Network Applications

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Assessing the cumulative environmental impact of hydropower construction on river systems based on energy network model

- Shaoqing Chen, Bin Chen, Brian D. Fath

Renewable and Sustainable Energy Reviews 42 (2015) 78–92

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

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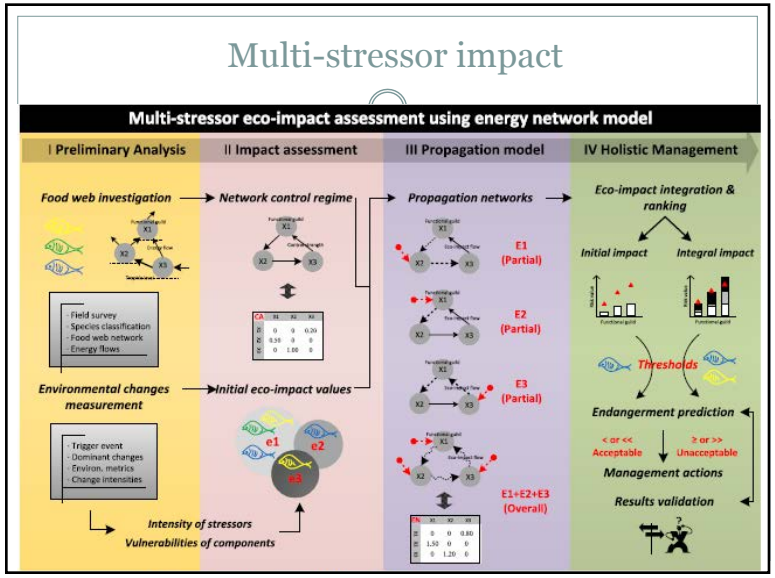

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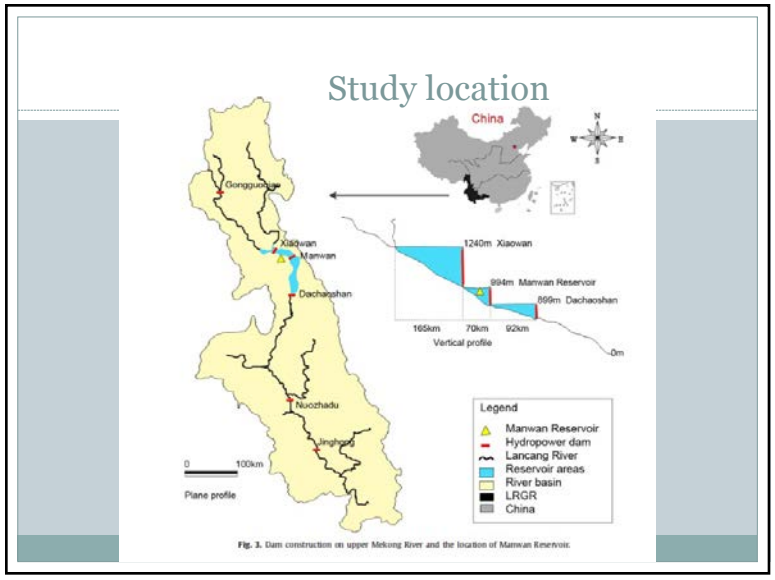

Fig. 3. Dam construction on upper Mekong River and the location of Manwan Reservoir.

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Ecosystem Food web

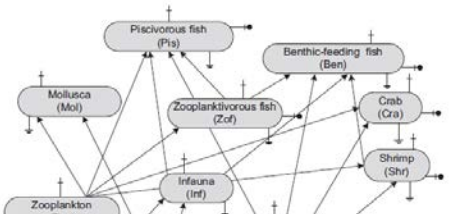

Table 1
Energy flow matrix of the Manwan Reservoir ecosystem (kJ m^{-2} yr^{-1}).

Donor /receptor	Pis	Det	Phy	Zop	Ben	Her	Cra	Shr	Mic	Mol	Zof	Inf	Input
Pis	0	2.4	0.3	2.6	0	1.5	1.0	2.0	0.3	0	0.6	0.5	0
Det	4.1	0	810.0	182.0	18.0	25.0	22.0	24.0	19.0	38.0	0	0	395.0
Phy	0	0	0	0	0	0	0	0	0	0	0	0	2607.0
Zop	0	344.0	254.0	0	0	0	0	0	0	0	0	0	0
Ben	0	0	0	41.0	0	0	0	8.0	0	0	3.8	13.2	0
Her	0	12.0	42.0	0	0	0	0	0	3.0	0	0	0	0
Cra	0	30.0	0	36.0	0	0	0	0	0	0	0	0	0
Shr	0	12.0	0	38.0	0	0	0	0	6.0	0	0	14.0	0
Mic	0	0	0	0	0	0	0	0	0	0	0	0	310.3
Mol	0	59.0	0	75.0	0	0	0	0	5.0	0	0	0	0
Zof	0	0	0	32.0	0	0	0	0	0	0	0	0	0
Inf	0	32.0	44.0	0	0	0	0	0	0	0	0	0	0
Output	7.1	1046.0	1457.0	191.4	48.0	30.5	43.0	36.0	277.0	101.0	27.6	48.3	0

The size of compartment is proportional to the total throughflow (i.e., total input or total output), and the thickness of the arrow is proportional to the magnitude of the energy flow. Fig. S4 shows the topology and structure of the energy flow model.

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Network control digraph

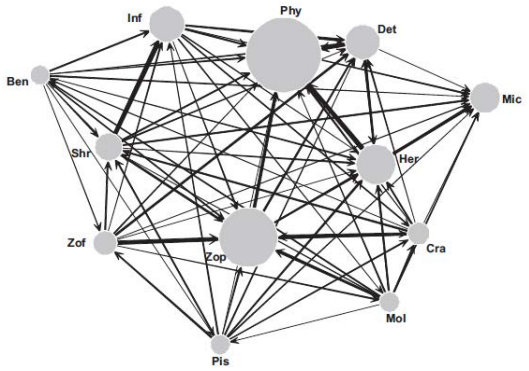

Fig. 5. Network control digraph of Manwan Reservoir ecosystem. *Note*: The size of compartment is proportional to the total control allocation coming from it, and the thickness of the arrow is proportional to the magnitude of the non-dimensional control flow.

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Initial eco-impacts

Table 3
Calculation of the initial eco-impacts caused by dam construction.

