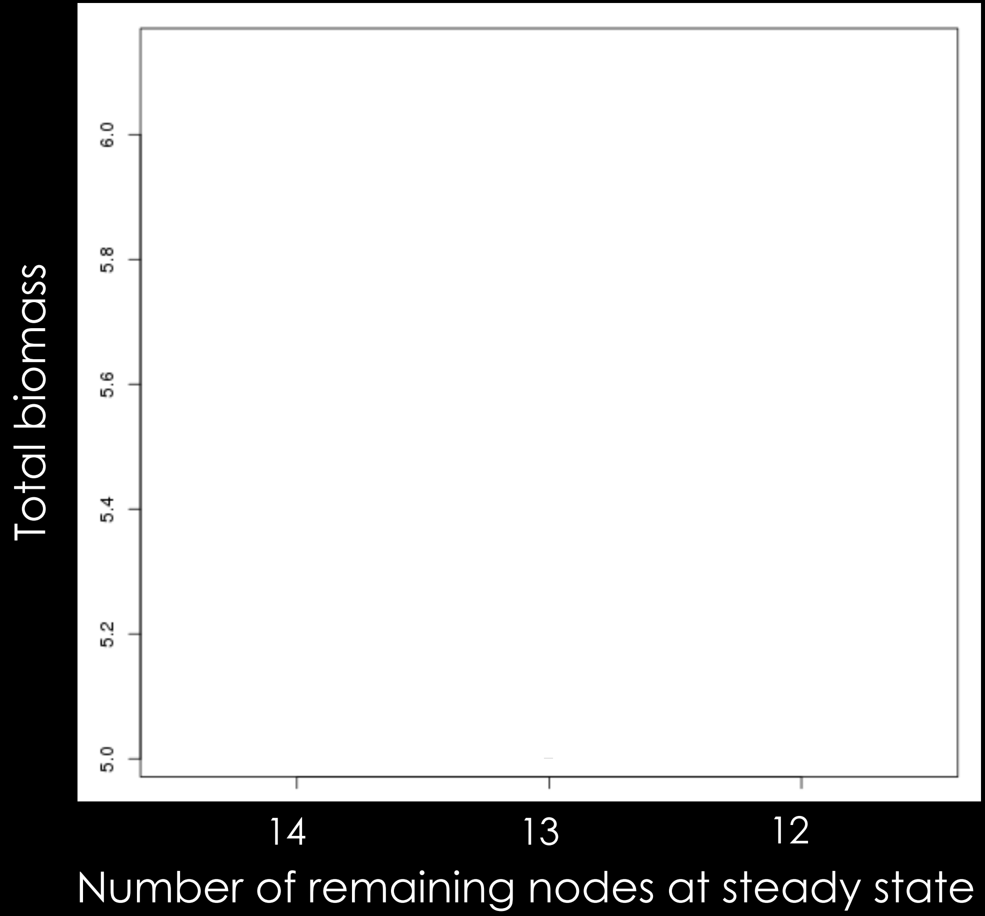
→ (i) Connectivity of the Chilean web

→ (ii) 500 random networks (keep degree sequence)

↓

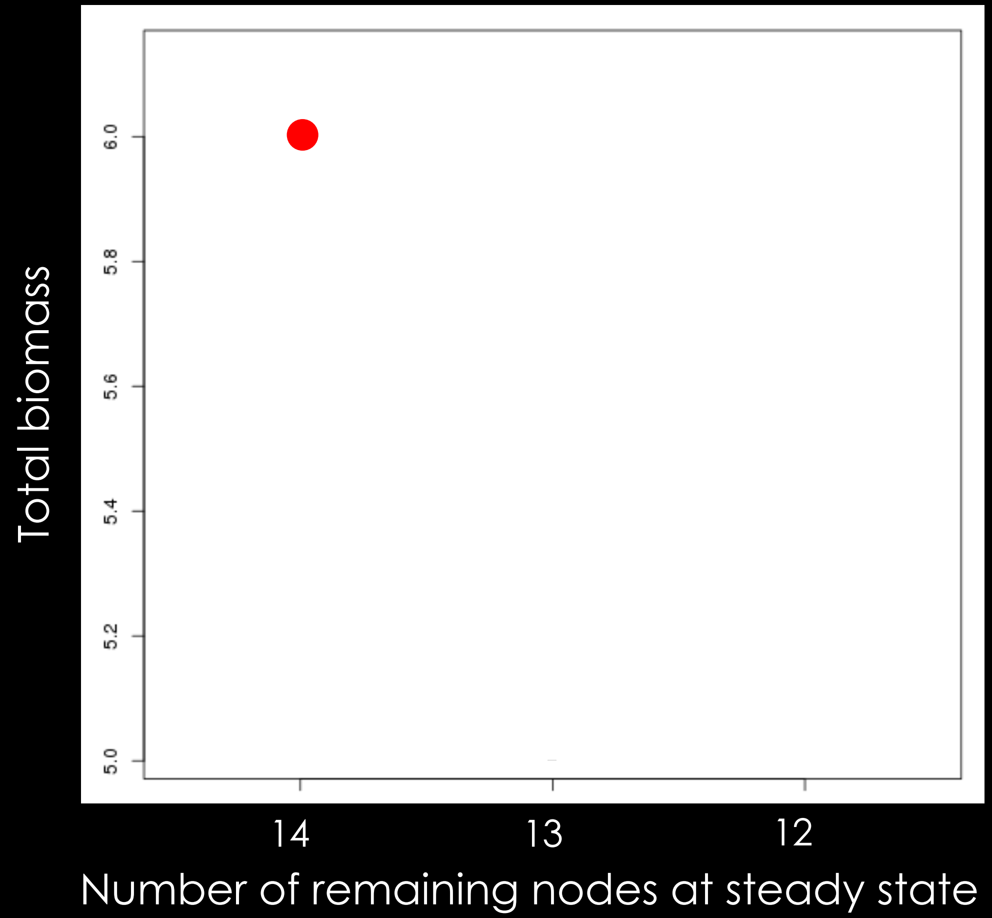
Calculate species diversity and total biomass

