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A New Topological Approach to Quantify the Interaction Structure of Food Web Network

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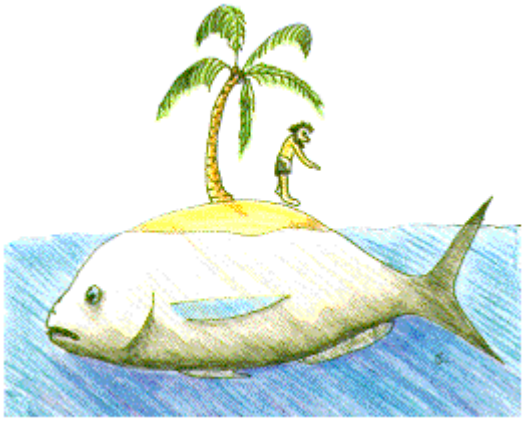
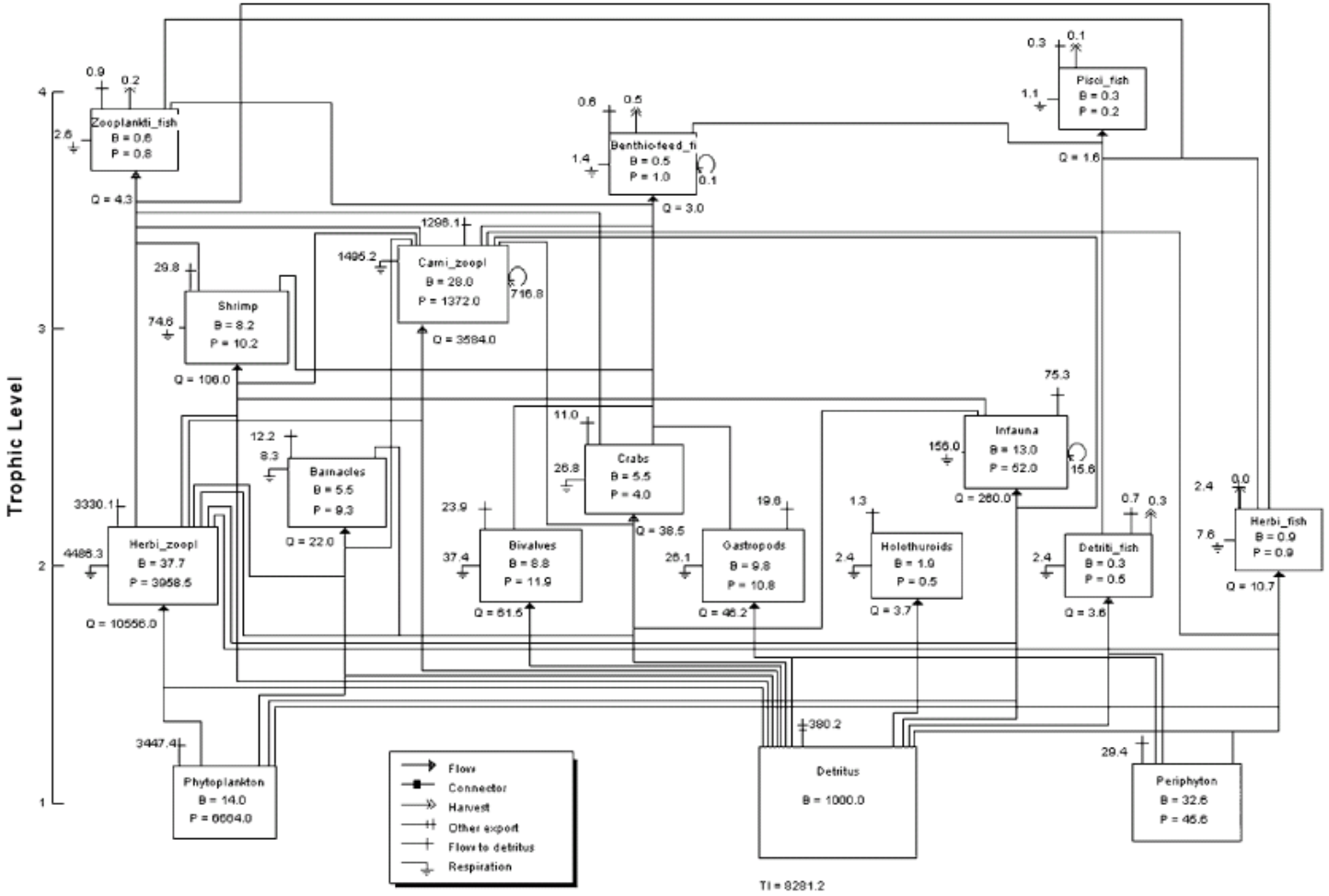
Ecosystem-Based Approach to me…

1. **Every component in the system is interacting with all others;**
2. **Catching a fish is not only about the fish you caught, but also effecting its preys, predators, competitors...**

No fish is an island…



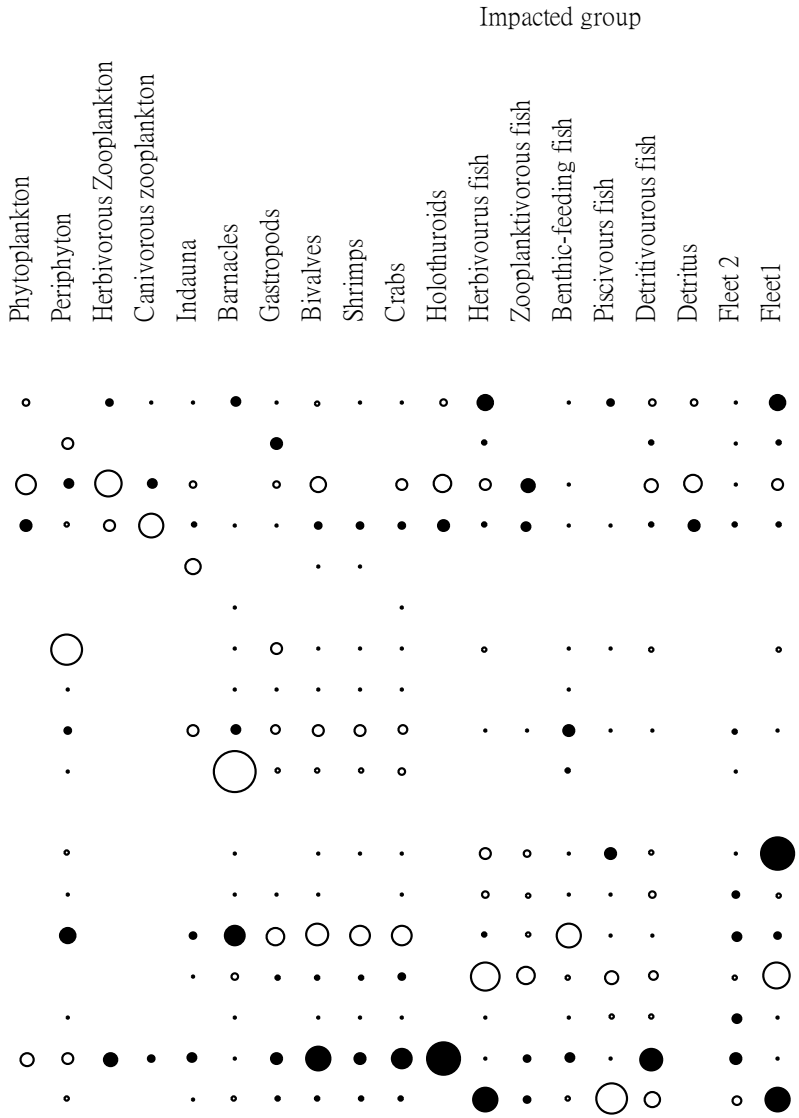
Mass-balanced food web modeling (i.e. Ecopath with Ecosim)



Lin et al. 2004

Mixed Trophic Index, MTI

(EwE v6: Network Analysis)



Based on Lin et al. 2004

Positive

Negative

Phytoplankton
Periphyton
Herbivorous Zooplankton
Canivorous zooplankton
Indauna
Barnacles
Gastropods
Bivalves
Shrimps
Crabs
Holothuroids
Herbivourus fish
Zooplanktivorous fish
Benthic-feeding fish
Piscivours fish
Detritivourous fish
Detritus
Fleet 2
Fleet1

Impacting group

However, Ecopath modeling do require a lot of Parameterizations

Biomass (B, g C m^{-2})

Production (P, g C m^{-2} d^{-1})

Consumption (Q, g C m^{-2} d^{-1})

