DEPARTMENT
OF ENVIRONMENTAL
STUDIES

Network analysis:

social, ecological, and social-ecological approaches

FSS:ENSb1315 (Spring 2024)

Yanhua Shi & Harald Waxenecker

Social Network Analysis (SNA)

Ecological Network Analysis (ENA)

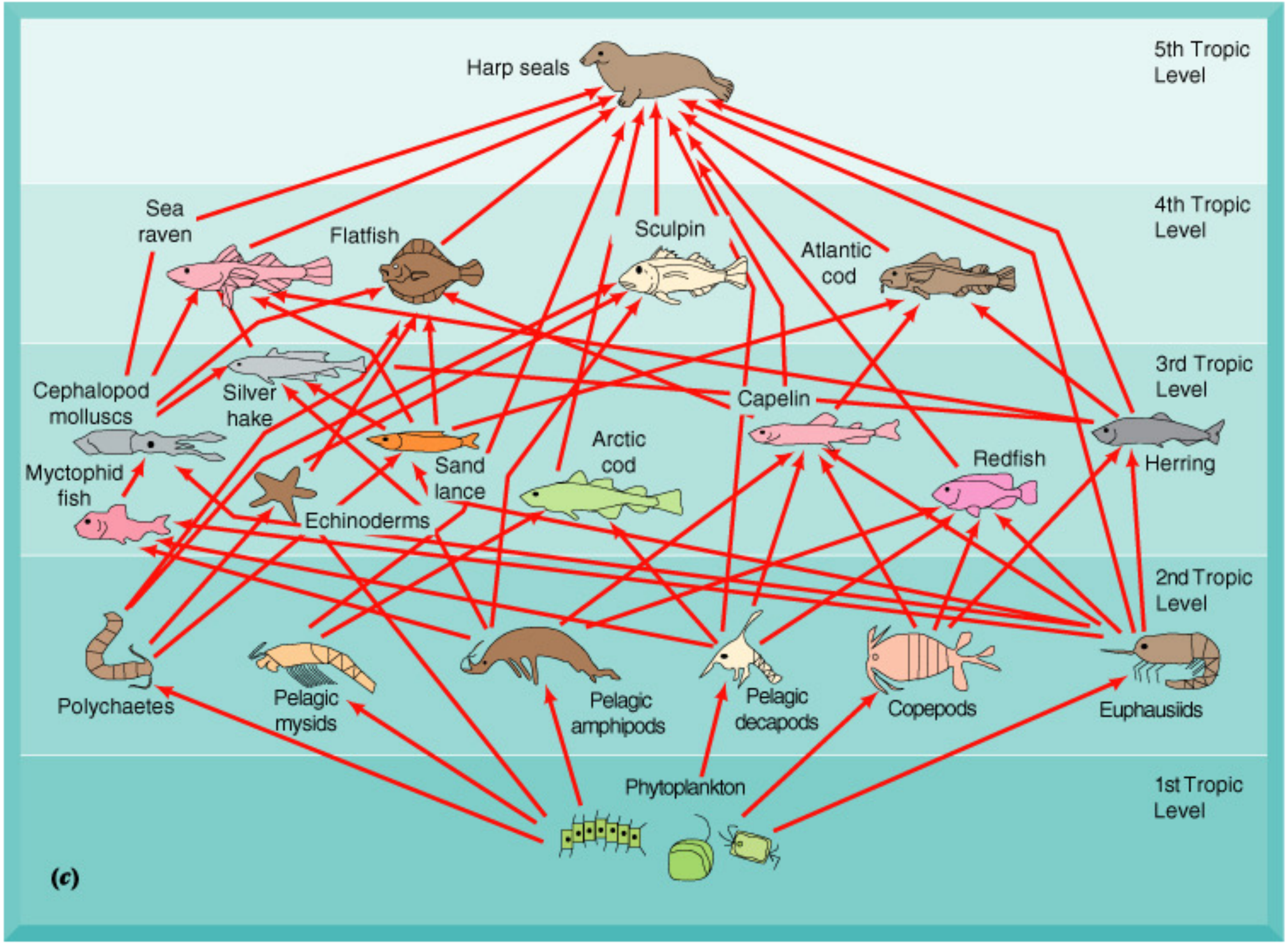
Social-Ecological Network Analysis (SENA)

Ecological networks

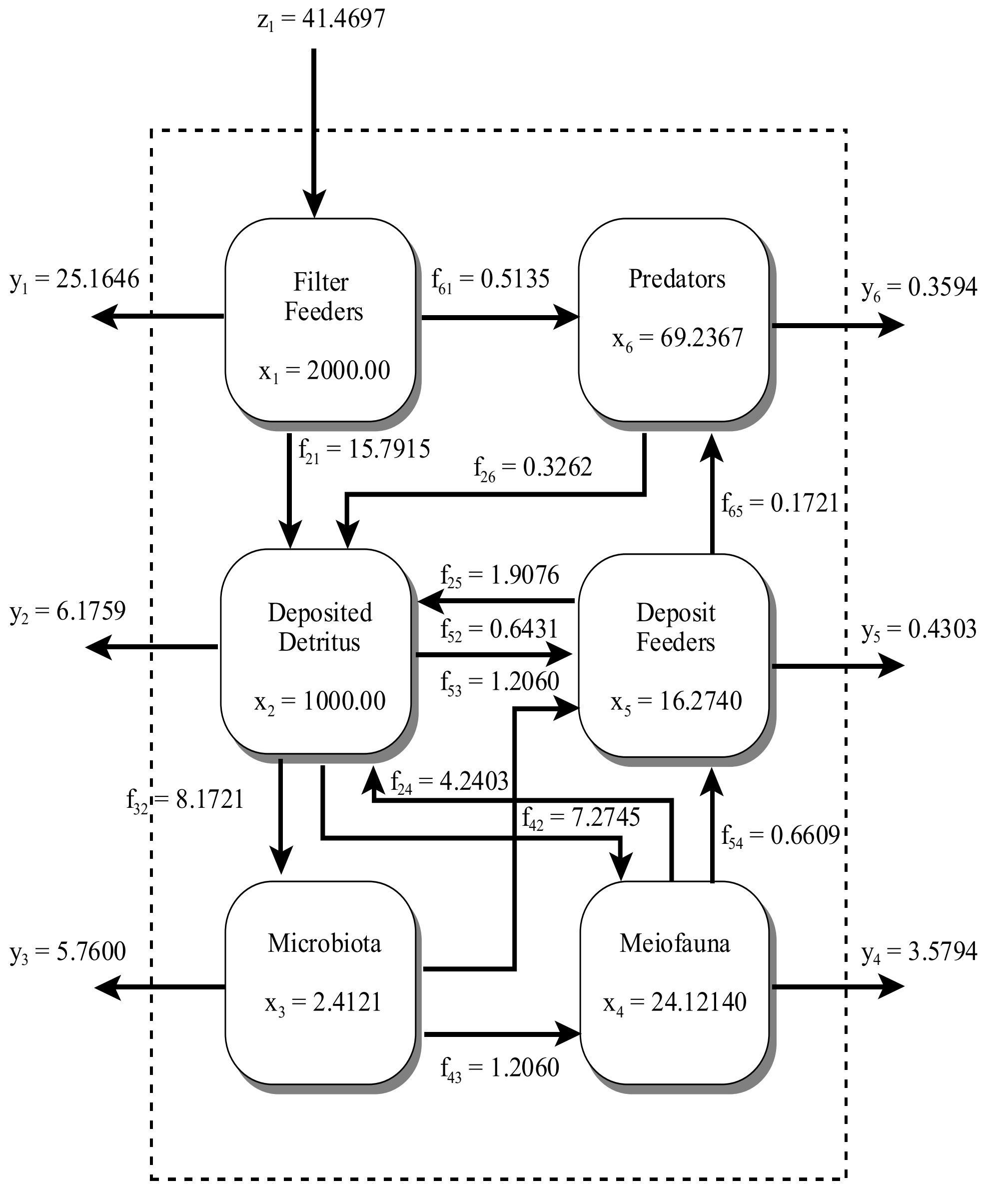
[Fiscus & Fath, 2018]