Kéfi, Miele *et al.* 2016 PLOS Biol.



Kéfi, Miele *et al.* 2016 PLOS Biol.

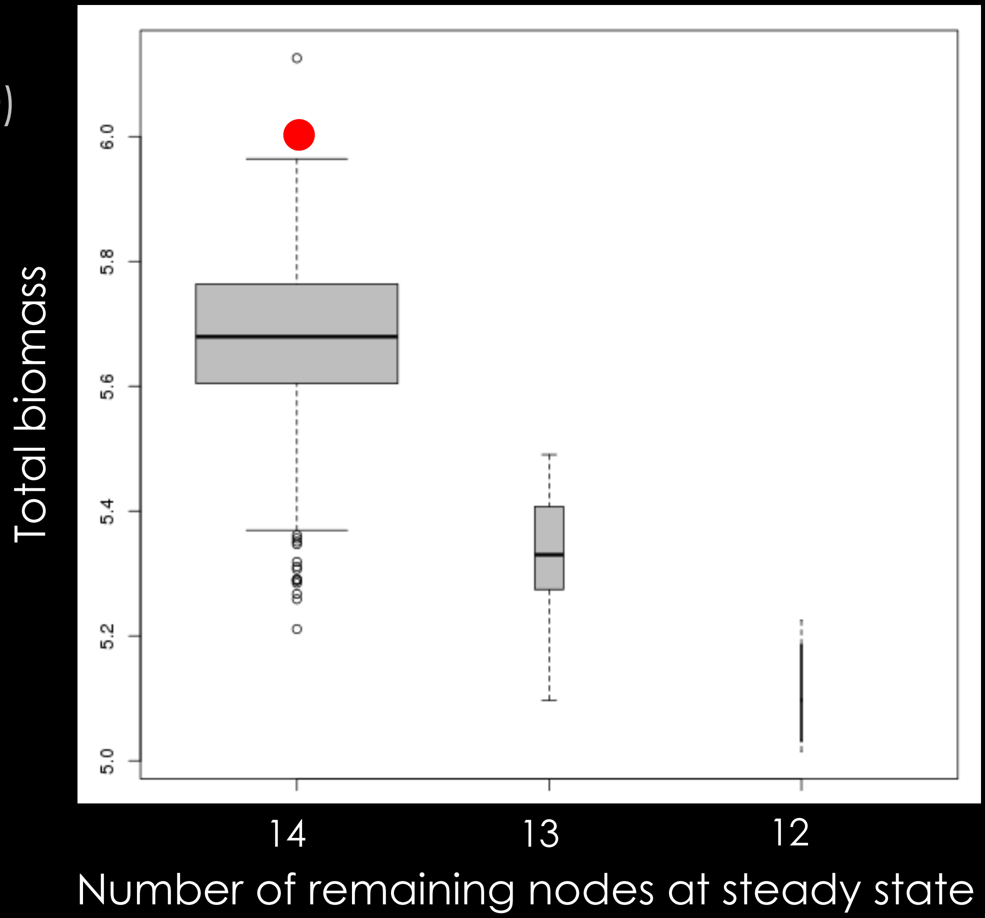
Chilean web



Kéfi, Miele *et al.* 2016 PLOS Biol.