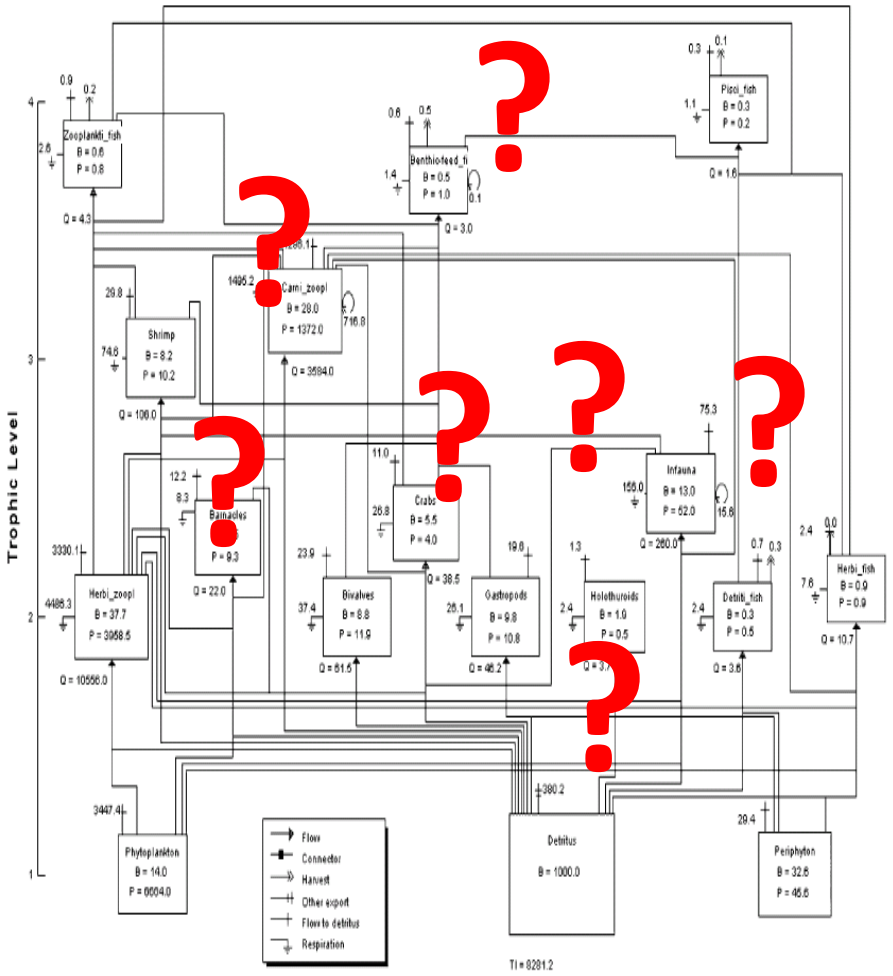
Catch

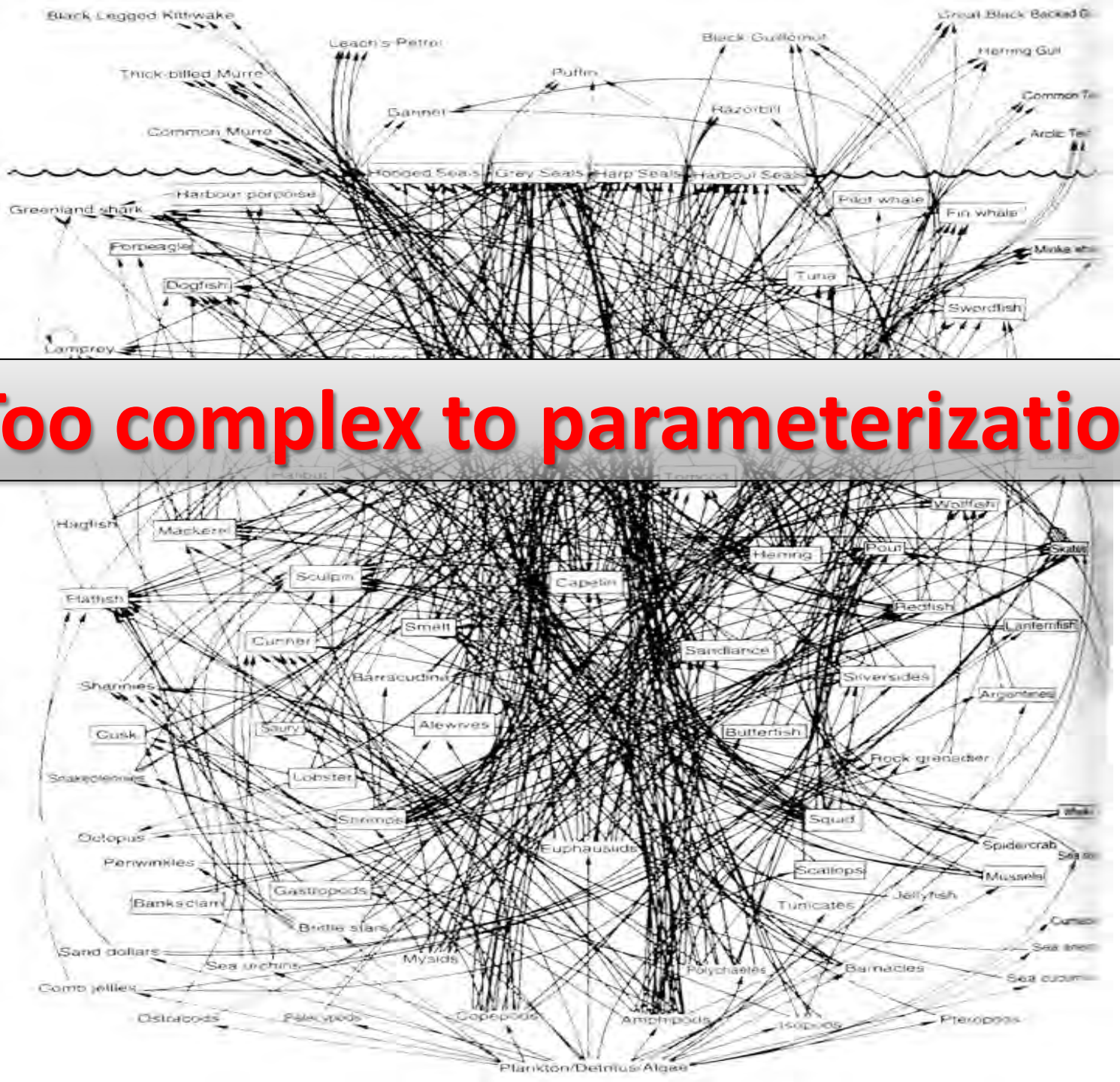
Ecotrophic Efficiency (EE)

Diet composition

Organic detritus (g C m^{-2})

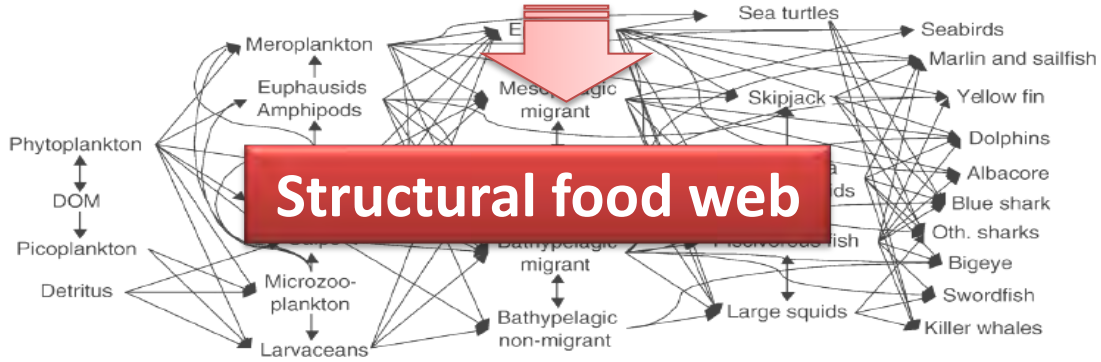
.....





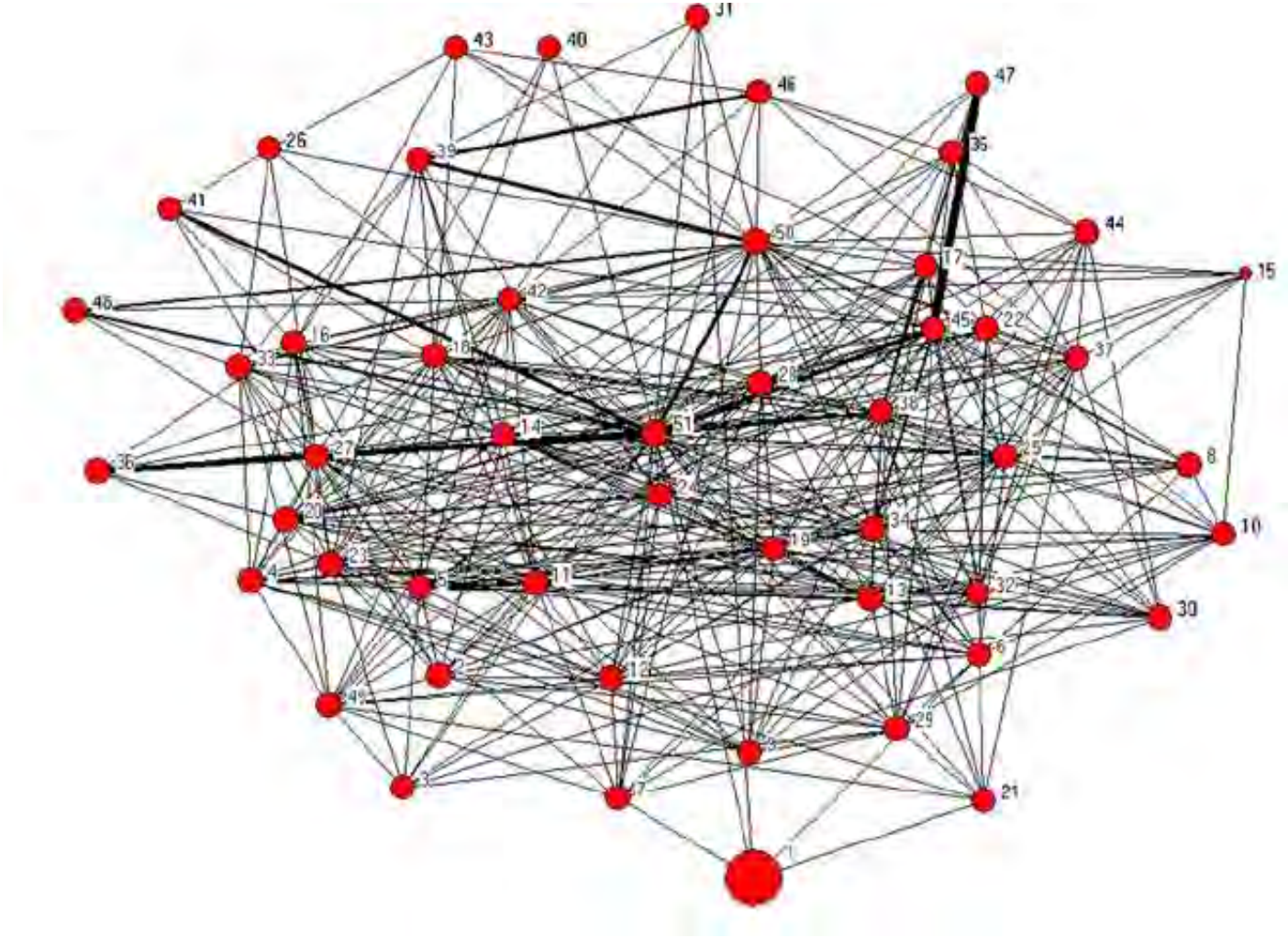
Too complex to parameterization?

Simply knowing only Who Eats Whom should be much easier...



Ex: Building structural food web using DNA barcoding

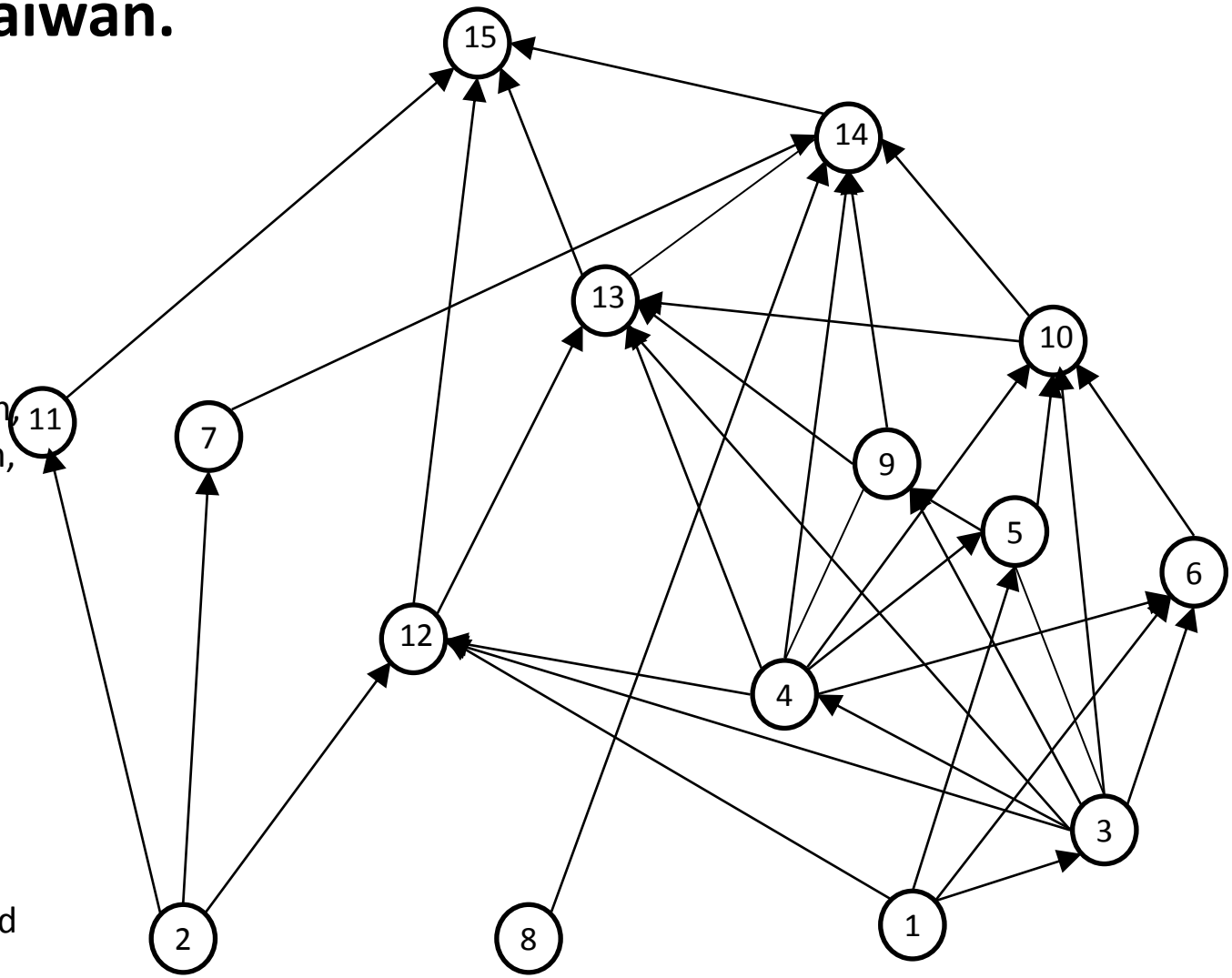
What can we learn from the structural food web along?