[including slides from the course "Framework for Sustainablity", Masaryk University, Dr. Brian Fath, 2022]

Ecological Food Web



Oyster Reef Model



Dame and Patten 1981 – flow is in kcal/(day m^2), storage in kcal/m^2

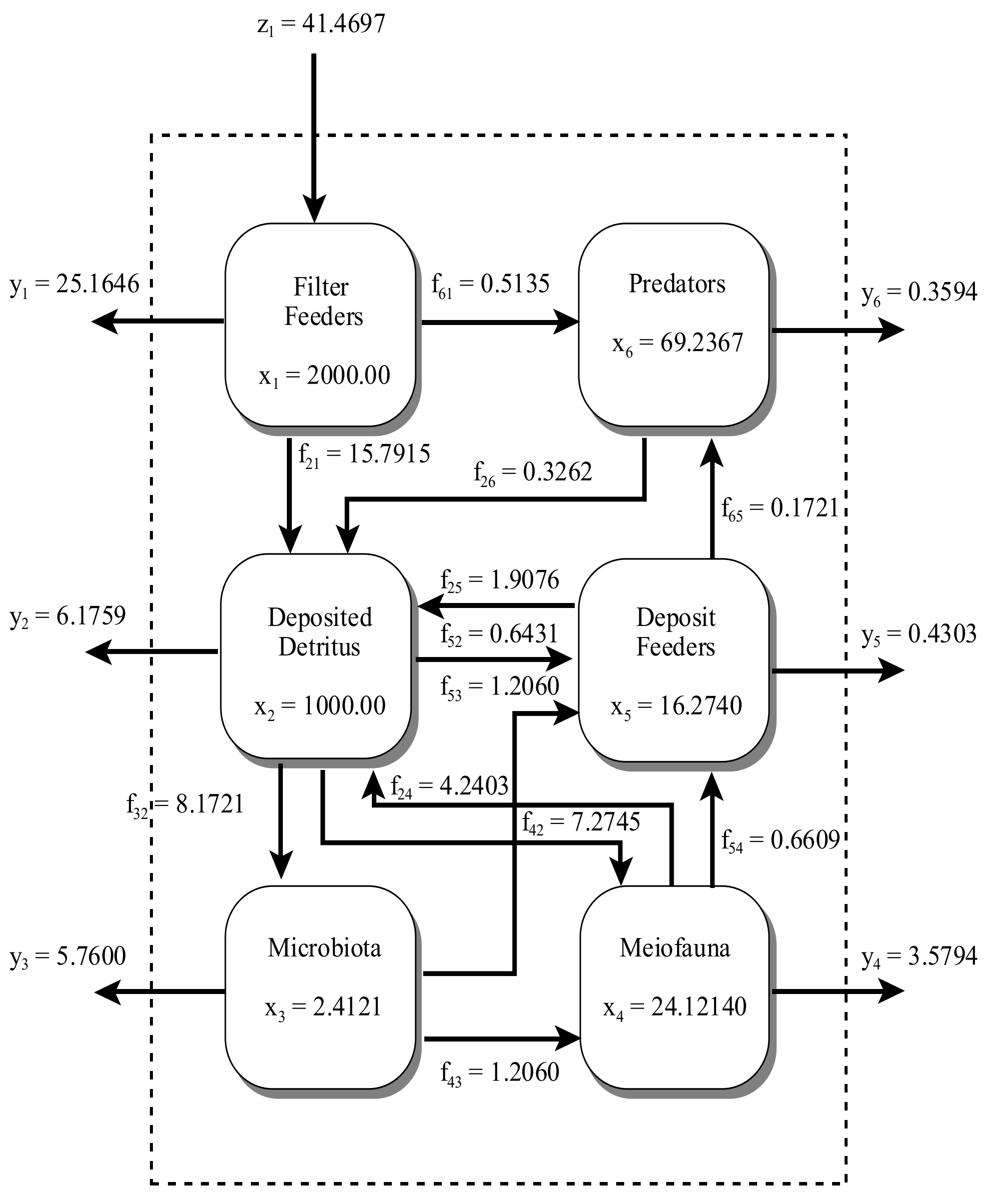
Ecosystem tendencies are consistent and mutually implicating

Three common properties:

1) First passage flow
2) Cycling
3) Retention time

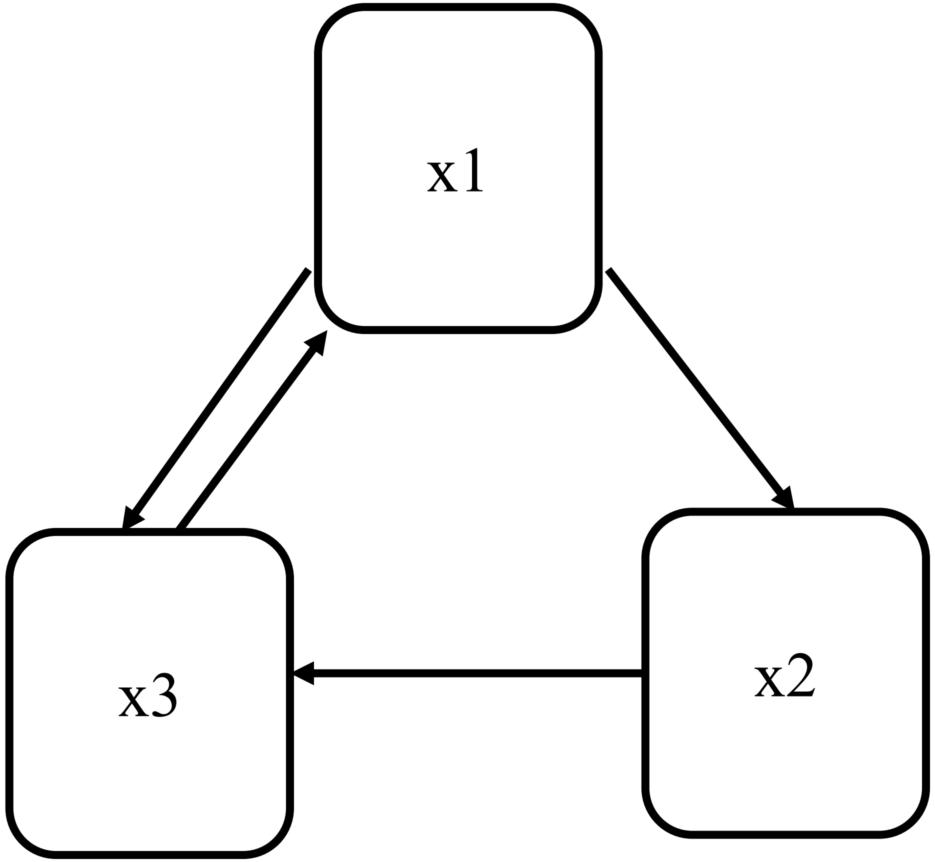
Get as much as it can (maximize first passage flow);
Hold on to it for as long as it can (maximize retention time); and
If it must let it go, then try to get it back (maximize cycling).

