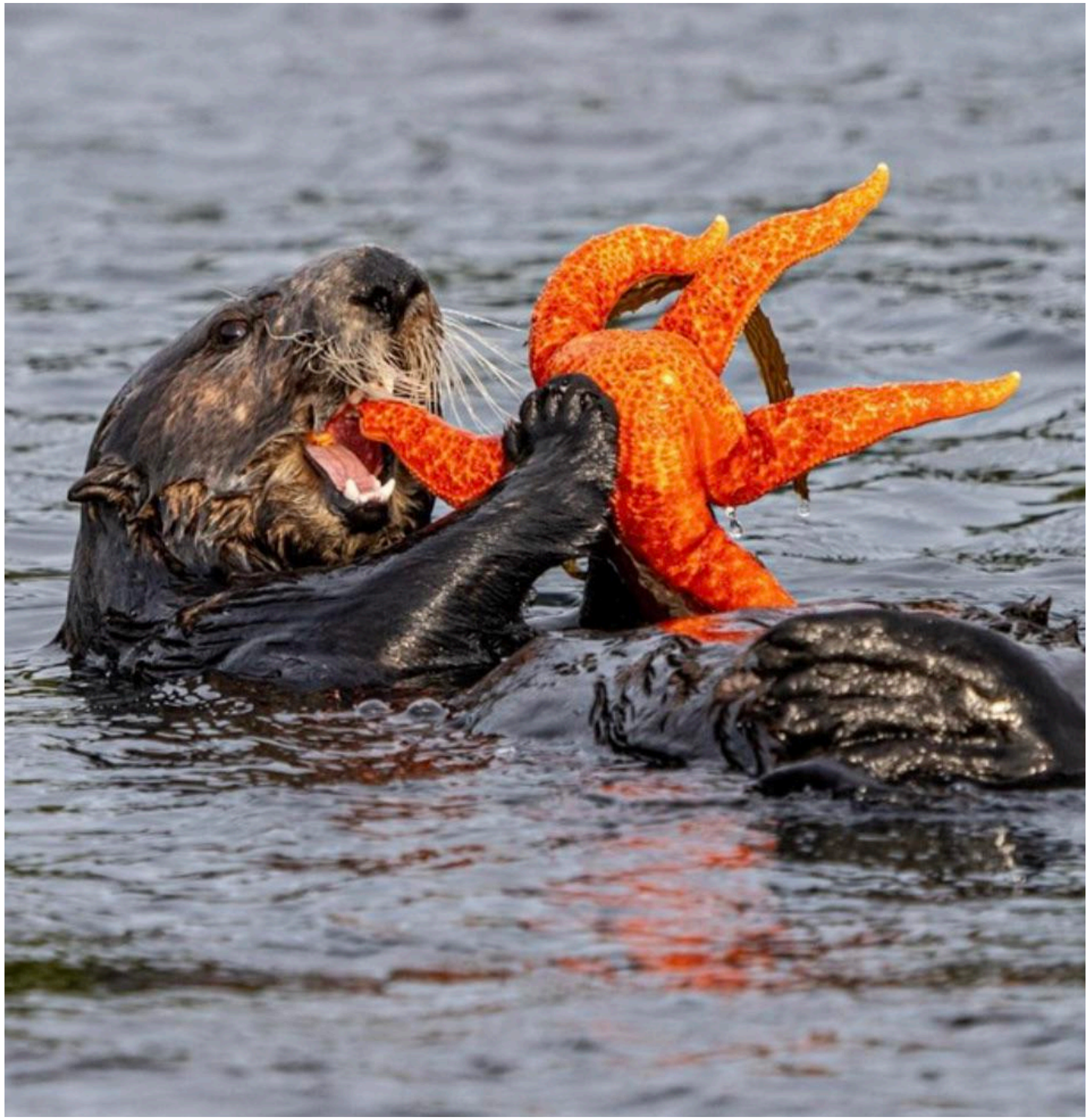
Food Webs

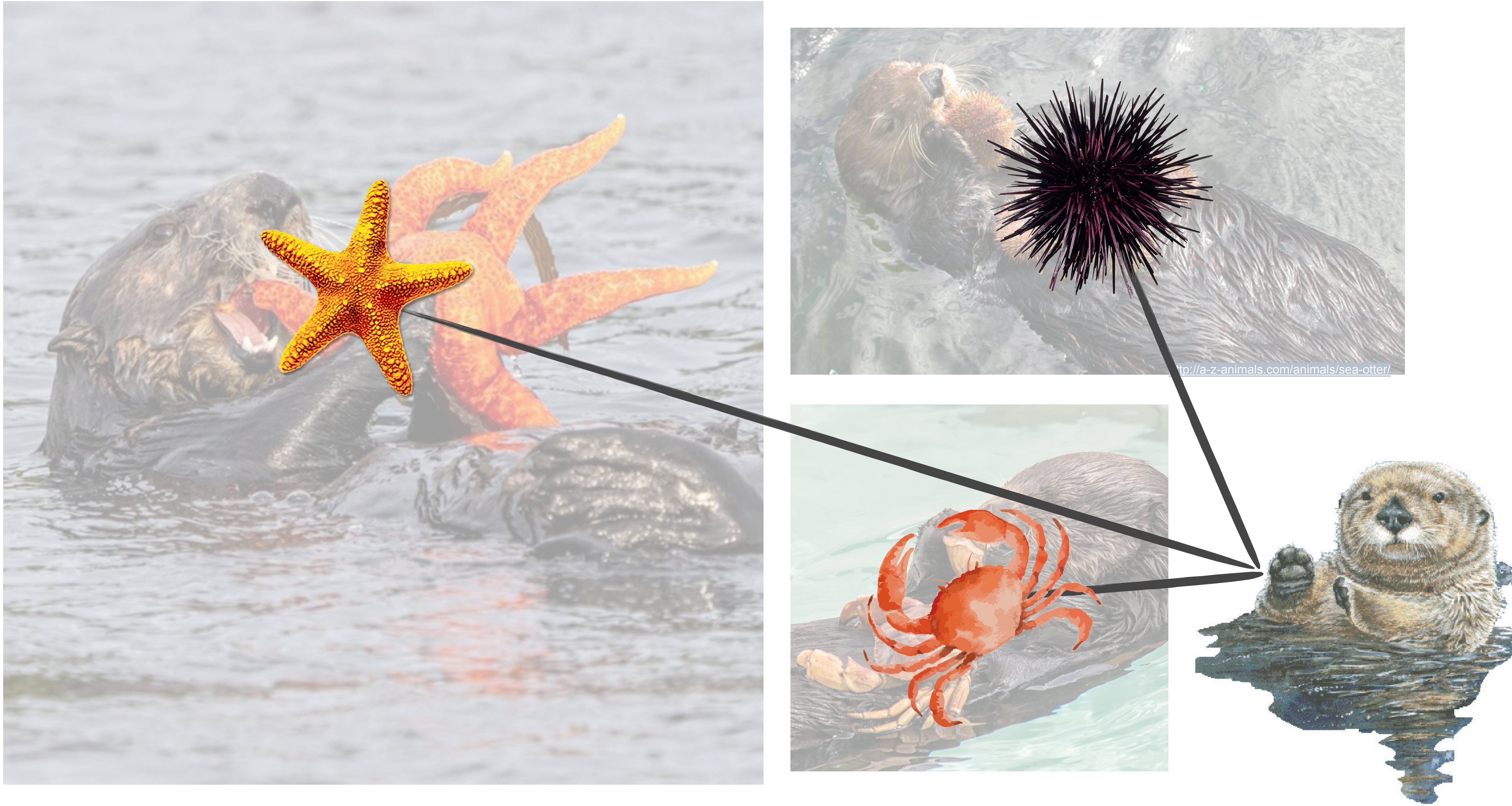
Marilia Palumbo Gaiarsa

Ecological Networks, March | 2022




http://a-z-animals.com/animals/sea-otter/


http://a-z-animals.com/animals/sea-otter/


tp://a-z-animals.com/animals/sea-otter/

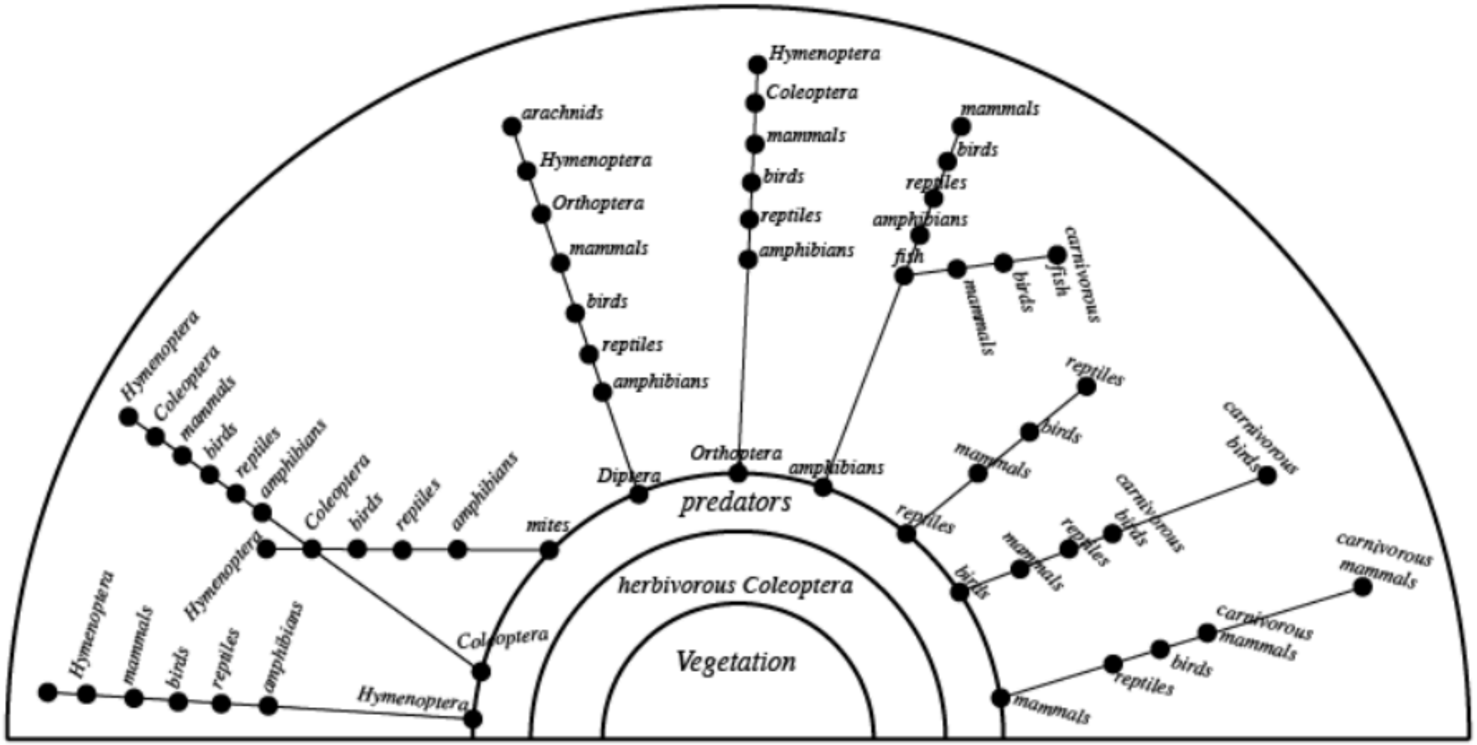


Figure 1. Simplified reproduction of the first food web reported in the literature (Camerano, 1880). The food web originally included more links (e.g. parasites) but was simplified for readability.

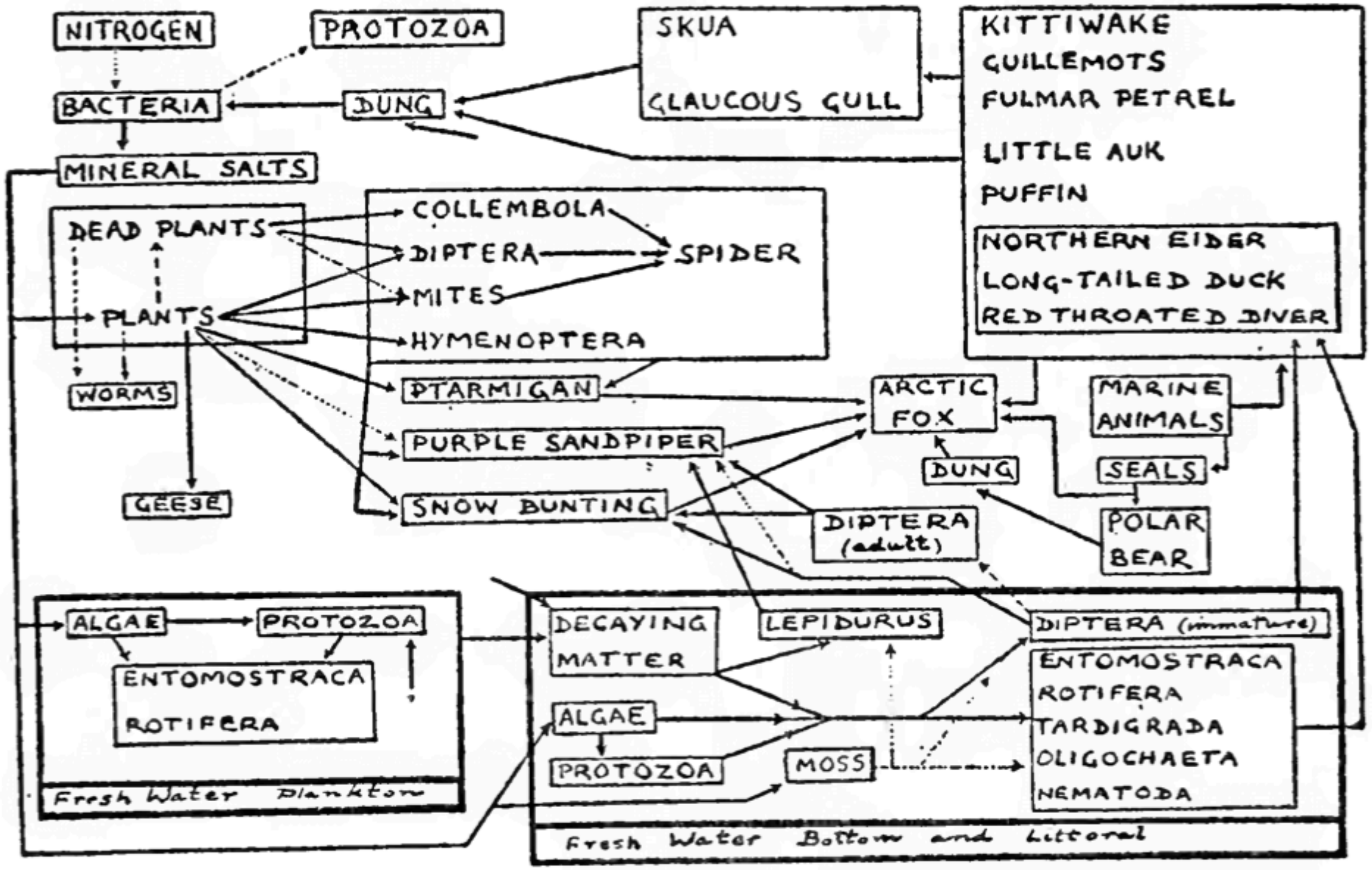


FIG. 4.—Food-cycle among the animals on Bear Island, a barren spot in the arctic zone, south of Spitsbergen. (The dotted lines represent probable food relations not yet proved.) The best way to read the diagram is to start at "marine animals" and follow the arrows. (From Summerhayes and Elton.[25])

Elton, 1927

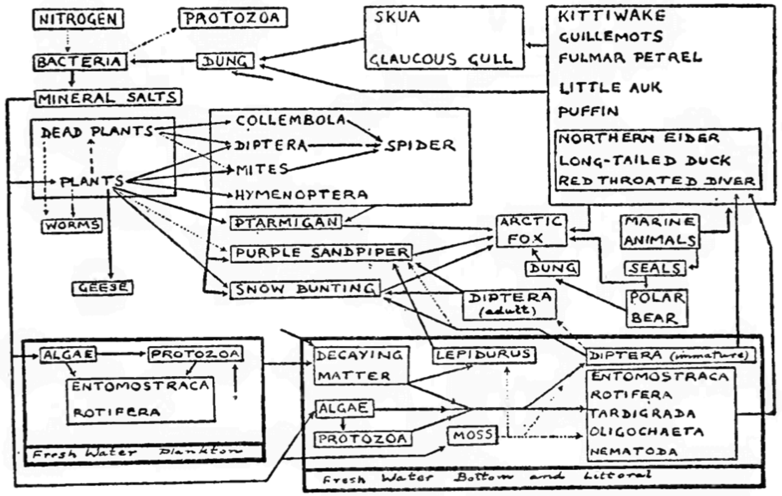
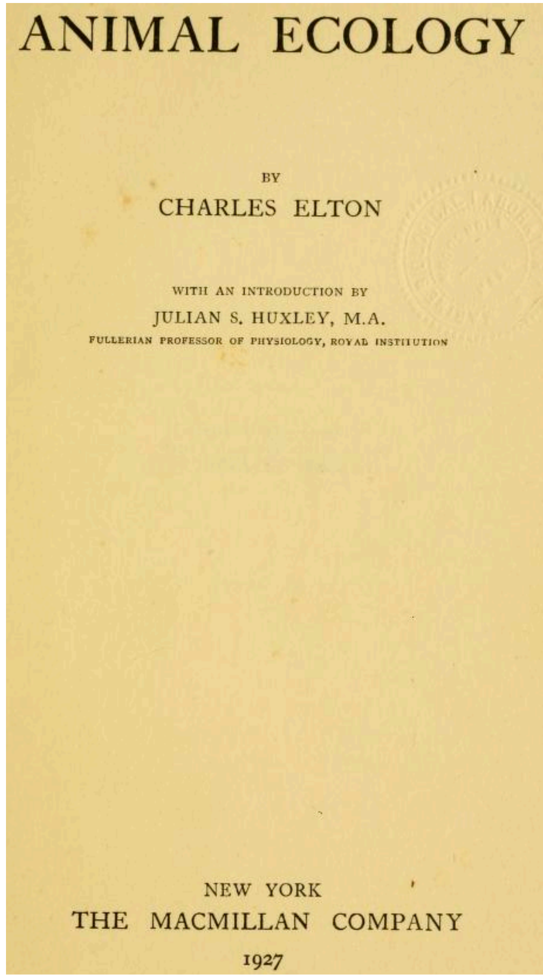


FIG. 4.—Food-cycle among the animals on Bear Island, a barren spot in the arctic zone, south of Spitsbergen. (The dotted lines represent probable food relations not yet proved.) The best way to read the diagram is to start at "marine animals" and follow the arrows. (From Summerhayes and Elton.[25])



ANIMAL ECOLOGY

BY

CHARLES ELTON

WITH AN INTRODUCTION BY

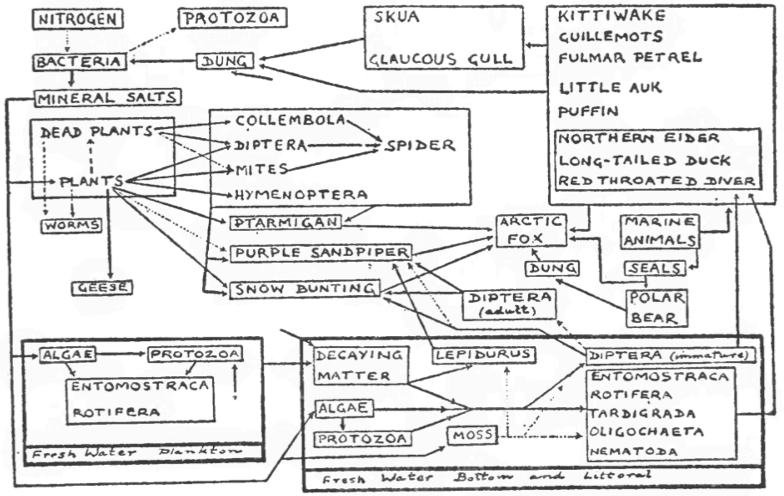
JULIAN S. HUXLEY, M.A.