Jordan et al. 2008

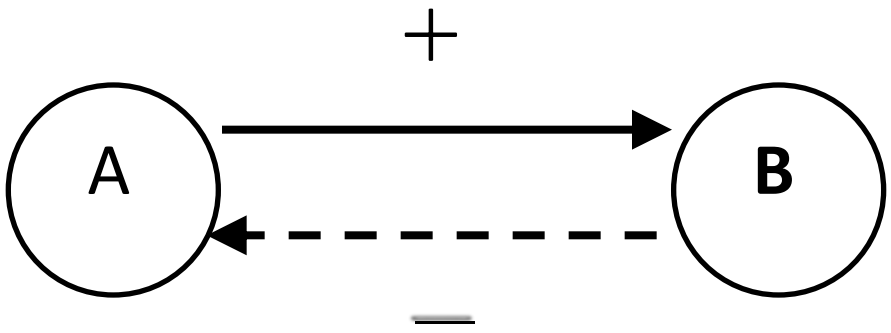
Consider a simple 15 species food web of a costal ecosystem; Kuoshen Bay in NE Taiwan.

(1) phytoplankton,
(2) periphyton,
(3) herbivorous zooplankton,
(4) carnivorous zooplankton,
(5) infauna,
(6) barnacles,
(7) gastropods,
(8) bivalves,
(9) shrimp,
(10) crabs,
(11) detritivorous fish,
(12) herbivorous fish,
(13) zooplanktivorous fish,
(14) benthic-feeding fish, and
(15) piscivorous fish.



Based on Lin et al. 2004 and after Jordan et al. 2009

1. Trophic interactions are directed and signed:



Simultaneously, every trophic interaction occurs with both positive and negative effect

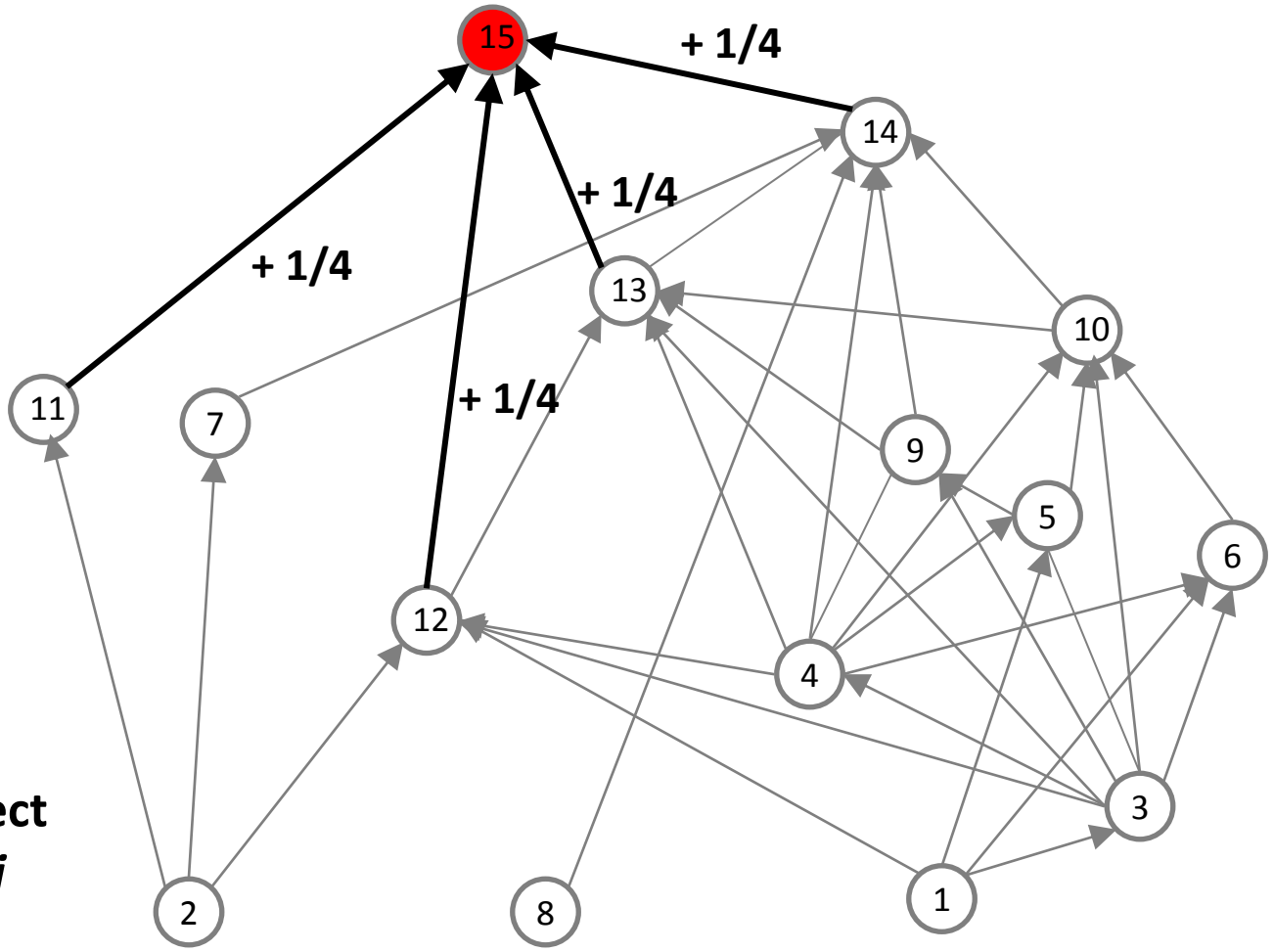
2a. The total magnitude of direct effect on any focal species = 1

$$\sum_{j=1}^{m} a_{j \to i^S} = 1$$

If not weighted,

$$a_{j \to i^S} = \frac{1}{m}$$

***a* : magnitude of effect**
m* : no. neighbor of *j



2b. The magnitudes of direct effects from a focal species depends on how many neighbors the effect receiver has

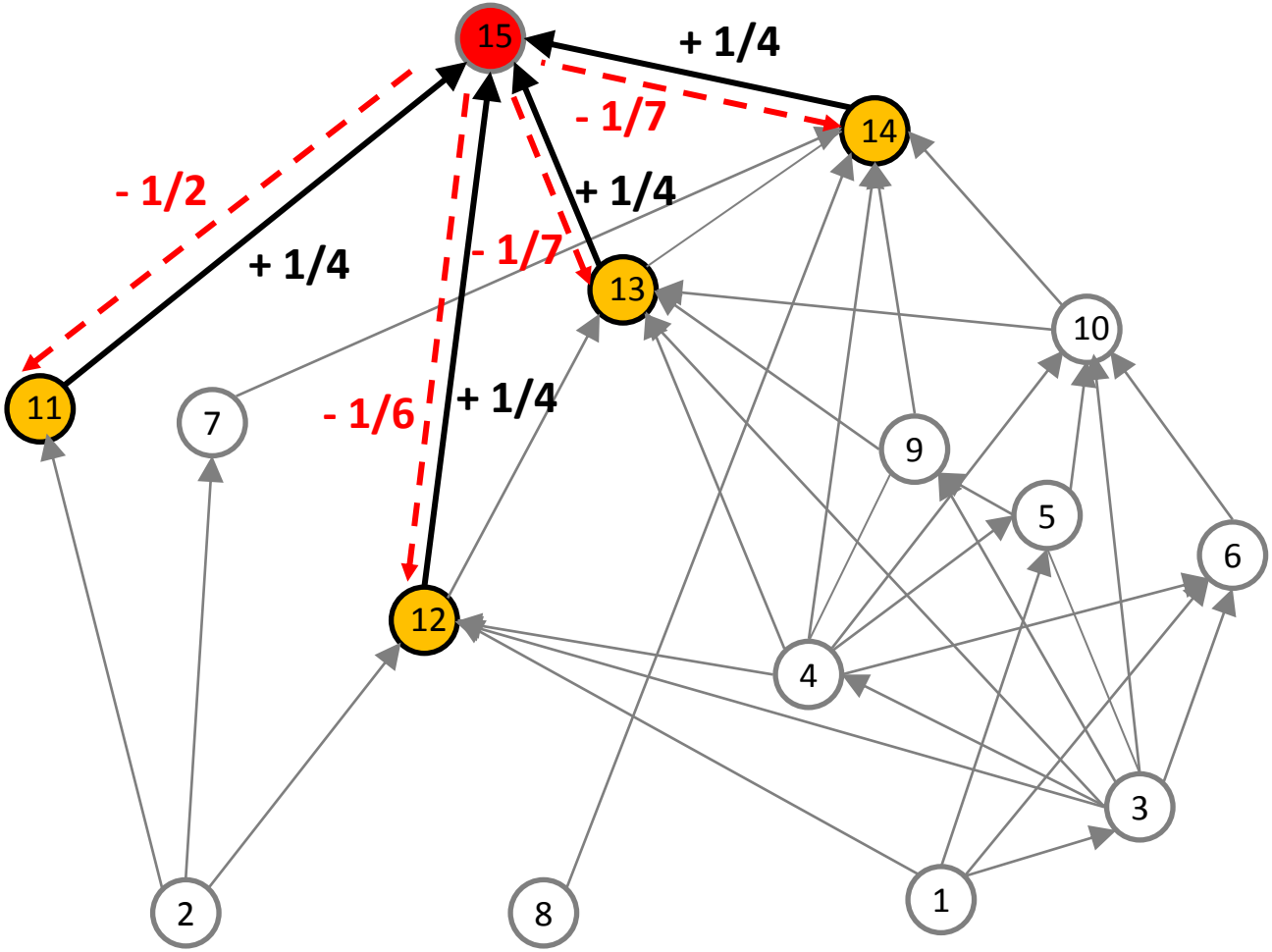


Table of 1-step positive (+) direct effects

	1	10	11	12	13	14	15	2	3	4	5	6	7	8	9
1	0.000	0.000	0.000	0.167	0.000	0.000	0.000	0.000	0.125	0.000	0.200	0.250	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.143	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.143	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.143	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.500	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000
3	0.000	0.167	0.000	0.167	0.143	0.000	0.000	0.000	0.000	0.125	0.200	0.250	0.000	0.000	0.200
4	0.000	0.167	0.000	0.167	0.143	0.143	0.000	0.000	0.000	0.000	0.200	0.250	0.000	0.000	0.200
5	0.000	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200
6	0.000	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.143	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table of 1-step negative (-) direct effects