How can we analize ecological networks?



How to measure structure and indirectness

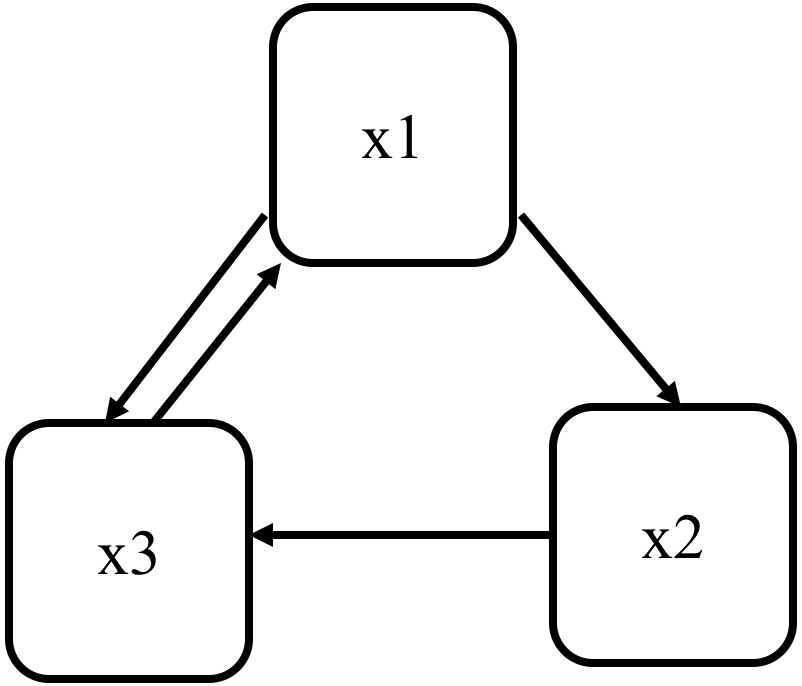
Example – digraph to adjacency matrix



$$A \square \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

Matrix multiplication gives
Higher Order (Indirect) Pathways

A^m, where $m > 1$



$$A^2 \square \begin{bmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 1 \end{bmatrix} \quad A^4 \square \begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 2 & 1 & 1 \end{bmatrix}$$

$$A^3 \square \begin{bmatrix} 1 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix} \quad A^5 \square \begin{bmatrix} 2 & 1 & 1 \\ 1 & 1 & 1 \\ 2 & 1 & 2 \end{bmatrix}$$

$$A \square \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

Powers of a matrix!!

A^1 are the direct paths.
A^2 are the paths that take two steps
A^3 are the paths that take three steps, etc.

= Dominance of Indirect Effects

Dominance of Indirectness occurs when indirect contribution is greater than direct. This occurs in the majority of food web models studied so far and is one of the key results of ecological network analysis and insights into understanding the role of networks on system organization.

Indirectness increases with increasing:

- connectivity
- cycling
- system order
- direct effects

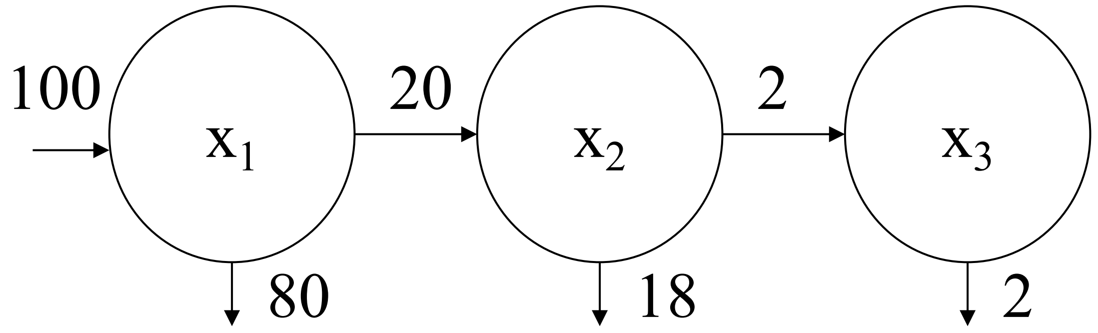
Make the direct observation, but analyze the whole system.
Direct observations give less than half the story.

$$A^5 \square \begin{bmatrix} 2 & 1 & 1 \\ 1 & 1 & 1 \\ 2 & 1 & 2 \end{bmatrix}$$

Notice that elements which were zero originally get filled in…

= All Life is Physically and Relationally Connected

Transaction – transfer of energy or matter between two directly connected components



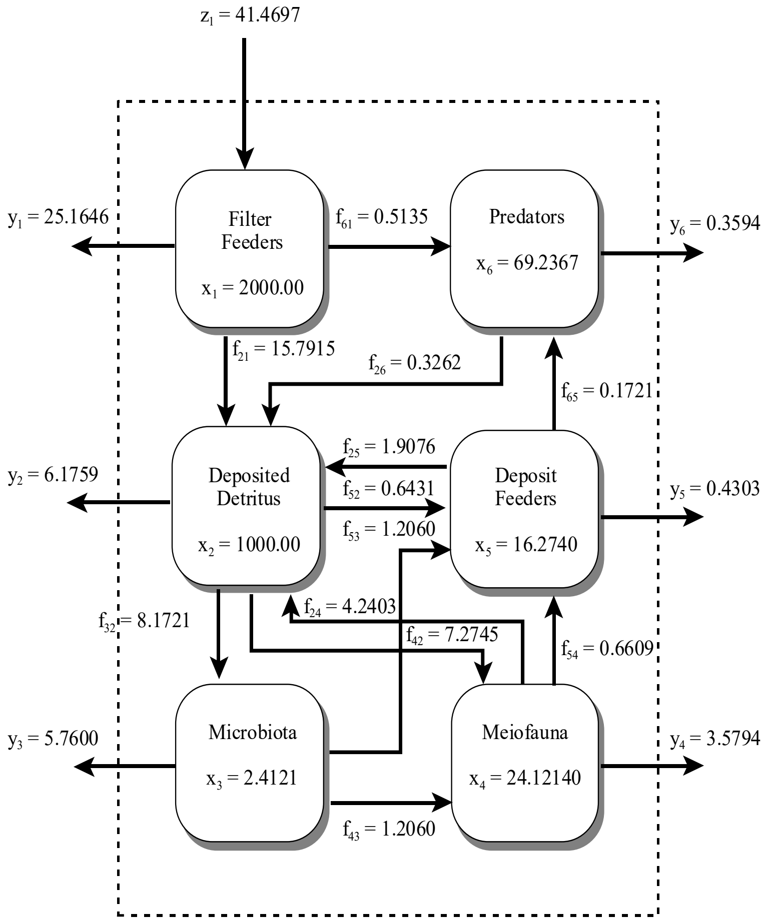
Relation – qualitative, value-oriented, direct or indirect interaction types. Nine possible interaction types