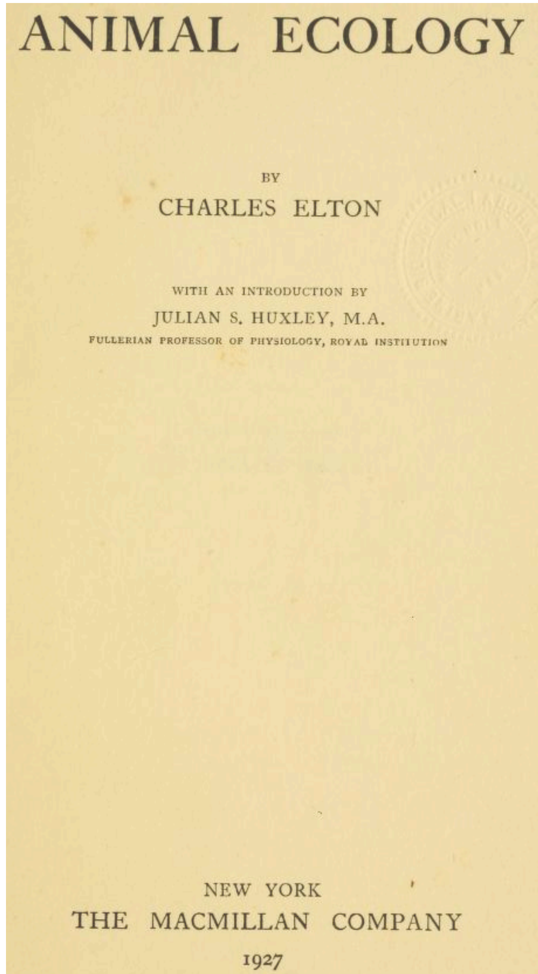
FULLERIAN PROFESSOR OF PHYSIOLOGY, ROYAL INSTITUTION

NEW YORK

THE MACMILLAN COMPANY

1927




ANIMAL ECOLOGY

BY

CHARLES ELTON

WITH AN INTRODUCTION BY

JULIAN S. HUXLEY, M.A.

FULLERIAN PROFESSOR OF PHYSIOLOGY, ROYAL INSTITUTION

NEW YORK

THE MACMILLAN COMPANY

1927

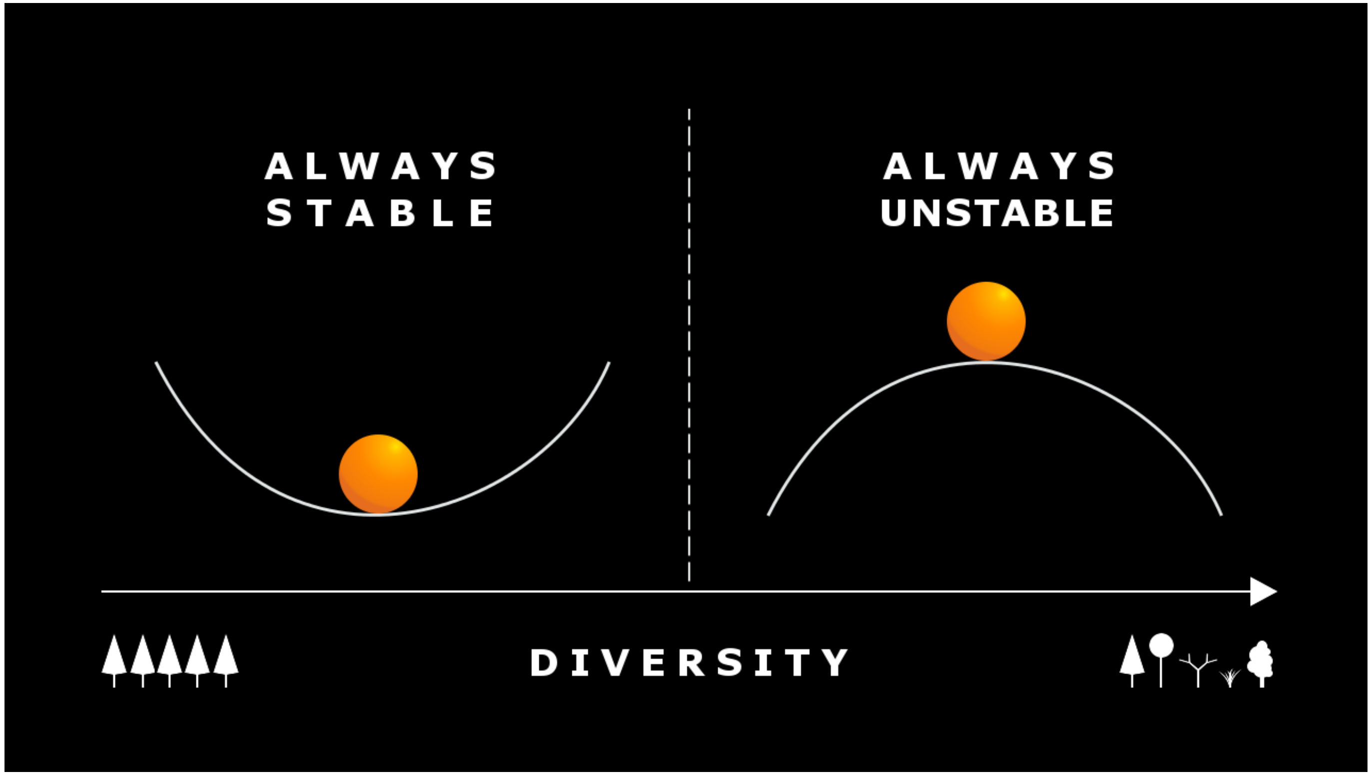
"It is a very long haul from handling a small group of four species like the lemon tree, the nightshade, the black scale, and a chalcid parasite, to the contemplation of the almost inconceivable and profuse richness of a tropical rain forest […].

It is a question for future research, but an urgent one, how far one has to carry complexity in order to achieve any sort of equilibrium."

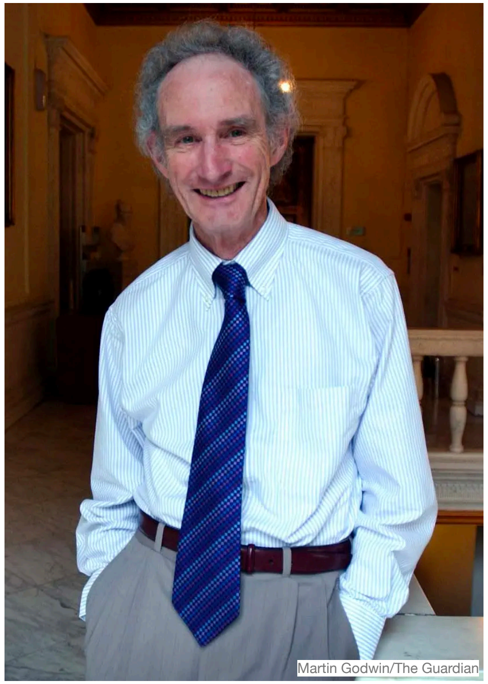
Charles Elton

Ecology of Invasions by Animals and Plants, 1958

The stability x complexity debate



The stability x complexity debate



a food web is stable if (May 1972):

interaction strength

number of species

$$\alpha < (n\ C)^{-\frac{1}{2}}$$

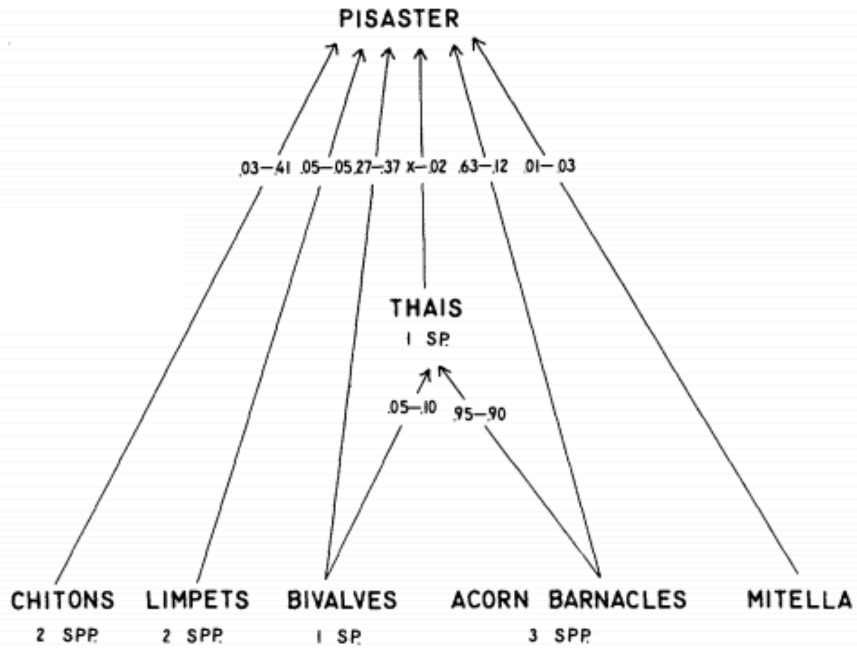
Connectance

Vol. 100, No. 910 The American Naturalist January–February, 1966

FOOD WEB COMPLEXITY AND SPECIES DIVERSITY

ROBERT T. PAINE

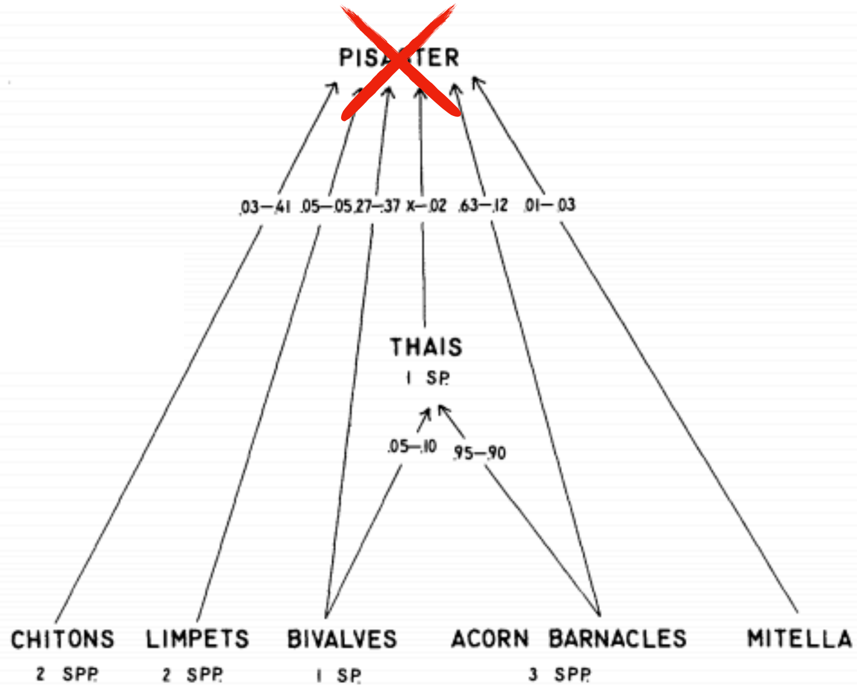
Department of Zoology, University of Washington, Seattle, Washington

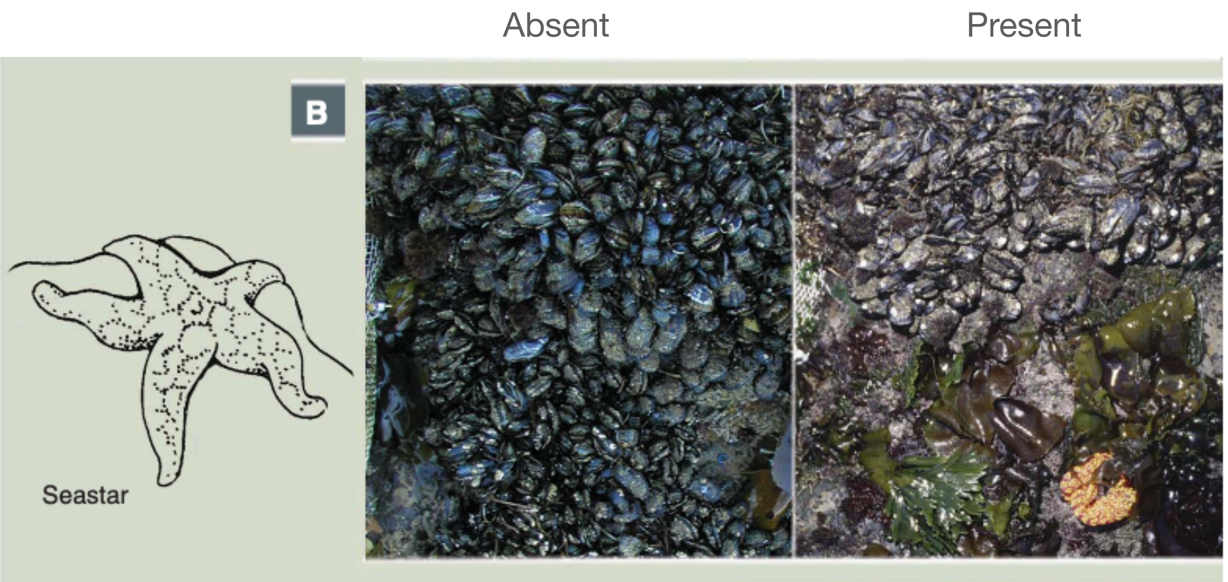


Vol. 100, No. 910 The American Naturalist January–February, 1966

FOOD WEB COMPLEXITY AND SPECIES DIVERSITY

ROBERT T. PAINE
Department of Zoology, University of Washington, Seattle, Washington



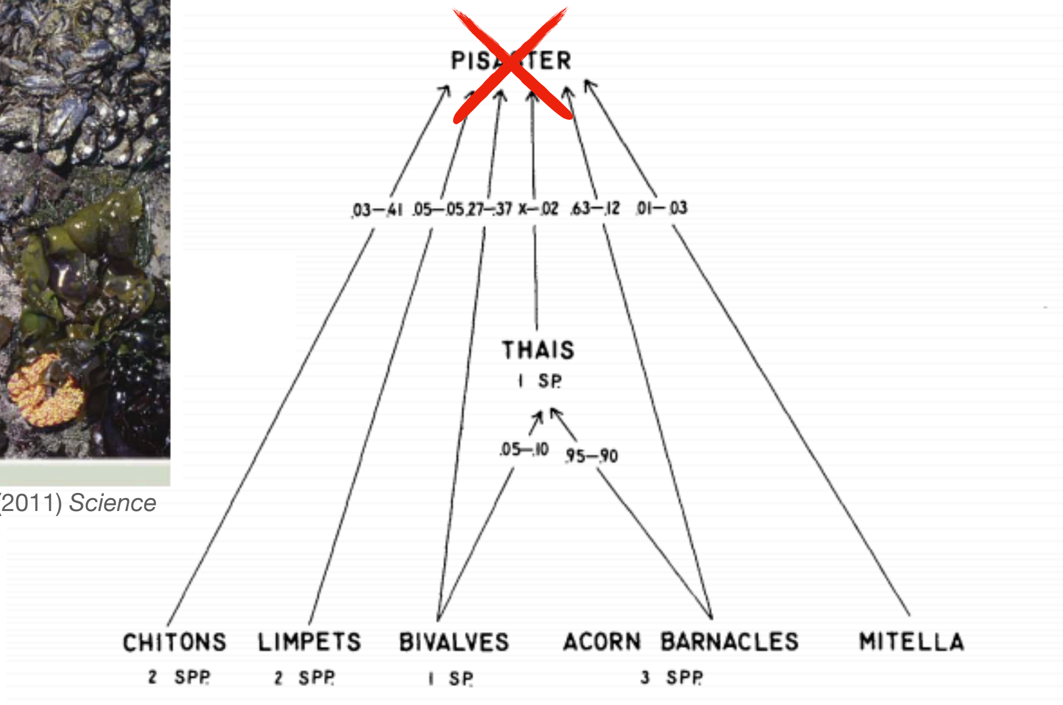


Estes *et al.* (2011) *Science*

Vol. 100, No. 910 The American Naturalist January–February, 1966

FOOD WEB COMPLEXITY AND SPECIES DIVERSITY

ROBERT T. PAINE
Department of Zoology, University of Washington, Seattle, Washington

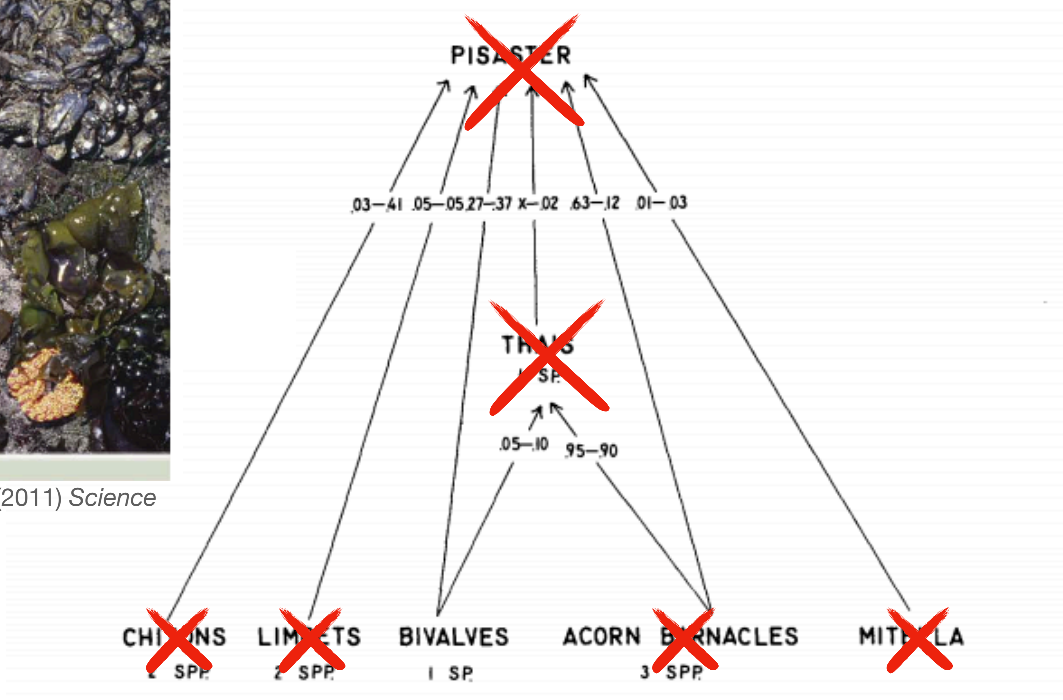


Estes *et al.* (2011) *Science*

Vol. 100, No. 910 The American Naturalist January–February, 1966

FOOD WEB COMPLEXITY AND SPECIES DIVERSITY

ROBERT T. PAINE
Department of Zoology, University of Washington, Seattle, Washington