	1	10	11	12	13	14	15	2	3	4	5	6	7	8	9	Row Sum
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	-0.200	-0.250	0.000	0.000	0.000	-0.70
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.33
12	-0.250	0.000	0.000	0.000	0.000	0.000	0.000	-0.333	-0.125	-0.125	0.000	0.000	0.000	0.000	0.000	-0.83
13	0.000	-0.167	0.000	-0.167	0.000	0.000	0.000	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	-0.200	-0.78
14	0.000	-0.167	0.000	0.000	-0.143	0.000	0.000	0.000	0.000	-0.125	0.000	0.000	-0.500	-1.000	-0.200	-2.13
15	0.000	0.000	-0.500	-0.167	-0.143	-0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.95
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
3	-0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.25
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	0.000	0.000	0.000	0.000	0.000	0.000	-0.12
5	-0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	0.000	-0.50
6	-0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	0.000	-0.50
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.33
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	-0.200	0.000	0.000	0.000	0.000	-0.45

Table of 1-step net direct effects

	1	10	11	12	13	14	15	2	3	4	5	6	7	8	9	Row Sum
1	0.000	0.000	0.000	0.167	0.000	0.000	0.000	0.000	0.125	0.000	0.200	0.250	0.000	0.000	0.000	0.74
10	0.000	0.000	0.000	0.000	0.143	0.143	0.000	0.000	-0.125	-0.125	-0.200	-0.250	0.000	0.000	0.000	-0.41
11	0.000	0.000	0.000	0.000	0.000	0.000	0.250	-0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.08
12	-0.250	0.000	0.000	0.000	0.143	0.000	0.250	-0.333	-0.125	-0.125	0.000	0.000	0.000	0.000	0.000	-0.44
13	0.000	-0.167	0.000	-0.167	0.000	0.143	0.250	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	-0.200	-0.39
14	0.000	-0.167	0.000	0.000	-0.143	0.000	0.250	0.000	0.000	-0.125	0.000	0.000	-0.500	-1.000	-0.200	-1.88
15	0.000	0.000	-0.500	-0.167	-0.143	-0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.95
2	0.000	0.000	0.500	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	1.16
3	-0.250	0.167	0.000	0.167	0.143	0.000	0.000	0.000	0.000	0.125	0.200	0.250	0.000	0.000	0.200	1.00
4	0.000	0.167	0.000	0.167	0.143	0.143	0.000	0.000	-0.125	0.000	0.200	0.250	0.000	0.000	0.200	1.14
5	-0.250	0.167	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	0.200	-0.13
6	-0.250	0.167	0.000	0.000	0.000	0.000	0.000	0.000	-0.125	-0.125	0.000	0.000	0.000	0.000	0.000	-0.33
7	0.000	0.000	0.000	0.000	0.000	0.143	0.000	-0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.19
8	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.14
9	0.000	0.000	0.000	0.000	0.143	0.143	0.000	0.000	-0.125	-0.125	-0.200	0.000	0.000	0.000	0.000	-0.16

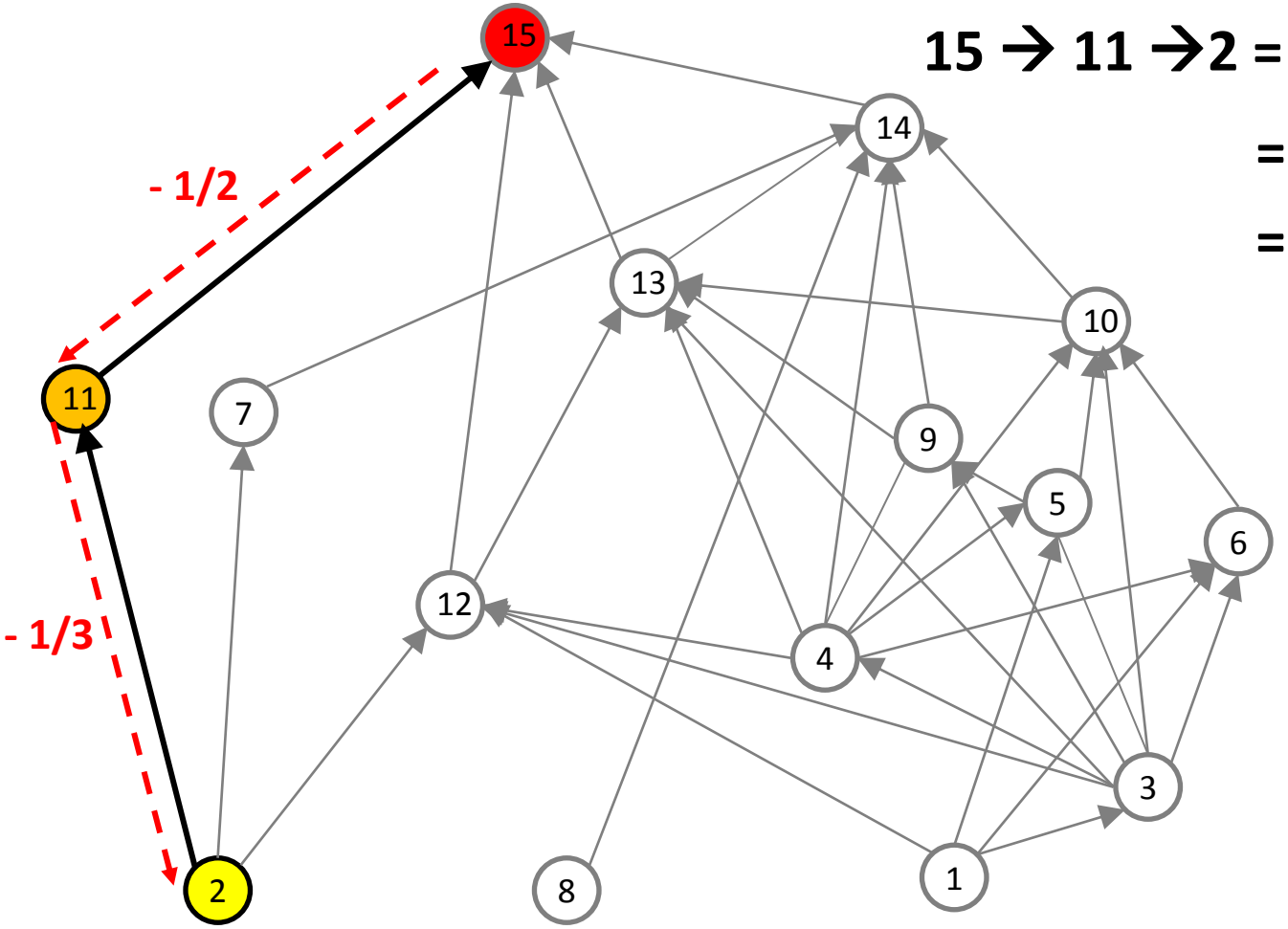
3a. The magnitude of n-step indirect effect is simply the product of the direct effects along the given n-step path

i.e. a 2-step effect Node 15 →2 via 11

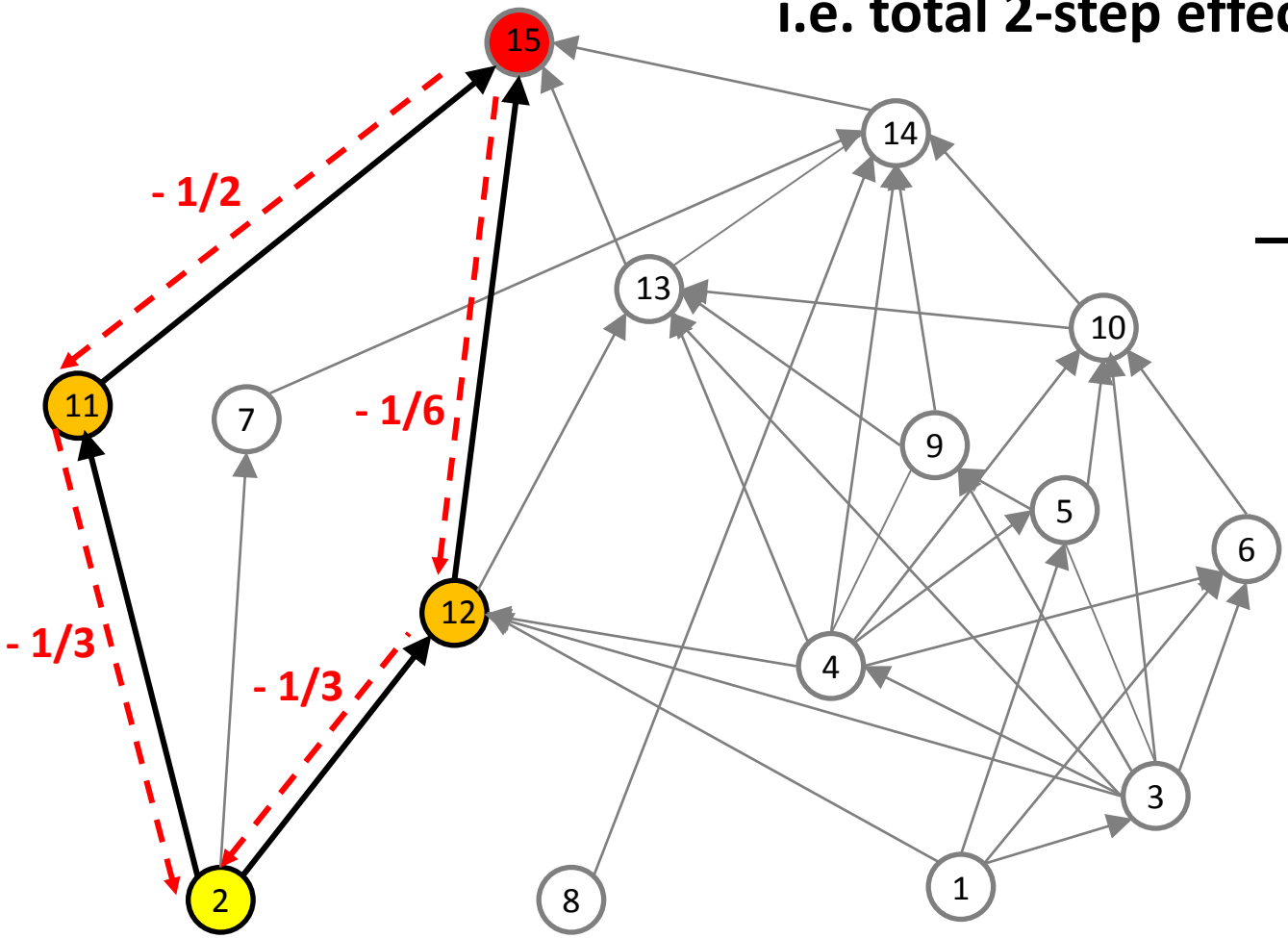
15 → 11 →2 = (15→11) X (11→2)