Chilean web

Random webs (500)

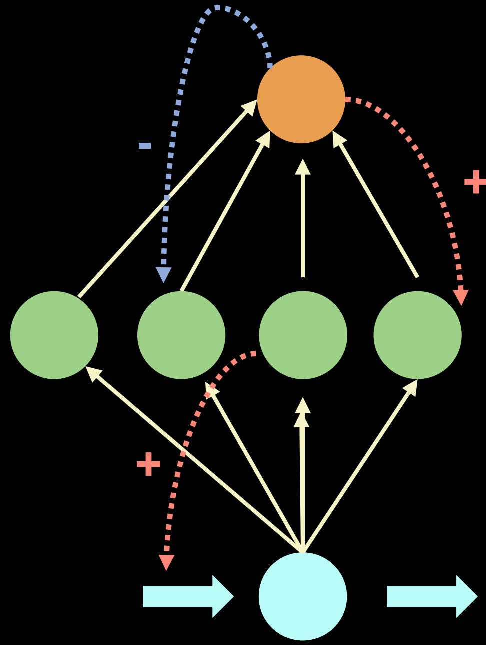


Kéfi, Miele *et al.* 2016 PLOS Biol.

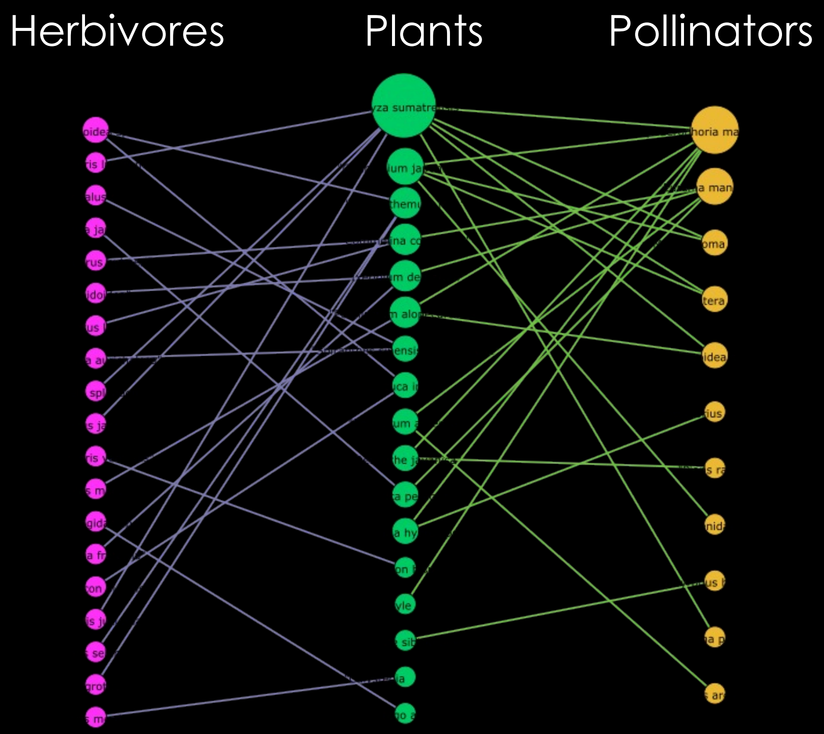
The specific 3-dimentional signature of the clusters in the Chilean web promotes:

- high species persistence
- high total biomass

Kéfi, Miele *et al.* 2016 PLOS Biol.