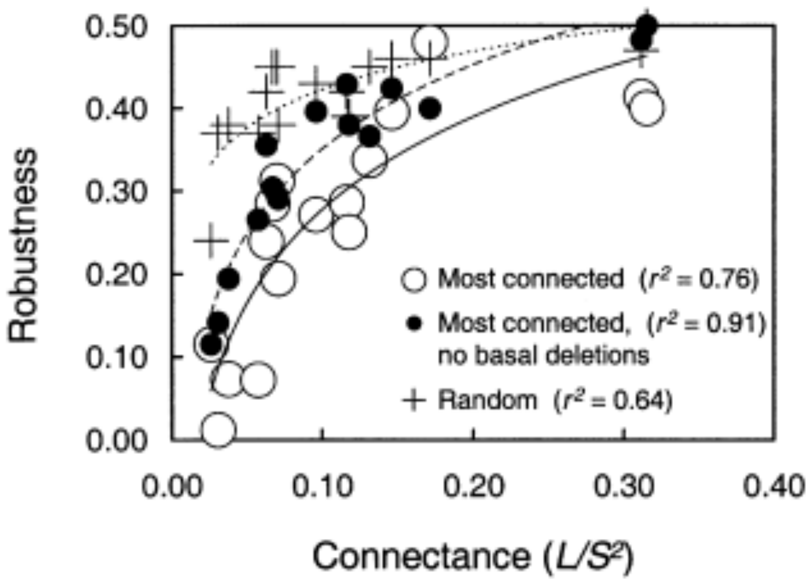
Keystone species

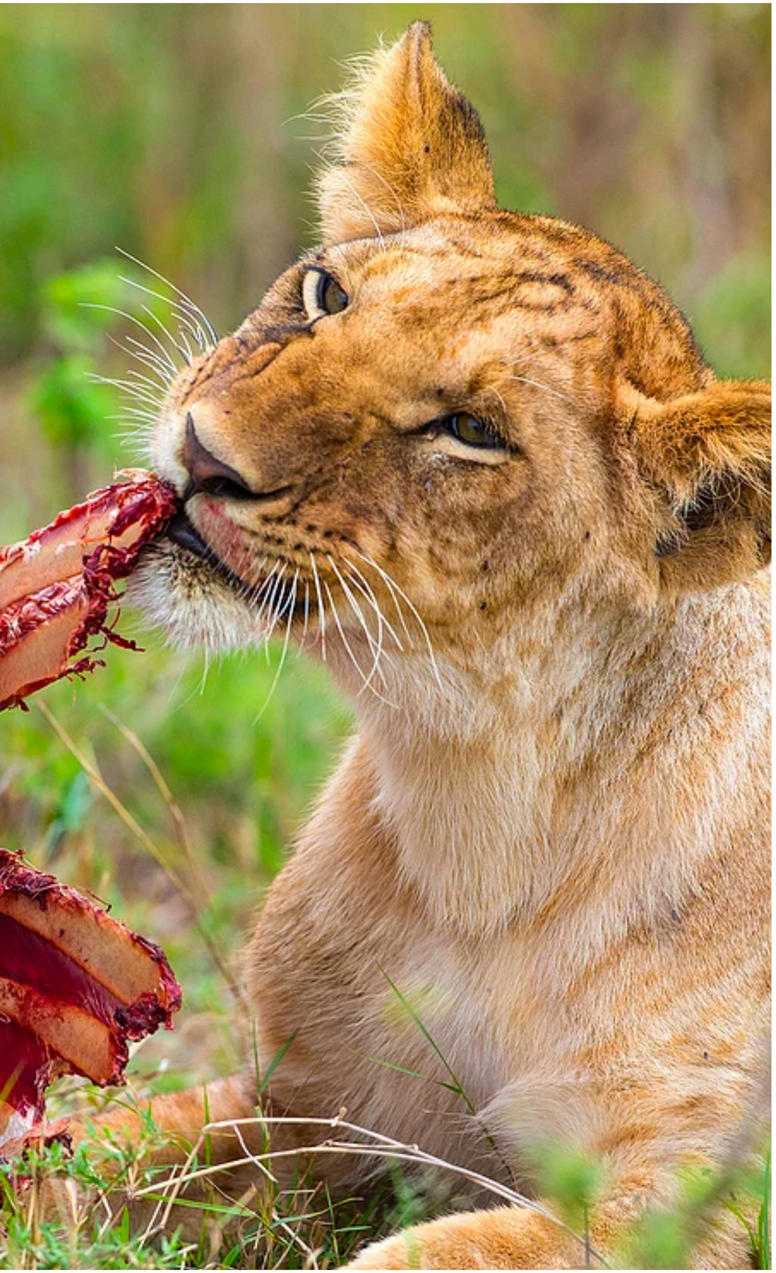
Full Access

Network structure and biodiversity loss in food webs: robustness increases with connectance

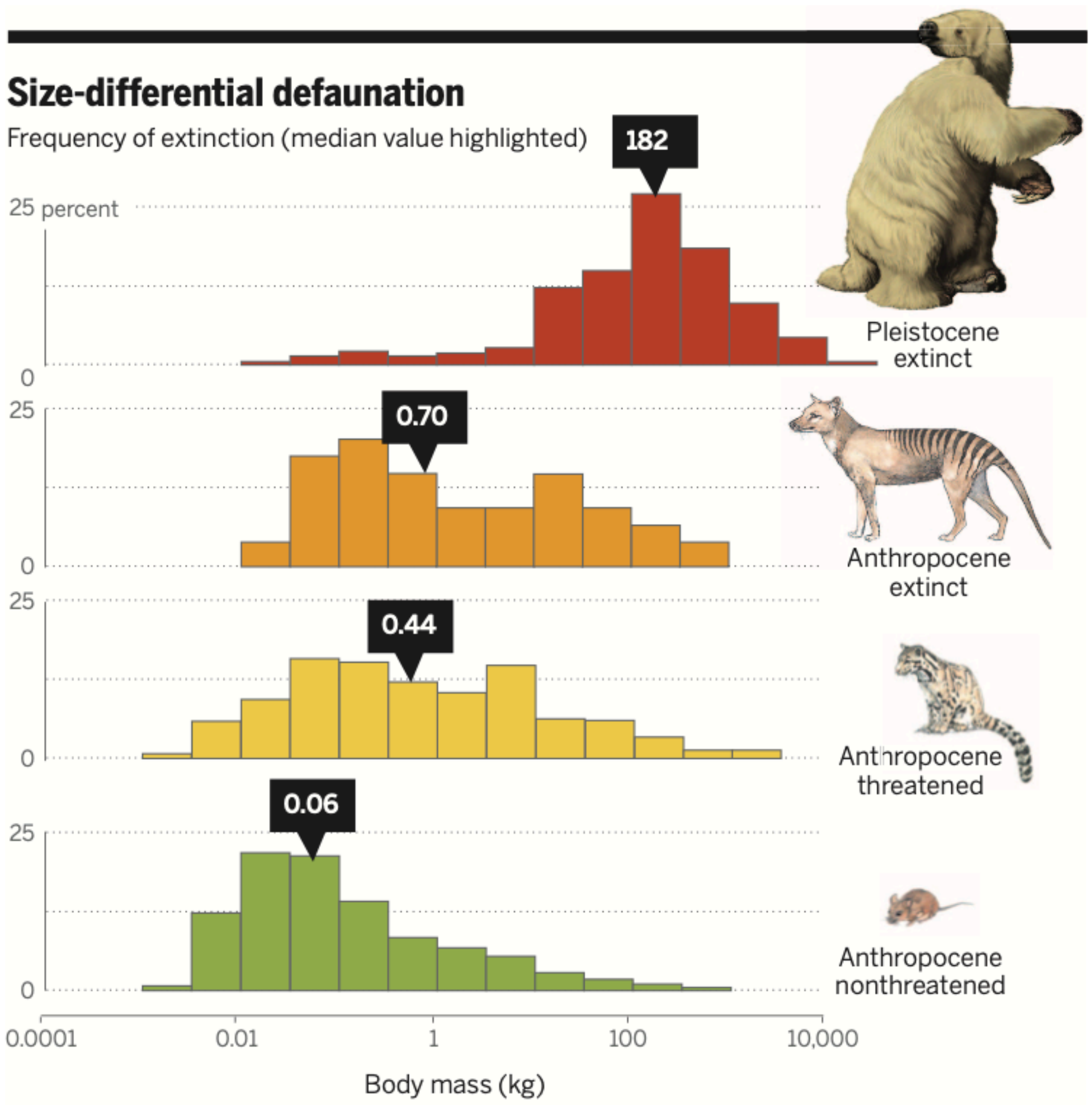
Jennifer A. Dunne, Richard J. Williams, Neo D. Martinez

First published: 10 July 2002 | https://doi.org/10.1046/j.1461-0248.2002.00354.x | Citations: 833