= (-1/2) X (-1/3)

= 1/6



3b. The total magnitude of n-step indirect effect from *i to j* is simply the sum of all n-step indirect effects between *i* → *j*



i.e. total 2-step effect Node 15 →2

(15 → 11 →2)

+(15 → 12 →2)

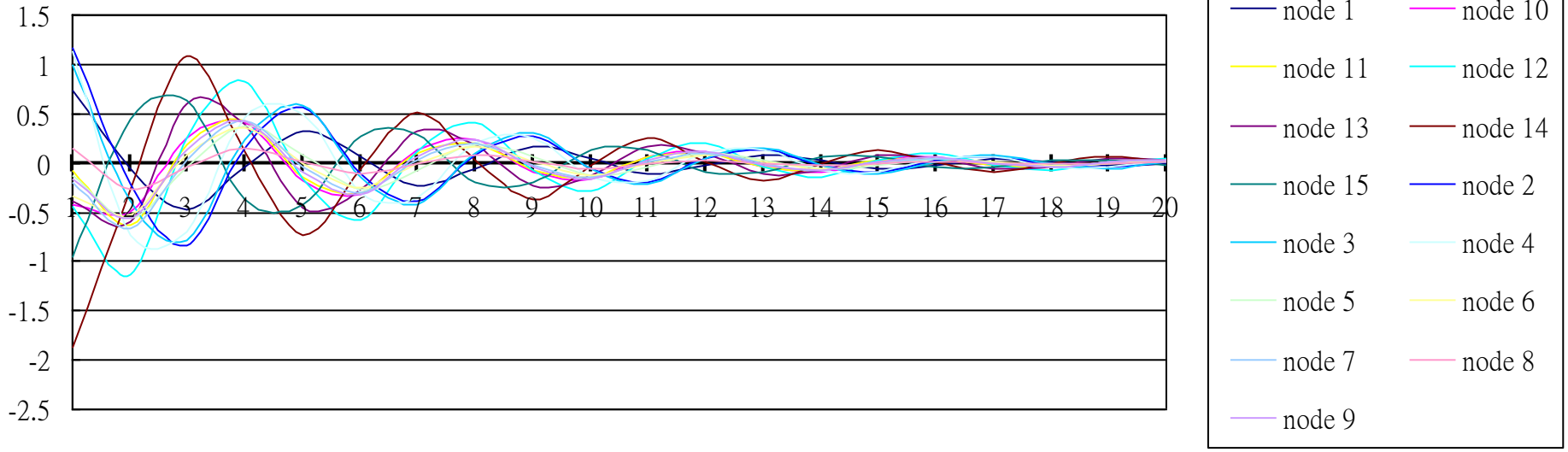
0.222

Table of 2-step net in-direct effect

	1	10	11	12	13	14	15	2	3	4	5	6	7	8	9
1	-0.185	0.096	0	0.021	0.042	0	0.042	-0.056	-0.077	-0.061	0.025	0.031	0	0	0.065
10	0.144	-0.164	0	-0.065	-0.056	0.002	0.071	0	0.054	0.005	-0.05	-0.063	-0.071	-0.143	-0.147
11	0	0	-0.292	-0.097	-0.036	-0.036	0	0	0	0	0	0	-0.167	0	0
12	0.031	-0.065	-0.292	-0.204	-0.071	-0.034	0.036	0	-0.033	-0.033	-0.1	-0.125	-0.167	0	-0.079
13	0.073	-0.065	-0.125	-0.083	-0.168	-0.106	-0.006	0.056	0.082	0.034	0.023	-0.021	-0.071	-0.143	-0.079
14	0	0.003	-0.125	-0.039	-0.106	-0.341	-0.036	0.167	0.079	0.064	0.048	0.011	0	0	0.004
15	0.042	0.048	0	0.024	-0.004	-0.02	-0.238	**0.222**	0.039	0.057	0	0	0.071	0.143	0.057
2	-0.042	0	0	0	0.024	0.071	0.167	-0.389	-0.021	-0.021	0	0	0	0	0
3	-0.154	0.072	0	-0.044	0.094	0.091	0.077	-0.056	-0.188	-0.141	-0.098	-0.073	0	0	0.036
4	-0.123	0.007	0	-0.045	0.038	0.073	0.113	-0.056	-0.141	-0.174	-0.098	-0.073	-0.071	-0.143	-0.042
5	0.031	-0.042	0	-0.083	0.016	0.034	0	0	-0.061	-0.061	-0.173	-0.167	0	0	-0.05
6	0.031	-0.042	0	-0.083	-0.012	0.006	0	0	-0.036	-0.036	-0.133	-0.167	0	0	-0.05
7	0	-0.024	-0.167	-0.056	-0.02	0	0.036	0	0	-0.018	0	0	-0.238	-0.143	-0.029
8	0	-0.024	0	0	-0.02	0	0.036	0	0	-0.018	0	0	-0.071	-0.143	-0.029
9	0.081	-0.123	0	-0.065	-0.056	0.002	0.071	0	0.023	-0.026	-0.05	-0.063	-0.071	-0.143	-0.147

The cumulative net effects will converge…

Net effects generated by each node from step1 to 20 in length



Cumulative effects generated by each node from step1 to 20 in length

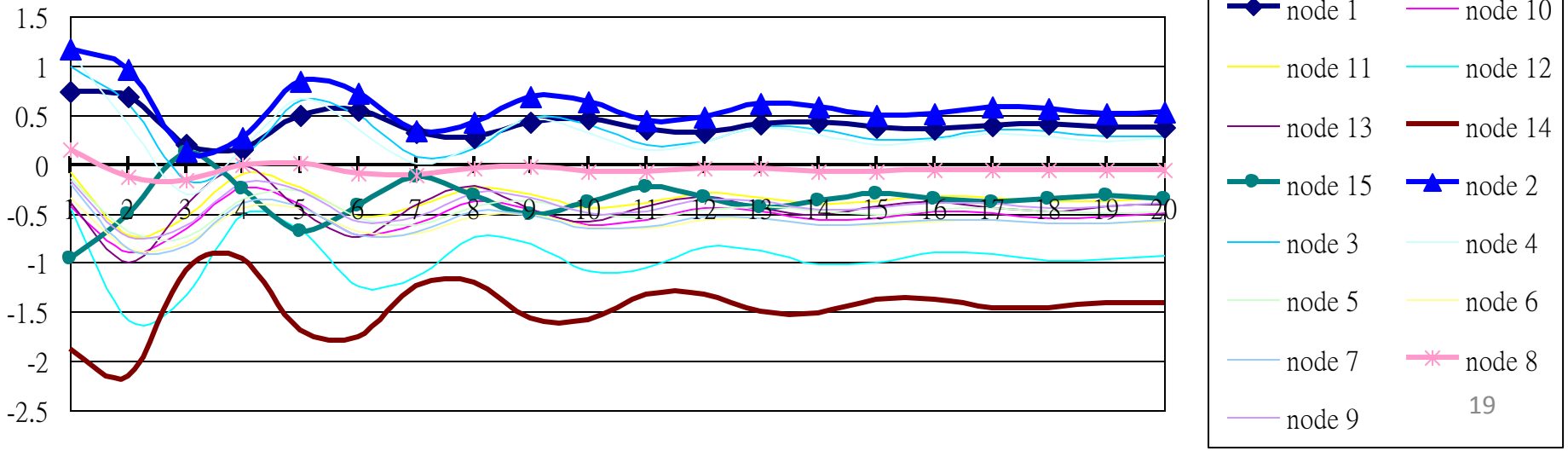
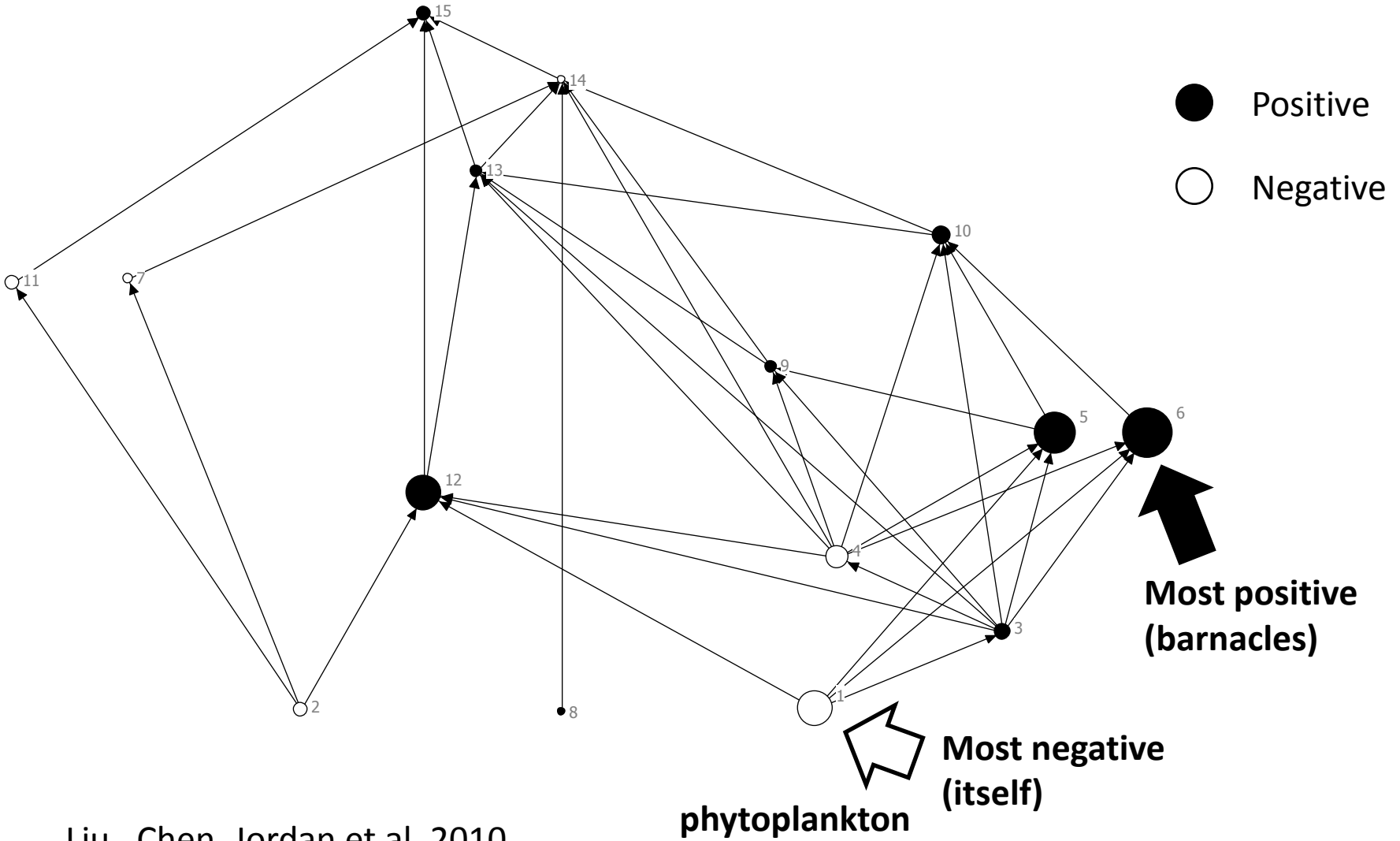