Environmental factor	Measurement of factors before/after damming	[a]Change of factor (ΔI_k)	[b]Probability (P_k)	[c]Vulnerable compartment/ Vulnerability (V_{ik})	Initial eco-impact (e_{i0})
Sedimentation (the amount of sediment trapped in a year)	6.02 /9.20 10^6 m^3	$\frac{\lvert I_{sed}-I_{0sed}\rvert}{\max(I_{sed}-I_{0sed})}$ $=\frac{\lvert 9.20-6.02\rvert}{9.20}$	1.00	Ben/1.00 Mic/1.00 Inf/0.60 Mol/0.36	0.350 0.350 0.210 0.126
Mean discharge in dry/wet season	1699 /2283 $m^3\ s^{-1}$	$\frac{\lvert I_{dis}-I_{0dis}\rvert}{\max(I_{dis}-I_{0dis})}$ $=\frac{\lvert 2283-1699\rvert}{2283}$	0.70	Zof/1.00 Zop/0.60 Phy/0.36 Pis/0.22 Her/0.22	0.175 0.105 0.063 0.039 0.039
Pb content in water body	0.006 /0.025 $mg\ kg^{-1}$	$\frac{\lvert I_{pb}-I_{0pb}\rvert}{\max(I_{pb}-I_{0pb})}$ $=\frac{\lvert 0.025-0.006\rvert}{0.025}$	0.82	Phy/1.00 Zop/0.47 Shr/0.13 Cra/0.09 Her/0.07 Mic/0.06 Zof/0.04 Pis/0.03	0.623 0.293 0.081 0.056 0.044 0.037 0.025 0.019

[a] The calculation of impact intensity is based on the comparison of pre-dam (1994) and post-dam (2004) situations).
[b,c] Calculation details of probability and species vulnerability were given in Table S1.

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Effect of sedimentation

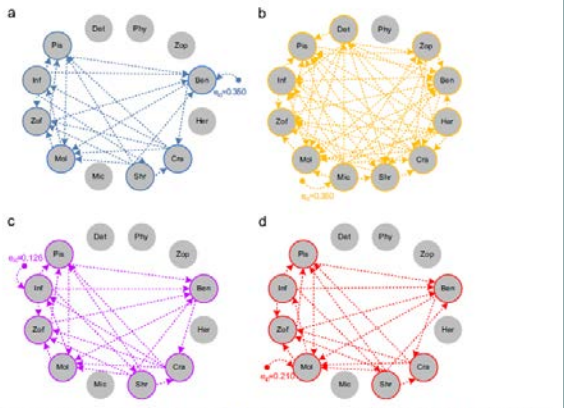

Fig. 6. Propagation of eco-impact within the reservoir ecosystem due to the effect of sedimentation on (a) benthic-feeding fish, (b) benthic microalgae, (c) infauna, and (d) molluscs.

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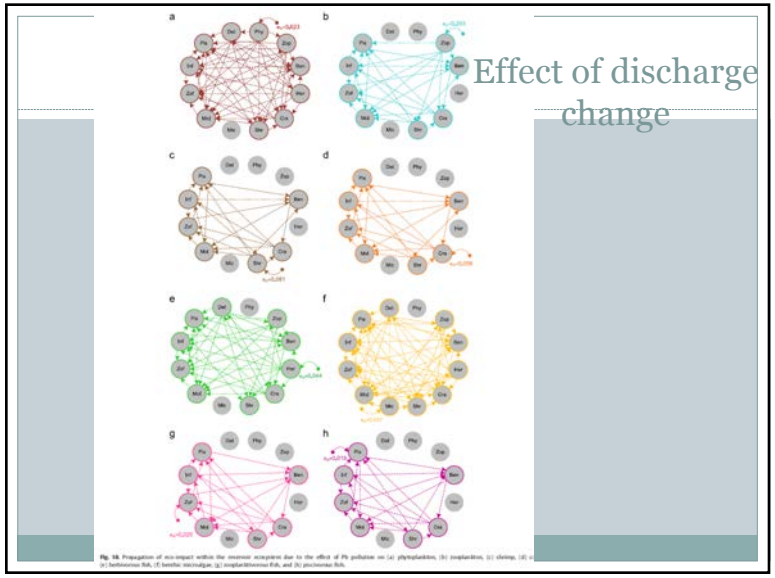

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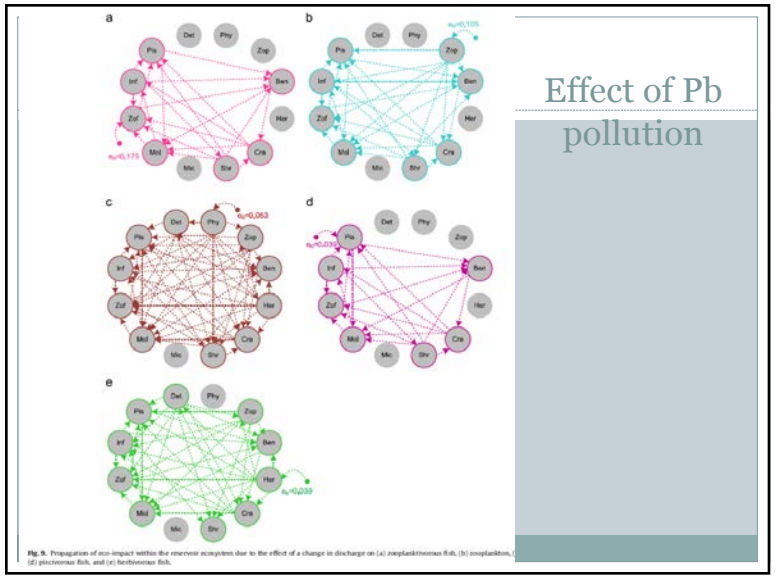

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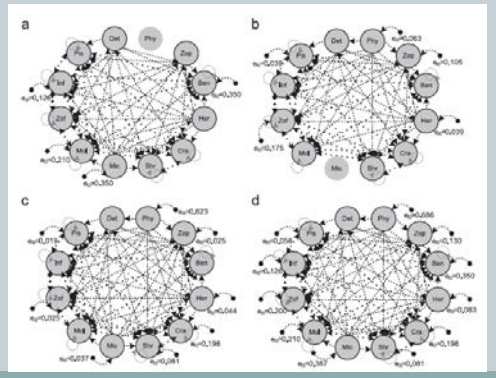
Cumulative Impacts