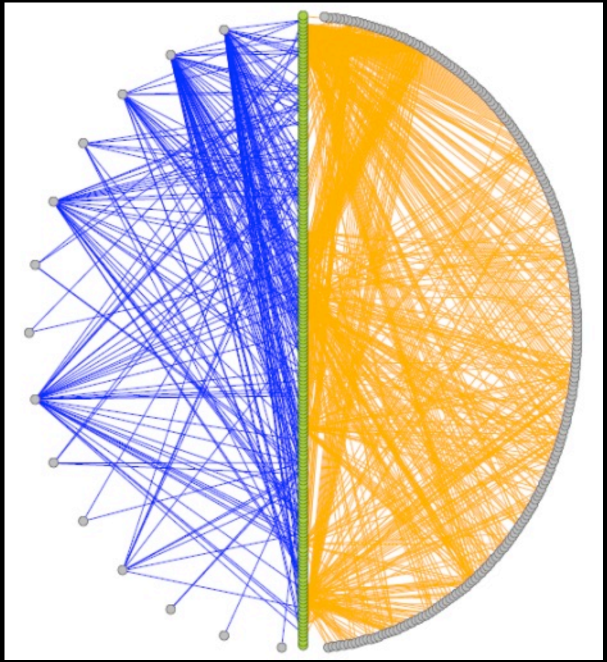


multiplex networks

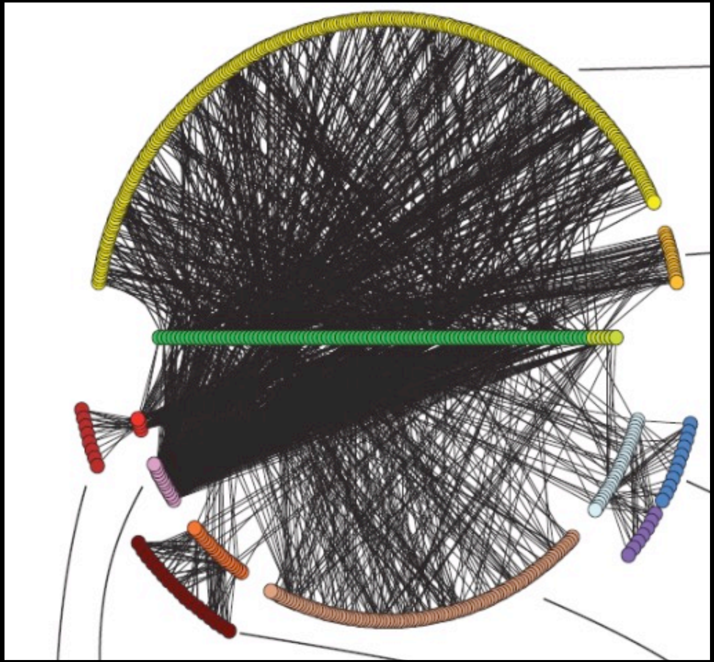


multipartite networks

Antagonistic Plantes Mutualistic



Melian et al. 2009
Donana Biological Reserve, Spain

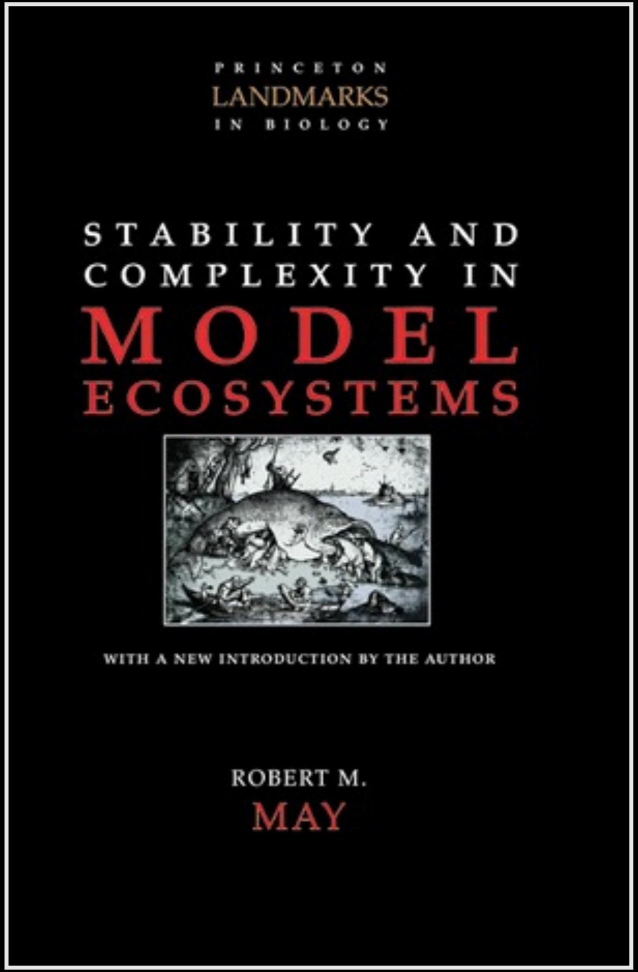


Pocock et al. 2012
Norwood Farm, Somerset, UK

« Complexity begets stability »

Odum 1953
MacArthur 1955
Elton 1958

Robert May


PRINCETON
LANDMARKS
IN BIOLOGY
STABILITY AND
COMPLEXITY IN
MODEL
ECOSYSTEMS
WITH A NEW INTRODUCTION BY THE AUTHOR
ROBERT M.
MAY

« In general mathematical models of multispecies communities, complexity tends to beget instability »

Robert May, 1973

« In general mathematical models of multispecies communities, complexity tends to beget instability »

Robert May, 1973

« The task, therefore, is to elucidate the **devious strategies** which make for stability in enduring natural systems »

Complex ecological communities

COMPLEX ECOLOGICAL COMMUNITIES

MANY SPECIES

Complex ecological communities

Many species

Many interaction types

multi-interaction networks

Thank you very much for your attention

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