Table of the cumulative net effects from 1 to 20 steps

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-0.13	-0.03	0.04	-0.07	0.15	0.2	-0.02	0	0.02	0.05	-0.03	0.13	0.02	0	0.03
2	-0.02	-0.25	-0.01	-0.01	-0.01	-0.01	0.35	-0.03	-0.01	-0.01	0.31	0.1	-0.01	0.02	0.11
3	-0.28	0	-0.12	0.02	0.06	0.12	-0.03	-0.05	0.15	0.14	-0.04	0.06	0.16	0.05	0.06
4	-0.03	0.01	-0.19	-0.12	0.09	0.14	-0.07	-0.13	0.1	0.11	-0.04	0.08	0.11	0.13	0.07
5	-0.15	0.02	-0.11	-0.13	-0.12	-0.12	0	-0.01	0.13	0.09	0.01	-0.06	-0.01	0.01	-0.01
6	-0.16	0.01	-0.1	-0.11	-0.08	-0.12	0.01	0.01	-0.05	0.1	0.01	-0.05	-0.03	-0.01	-0.02
7	0	-0.23	0.01	0	0.01	0.01	-0.16	-0.1	-0.01	-0.01	-0.11	-0.03	-0.02	0.1	-0.02
8	0	0.02	0.01	-0.01	0.01	0	-0.05	-0.11	-0.02	-0.01	0	0	-0.02	0.11	0.02
9	0.07	0.03	-0.06	-0.1	-0.18	0	-0.03	-0.09	-0.1	-0.08	0	-0.03	0.07	0.09	0.03
10	0.11	0.02	-0.04	-0.07	-0.16	-0.22	-0.03	-0.09	-0.09	-0.11	-0.01	-0.01	0.08	0.09	0.03
11	0.01	-0.22	0.01	0.01	0	0.01	-0.09	0.03	0.02	0.01	-0.19	-0.06	-0.02	-0.03	0.17
12	-0.16	-0.2	-0.09	-0.09	-0.05	-0.07	-0.07	0.05	-0.05	-0.05	-0.18	-0.13	0.06	-0.05	0.17
13	0.03	0.07	-0.04	-0.06	0.06	0.02	0.02	-0.03	-0.19	-0.16	-0.05	-0.17	-0.12	0.04	0.17
14	-0.03	0.11	0.04	-0.05	0.04	0.02	-0.32	-0.76	-0.11	-0.09	-0.01	0.02	-0.16	-0.23	0.15
15	0.02	0.11	0.01	0.03	-0.01	0.01	0.11	0.09	0.05	0.04	-0.36	-0.09	-0.1	-0.09	-0.16

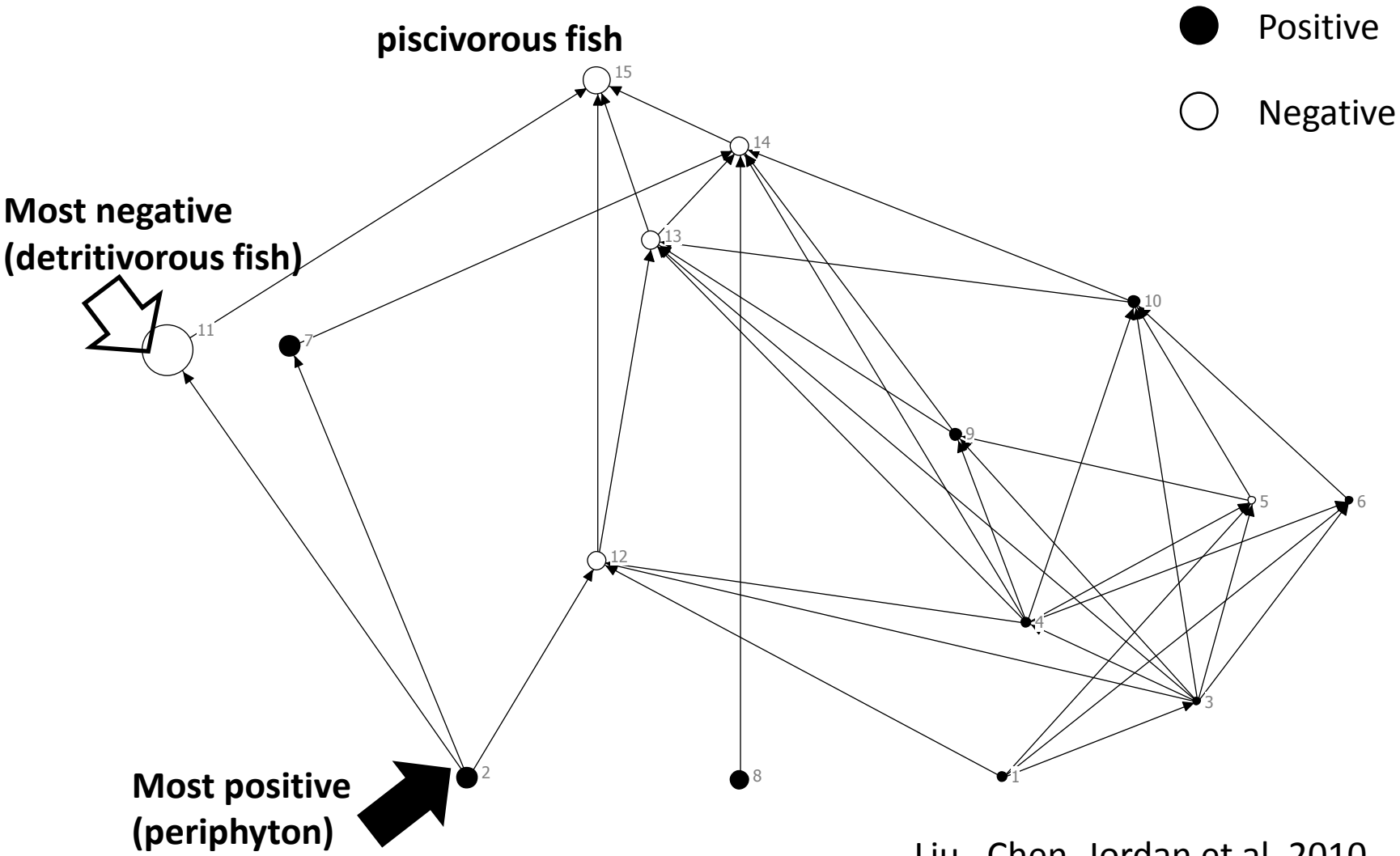
The matrix of the signed interaction magnitude (SIM) based on food web topology along

The effects from a basal species (phytoplankton, node 1)



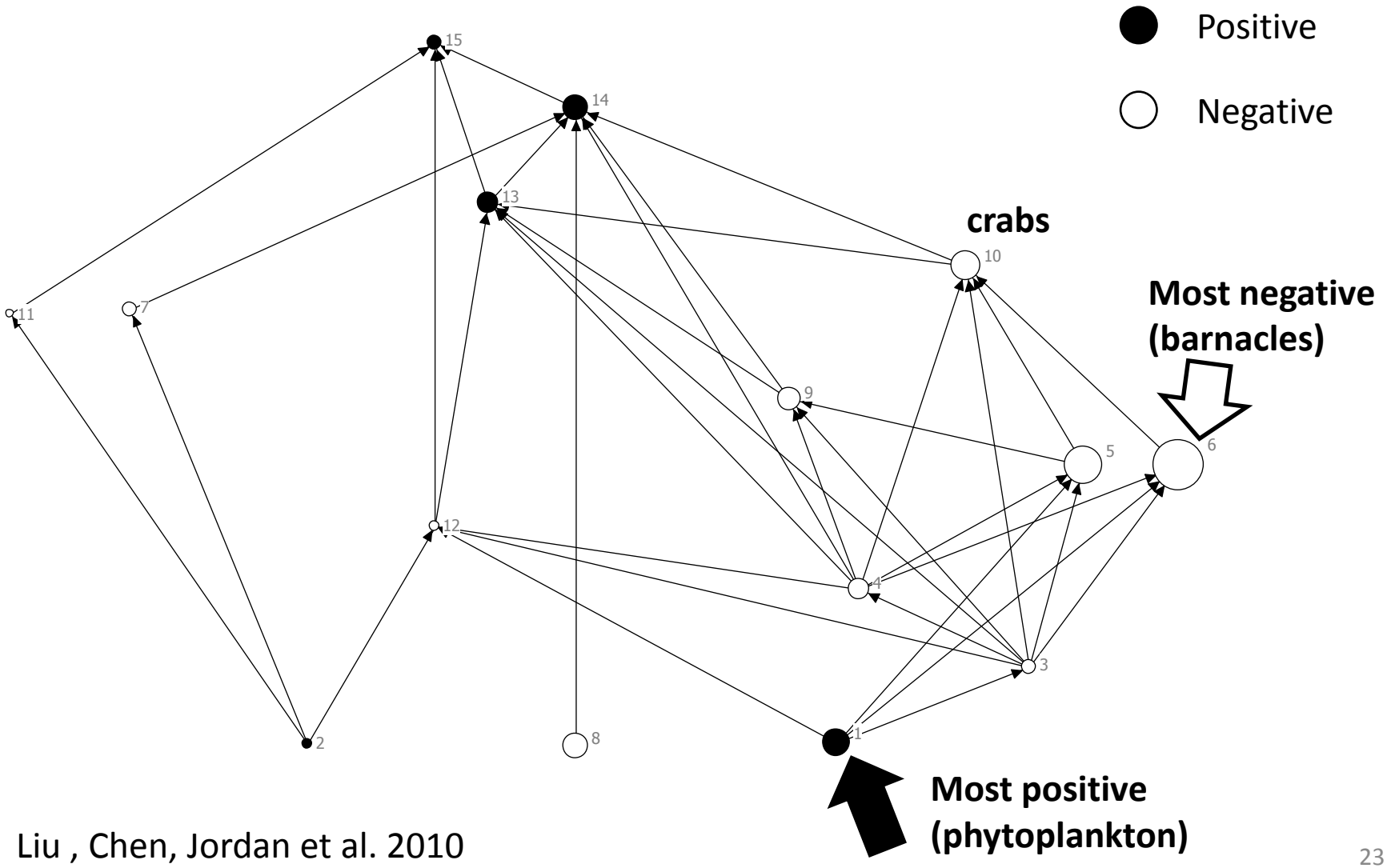
Liu , Chen, Jordan et al. 2010

The effects from a top species (piscivorous fish, node 15)