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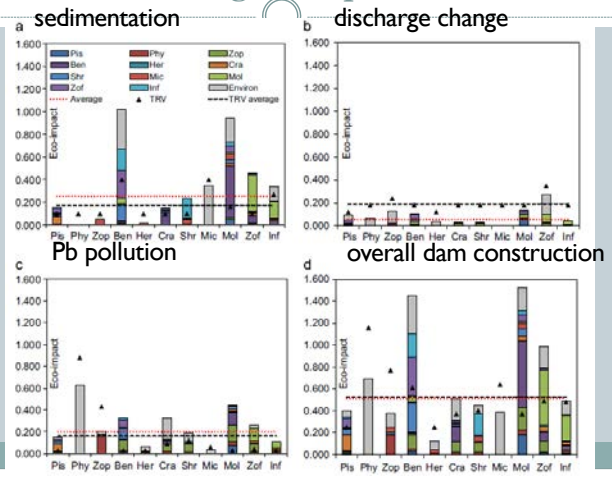
Integral Impacts



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Journal of Environmental Management 190 (2017) 243–251

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Research article

Coupling ecological and social network models to assess "transmission" and "contagion" of an aquatic invasive species

Danielle M. Haak [a, *], Brian D. Fath [b, c], Valery E. Forbes [d], Dustin R. Martin [e], Kevin L. Pope [f]

Danielle Haak – YSSP 2014

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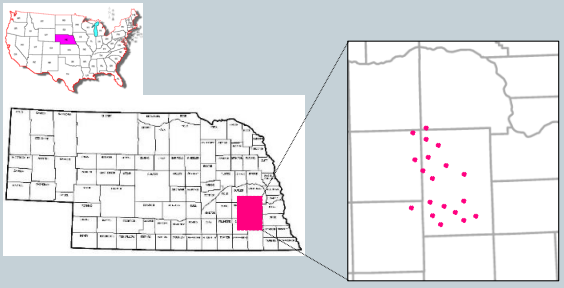
Motivations

1. Provide resilient fishery to anglers in Southeast Nebraska



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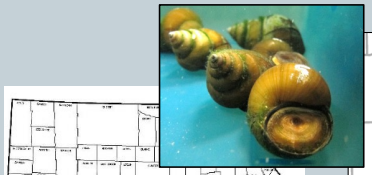
Motivations

1. Provide resilient fishery to anglers in Southeast Nebraska
2. Prevent introductions of non-native species

Chinese mystery snail



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Novel approach

Social network for region: depicting human movement

Social network
Ecological network → Coupled network

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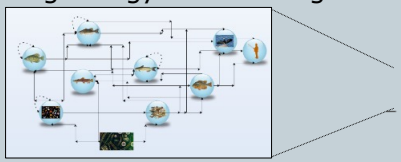
Novel approach

Social network for region: depicting human movement

Ecological networks for individual lakes: depicting energy flows through food web



Social network
Ecological network → Coupled network

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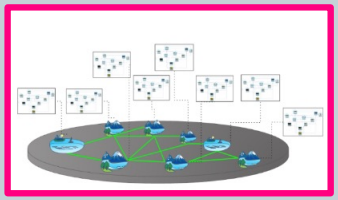
Research question

How can we utilize network analysis to analyze ecological effects and movement of invasive species?



Social network
Ecological network → **Coupled network**

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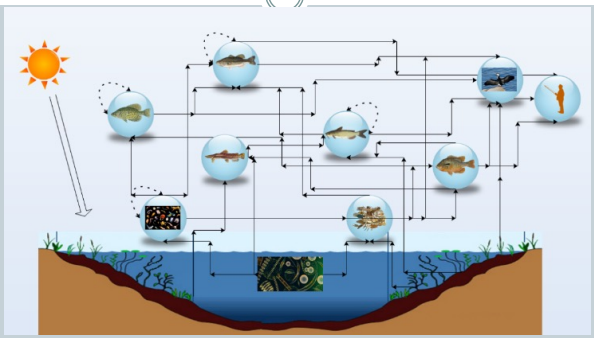
Development of trophic food webs



Social network
Ecological network
Coupled network

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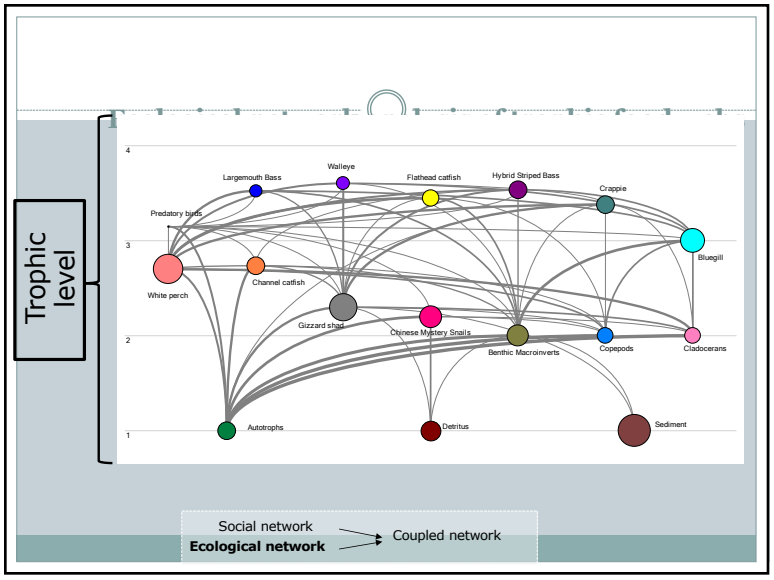

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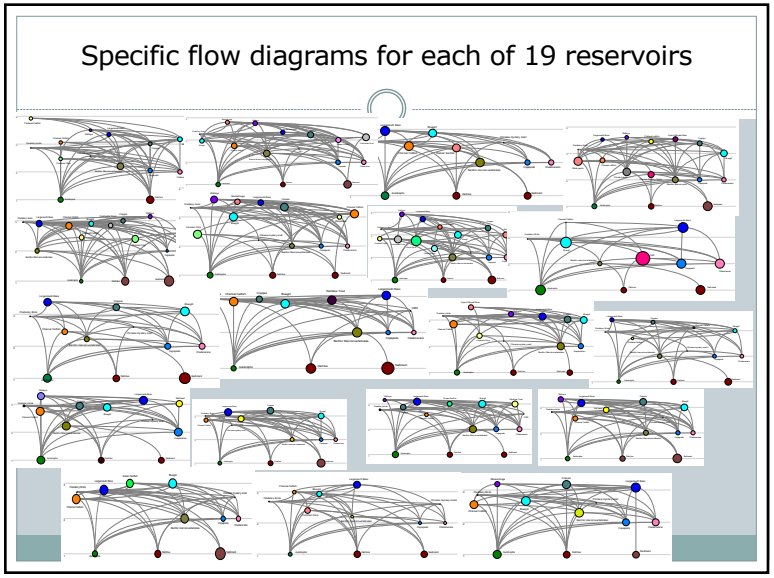
Specific flow diagrams for each of 19 reservoirs