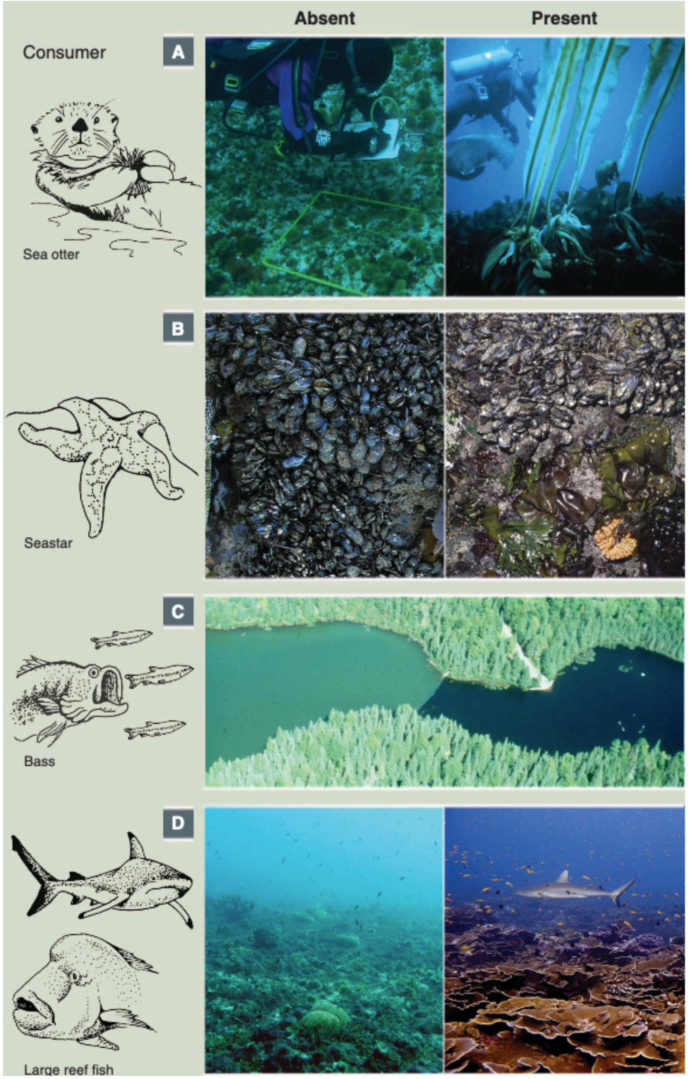


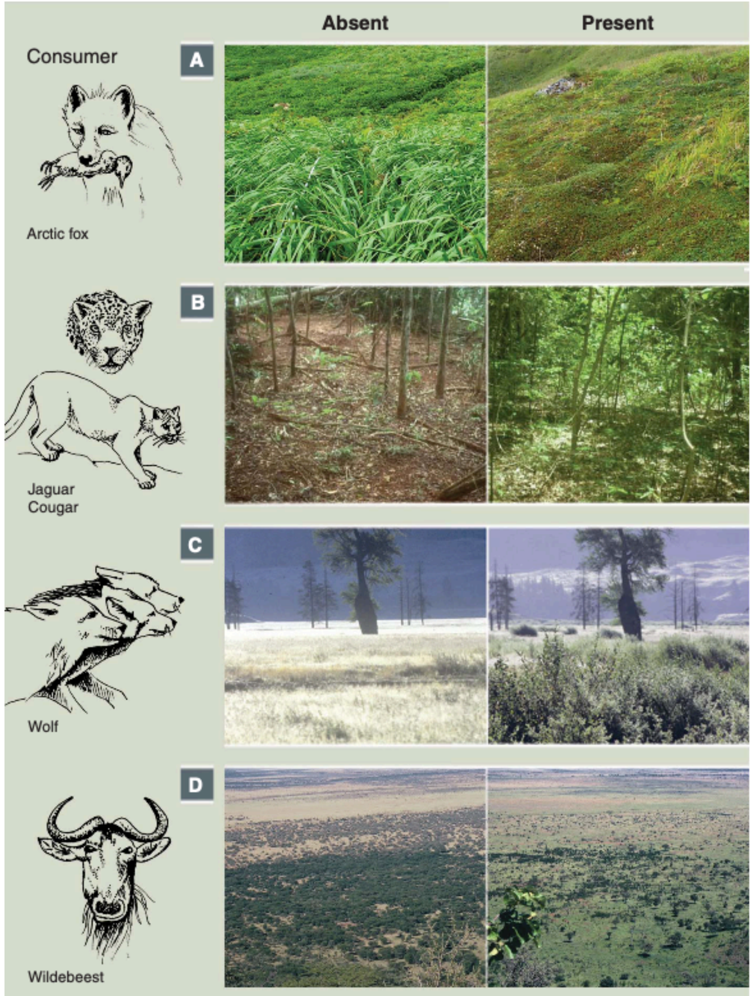

João Paulo Krajewski



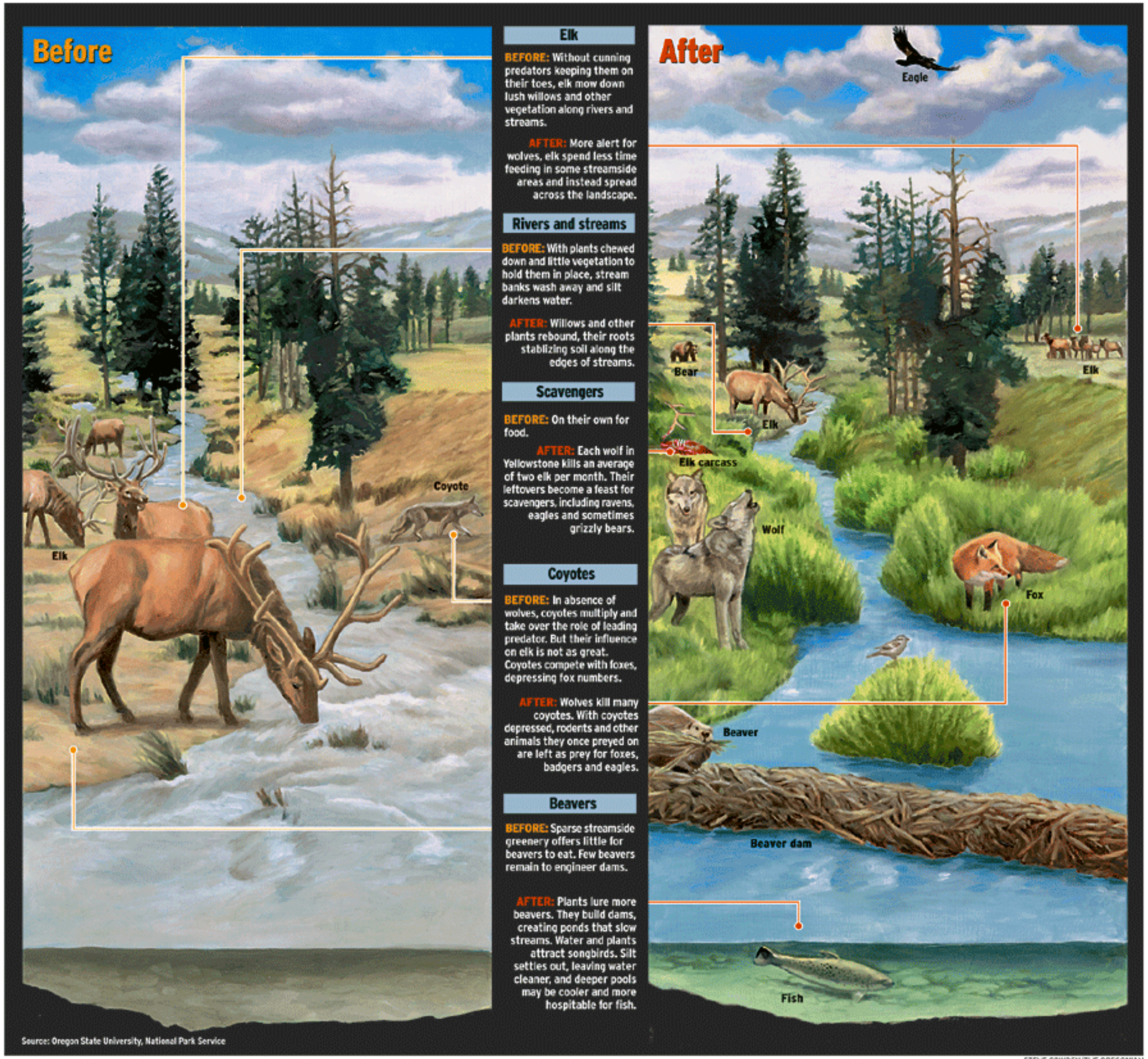
Dirzo *et al.* (2014) *Science*

Trophic downgrading of Planet Earth

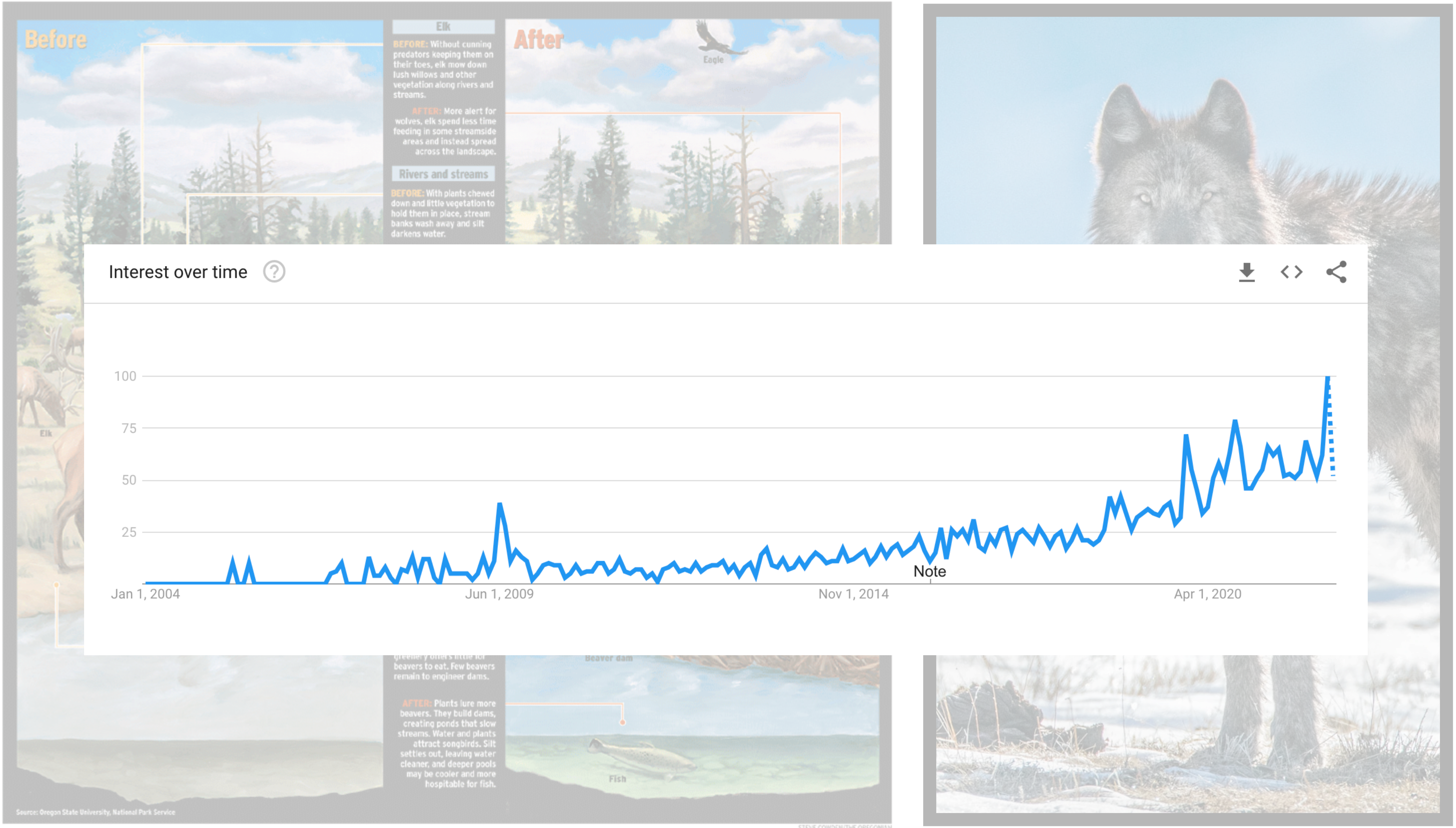




Estes *et al.* (2011) *Science*



STEVE COWDEN/THE OREGONIAN

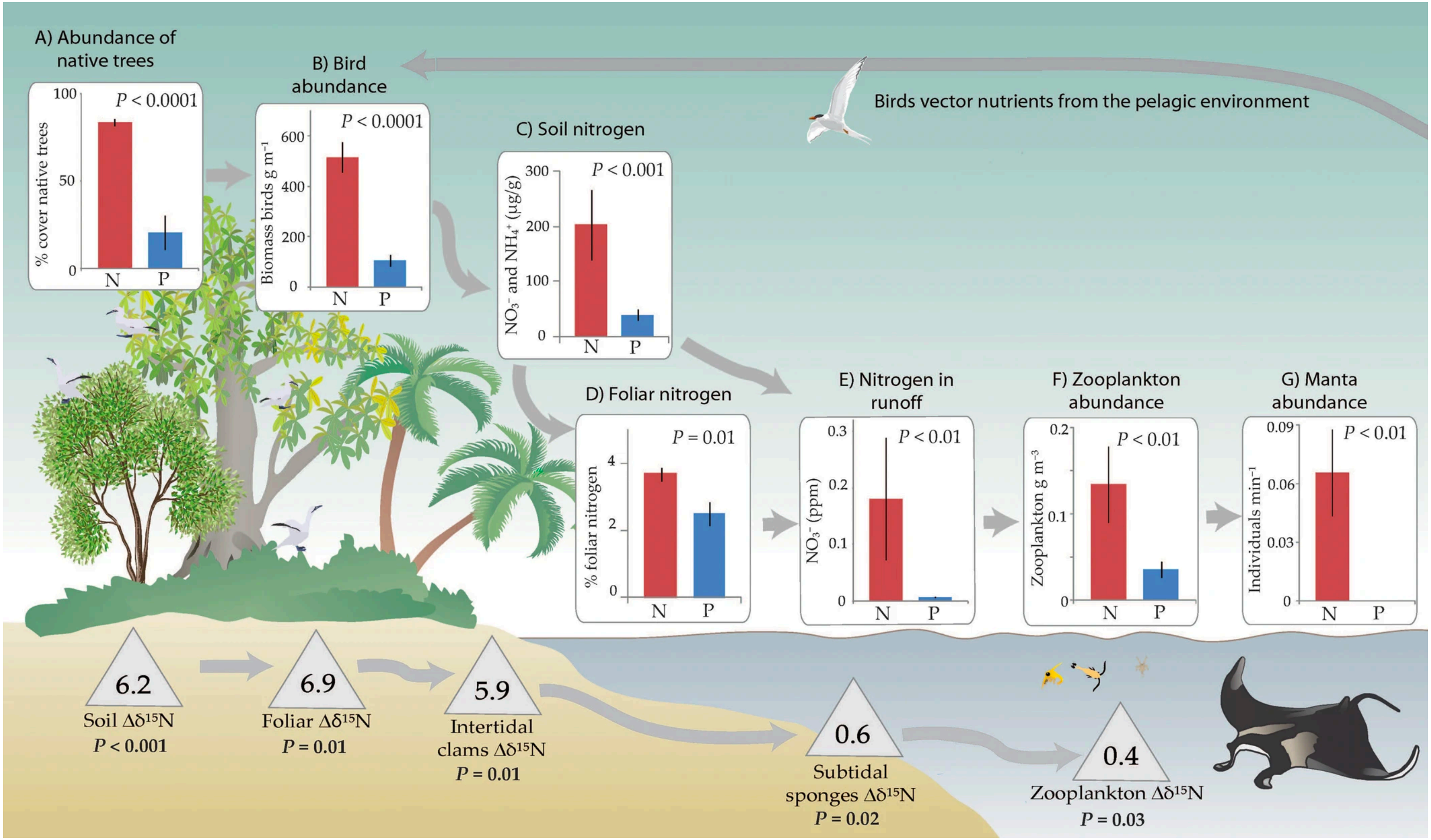

Before
Elk
BEFORE: Without cunning predators keeping them on their toes, elk mow down lush willows and other vegetation along rivers and streams.
AFTER: More alert for wolves, elk spend less time feeding in some streamside areas and instead spread across the landscape.
Rivers and streams
BEFORE: With plants chewed down and little vegetation to hold them in place, stream banks wash away and silt darkens water.
After
Eagle
Elk
beavers to eat. Few beavers remain to engineer dams.
AFTER: Plants lure more beavers. They build dams, creating ponds that slow streams. Water and plants attract songbirds. Silt settles out, leaving water cleaner, and deeper pools may be cooler and more hospitable for fish.
Beaver dam
Fish
Source: Oregon State University, National Park Service
STEVE COWDEN/THE OREGONIAN
Interest over time
100
75
50
25
Note
Jan 1, 2004
Jun 1, 2009
Nov 1, 2014
Apr 1, 2020

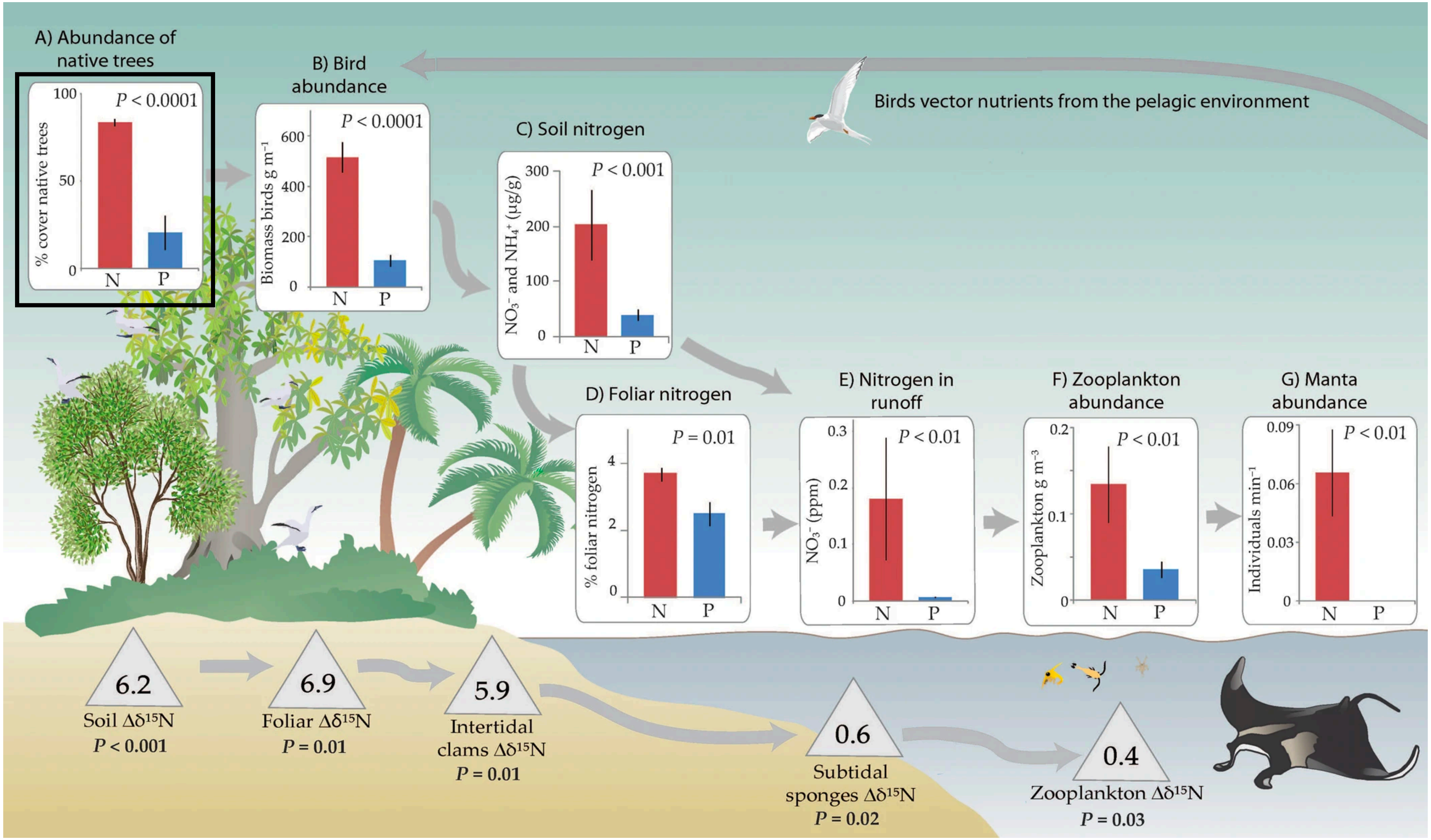
From wing to wing: the persistence of long ecological interaction chains in less-disturbed ecosystems

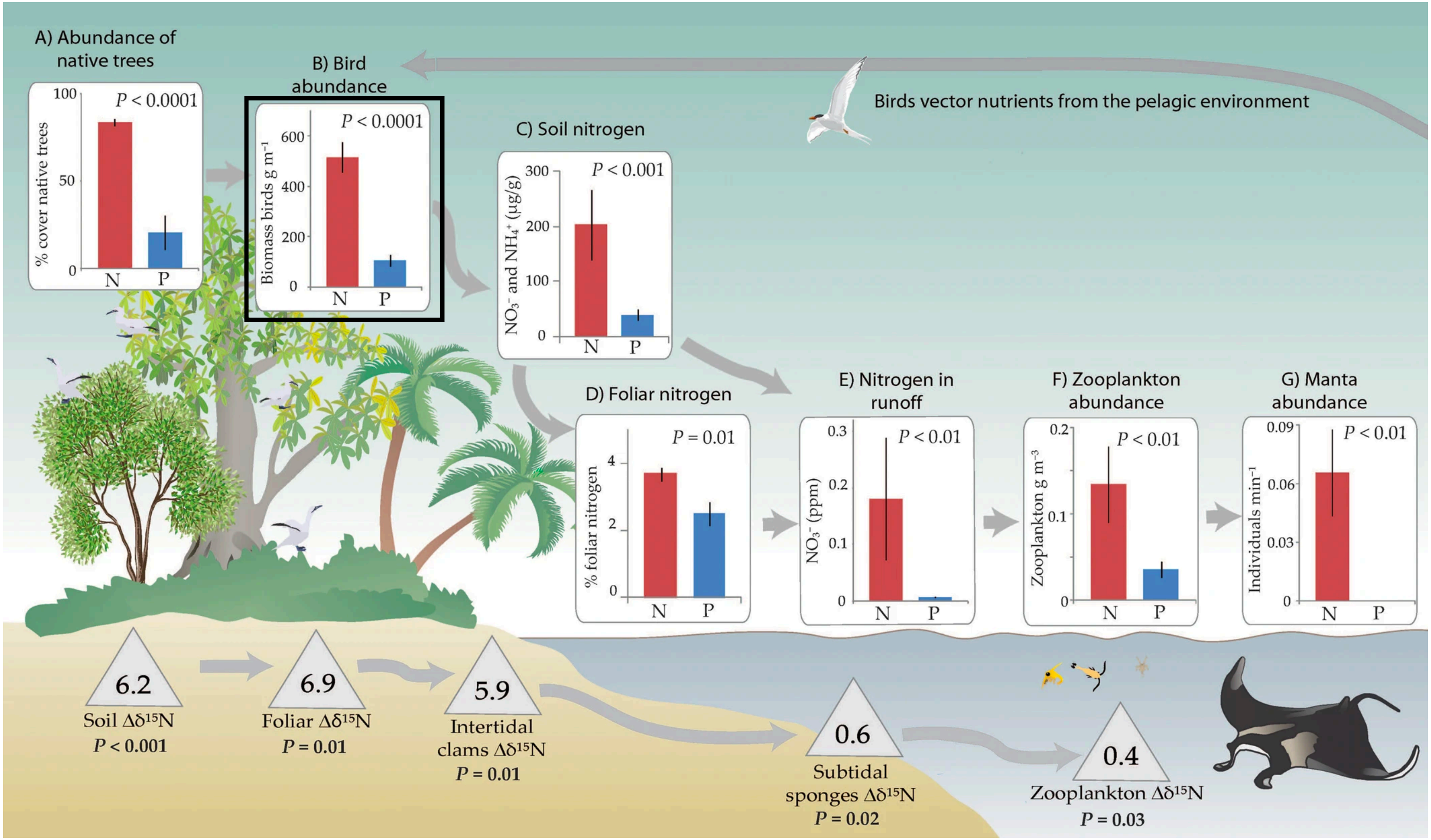
Douglas J. McCauley, Paul A. DeSalles, Hillary S. Young, Robert B. Dunbar, Rodolfo Dirzo, Matthew M. Mills
& Fiorenza Micheli

Scientific Reports **2**, Article number: 409 (2012) | Cite this article

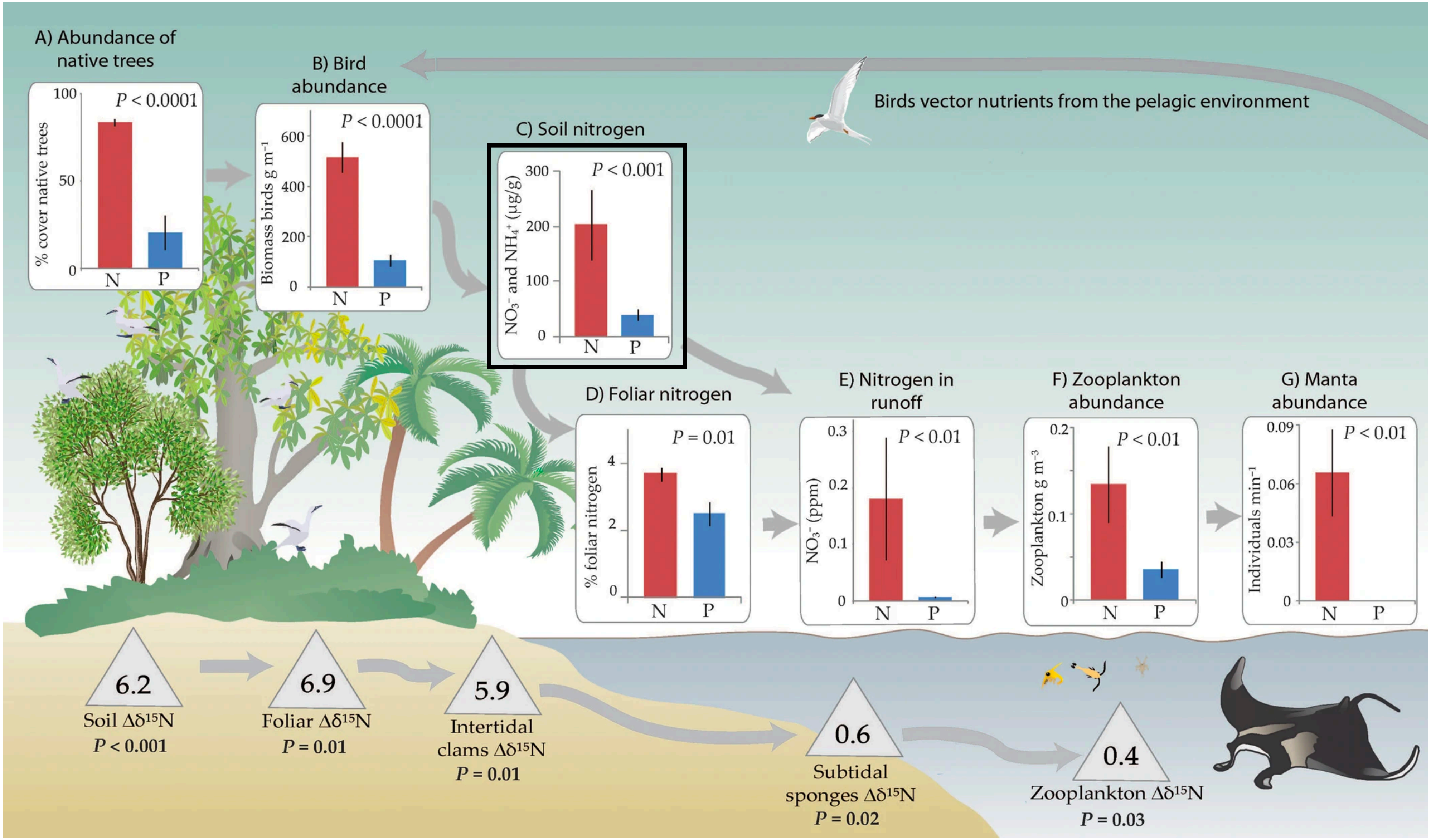
2505 Accesses | **59** Citations | **42** Altmetric | Metrics