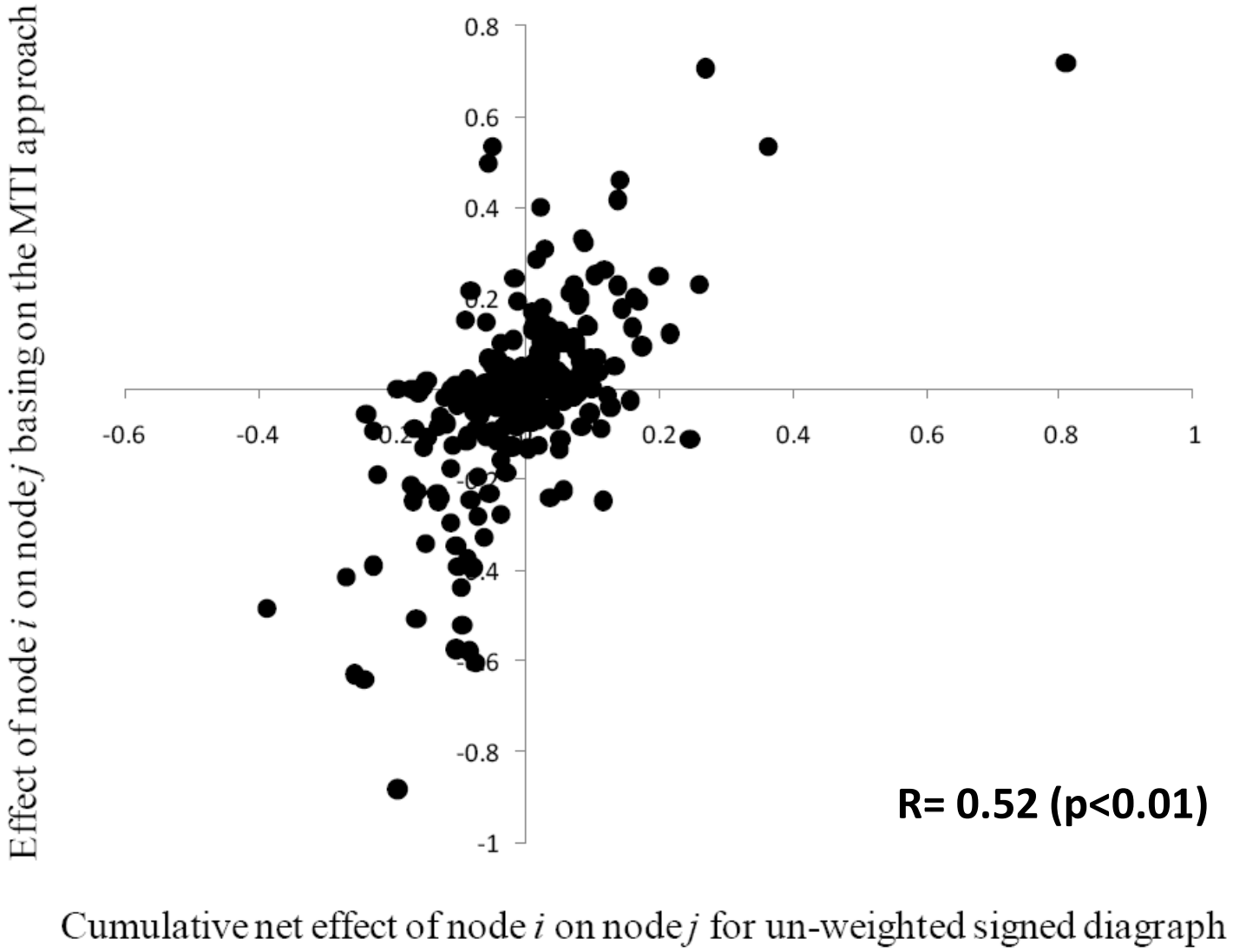
Liu , Chen, Jordan et al. 2010

The effects from a middle species (crabs, node 10)



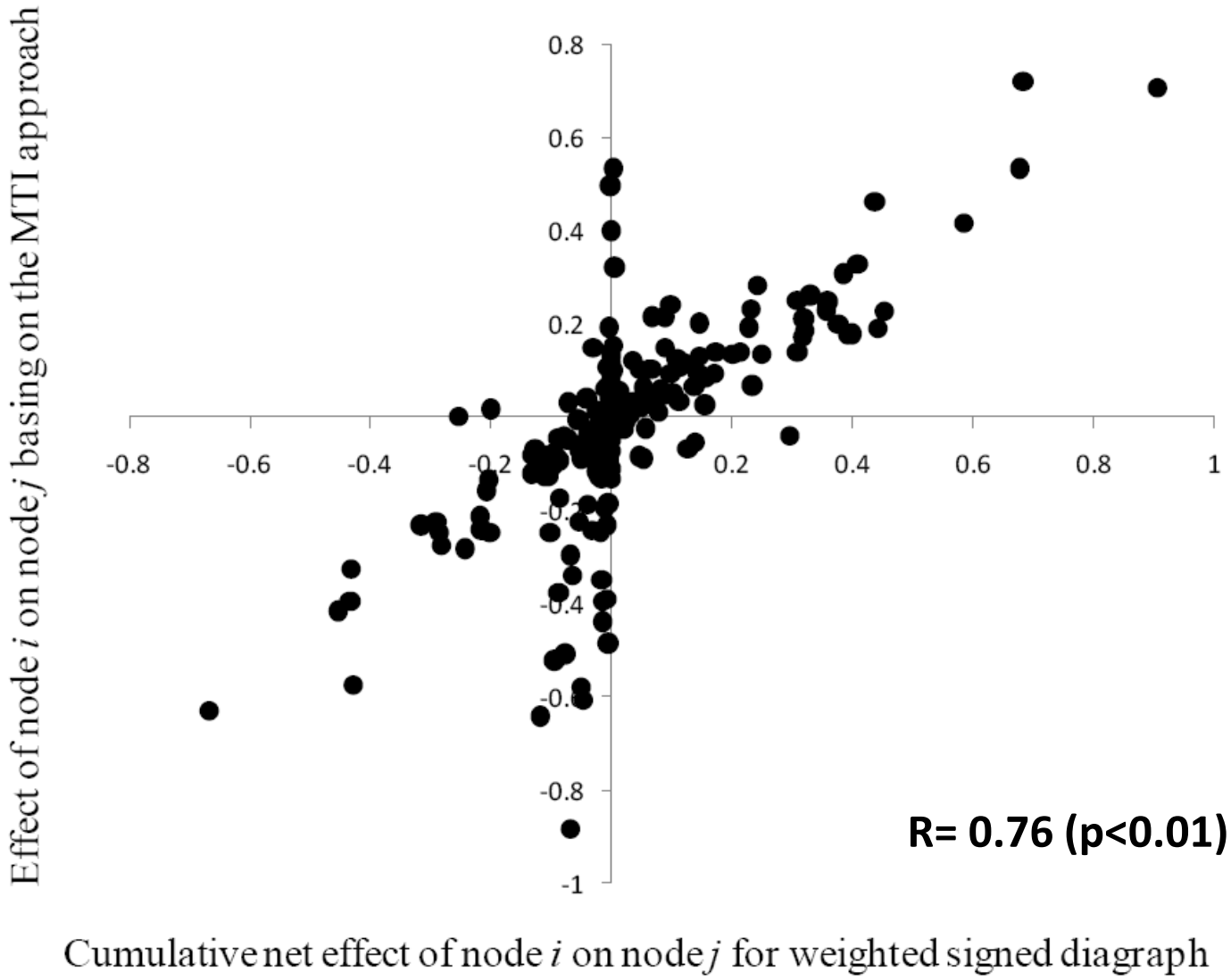
Liu , Chen, Jordan et al. 2010

MTI vs. signed interaction magnitude (SIM)



Liu , Chen, Jordan et al. 2010

MTI vs. weighted SIM



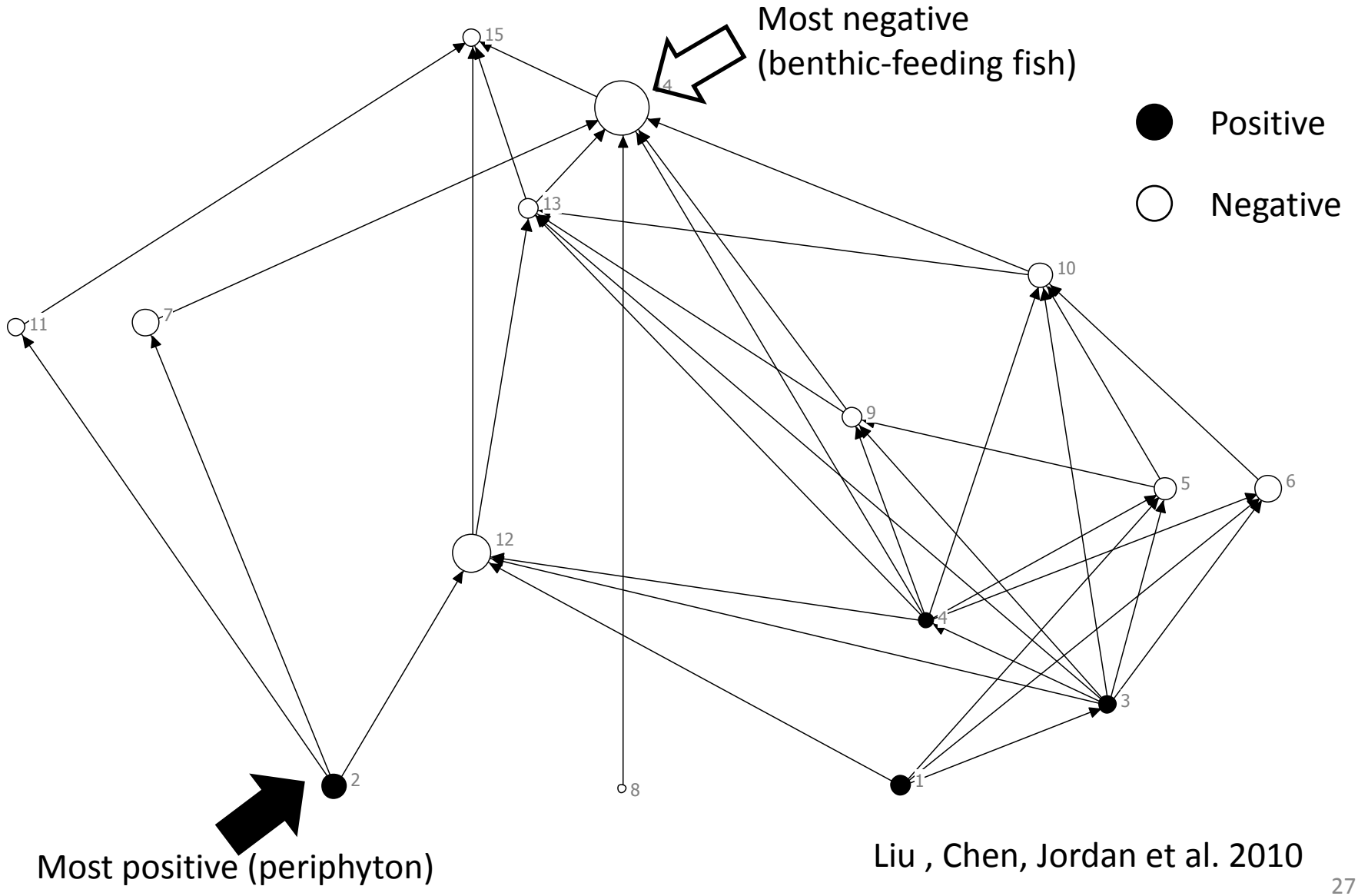
Liu , Chen, Jordan et al. 2010

The overall effect from a node to system (1-20 step)