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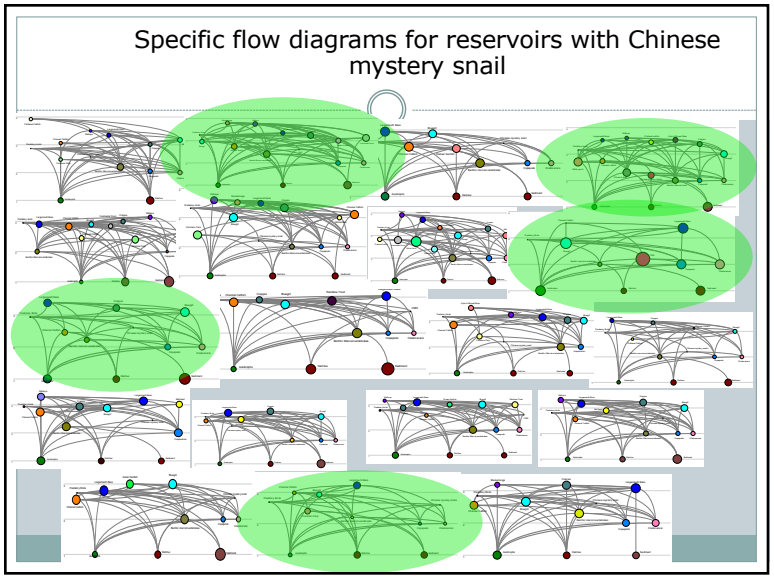
Specific flow diagrams for reservoirs with Chinese mystery snail

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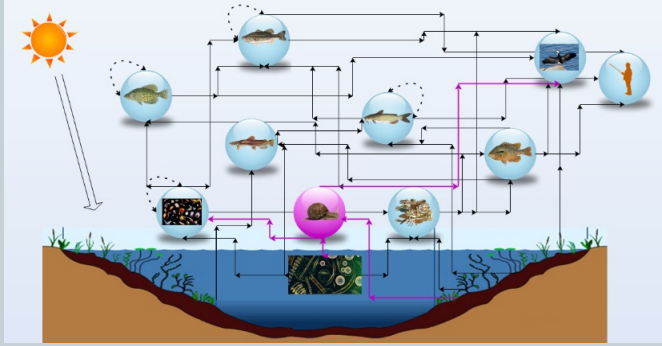
Ecological network analysis of trophic food webs



Social network
Ecological network
→ Coupled network

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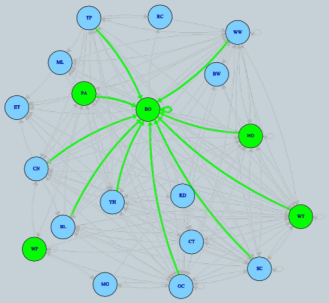
Social networks inform movement of invasive species through angler movements

"At which Salt Valley, Nebraska water body did you last fish with your boat?"

Reservoir with Chinese mystery snail

Reservoir without Chinese mystery snail



Data from Martin 2013

Social network
Ecological network
→ Coupled network

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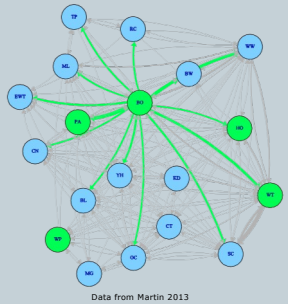
Social networks inform movement of invasive species through angler movements

"If this reservoir closed right now, where would you relocate to?"

Reservoir with Chinese mystery snail

Reservoir without Chinese mystery snail



Data from Martin 2013

Social network
Ecological network
→ Coupled network

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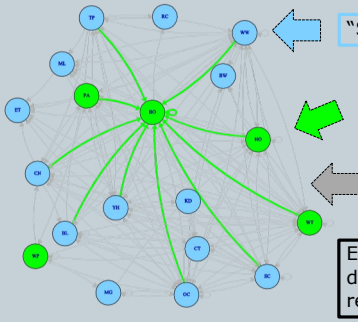
How can we couple them?

- Infectious disease network models



"Susceptible" reservoir

"Infected" reservoir

Weighted connections used to determine "transmission" rates

Ecological models used to determine "incubation" time before reservoir becomes "contagious"

Social network
Ecological network
→ **Coupled network**

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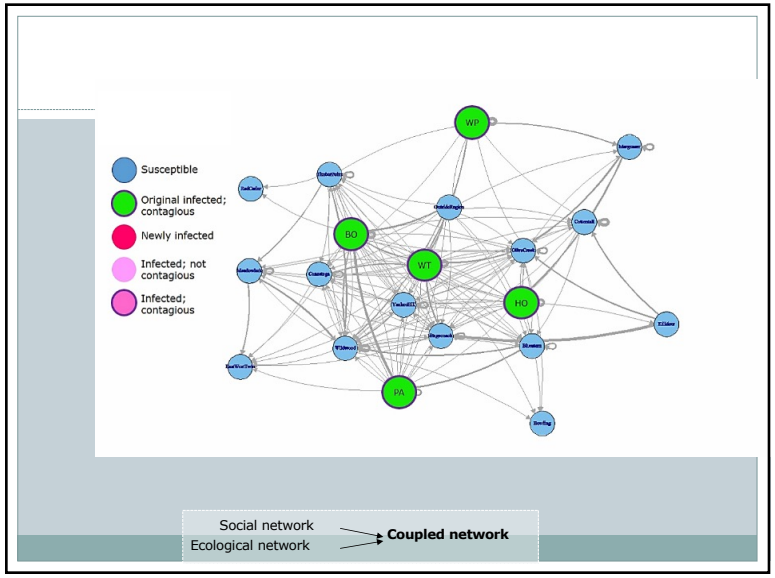
Susceptible
Original infected; contagious
Newly infected
Infected; not contagious
Infected; contagious
WP
BO
WT
HO
PA
Social network
Ecological network
Coupled network