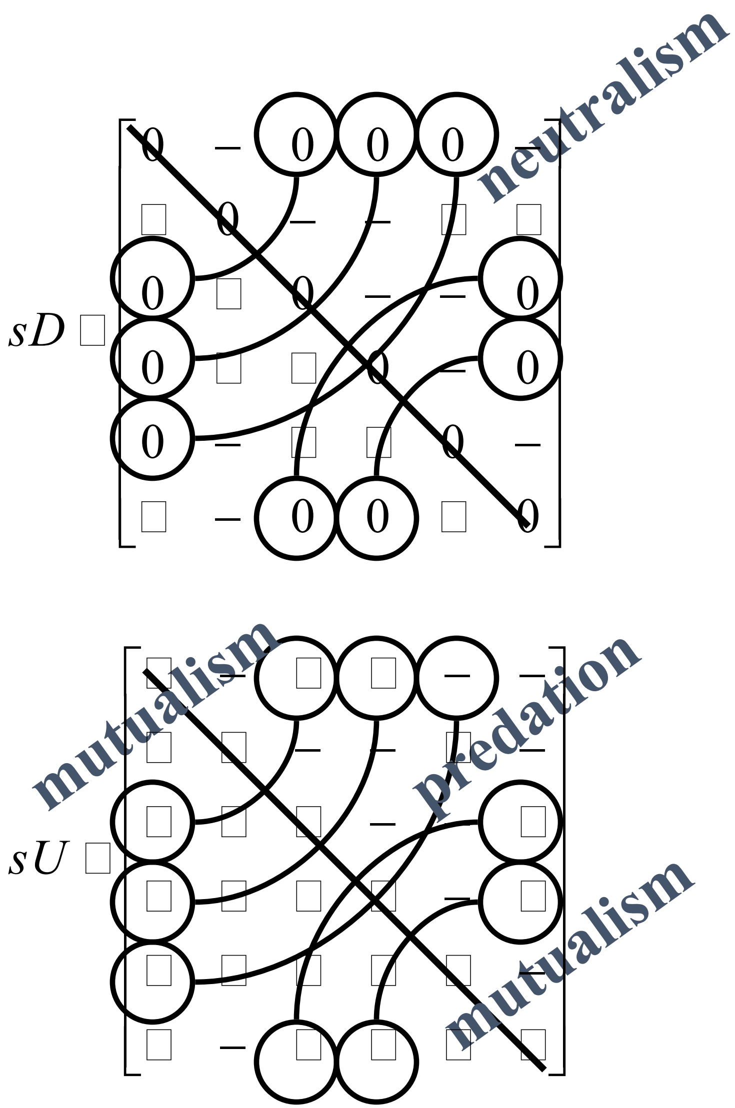
	□	0	–
□	(□,□)	(□,0)	(□,–)
0	(0,□)	(0,0)	(0,–)
–	(–,□)	(–,0)	(–,–)

	□	0	–
□	(□,□)	(□,0)	(□,–)
0	(0,□)	(0,0)	(0,–)
–	(–,□)	(–,0)	(–,–)

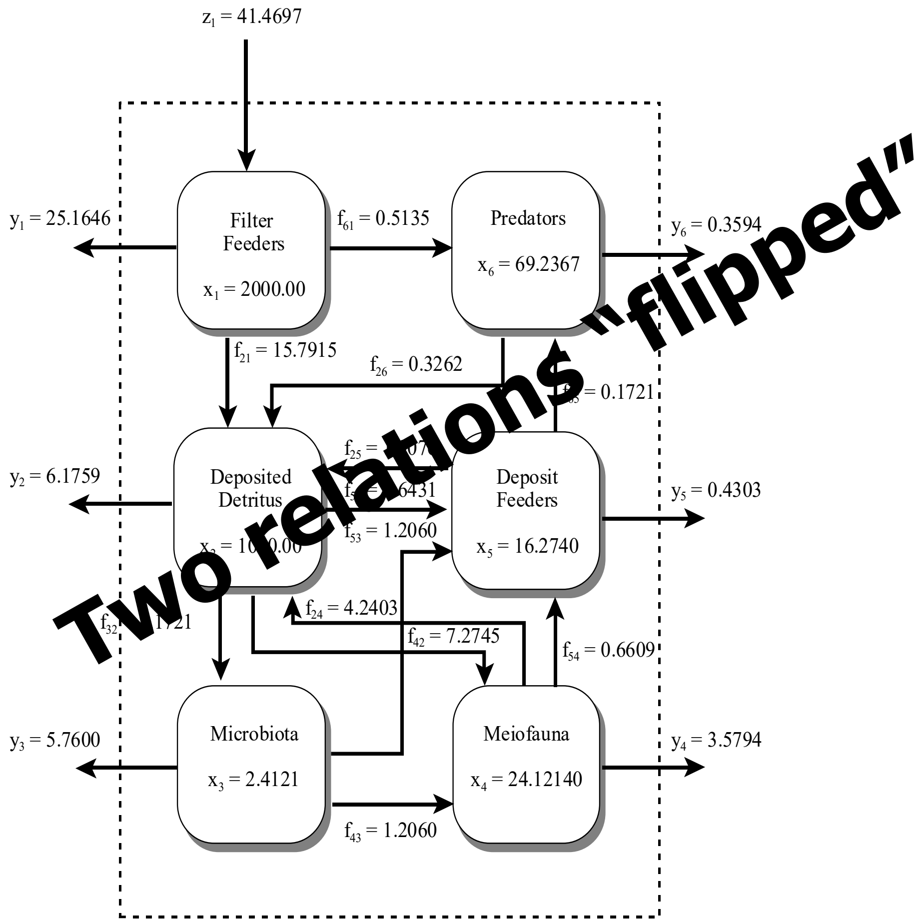
(0, 0) → neutralism
(–, –) → competition
(+, –) → predation
(+, +) → **mutualism**