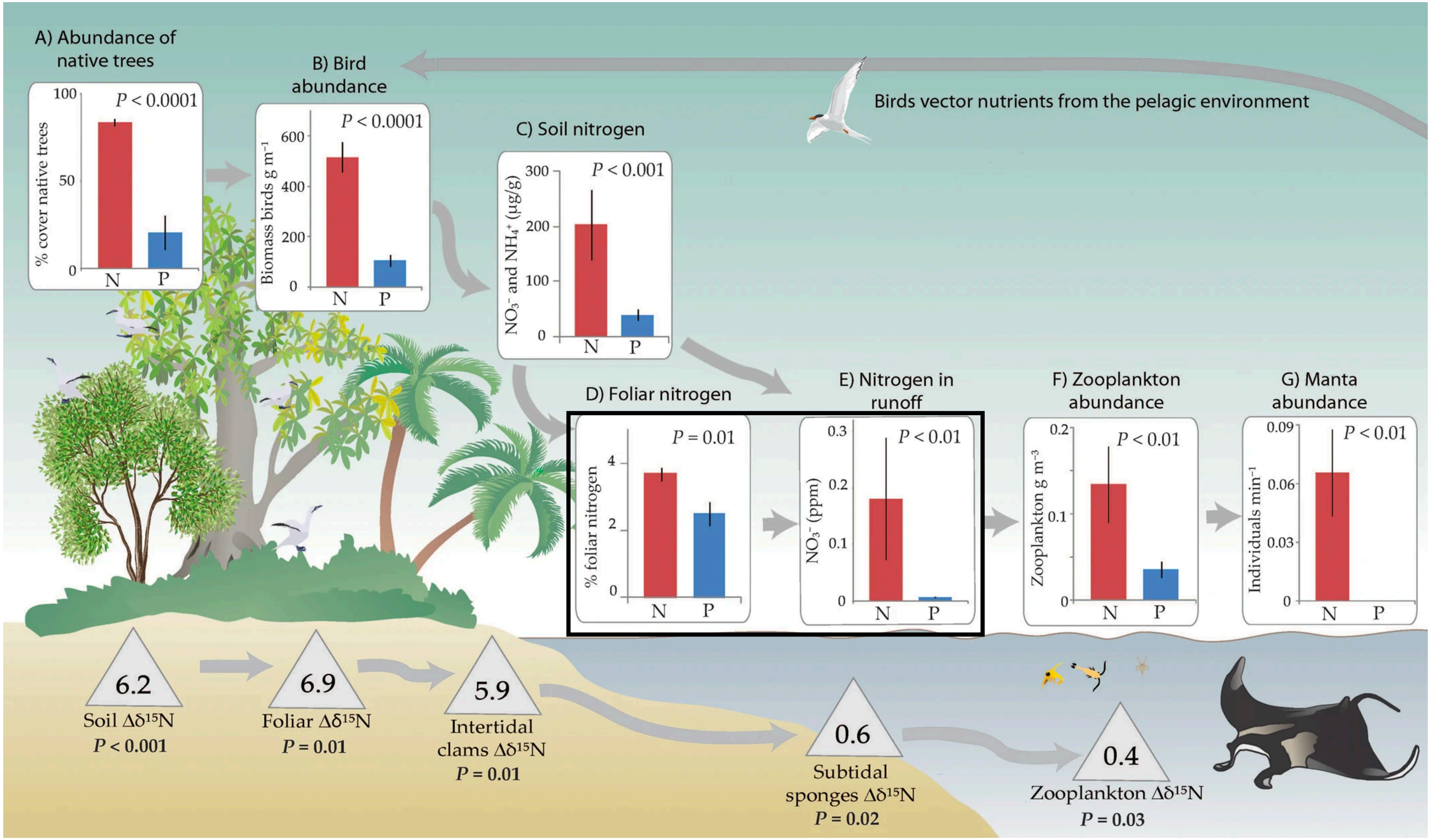

A) Abundance of native trees
P < 0.0001
% cover native trees
100
50
0
N
P
B) Bird abundance
P < 0.0001
Biomass birds g m⁻¹
600
400
200
0
N
P
Birds vector nutrients from the pelagic environment
C) Soil nitrogen
P < 0.001
NO₃⁻ and NH₄⁺ (µg/g)
300
200
100
0
N
P
D) Foliar nitrogen
P = 0.01
% foliar nitrogen
4
2
0
N
P
E) Nitrogen in runoff
P < 0.01
NO₃⁻ (ppm)
0.3
0.2
0.1
0
N
P
F) Zooplankton abundance
P < 0.01
Zooplankton g m⁻³
0.2
0.1
0
N
P
G) Manta abundance
P < 0.01
Individuals min⁻¹
0.09
0.06
0.03
0
N
P
6.2
Soil Δδ15N
P < 0.001
6.9
Foliar Δδ15N
P = 0.01
5.9
Intertidal clams Δδ15N
P = 0.01
0.6
Subtidal sponges Δδ15N
P = 0.02
0.4
Zooplankton Δδ15N
P = 0.03


A) Abundance of native trees
% cover native trees
100
50
0
P < 0.0001
N
P
B) Bird abundance
Biomass birds g m⁻¹
600
400
200
0
P < 0.0001
N
P
Birds vector nutrients from the pelagic environment
C) Soil nitrogen
NO₃⁻ and NH₄⁺ (µg/g)
300
200
100
0
P < 0.001
N
P
D) Foliar nitrogen
% foliar nitrogen
4
2
0
P = 0.01
N
P
E) Nitrogen in runoff
NO₃⁻ (ppm)
0.3
0.2
0.1
0
P < 0.01
N
P
F) Zooplankton abundance
Zooplankton g m⁻³
0.2
0.1
0
P < 0.01
N
P
G) Manta abundance
Individuals min⁻¹
0.09
0.06
0.03
0
P < 0.01
N
P
6.2
Soil Δδ¹⁵N
P < 0.001
6.9
Foliar Δδ¹⁵N
P = 0.01
5.9
Intertidal clams Δδ¹⁵N
P = 0.01
0.6
Subtidal sponges Δδ¹⁵N
P = 0.02
0.4
Zooplankton Δδ¹⁵N
P = 0.03

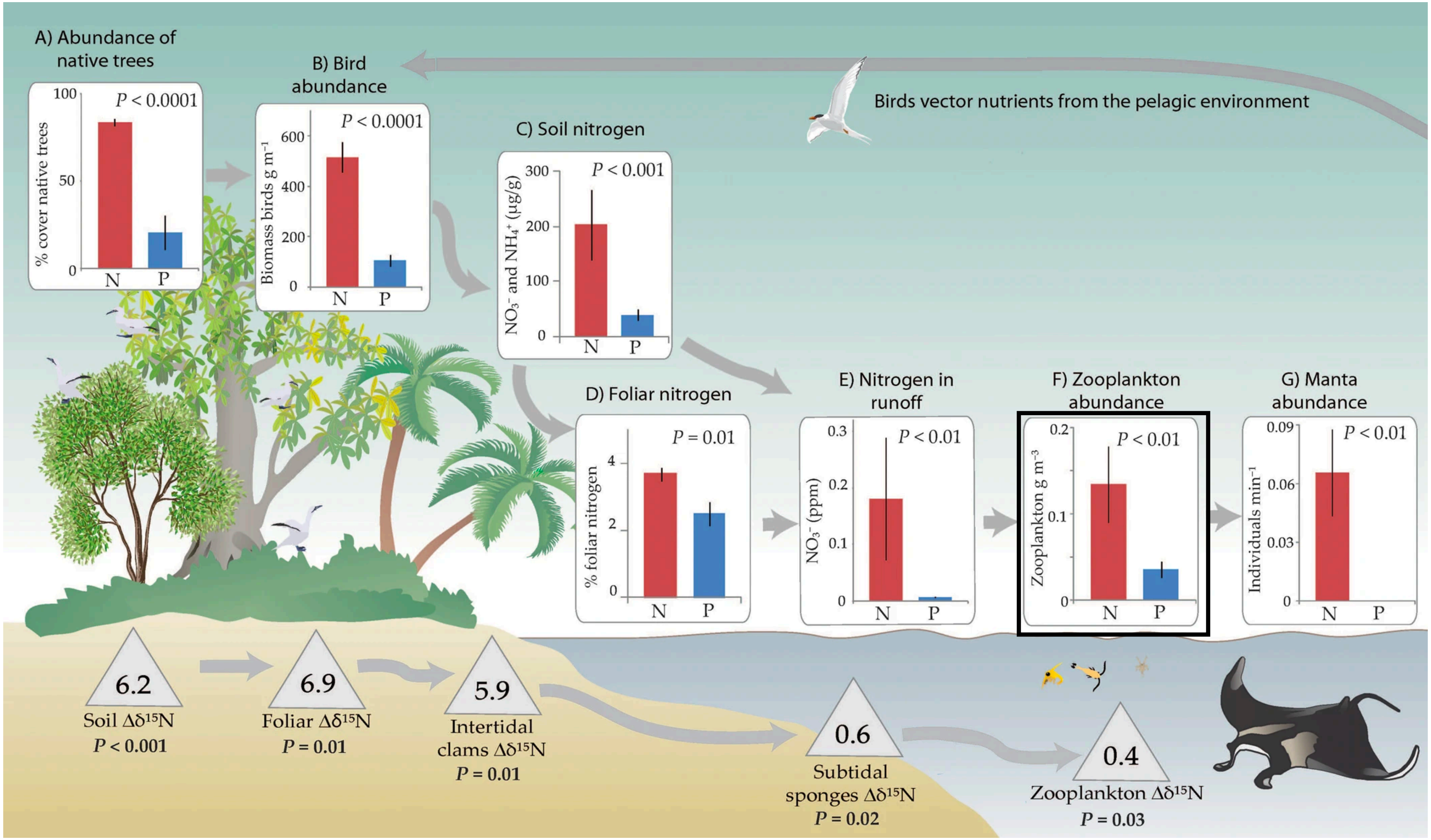


A) Abundance of native trees
% cover native trees
P < 0.0001
B) Bird abundance
Biomass birds g m⁻¹
P < 0.0001
Birds vector nutrients from the pelagic environment
C) Soil nitrogen
NO3⁻ and NH4⁺ (µg/g)
P < 0.001
D) Foliar nitrogen
% foliar nitrogen
P = 0.01
E) Nitrogen in runoff
NO3⁻ (ppm)
P < 0.01
F) Zooplankton abundance
Zooplankton g m⁻³
P < 0.01
G) Manta abundance
Individuals min⁻¹
P < 0.01
N
P
6.2
Soil Δδ15N
P < 0.001
6.9
Foliar Δδ15N
P = 0.01
5.9
Intertidal clams Δδ15N
P = 0.01
0.6
Subtidal sponges Δδ15N
P = 0.02
0.4
Zooplankton Δδ15N
P = 0.03

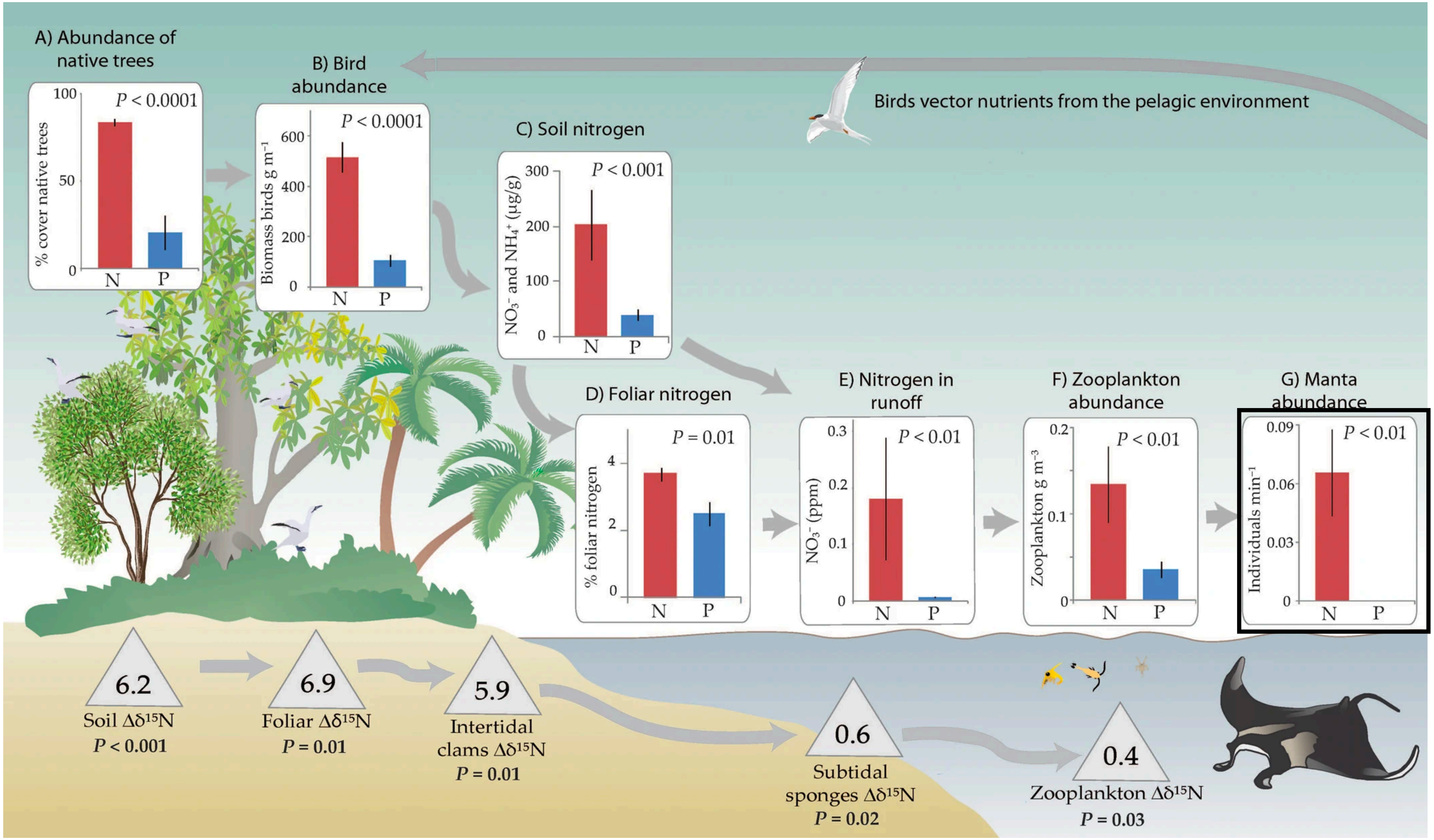

A) Abundance of native trees
% cover native trees
100
50
0
P < 0.0001
N
P
B) Bird abundance
Biomass birds g m⁻¹
600
400
200
0
P < 0.0001
N
P
C) Soil nitrogen
NO3⁻ and NH4⁺ (µg/g)
300
200
100
0
P < 0.001
N
P
Birds vector nutrients from the pelagic environment
D) Foliar nitrogen
% foliar nitrogen
4
2
0
P = 0.01
N
P
E) Nitrogen in runoff
NO3⁻ (ppm)
0.3
0.2
0.1
0
P < 0.01
N
P
F) Zooplankton abundance
Zooplankton g m⁻³
0.2
0.1
0
P < 0.01
N
P
G) Manta abundance
Individuals min⁻¹
0.09
0.06
0.03
0
P < 0.01
N
P
6.2
Soil Δδ15N
P < 0.001
6.9
Foliar Δδ15N
P = 0.01
5.9
Intertidal clams Δδ15N
P = 0.01
0.6
Subtidal sponges Δδ15N
P = 0.02
0.4
Zooplankton Δδ15N
P = 0.03



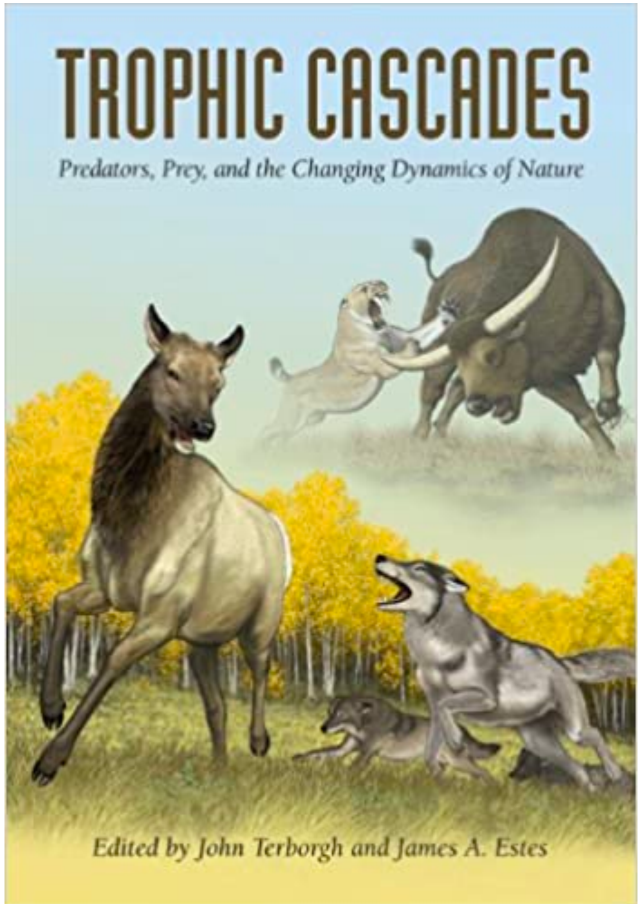
A) Abundance of native trees
% cover native trees
P < 0.0001
B) Bird abundance
Biomass birds g m⁻¹
P < 0.0001
C) Soil nitrogen
NO3⁻ and NH4⁺ (µg/g)
P < 0.001
Birds vector nutrients from the pelagic environment
D) Foliar nitrogen
% foliar nitrogen
P = 0.01
E) Nitrogen in runoff
NO3⁻ (ppm)
P < 0.01
F) Zooplankton abundance
Zooplankton g m⁻³
P < 0.01
G) Manta abundance
Individuals min⁻¹
P < 0.01
N
P
6.2
Soil Δδ15N
P < 0.001
6.9
Foliar Δδ15N
P = 0.01
5.9
Intertidal clams Δδ15N
P = 0.01
0.6
Subtidal sponges Δδ15N
P = 0.02
0.4
Zooplankton Δδ15N
P = 0.03