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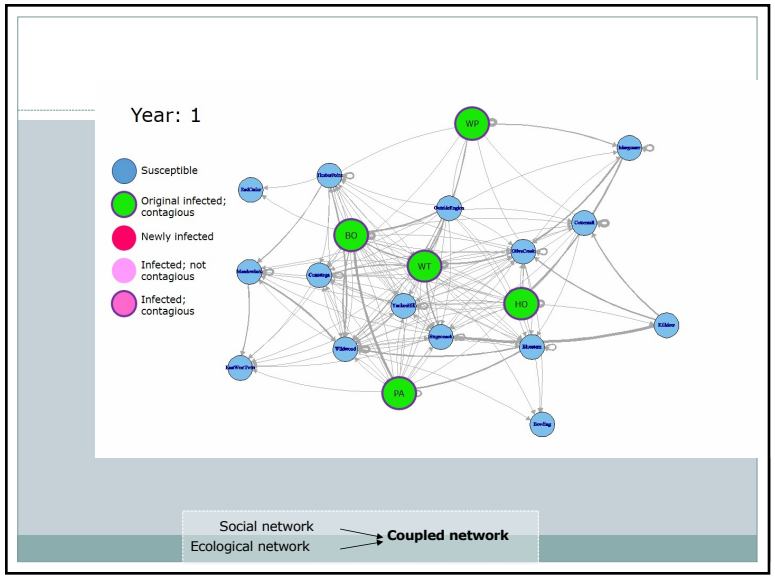
Year: 1
Susceptible
Original infected; contagious
Newly infected
Infected; not contagious
Infected; contagious
WP
BO
WT
HO
PA
Social network
Ecological network
Coupled network

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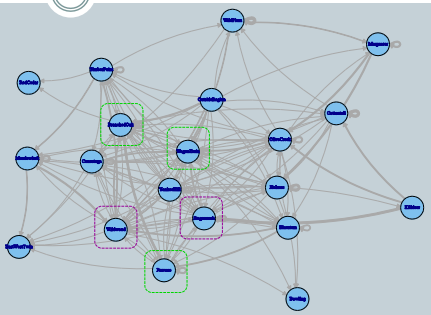
Reservoir prioritization

Prevent outgoing individuals:

1. Wagon Train
2. Branched Oak
3. Pawnee
4. Holmes

Prevent incoming individuals:

1. Wildwood
2. Stagecoach
3. Olive Creek
4. Conestoga
5. Cottontail
6. Yankee Hill
7. Bluestem



Social network
Ecological network
Coupled network

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Economic and trade networks

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Application of Network Utility analysis to economic input-output data:

1. Holistic measure of economic relations
2. New application for I-O analysis
3. Identifies specific sectoral relations
4. Effective for national accounts scale data

Differences between economic and ecological systems

1) More data
2) More nodes
3) More direct connections
4) Still many indirect pathways of influence and dependence – unexpected results

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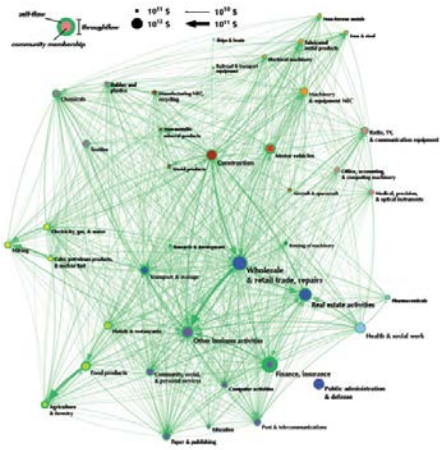
Economic Network – flows of money between industrial sectors of USA



McNerney et al., 2013

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Original Leontief Input-Output Model for U.S. Economy 1947

37 sectors:

agriculture	fuels	other trans equip	finance
food	rubber	science equip	real estate
textile mill	leather	manufacturing	business services
apparel	stone, glass	utilities	repair services
lumber	primary metals	railroad	nonprofits
furniture	fabricated metals	ocean	amusements
paper	machinery	other trans	scrap industries
printing	electric motors	trade	restaurants
chemicals	motor vehicles	communications	new construction

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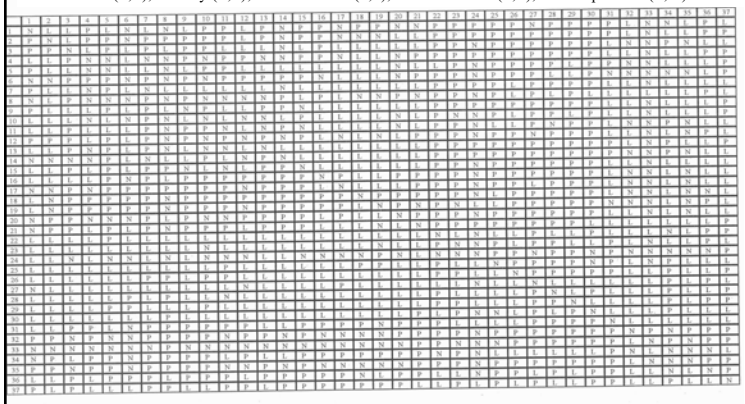
U.S. economy (1947) direct interaction matrix.

P=Predation (+,−); L=Prey (−,+); N=neutralism (0,0); M=mutualism (+,+); K=competition (−, −)



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Direct and Indirect relations in U.S.
Leontief 1947, 37 sector I-O Table

	Neutralism (N)	Exploitation (P)	Exploited (L)	Competition (K)	Mutualism (M)
Direct	281	544	544	0	0
Integral	0	446	446	232	245

Changes between relation types from direct to integral in U.S.

P→P	L→L	N→M	N→P	N→L	N→K	P→L	P→K	P→M	L→P	L→K	L→M
413	413	139	27	27	88	6	72	53	6	72	53

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Sample holistic interactions for each sector

Sector	Mutualism	Predation	Prey	Competition
agriculture	9	14	6	8
food	7	17	5	8
textile mill	3	17	12	5
Apparel	7	15	8	7
Lumber	5	8	15	9
Furniture	4	15	7	11
Paper	6	6	22	3

Sector with most mutualism: printing & restaurants
competition: stone/glass & amusements
predation: other transportation

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Agriculture and Fisheries Sector

Exploits:	Exploited by:	Mutualistic with:	Competition with:
petroleum and coal	food	agriculture	lumber and wood
rubber products	textile	apparel	paper
machinery	printing	furniture	chemicals
motor vehicles	metals	leather	stone and glass
other trans.	communications	electrical	fabricated metals
misc. manufacture	nonprofit	professional equip.	business services
railroad	organizations	electric power	amusements
ocean trans.		scrap ind.	undistributed
other trans.		restaurants	
trade			
finance			
real estate			
repair services			
new construction			

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Urban Metabolism

- Application of network methods and
- Ecological principles to

- Flows of energy and material in cities

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URBAN SYSTEM BOUNDARIES

Open system with connections and dependencies on the countryside

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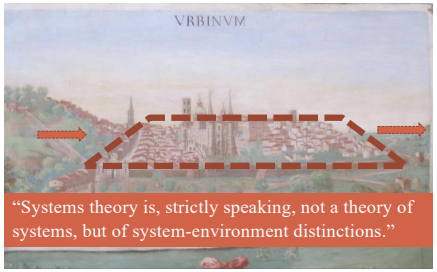
City as system

Inputs: air, water, food, fuels, raw materials, people
Outputs: waste heat, finished goods, ideas, wastewater, solid wastes, air pollutants



"Systems theory is, strictly speaking, not a theory of systems, but of system-environment distinctions."

