

Introduction to Network Models

1. Network Elements
2. Example Network Models
3. Why Network Models
4. Network Ecology

Stuart R. Borrett
University of North Carolina Wilmington

Network Elements

Network Science

“the science of connectivity”

Network: Any thing reticulated or decussated, at equal distances, with interstices between the intersections.
Samuel Johnson
A Dictionary of the English Language, First Edition, 1755

Network: A large system consisting of many similar parts that are connected together to allow movement or communication between or along the parts or between the parts and a control centre.
Cambridge Advanced Learner's Dictionary.
on-line, 2010

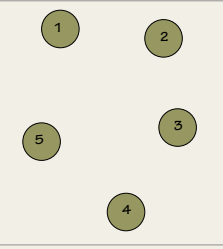
Note how similar the second one is to our reductionist definition of a system.

Estrada et al. 2010

What is a network model?

Network models begin with a set of **objects** (nodes)

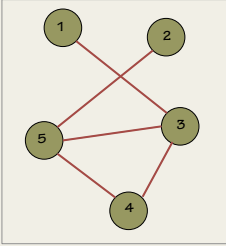
Map **relationships** among the objects using **edges**



What is a network model?

Network models begin with a set of **objects** (nodes)

Map **relationships** among the objects using **edges**



Graph

$G = \{N, E\}$

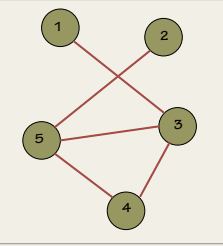
N = nodes -- objects

E = edges -- relationship

What is a network model?

Network models begin with a set of **objects** (nodes)

Map **relationships** among the objects using **edges**



Graph

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

oriented from column to row

Matrix

The analytical power of graph theory and linear algebra

Generalized Network Models

(a) (b) (c) (d)

Multiple node or edge types, directed, weighted

Newman 2003 SIAM

Network are just one type of model

What is a model?

Model
 A **model** is an abstract (perhaps idealized), non-unique, description of a natural **system** that captures its features essential for addressing the modeling objectives.

Patten, pers. Com.

Observed
 Abstract
 Idealized

Ahl & Allen 1996

All Models are wrong, some are useful

George Box

Box, G.E.P., Robustness in the strategy of scientific model building, in Robustness in Statistics, R.L. Launer and G.N. Wilkinson, Editors. 1979, Academic Press: New York

Example Networks

The goal here is to highlight different ways network models can be used.

Internet

$G = \{N, E\}$

Nodes
 Autonomous systems (computer groups)

Edges
 Physical Internet connection

"...at the level of "autonomous systems"—local groups of computers each representing hundreds or thousands of machines. Picture by Hal Burch and Bill Cheswick, courtesy of Lumeta Corporation. " Newman 2003