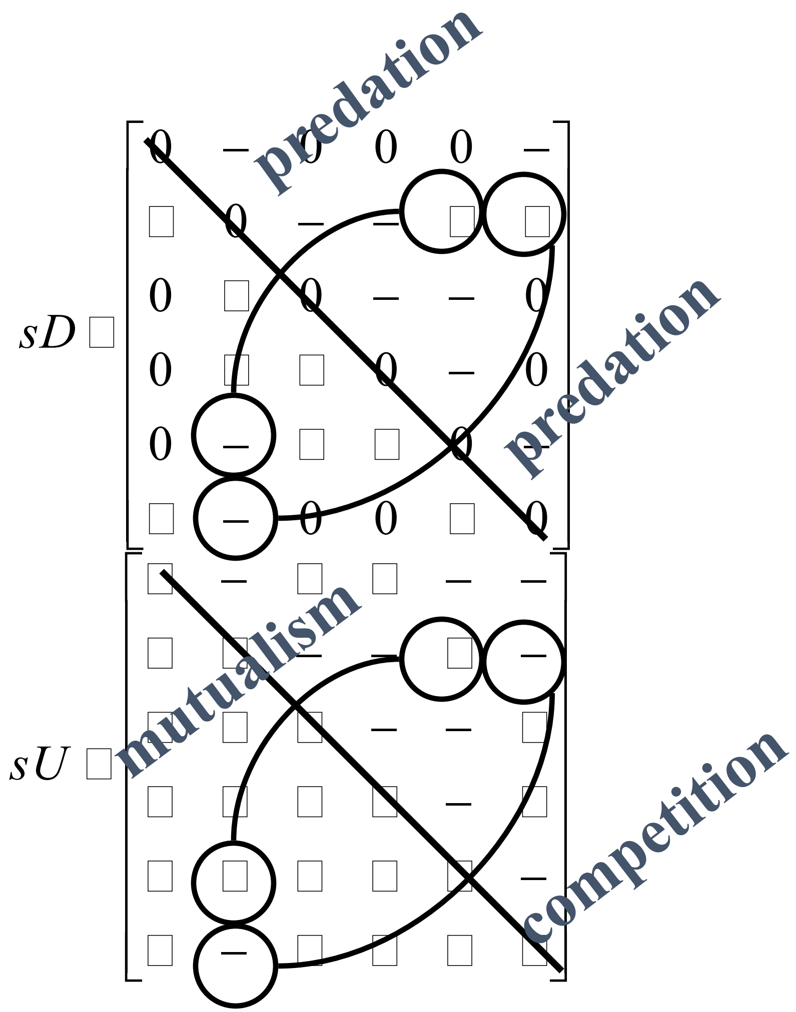
Oyster Reef Model





Oyster Reef Model

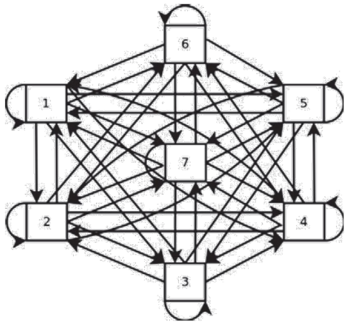




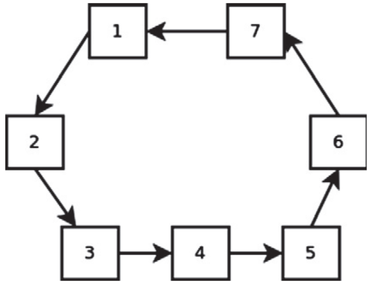
Community-level relations are more positive than the direct relations that produced them: This is network mutualism.

Two example networks

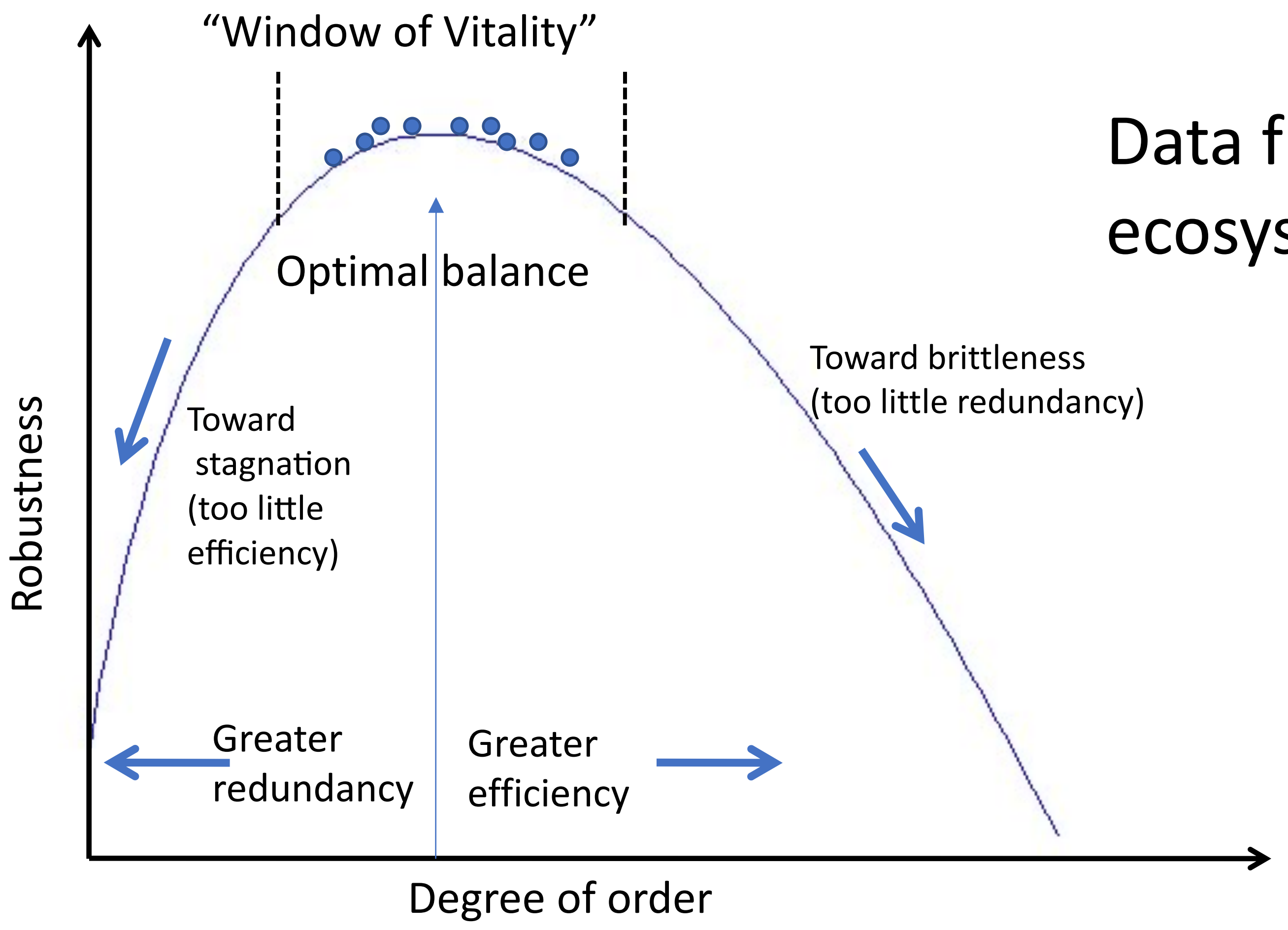
Fully connected



Minimally connected



Robustness combines both efficiency and redundancy = network balance



Data from ecosystems

Ulanowicz 2009 A Third Window

Principles

Dominance of Indirect Effects

All Life is Physically and Relationally Connected

Mutualism is Common and Crucial

Ecosystems Balance Efficiency and Adaptability

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Ecological network analysis metrics: The need for an entire ecosystem approach in management and policy