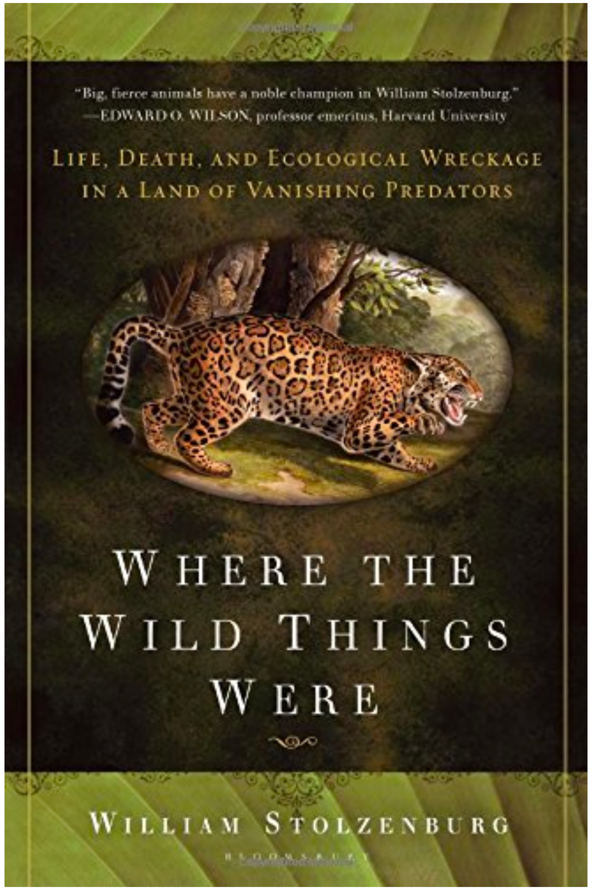


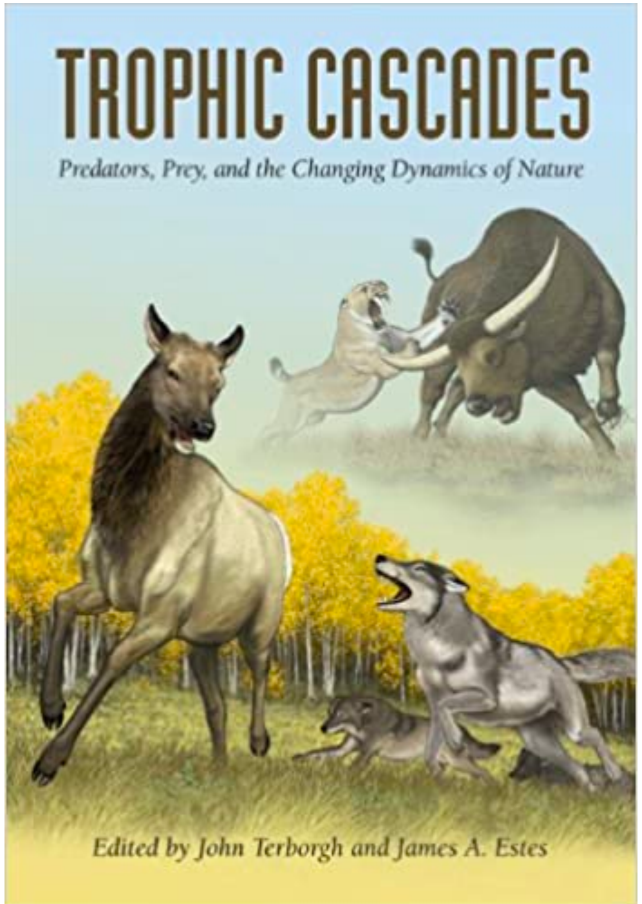
A) Abundance of native trees
% cover native trees
100
50
0
$P < 0.0001$
N
P
B) Bird abundance
Biomass birds g m^{-1}
600
400
200
0
$P < 0.0001$
N
P
C) Soil nitrogen
NO_3^- and NH_4^+ (µg/g)
300
200
100
0
$P < 0.001$
N
P
Birds vector nutrients from the pelagic environment
D) Foliar nitrogen
% foliar nitrogen
4
2
0
$P = 0.01$
N
P
E) Nitrogen in runoff
NO_3^- (ppm)
0.3
0.2
0.1
0
$P < 0.01$
N
P
F) Zooplankton abundance
Zooplankton g m^{-3}
0.2
0.1
0
$P < 0.01$
N
P
G) Manta abundance
Individuals min^{-1}
0.09
0.06
0.03
0
$P < 0.01$
N
P
6.2
Soil Δδ15N
$P < 0.001$
6.9
Foliar Δδ15N
$P = 0.01$
5.9
Intertidal clams Δδ15N
$P = 0.01$
0.6
Subtidal sponges Δδ15N
$P = 0.02$
0.4
Zooplankton Δδ15N
$P = 0.03$

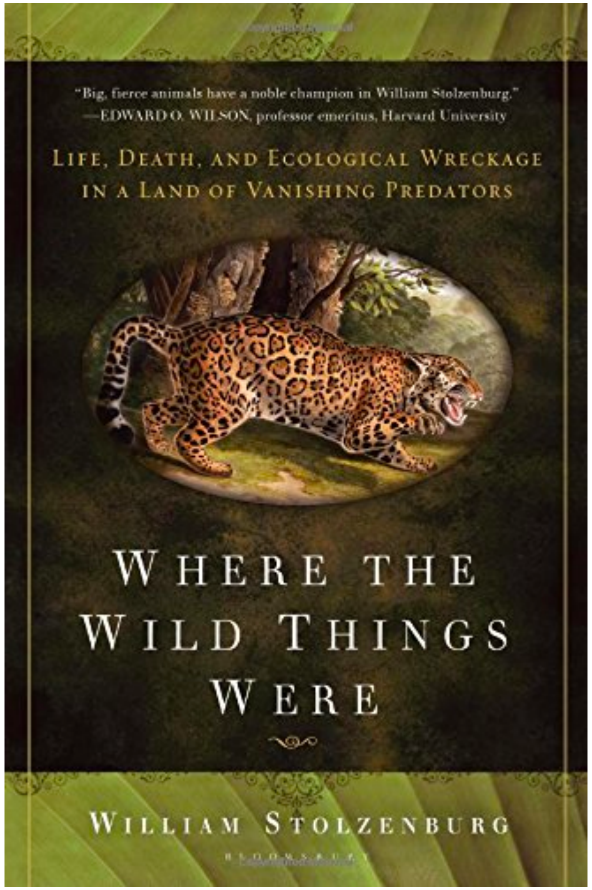

A) Abundance of native trees
P < 0.0001
% cover native trees
100
50
0
N
P
B) Bird abundance
P < 0.0001
Biomass birds g m−1
600
400
200
0
N
P
C) Soil nitrogen
P < 0.001
NO3− and NH4+ (µg/g)
300
200
100
0
N
P
Birds vector nutrients from the pelagic environment
D) Foliar nitrogen
P = 0.01
% foliar nitrogen
4
2
0
N
P
E) Nitrogen in runoff
P < 0.01
NO3− (ppm)
0.3
0.2
0.1
0
N
P
F) Zooplankton abundance
P < 0.01
Zooplankton g m−3
0.2
0.1
0
N
P
G) Manta abundance
P < 0.01
Individuals min−1
0.09
0.06
0.03
0
N
P
6.2
Soil Δδ15N
P < 0.001
6.9
Foliar Δδ15N
P = 0.01
5.9
Intertidal clams Δδ15N
P = 0.01
0.6
Subtidal sponges Δδ15N
P = 0.02
0.4
Zooplankton Δδ15N
P = 0.03




TROPHIC CASCADES
Predators, Prey, and the Changing Dynamics of Nature
Edited by John Terborgh and James A. Estes


"Big, fierce animals have a noble champion in William Stolzenburg."
—EDWARD O. WILSON, professor emeritus, Harvard University
LIFE, DEATH, AND ECOLOGICAL WRECKAGE IN A LAND OF VANISHING PREDATORS
WHERE THE WILD THINGS WERE
WILLIAM STOLZENBURG

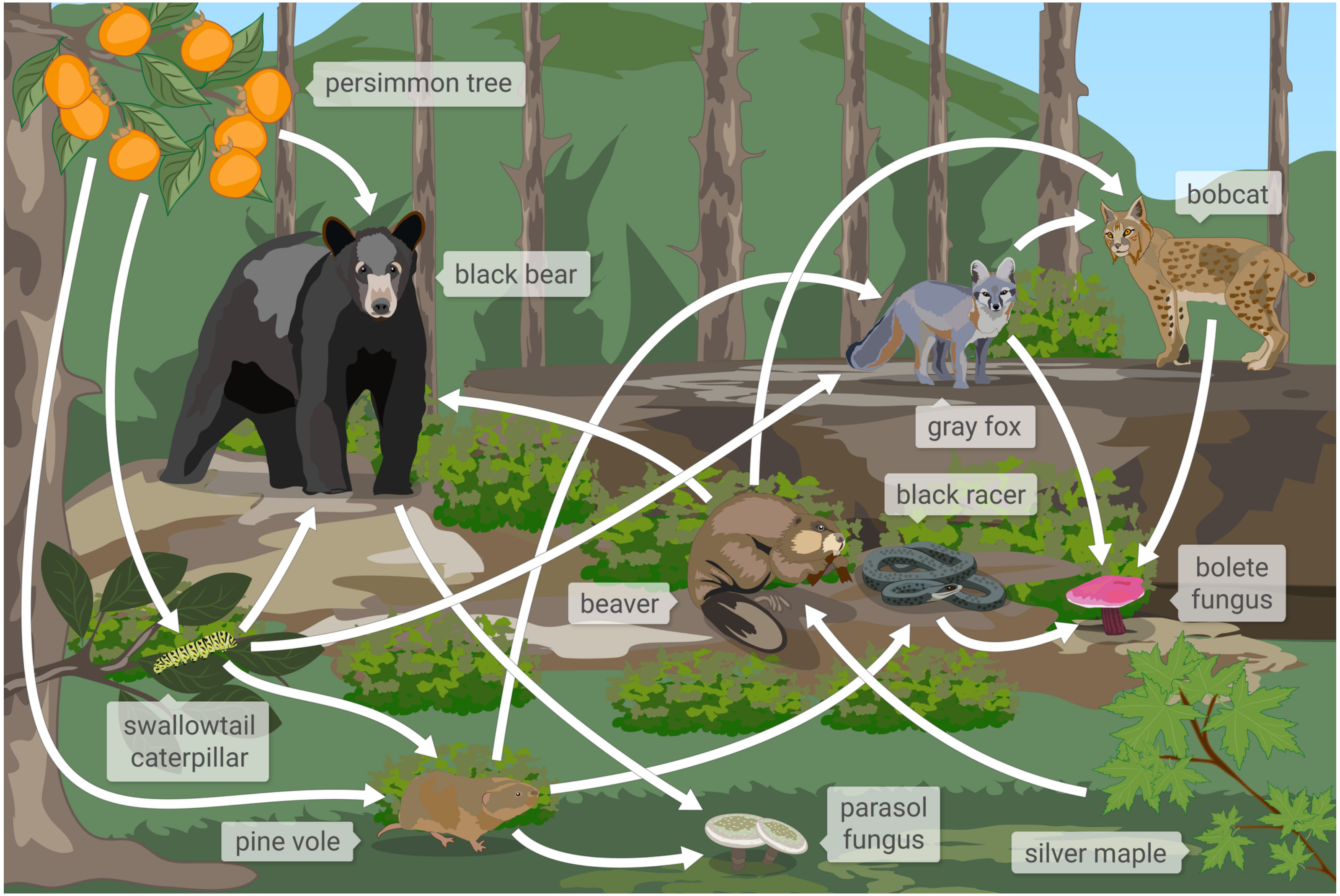

TROPHIC CASCADES
Predators, Prey, and the Changing Dynamics of Nature
Edited by John Terborgh and James A. Estes

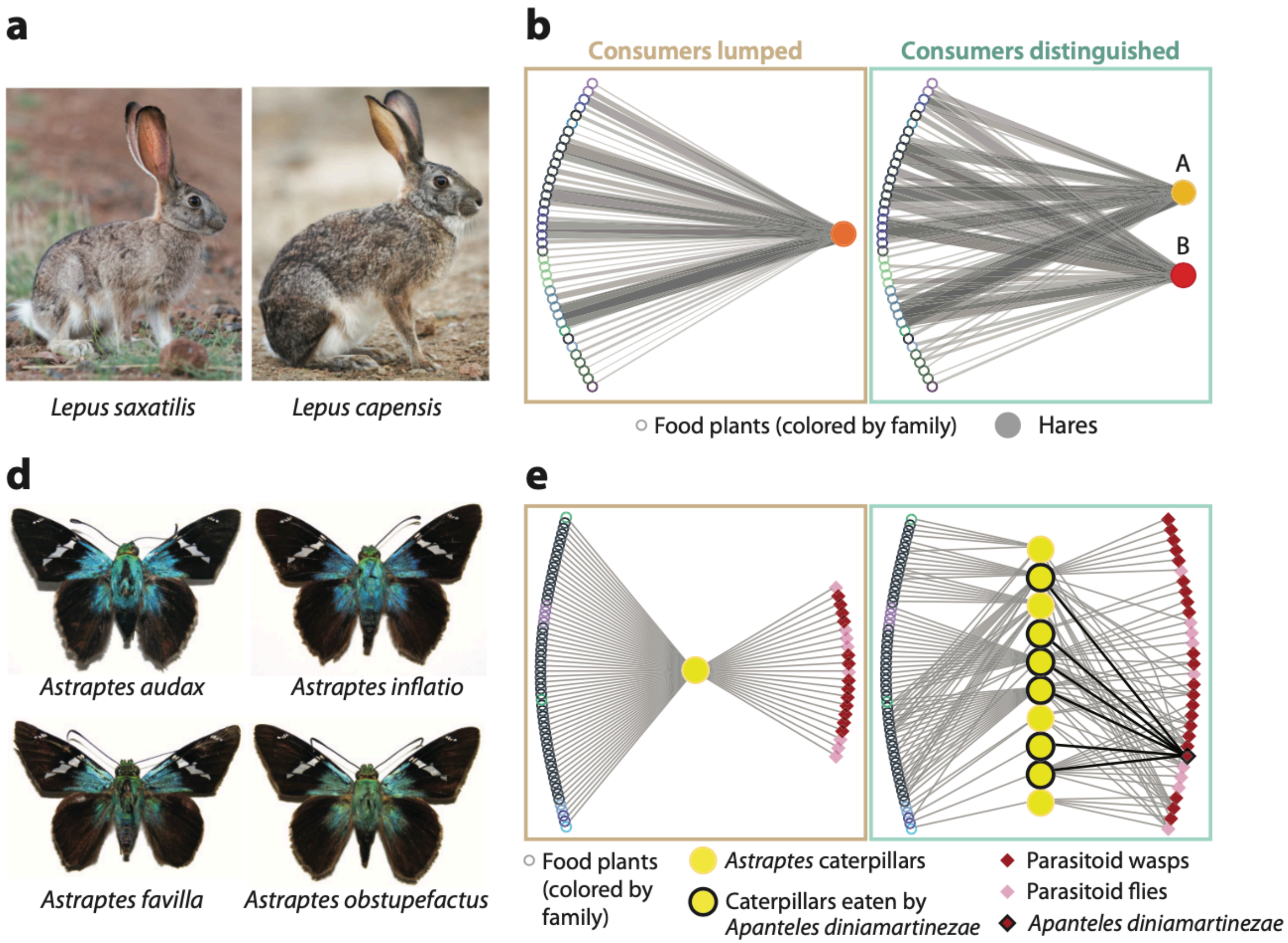

"Big, fierce animals have a noble champion in William Stolzenburg."
—EDWARD O. WILSON, professor emeritus, Harvard University
LIFE, DEATH, AND ECOLOGICAL WRECKAGE IN A LAND OF VANISHING PREDATORS
WHERE THE WILD THINGS WERE
WILLIAM STOLZENBURG

"Do food webs display universal structure similar to other types of networks?"

"Do food webs display universal structure similar to other types of networks?"

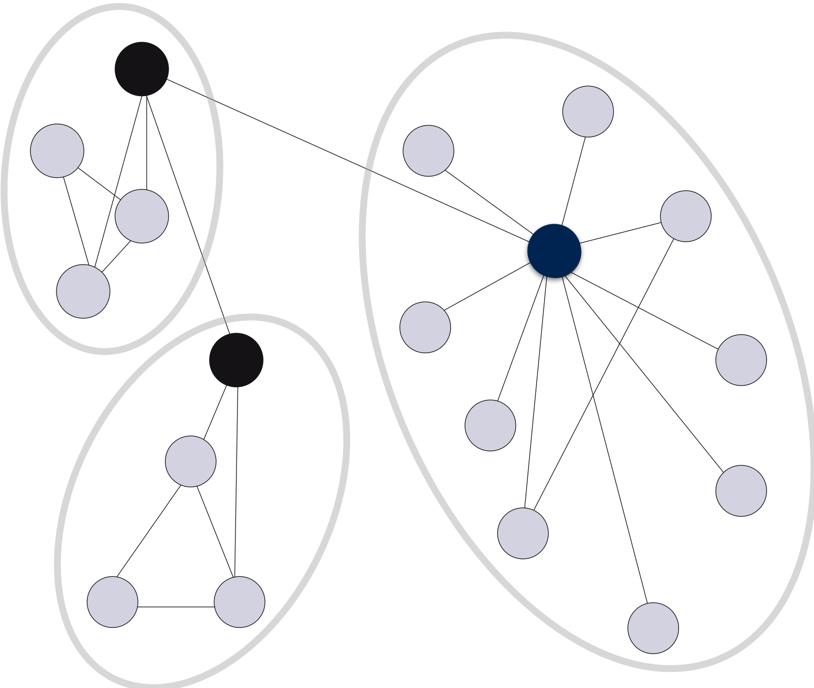
How do we characterize the structure of Ecological networks?


persimmon tree
black bear
bobcat
gray fox
black racer
beaver
bolete fungus
swallowtail caterpillar
pine vole
parasol fungus
silver maple

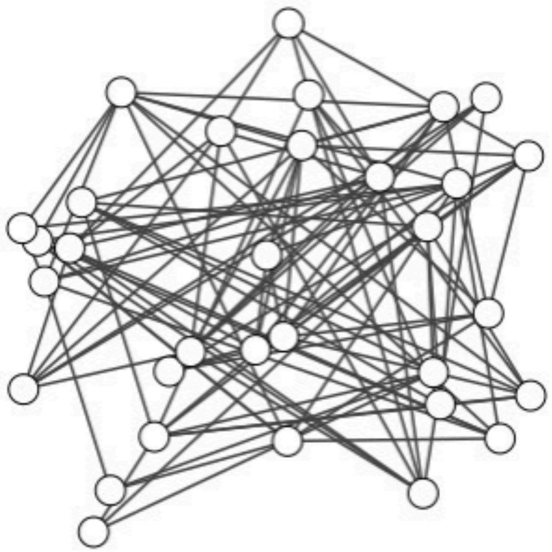


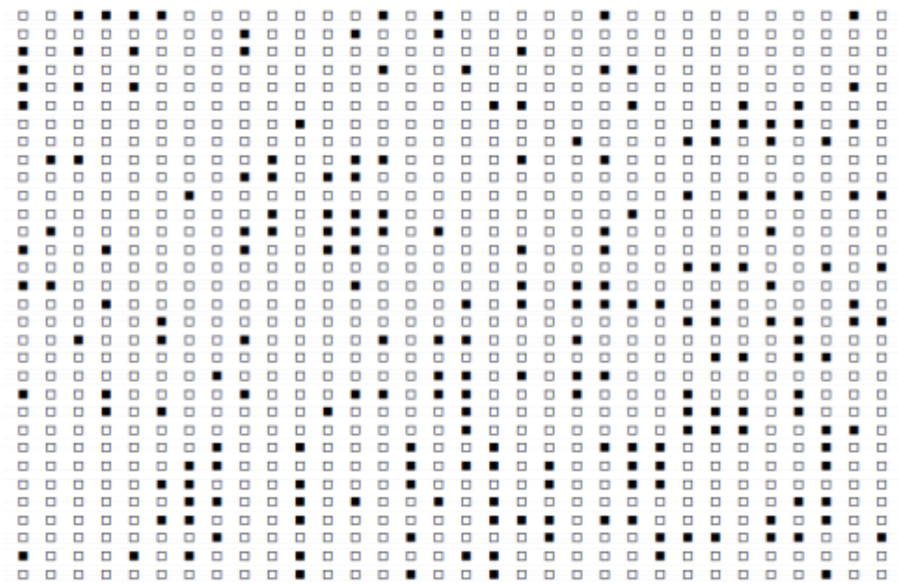
Pringle & Hutchinson (2020) *AREES*

“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)



$$M = \sum_{\text{all modules}} \left(\text{fraction of edges within module } i \right) - \left(\text{expected fraction of edges within module } i \right)$$