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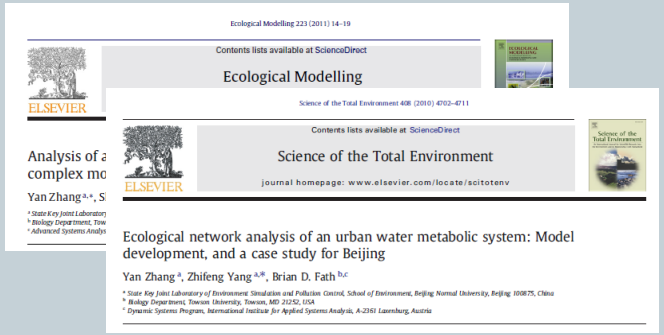
Quantitative analysis of urban metabolism and health



Ecological Modelling 223 (2011) 14–19

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Analysis of a
complex mo

Yan Zhang [a,*], S

[a] State Key Joint Laboratory
[b] Biology Department, Tow
[c] Advanced Systems Analys

Science of the Total Environment 408 (2010) 4702–4711

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Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Ecological network analysis of an urban water metabolic system: Model development, and a case study for Beijing

Yan Zhang [a], Zhifeng Yang [a,*], Brian D. Fath [b,c]

[a] State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China
[b] Biology Department, Towson University, Towson, MD 21252, USA
[c] Dynamic Systems Program, International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria

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Urban Metabolism:
Case study of Four Chinese Cities

Zhang et al. 2010. Ecol. Model.

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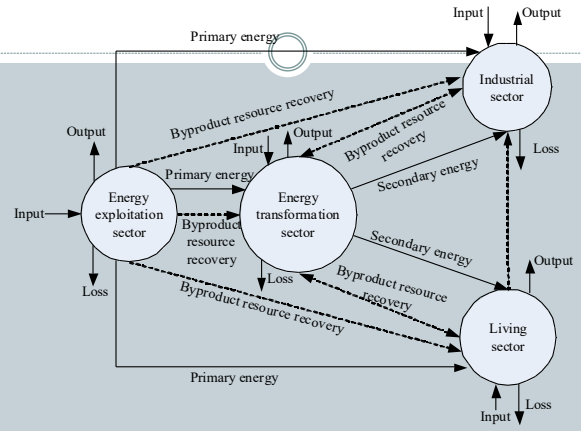

Conceptual model of urban energy metabolic processes

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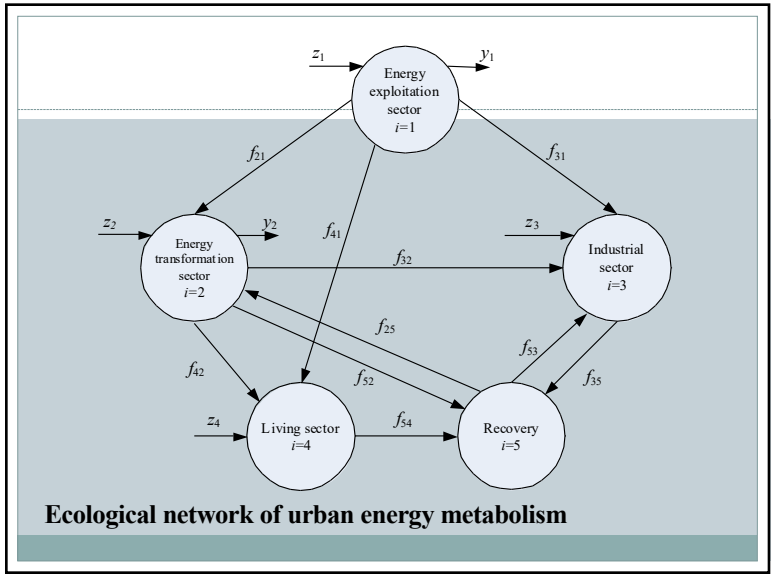

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Direct flows among sectors (units: 10^7 t standard coal eq.)

Beijing (F_B)

	1	2	3	4	5
1	0	0	0	0	0
2	0.087	0	0	0	0
3	0	1.929	0	0	0
4	0	0.080	0	0	0
5	0	0	0	0	0

Shanghai (F_S)

	1	2	3	4	5
1	0	0	0	0	0
2	0.093	0	0	0	1.036
3	0.009	2.946	0	0	0.008
4	0	0.143	0	0	0
5	0	0.004	1.032	0.008	0

Tianjin (F_T)

	1	2	3	4	5
1	0	0	0	0	0
2	0.517	0	0	0	0.080
3	0.024	1.045	0	0	0.119
4	0	0.175	0	0	0
5	0	0	0.199	0	0

Chongqing (F_C)

	1	2	3	4	5
1	0	0	0	0	0
2	1.425	0	0	0	0.082
3	1.514	0.627	0	0	0.346
4	0.106	0	0	0	0
5	0	0.001	0.427	0	0

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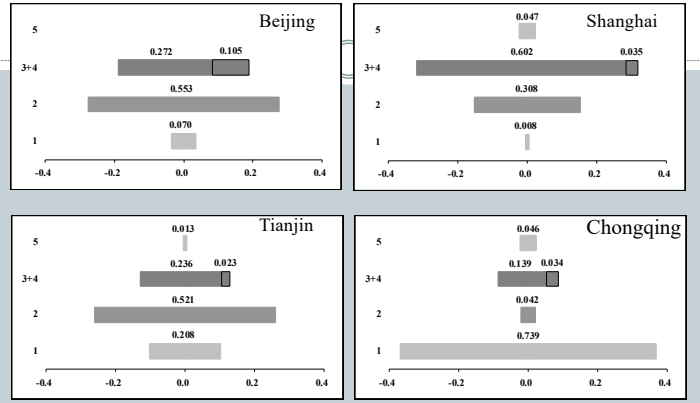

Ecological structure of the urban energy metabolic system.
Sectors: 1 energy exploitation; 2 energy transformation; 3 industrial; 4 household; 5 recovery.