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A R T I C L E I N F O

Keywords:
Ecological network analysis
Cycling
Trophic length
Marine and coastal environment
Food web

A B S T R A C T

In this paper, we identified seven ecological network analysis (ENA) metrics that, in our opinion, have high potential to provide useful and practical information for environmental decision-makers and stakeholders. Measurement and quantification of the network indicators requires that an ecosystem level assessment is implemented. The ENA metrics convey the status of the ecological system state variables, and mostly, the flows and relations between the various nodes of the network. The seven metrics are: 1) Average Path Length (APL), 2) Finn Cycling Index (FCI), 3) Mean Trophic level (MTL), 4) Detritivory to Herbivory ratio (D:H), 5) Keystoneness, 6) Structural Information (SI), and 7) Flow-based Information indices. The procedure for calculating each metric is detailed along with a short evaluation of their potential assessment of environmental status.

1. Introduction

and the Wadden Sea. The focus of the workshop was to determine how to reach a broader audience, specifically environmental managers and

[Fath et al., 2019]

Table 1
Step one. List of network properties that emerged from workshop brainstorming session.

- Number of compartments (n)
- Mean Node degree, In degree, Out degree
- Average Path Length (APL)
- Finn Cycling Index (FCI)
- Mean Trophic Level (MTL)
- Relative Ascendency (ASC)
- Relative Overhead (Φ)
- Robustness
- Relative Redundancy (R)
- Total Systems Throughflow (TST_{flow}) and Total System Throughput (TST_{put})
- Indirect/direct relationships
- Network homogenization
- Network aggradation
- Mutualism and Synergism ratios
- Keystoneness
- Structural Information (SI)
- Flow Diversity
- Detritivory/Herbivory ratio (D:H)

[Fath et al., 2019]

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Overview · Repositories 9 · Projects · Packages · People

Popular repositories

enaR (Public)
enaR = Ecological Network Analysis in R
R · 20 · 11

trophic-aggregations (Public)
This repository creates codes for obtaining the Results of the segments Lindeman Trophic Aggregations (Containing the Trophic Spine) and the Biogeochemical Cycle Analysis (to be added later) of the...
R · 1 · 1

NEA (Public)
Repository for code related specifically to the "Network Environ Analysis" branch of "Ecological Network Analysis"
1

enaR_development (Public)
Development tools for enaR
R

https://github.com/SEELab

https://www.researchgate.net/profile/Matthew-Lau-4/publication/267457244_enaR_An_R_package_for_Ecosystem_Network_Analysis/links/6577ea966610947889b9c412/enaR-An-R-package-for-Ecosystem-Network-Analysis.pdf

Socio-ecological networks

https://www.seslink.org

SEN

Voutsa et al., 2021: 13-15

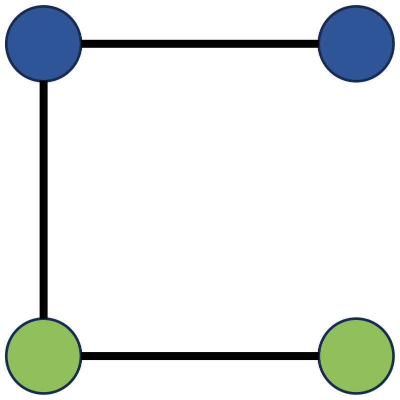
Social-ecological systems (SES) are complex adaptive and multilevel (polycentric) systems attributed with interplays between human and non-human entities (nodes) at spatial and temporal scales [Folke et al., 2016], through the metabolic flows of material and energy (links).

A rich body of literature on social-ecological system analysis focuses on the structures and patterns of interdependent social and ecological interactions… […] More specifically, it investigates the actor-to-actor relationship in the social system, the ecological component-to-component interdependencies in the ecological system, as well as the actor-to-component relationship across the social and ecological system. [Bodin et al., 2020]

Altogether it forms a multilevel network configuration made of nodes and links between different system entities.

"These interactions can be interactions between people (social-social), for instance in social networks, communities, or policy making arenas…"

actor-to-actor relationship



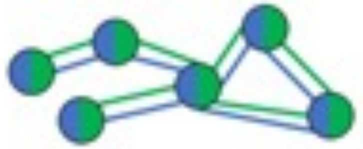
actor-to-component relationship

"…between people and biophysical entities (social-ecological), for instance when a farmer plants a crop, or an organization implements a conservation area, or when marshlands provide protection to settlements against spring tides…"

component-to-component interdependencies

"…between biophysical entities (ecological-ecological), for instance when one species preys on another."

Schlüter et al., 2019

Degree of social-ecological network articulation	Non-articulated	Partially articulated	Fully articulated
Illustration *Blue circles = social nodes* *Green circles = ecological nodes* *Blue/green circles = nodes with social and ecological attributes* *Blue/green lines = linkages with social and ecological characteristics*			
Examples of applications	How do environmental governance outcomes depend upon patterns of social and/or ecological connectivity among locations?	How do patterns of social interaction affect resource use?	How does ecological connectivity shape social interaction via human-environment interaction?
Empirical examples	Easdale et al. 2016	Rathwell and Peterson 2012	See list of reviewed papers in Table 3.