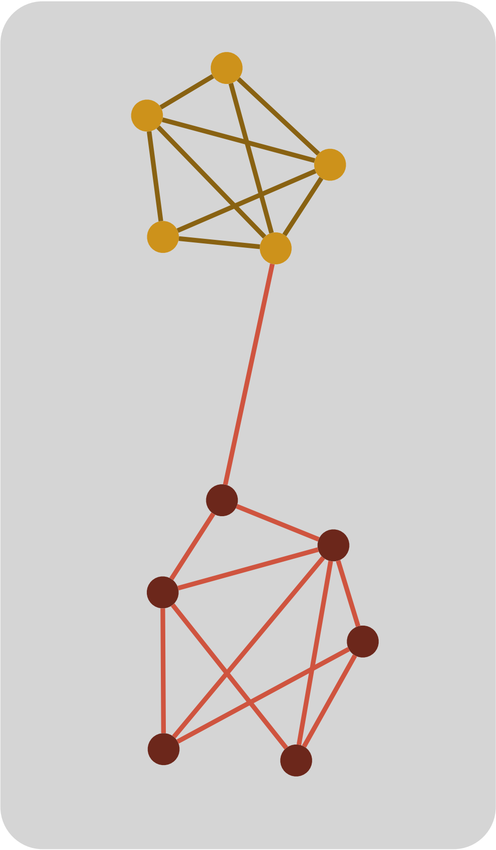


Modularity

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, Guimerà & Amaral, 2005)

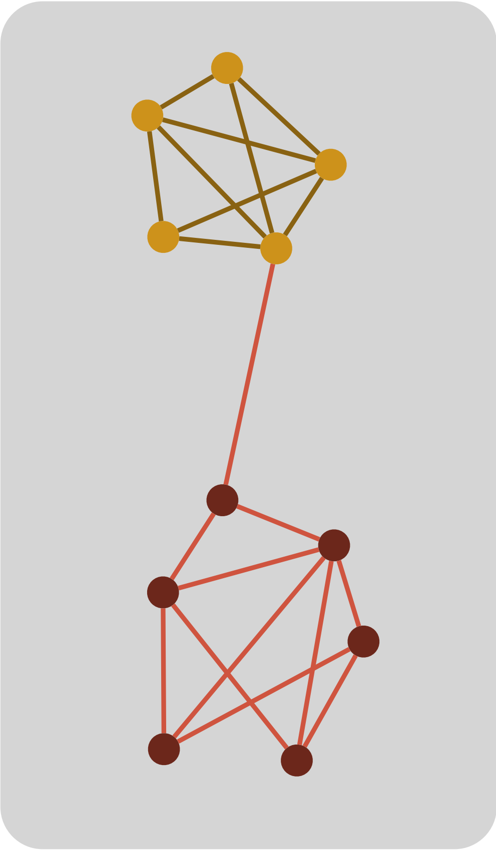


The metric M

# of interactions inside module s

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

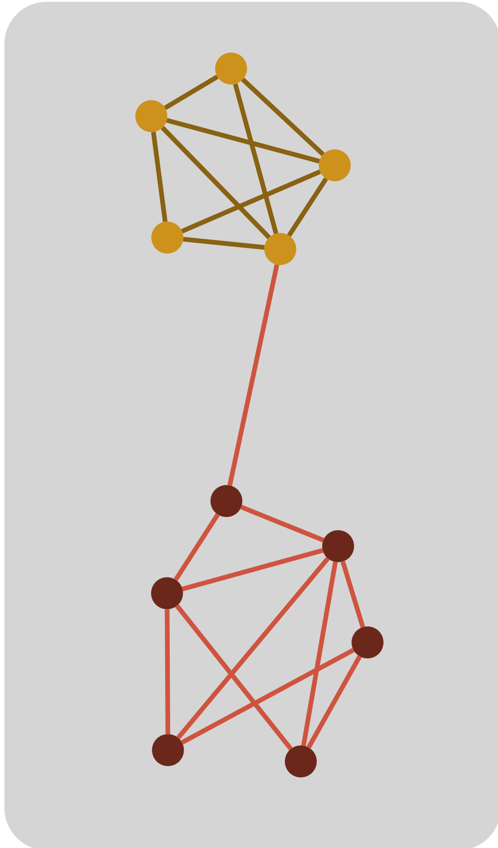
# of interactions in the whole network



The metric M

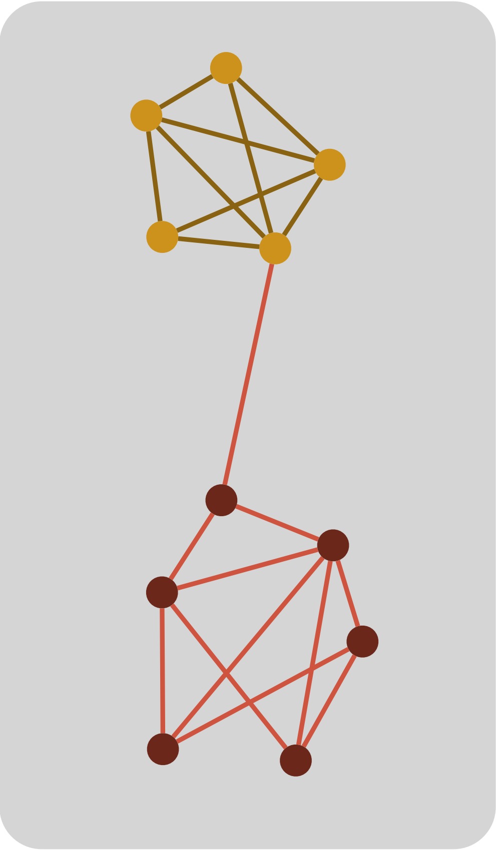
Sum of the species' degree inside module s

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



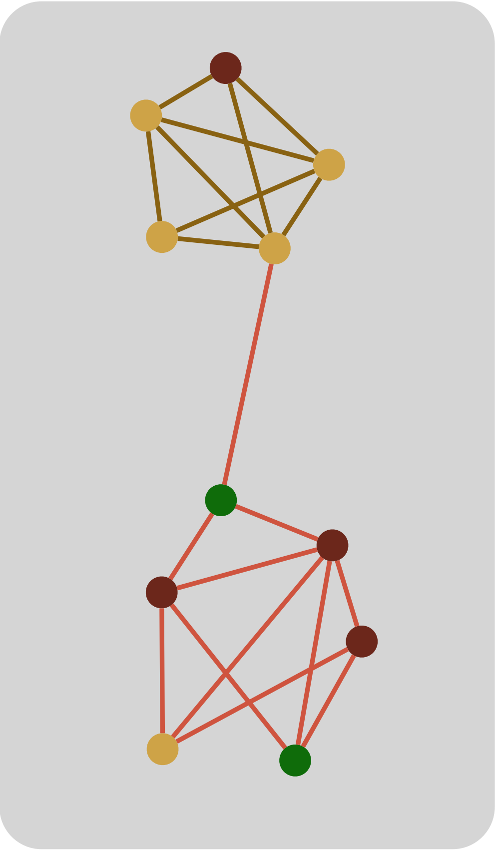
How to find the modules?

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



How to find the modules?

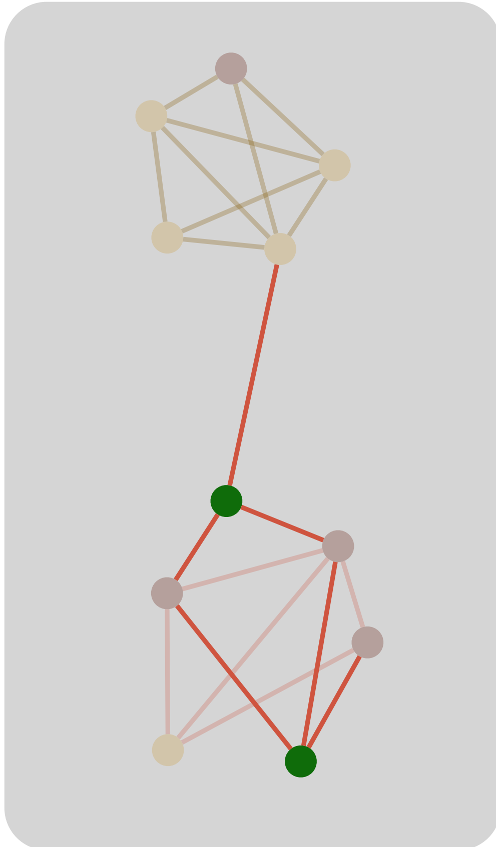
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$



How to find the modules?

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

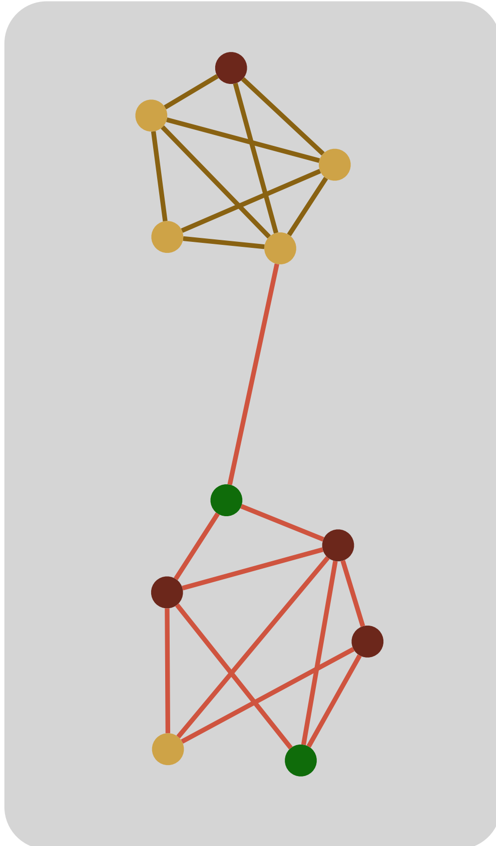
(0/20) – (6/40)²



How to find the modules?

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

- (dark red) $(2/20) - (15/40)^2$
- (yellow) $(6/20) - (18/40)^2$
- (green) $(0/20) - (6/40)^2$



How to find the modules?

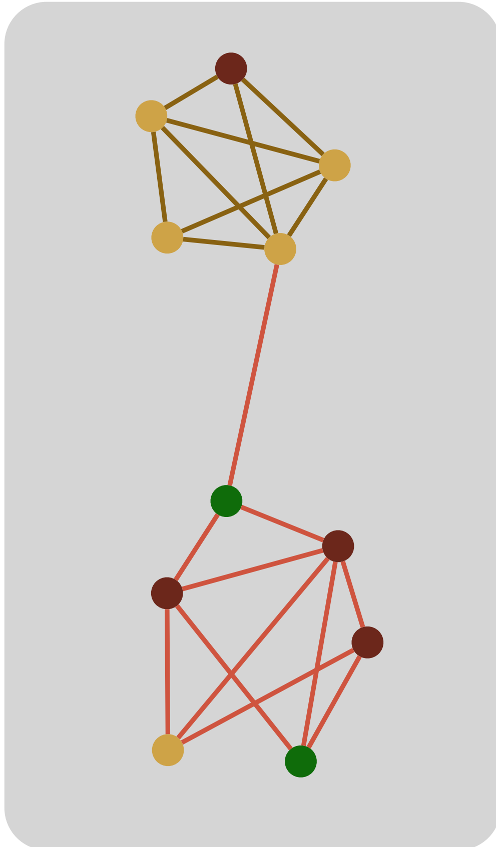
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

- 0.04

0.10

- 0.02

M = 0.04



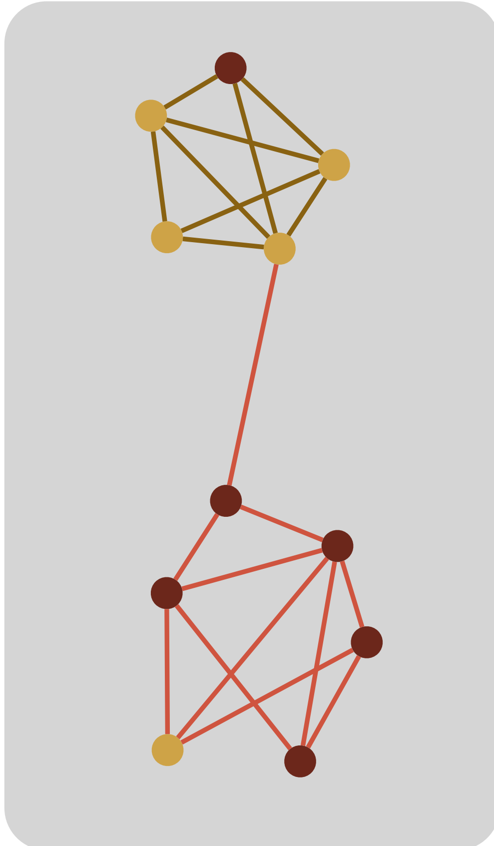
How to find the modules?

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

0.01

0.15

M = 0.16



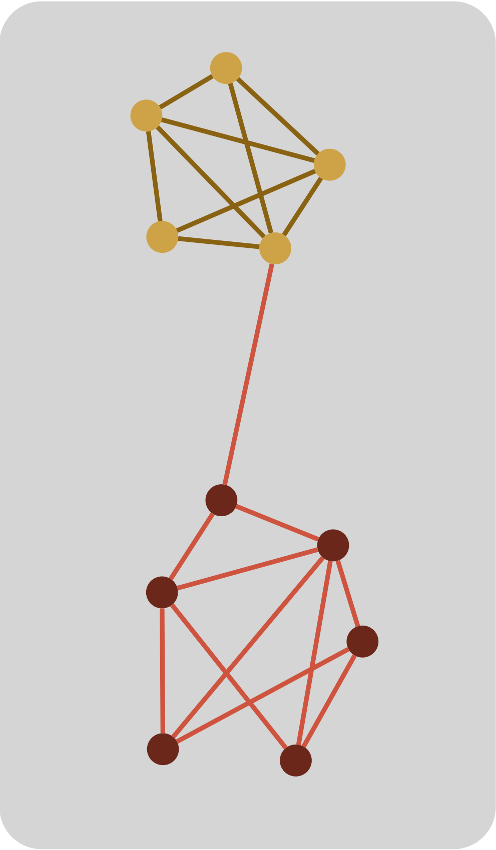
How to find the modules?

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

● 0.22

● 0.25

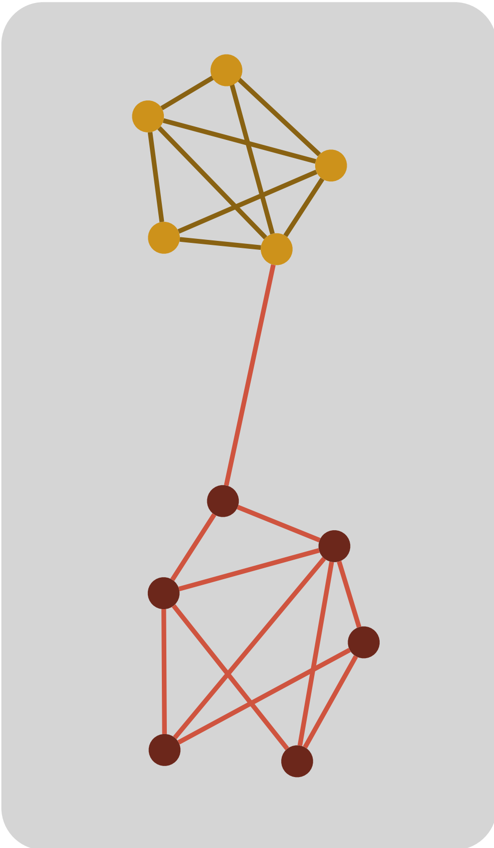
M = 0.47



11 species: 1 – 11 modules;

Different sizes;

How to optimize?

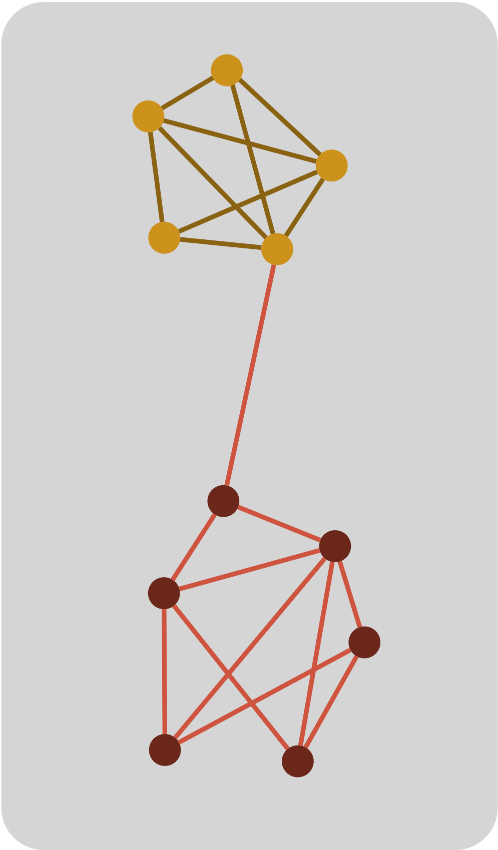


11 species: 1 – 11 modules;

Different sizes;

How to optimize?