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Water network model of Beijing

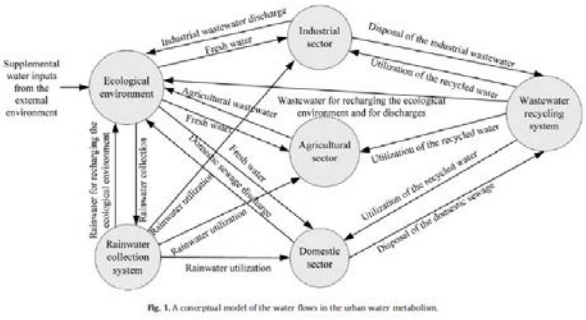

Fig. 1. A conceptual model of the water flows in the urban water metabolism.

Zhang et al. 2011. Science of Tot. Env.

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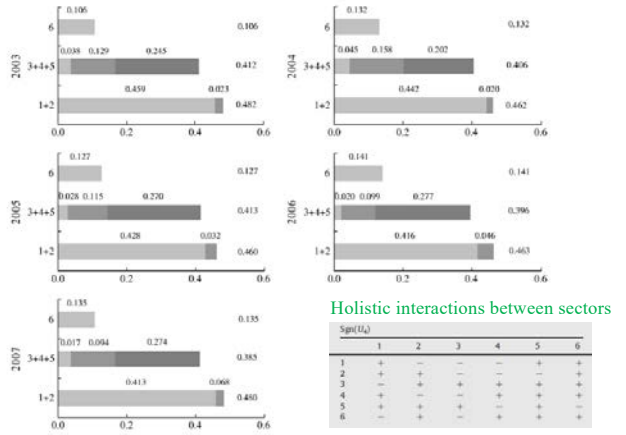
"Trophic" water structure of Beijing



Holistic interactions between sectors

$\mathrm{Sgn}(\Pi_{ij})$	1	2	3	4	5	6
1	+	−	−	−	+	+
2	+	+	−	−	−	+
3	−	+	+	+	+	+
4	+	−	−	+	+	+
5	+	+	+	−	+	−
6	−	+	−	+	+	+

Fig. 3. Summary of the weights of each compartment in Beijing's water metabolic system from 2003 to 2007. Compartments: 1, local ecological environment; 2, rainwater collection sector; 3, industrial sector; 4, agricultural sector; 5, domestic sector; and 6, wastewater recycling sector. The lengths of the bars have been normalized so that each bar or segment of a bar represents the proportion of the total flow (which equals 1.0) for that component. Numbers to the right of the bars represent the total length of that bar.

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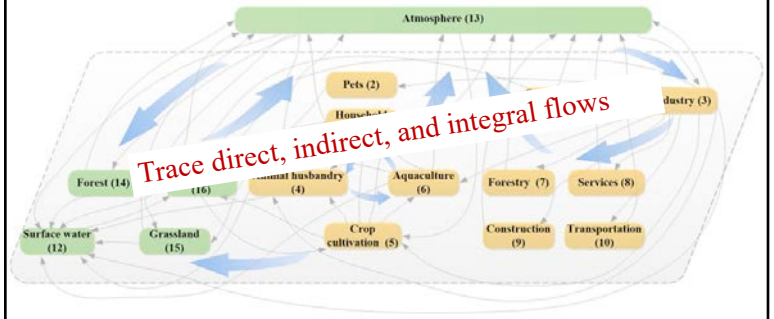
Urban Metabolic Nitrogen model of Beijing



Network model of the nitrogen metabolic processes in Beijing's urban ecosystem

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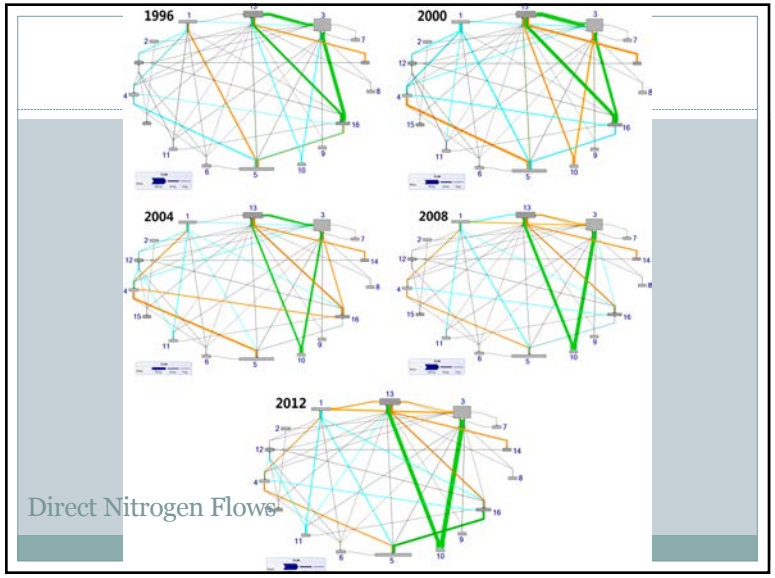
1996
2000
2004
2008
2012
Direct Nitrogen Flows

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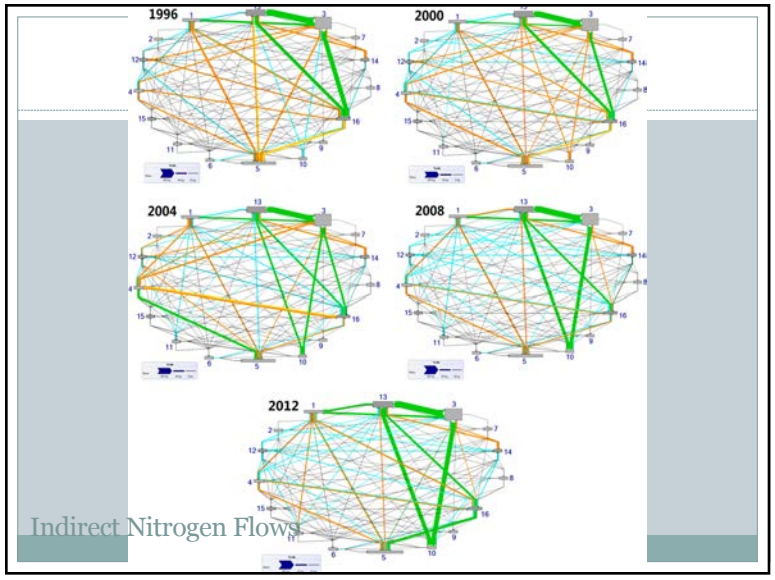
1996
2000
2004
2008
2012
Indirect Nitrogen Flows