[illegible], 2019

Overview

[Sayles et al., 2019]

22 SEN papers, directly and indirectly interconnected (citations)

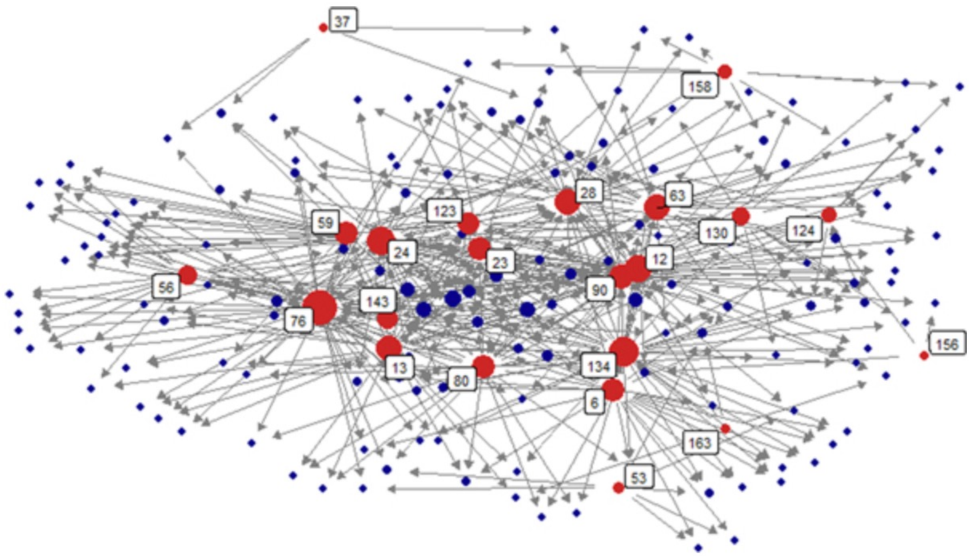


Table 3. List of 22 identified SEN papers sorted by year and alphabetically. IDs indicate papers in the network diagram, figure 3.

SEN papers (1–11)	ID in figure 3	SEN papers (12–22)	ID in figure 3
Ekstrom and Young (2009)	59	Bodin *et al* (2016)	24
Ernstson *et al* (2010)	63	Dragicevic and Shogren (2017)	53
Bodin and Tengö (2012)	28	Ekstrom and Crona (2017)	56
Bergsten *et al* (2014)	12	Pittman and Armitage (2017)	123
Bodin *et al* (2014)	23	Sayles and Baggio (2017a)	134
Chopra and Khanna (2014)	37	Xiu *et al* (2017)	156
Guerrero *et al* (2015)	76	Baggio and Hillis (2018)	6
Kininmonth *et al* (2015)	90	Yletyinen *et al* (2018)	158
Prager and Pfeifer (2015)	124	Zhao *et al* (2018)	163
Roldan *et al* (2015)	130	Bergsten *et al* (2019)	13
Treml *et al* (2015)	143	Hamilton *et al* (2019)	80

The SEN approach has immense potential to help understand social-ecological systems and address environmental problems. What we have termed 'fully articulated SENs' provide a particularly attractive approach because diverse social, ecological, and coupled relationships can be represented and analyzed.

[…]

Transdisciplinary collaborations may be an important step to advance the applied and policy theme that, as we documented, runs strong within fully articulated SEN research.

[Sayles et al., 2019]

"Many treat the social and the ecological as two separate subsystems that are connected through links such as ecosystem services (Nassl and Löffler 2015) and take either an ecocentric or an anthropocentric perspective (Binder et al. 2013, Partelow and Winkler 2016). This limits the possibility of accounting for the embeddedness of humans in ecosystems, which manifests itself in the many, continuously evolving relations and interactions between humans and elements of their biophysical environment. These interactions can be of different types, from the extraction of natural resources for material benefits, or the consumption."

= Social-ecological action situations (SE-AS)

Schlüter et al., 2019

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SEN approach

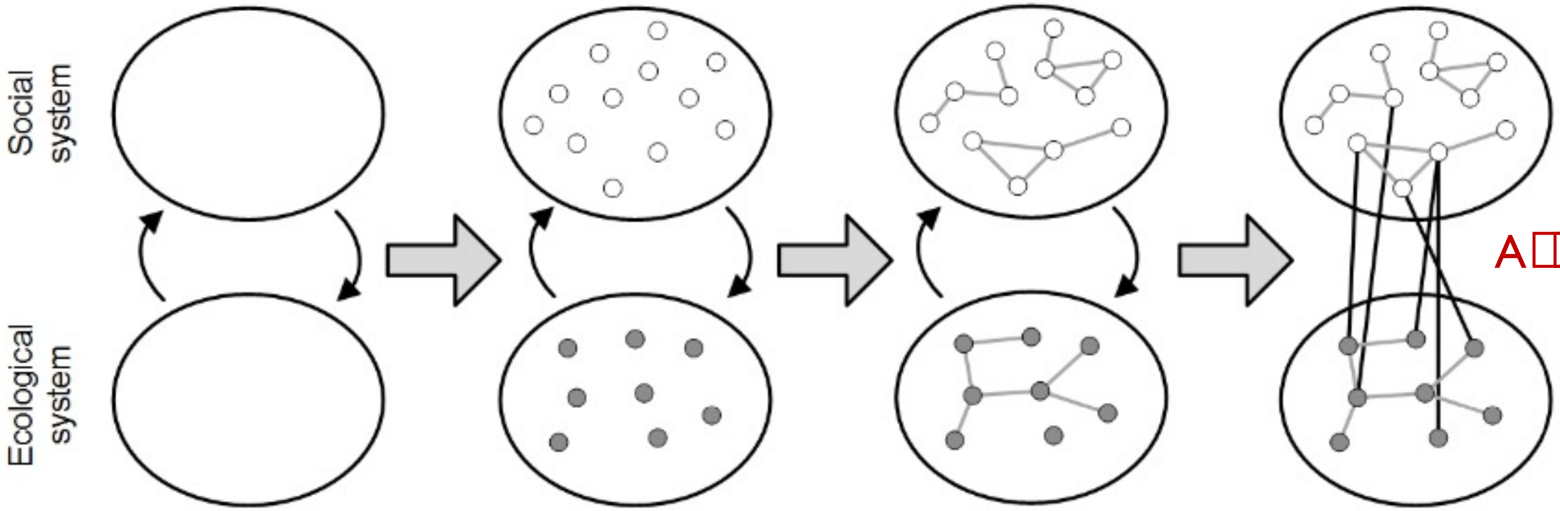
Theorizing benefits and constraints in collaborative environmental governance: a transdisciplinary social-ecological network approach for empirical investigations

Social-ecological interdependencies: "Ecosystems consist of numerous species and habitats interconnected across geographical and temporal scales […]. Likewise, human actors ranging from local resource users to actors operating on the global arena are increasingly interconnected through globalized markets, various types of resource flows, and migration […]."

Collaborative environmental governance: "…a central hypothesis from contemporary research has been that governance arrangements incorporating collaboration across multiple scales and jurisdictions are needed to meet the collective dilemmas arising from a world being socially and ecologically increasingly interconnected […]."

"To that end we demonstrate how recent advances in stochastic modeling of multilevel social networks can be integrated with a newly developed social-ecological systems (SES) modeling approach…"

[Bodin et al., 2016]


Social system
Ecological system

Case study:

"…different clans (social nodes) are managing different forest patches (ecological nodes) in an agricultural landscape in Madagascar […]. This case study is particularly intriguing because it represents a comparatively successful example of environmental governance. The forest patches have been remarkably well preserved in spite of an increased demand for land and forest resources.