Optimization algorithms

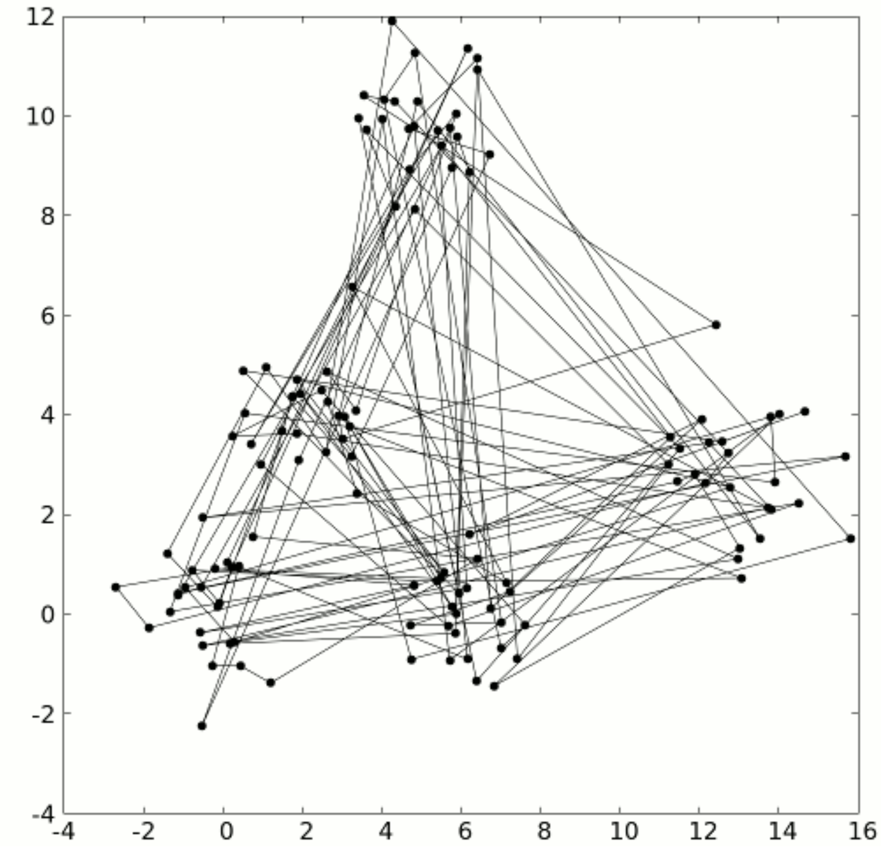


11 species: 1 – 11 modules;

Different sizes;

How to optimize?

Simulated annealing



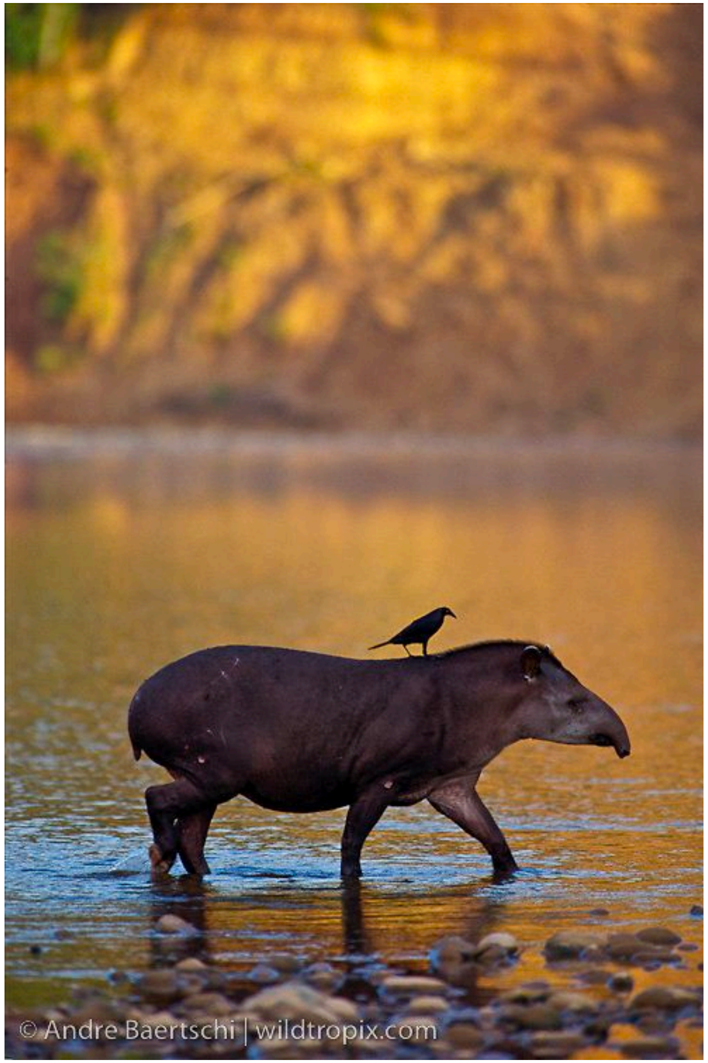
Journal of Animal Ecology 1996, **65**, 339–347

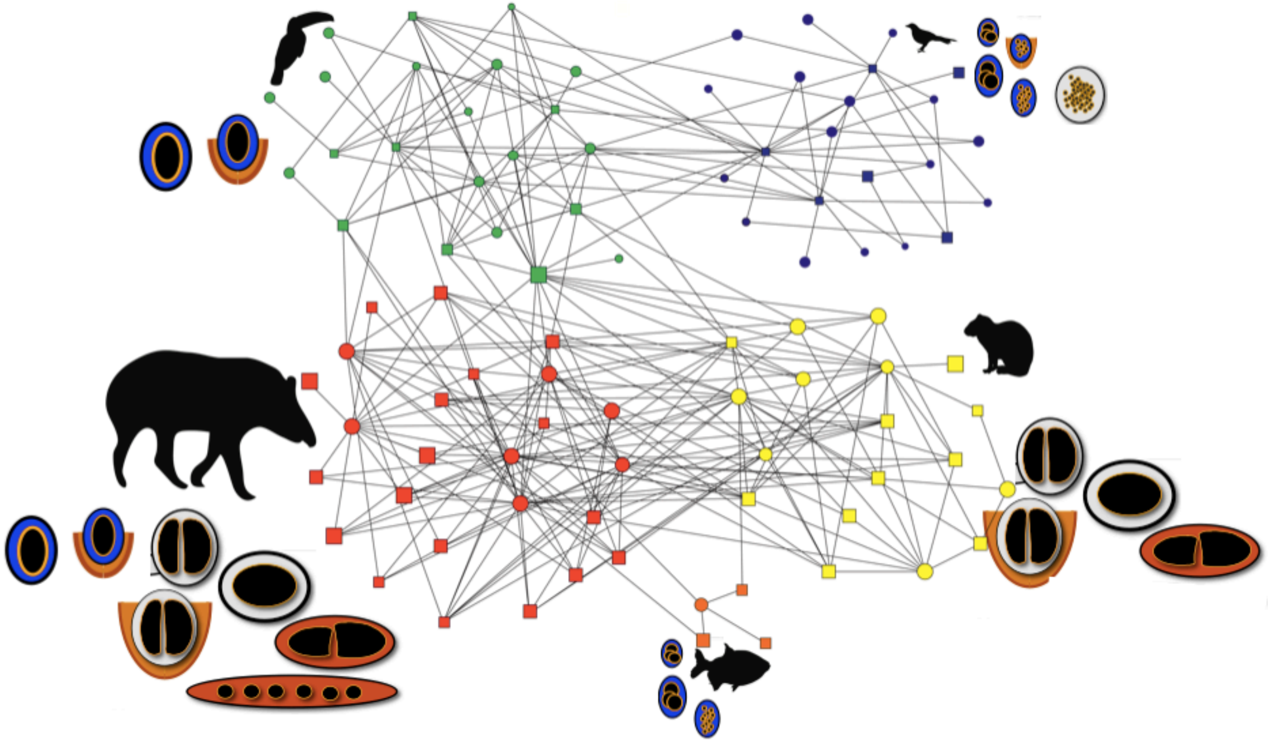
Asymmetries, compartments and null interactions in an Amazonian ant-plant community

CARLOS ROBERTO FONSECA* and GISLENE GANADE†

**Animal Behaviour Research Group, Department of Zoology, South Parks Road, Oxford, OX1 3PS, UK; and,*
†NERC Centre for Population Biology and Department of Biology, Imperial College at Silwood Park, Ascot, Berks SL5 7PY, UK

MYRMECOPHYTES & ANTS	*Cecropia purpuracens*	*Cecropia concolor*	*Cecropia distachya*	*Cecropia ficifolia*	*Pourouma heterophylla*	*Hirtella myrmecophila*	*Hirtella physophora*	*Duroia saccifera*	*Cordia nodosa*	*Cordia aff. nodosa*	*Tococa bullifera*	*Maieta guianensis*	*Maieta poeppiggi*	*Tachigali polyphylla*	*Tachigali myrmecophila*	*Amaioua aff. guianensis*
Camponotus balzanii	11															
Azteca alfari	1															
Azteca isthmica	1	1	1	1												
Azteca aff. isthmica	1			2												
Allomerus D					23											
Allomerus prancei							5									
Allomerus aff. octoarticulata						3	70	27								
Solenops A							3	1								
Allomerus auripunctata								2		2						
Crematogaster B								1	1	1						
Azteca HC										3						
Azteca G										24	11	2				
Crematogaster D										3	2					
Azteca CO										1						
Pheidole minutula											1	93	28			
Crematogaster A							1				7	7	1			
Azteca TO											1					
Crematogaster C											3		3			
Azteca schummani														2	1	
Pseudomyrmex nigrescens														7	16	
Pseudomyrmex concolor														16	18	
Azteca D															1	
Azteca polymorpha															2	
Crematogaster E										1					1	
Azteca Q																3
Unoccupied plants	14	0	0	0	0	0	3	8	0	31	0	5	5	6	5	0



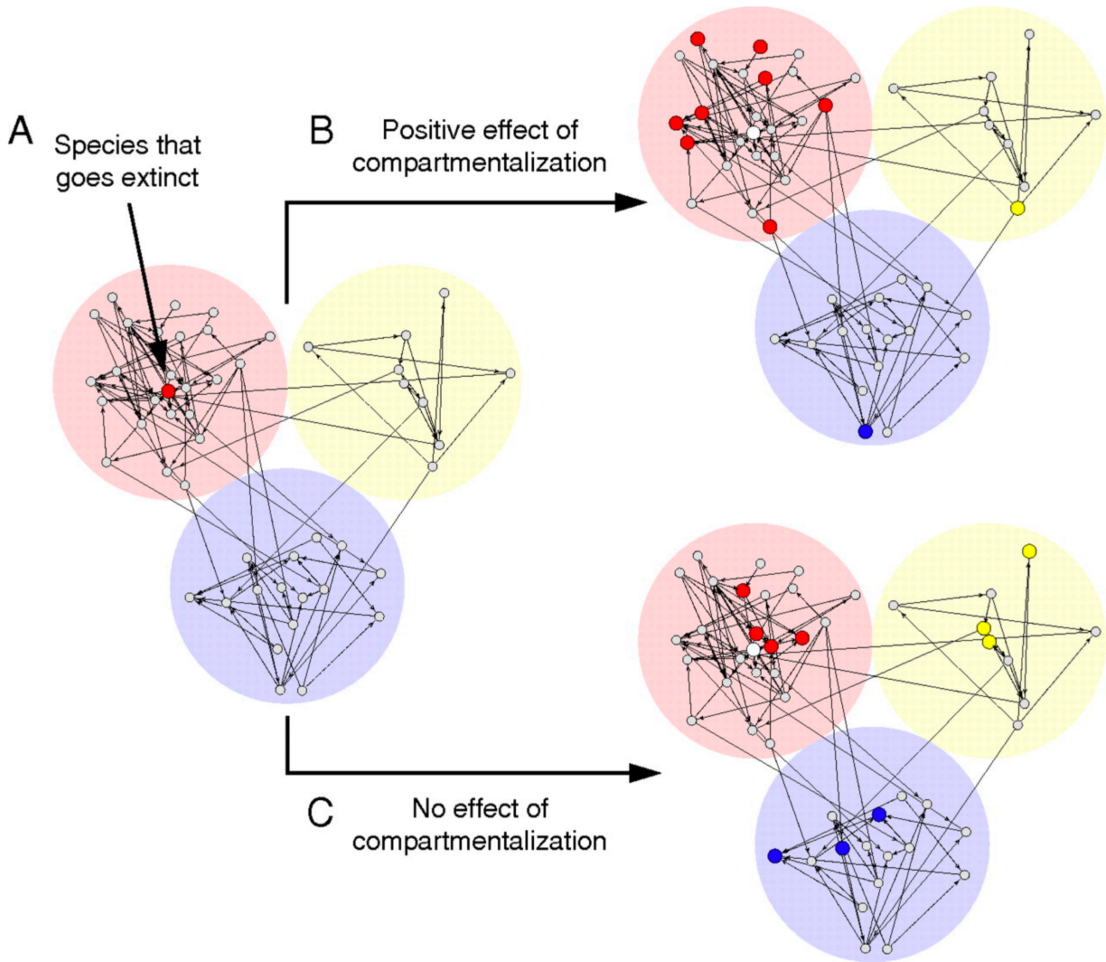


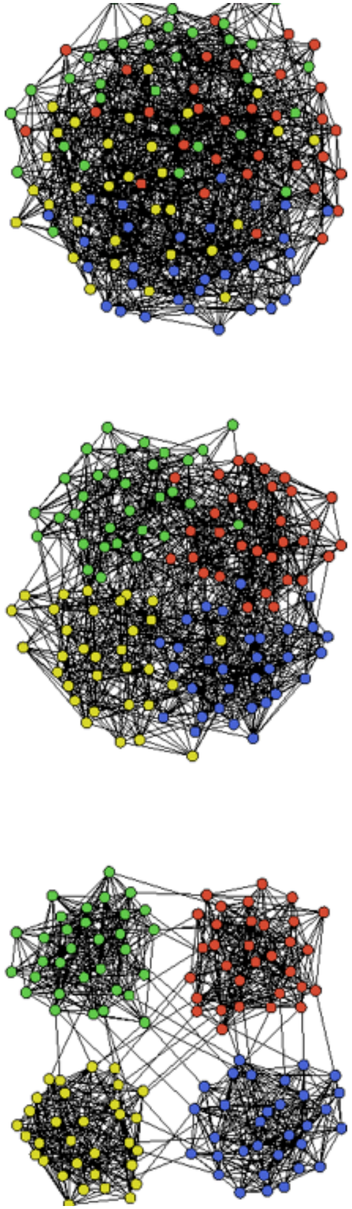
Donatti *et al.* (2012) *Eco. Lett.*

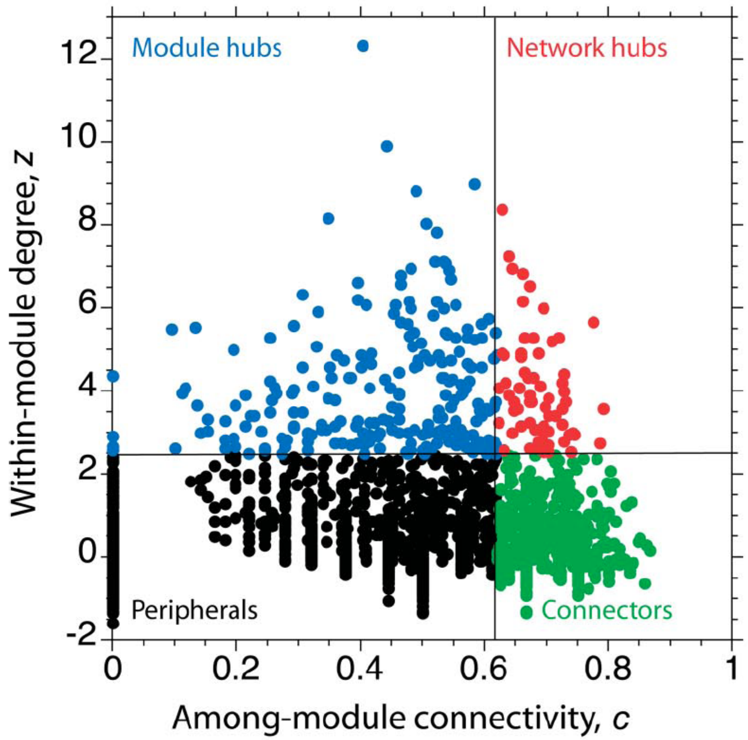
Compartmentalization increases food-web persistence

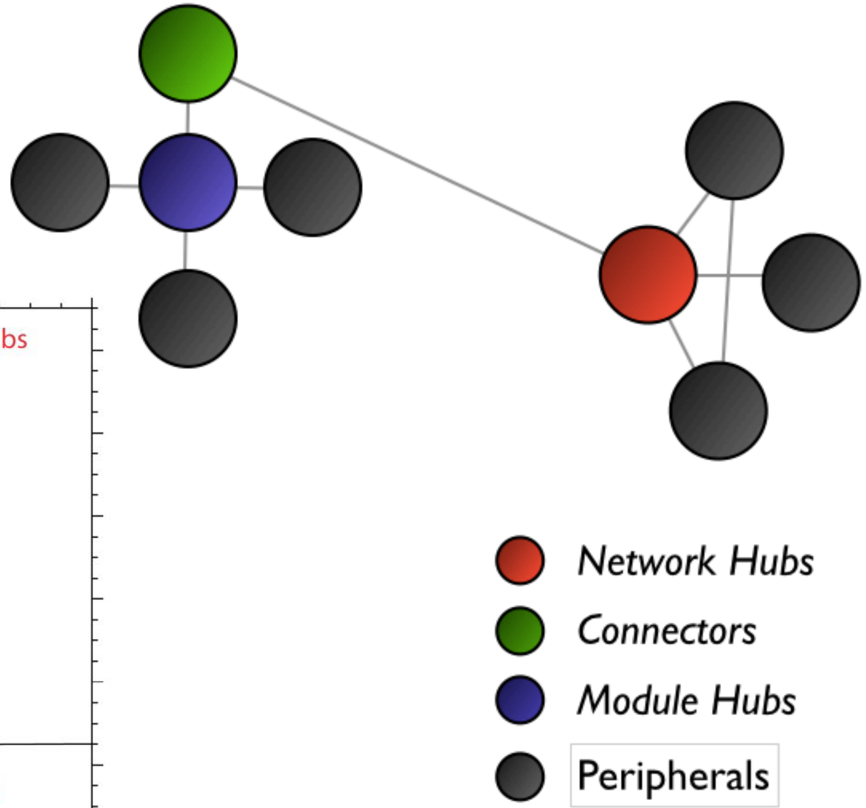
Daniel B. Stouffer and Jordi Bascompte
+ See all authors and affiliations

PNAS March 1, 2011 108 (9) 3648-3652; https://doi.org/10.1073/pnas.1014353108









Olesen *et al.* (2007) *PNAS*

Afternoon:

Calculating modularity in R

gaiarsa.mp@gmail.com

@magaiarsa

mariliagaiarsa.weebly.com

Ecological Networks, March | 2022

Calculating modularity in R

Daniel Wechsler & Marilia P. Gaiarsa

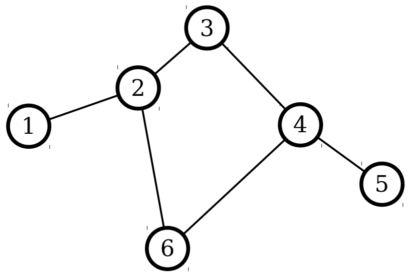
gaiarsa.mp@gmail.com

@magaiarsa

mariliagaiarsa.weebly.com

Ecological Networks, March | 2022

Graph Theory - Representations



:= node, vertex

:= edge, link, connection

n := number of nodes in the graph.

m := number of edges in the graph.

Edge list:

$$E = \{(1,2),\ (2,3),\ (2,6),\ (3,4),\ (4,5),\ (4,6)\}$$

Adjacency matrix:

$$\begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array}$$

$$A_{u,v} = \begin{cases} 1 & \text{if node u and node v are connected} \\ 0 & \text{otherwise} \end{cases}$$

Let’s go to R now

The metric M

# of interactions inside module s

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

Barber 2007, Guimerà et al. 2007

# of interactions in the whole network