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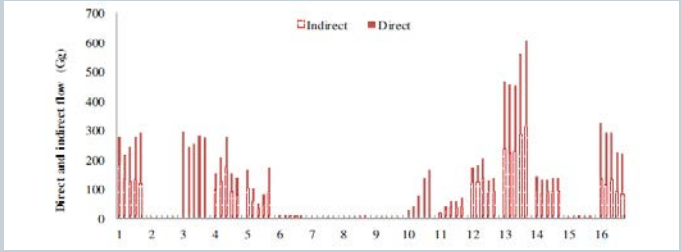
Importance of indirect flows



Metabolic Network tracking of nitrogen flows in Beijing is used to analyze that the major emission sectors were dominated by indirect flows (Animal Husbandry, Crop Cultivation, Sewage Treatment,

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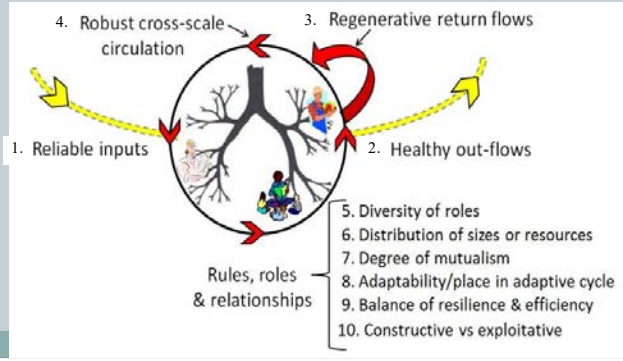
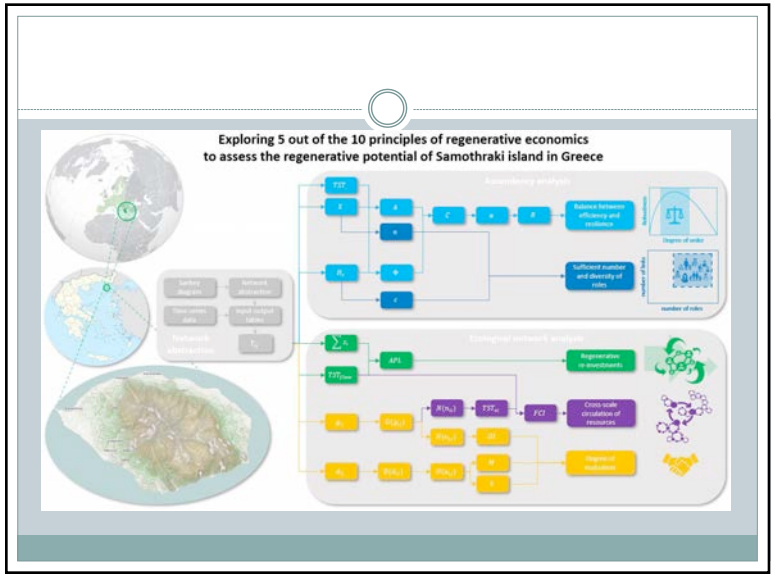
Regenerative economy

Input, Output, and System Dynamics



54


Exploring 5 out of the 10 principles of regenerative economics
to assess the regenerative potential of Samothraki island in Greece

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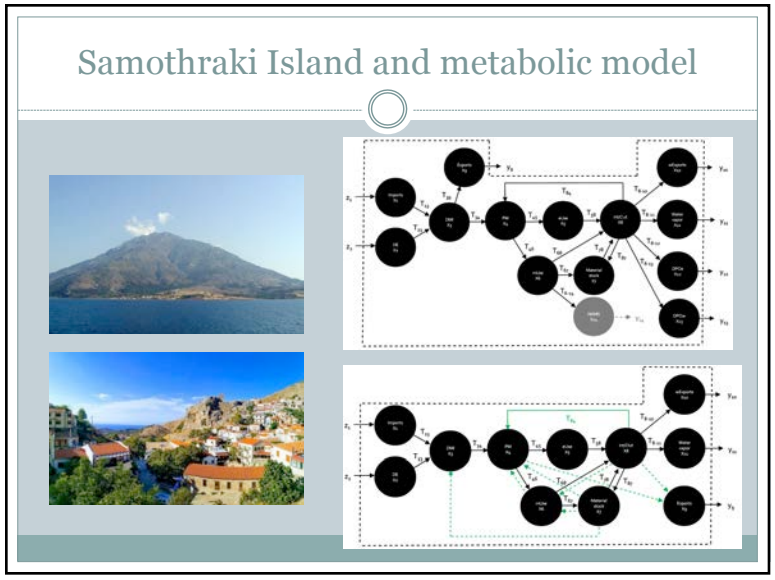
Samothraki Island and metabolic model

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Table 3. Results from scenario analysis compared to the values of 2019.

Principle	Symbol	Units	2019	Scenario 1	2	3
Cross-scale circulation	Σ_{Z_i}	kt/year	56	41	39	40
	TST	kt/year	386	280	269	339
	TST_{flow}	kt/year	273	198	190	259
	APL	-	4.9	4.9	4.8	6.5
Regenerative re-investments	FCI	%	1.3%	1.3%	1.3%	16.4%
Balance between efficiency & resilience	X	bits	2.1	2.1	2.1	1.9
	H_t	bits	0.7	0.7	0.7	1.1
	H	bits	2.8	2.8	2.7	3.1
	A	kt bits/year	799	580	556	661
	Φ	kt bits/year	264	192	183	378
	C	kt bits/year	1,063	772	740	1,039
	α	-	0.751	0.751	0.752	0.636
	R	-	0.215	0.215	0.214	0.288
Sufficient number & diversity of roles	n	-	4.2	4.2	4.2	3.9
	c	-	1.3	1.3	1.3	1.5
Degree of mutualism	Direct flow	-	8	8	8	8
	Total flow	-	25	24	25	39
	Indirect flow	-	17	17	17	31
	DI	-	2.1	2.1	2.1	3.9
	Indirect effects	%	68%	68%	68%	79%
	M	-	1.000	0.989	0.989	1.329
	S	-	1.002	1.013	1.013	1.044

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Conclusions: What do socio-economic networks tell us?

1. Networks are everywhere!
2. Complex networks have many interacting pathways and need new methods to understand
3. Multiple stressors often affect the system (e.g., dam construction, invasives).
4. "Seeing" systems and indirect effects may reduce unintended consequences
5. Linking social and ecological networks provides a "networks of networks" view

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THANK YOU FOR YOUR ATTENTION

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