Ecological system:

- Forest patches: 3 to more than 90 ha
- Interconnected through seed dispersal

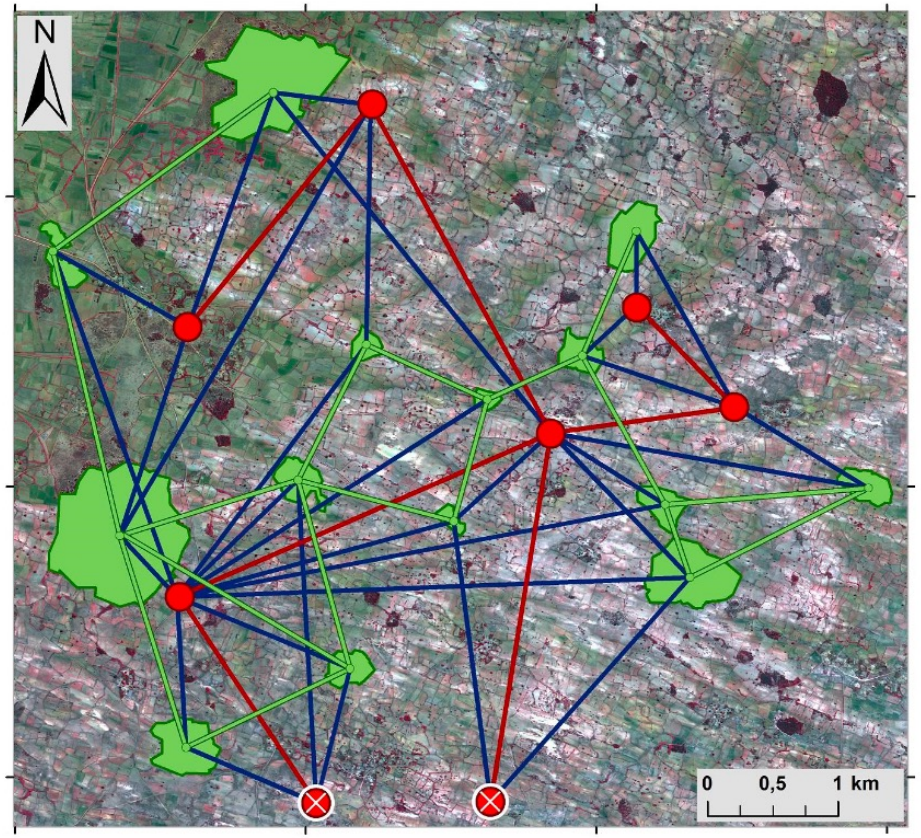
Social system:

- Clans
- Shared ancestry, agreed kinship and/or historical dependence relationships

Actor-to-resource ties:

"…the ties between clans and forest patches represent use and managerial responsabilities…"

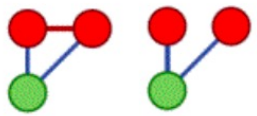
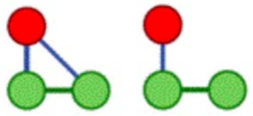
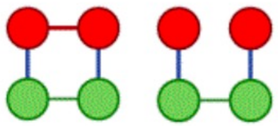
[Bodin et al., 2016]



In social-ecological network terms, a social-ecological building block consists of a minimal set of nodes (actors and ecological resources) and ties (their interdependencies) that capture a theoretically important configuration (pattern of social-, ecological-, and social-ecological interdependencies).

The SES building block approach aims to theoretically link these patterns to specific governance processes and associated governance challenges, and compare the structure of social-ecological networks across cases and contexts.

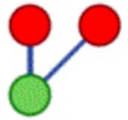
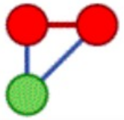
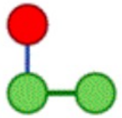
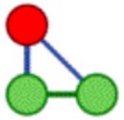
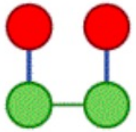
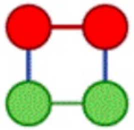
[Bodin et al., 2016]

Social-ecological building block	**Governance challenge**
Common-pool resource management	
Resource sharing with and without a social tie (closed and open common pool triangle) 	If two (or more) noncooperating actors share a resource (right), there may be a strong incentive for these actors to overharvest the resource. This governance challenge can, however, be addressed if the actors collaborate and agree on some common resource regulations (Ostrom 1990). This implies that the two actors need to be socially tied (left). Note that this does not imply that actors being tied to other actors is good in general, rather it emphasizes that collaboration is beneficial for actors sharing common ecological resources (Bodin et al. 2014).
Social-ecological fit and alignment	
Managing an ecosystem versus managing a subcomponent (closed and open ecosystem triangles) 	If an interconnected ecological resource is managed as separate entity (right), the governing structure is not well aligned with the structure of the ecosystems (Cumming et al. 2006, Bodin et al. 2014). This governance challenge resembles the notion of social-ecological misfit implying that the effect of management activities can, through ecological interdependency, spread to other resources beyond the realm of managing actor. Thus, a closed triangle (left) hypothetically suggests a better fitting building block because ecological costs and benefits occurring beyond the managed resource are internalized (Bodin et al. 2014).
Two actors managing interconnected resources being socially connected or disconnected (closed and open four-cycle) 	A lack of collaboration between two actors managing interconnected ecological resources (right) represents a similar type of governance challenge as above because the extent of the interconnected ecological resources is not aligned with the extent of the governance structure (social-ecological scale mismatch; Cumming et al. 2006). If the actors are socially tied (left), a better social-ecological scale alignment (fit) is accomplished (Bodin and Tengö 2012).

Results

[Bodin et al., 2016]

Fig. 4. Results from the frequency analysis and the multilevel exponential random graph models (ERGM).

Social-ecological building block[1]	**Frequency analysis[2]**	**Multilevel ERGM[3]**
Open common pool resource (CPR) triangle 	-4.11**	- 6.52*
Closed common pool resource (CPR) triangle 	2.78**	3.13*
Open ecosystem triangle 	-3.89**	-
Closed ecosystem triangle 	3.41**	1.66*
Open four-cycle 	-1.38	-
Closed four-cycle 	-1.93*	-0.76*

Discussion

[Bodin et al., 2016]

The interdisciplinary social-ecological network modeling framework […] provides for new and innovative ways of studying social-ecological systems. This can substantially increase our understanding of the processes and structures that make collaborative natural resource governance more or less effective.

Instead of simplistic assertions that collaboration between all possible pairs of actors is necessarily good, and the more collaborative ties there are, the merrier, the approach can be used to develop explicitly and precisely defined, empirically testable, and theoretically driven hypotheses on how different patterns of interdependencies between and among actors and ecological resources relate to the effectiveness of different collaborative arrangements.

Social-ecological systems cannot be simultaneously optimized for all types of governance challenges. But, a comparative use of this approach could identify social- ecological networks that foster good outcomes across a broad set of possible challenges

Social Network Analysis (SNA)

Ecological Network Analysis (ENA)

Social-Ecological Network Analysis (SENA)

Ideas, questions, comments, discussions, etc.?

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