	1	2	3	4	5	6	7	8	9	10	11	12	13	Row Sum
1	-0.13	-0.03	0.04	-0.07	0.15	0.2	-0.02	0	0.02	0.05	-0.03	0.13	0.02	0.37
2	-0.02	-0.25	-0.01	-0.01	-0.01	-0.01	0.35	-0.03	-0.01	-0.01	0.31	0.1	-0.01	0.53
3	-0.28	0	-0.12	0.02	0.06	0.12	-0.03	-0.05	0.15	0.14	-0.04	0.06	0.16	0.29
4	-0.03	0.01	-0.19	-0.12	0.09	0.14	-0.07	-0.13	0.1	0.11	-0.04	0.08	0.11	0.27
5	-0.15	0.02	-0.11	-0.13	-0.12	-0.12	0	-0.01	0.13	0.09	0.01	-0.06	-0.01	-0.47
6	-0.16	0.01	-0.1	-0.11	-0.08	-0.12	0.01	0.01	-0.05	0.1	0.01	-0.05	-0.03	-0.58
7	0	-0.23	0.01	0	0.01	0.01	-0.16	-0.1	-0.01	-0.01	-0.11	-0.03	-0.02	-0.56
8	0	0.02	0.01	-0.01	0.01	0	-0.05	-0.11	-0.02	-0.01	0	0	-0.02	-0.06
9	0.07	0.03	-0.06	-0.1	-0.18	0	-0.03	-0.09	-0.1	-0.08	0	-0.03	0.07	-0.39
10	0.11	0.02	-0.04	-0.07	-0.16	-0.22	-0.03	-0.09	-0.09	-0.11	-0.01	-0.01	0.08	-0.49
11	0.01	-0.22	0.01	0.01	0	0.01	-0.09	0.03	0.02	0.01	-0.19	-0.06	-0.02	-0.34
12	-0.16	-0.2	-0.09	-0.09	-0.05	-0.07	-0.07	0.05	-0.05	-0.05	-0.18	-0.13	0.06	-0.92
13	0.03	0.07	-0.04	-0.06	0.06	0.02	0.02	-0.03	-0.19	-0.16	-0.05	-0.17	-0.12	-0.41
14	-0.03	0.11	0.04	-0.05	0.04	0.02	-0.32	-0.76	-0.11	-0.09	-0.01	0.02	-0.16	-1.4
15	0.02	0.11	0.01	0.03	-0.01	0.01	0.11	0.09	0.05	0.04	-0.36	-0.09	-0.1	-0.35

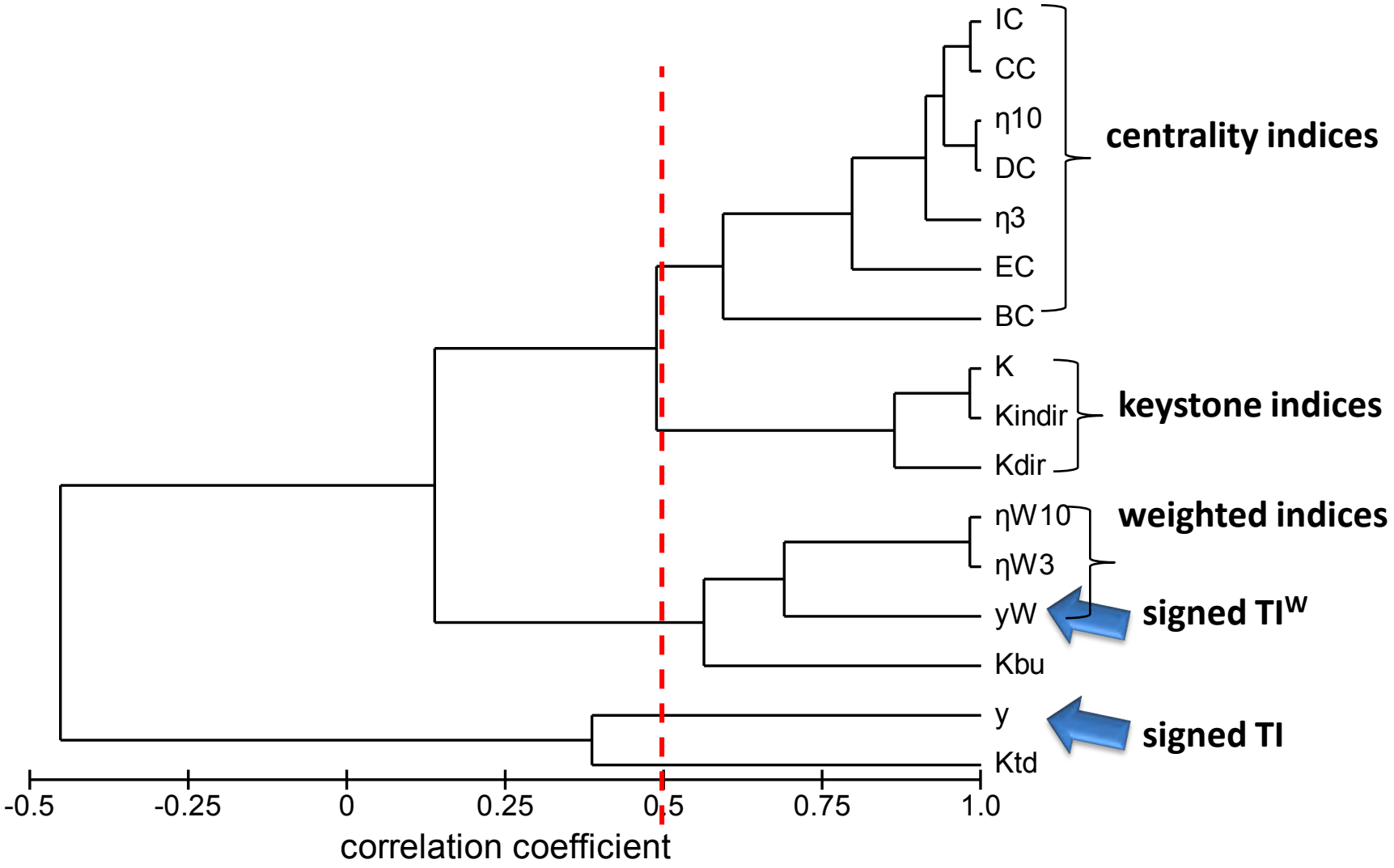
A new food web topological index (signed TI)

Effects exerted by species (signed TI) in food web



Liu , Chen, Jordan et al. 2010

Signed TI vs. other food web network indices



Modified from Liu , Chen, Jordan et al. 2010

Conclusion Remarks

- **The signed diagraph method provides a simple, intuitive way to reckon the species interaction structure based on the structural food web along.**

- **The matrix of signed interaction magnitude (SIM) seem comparable with the mixed trophic index (MTI), which is based on the mass-balanced model.**

- **While the dynamics nature of complex ecosystem can not be fully represented by simple static food web structure,**

- **our approach do provide a handy alternative means to assess species interaction and potential management consequences in species-rich, reticulate food webs.**

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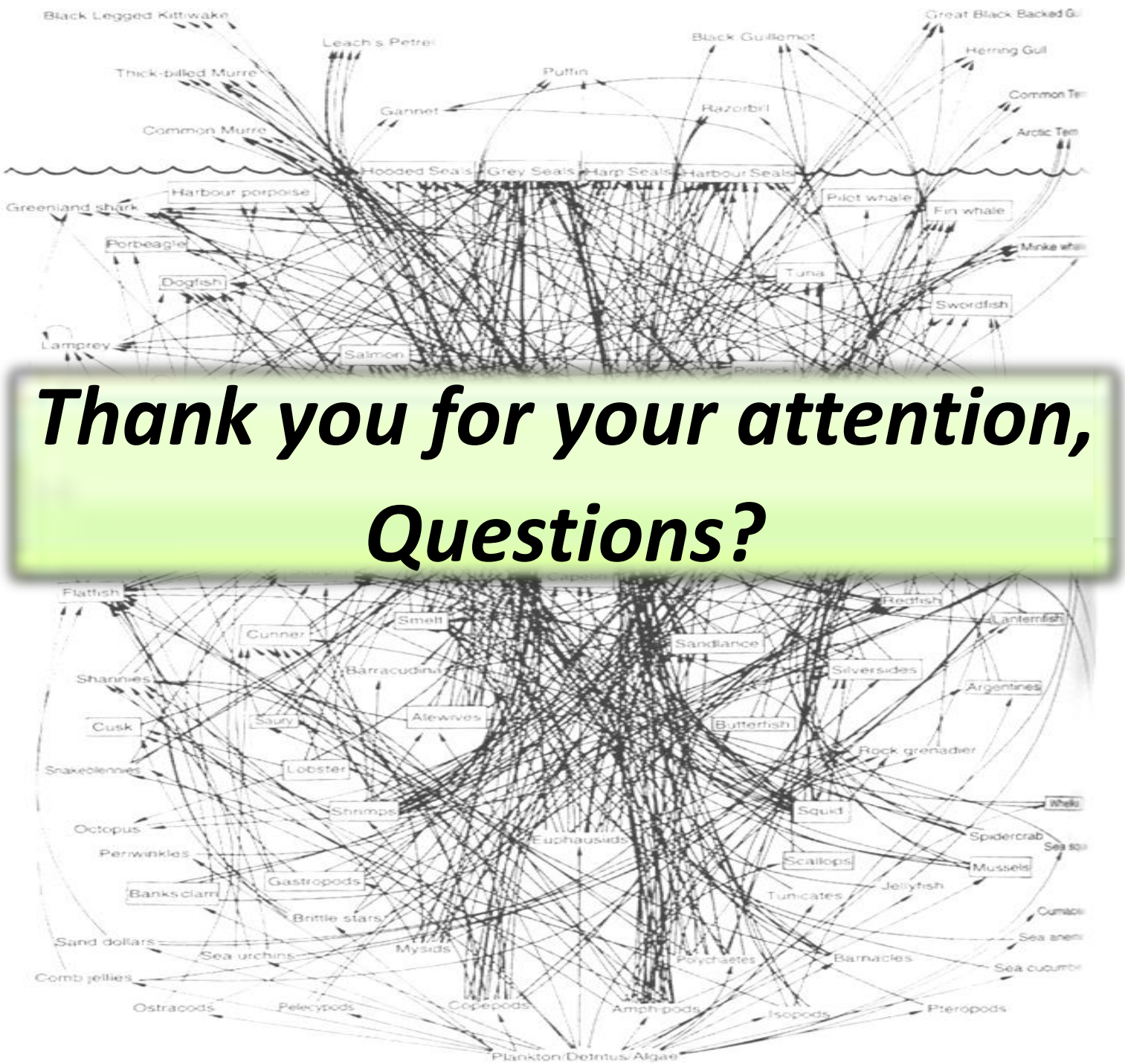
- My supervisors: Dr. Kwang-Tsao Shao, Biodiversity Research Center, Academia Sinica. Professor Shou-Hsien Li, Dept. of Life Science, National Taiwan Normal University.
- Food web data used here is published and provided by Dr. Hsing-Juh Lin, National Chung-Hsin University.
- I am also grateful for the travel fund provided by Academia Sinica for this meeting and the food web research grant to KHS from National Science Council, Taiwan.
- A pack of programs to generate the species interaction matrix based on food web topologies presented here can be requested via emails made to me (chen7@sinica.edu.tw) or Dr. W.-C. Liu (wliu56@gate.sinica.edu.tw).
- The research presented here is part of my doctoral research conducted together with W.-C. Liu, W.-S. Lin and F. Jordan. Also, part of this research has published recently and can be cited as “Liu, W.-C., H.-W. Chen, F. Jordan, W.-H. Lin, and C. W.-J. Liu. 2010. Quantifying the interaction structure and the topological importance of species in food webs: A signed digraph approach. Journal of Theoretical Biology 267:355-362. “



Thank you for your attention, Questions?