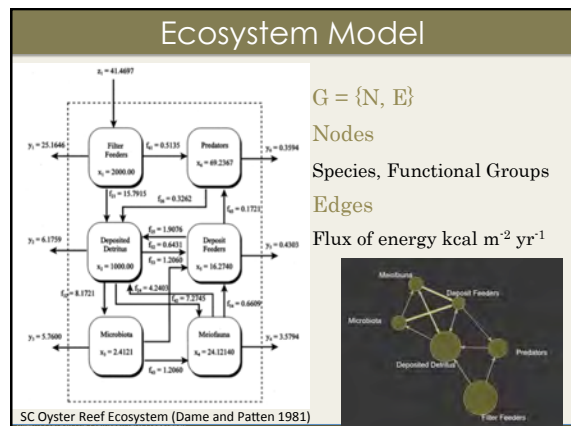
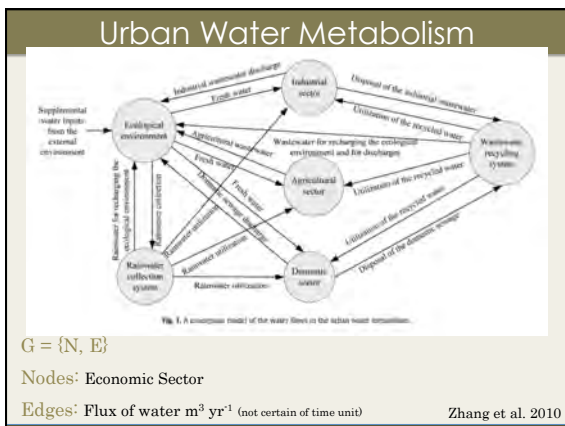
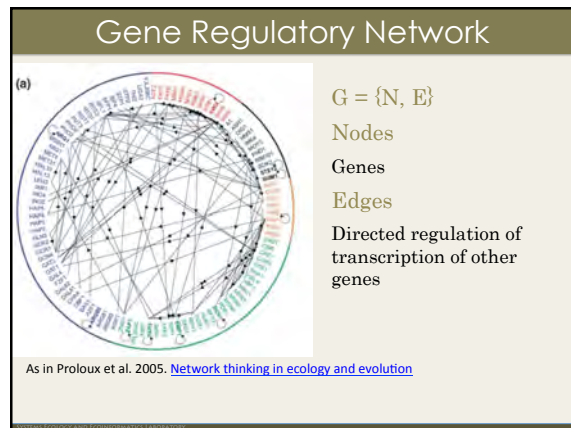
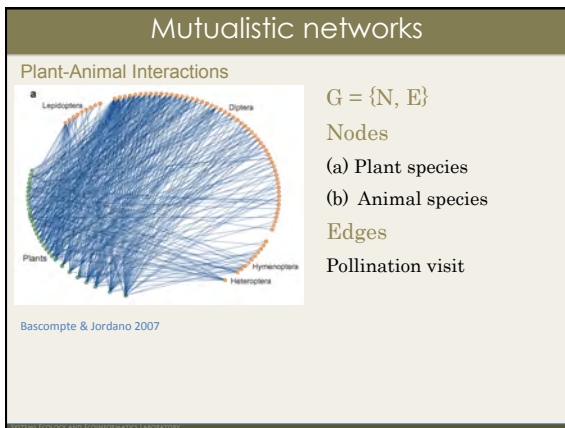
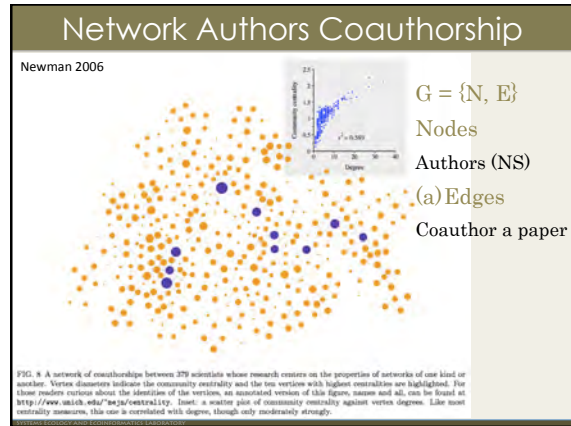
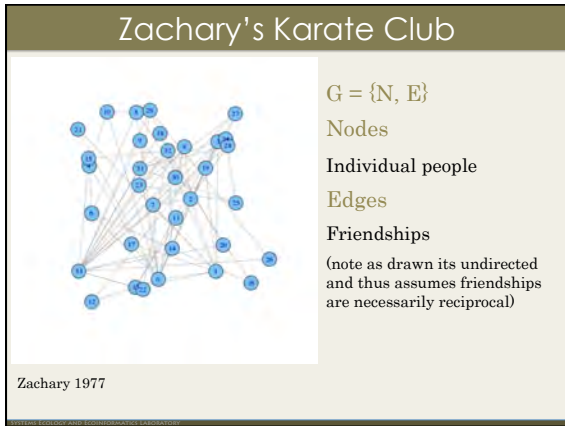
Sexual Contacts - HIV

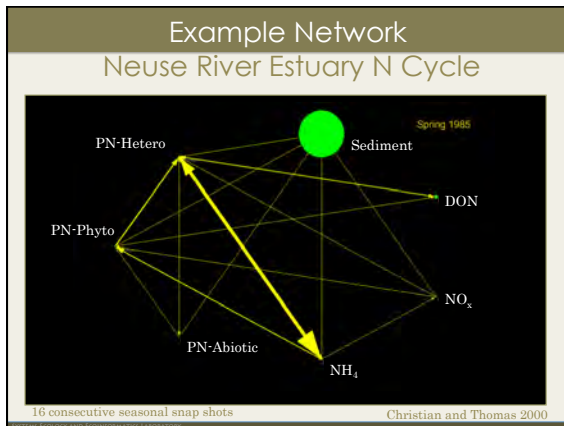
$G = \{N, E\}$

Nodes
 Individual people

Edges
 Sexual Intercourse

Potterat et al. 2002, as in Newman 2003





Why Network Models?

Why Networks?

- Networks are everywhere
- Superb for analyzing relational data
- Can have complex statistical dependencies
- Many analytical methods work for high dimensional data
- Disadvantage: data hungry

General Research Questions in Network Science

What are the properties of the network?

- e.g. patterns of connections, longest paths, cycles
- Describe the network architecture
- Are the patterns unique or general?

What are the consequences of the properties?

- How does the architecture influence function or behavior?



What processes generate the properties?

- Generating models

Another way to parse NS questions

- Network Statics
 - How do I describe the network?
- Dynamics ON Network
 - Disease, information transmission
 - Flow
- Dynamics OF Networks
 - How do networks change through time? Why?

Network Ecology

S.R. Borrett, J. Moody, A. Edelmann

In prep.


Preliminary Results

First presented at the Systems Ecology Symposium in Honor of Dr. Patten, 2012

Motivation



Dr. Patten's 1968 recruitment talk for UGA

Network Variable in Ecology



2013

Systems Ecology
A Network Perspective and Retrospective

Patten 1975

Network Ecology

Initial Definition

Study of **ecological systems** using network models and analysis to characterize their structure, function, and evolution.

Borrett, Christian, Ulanowicz 2012
Encyclopedia of Environmetrics

Field of Network Ecology?

Focal Questions

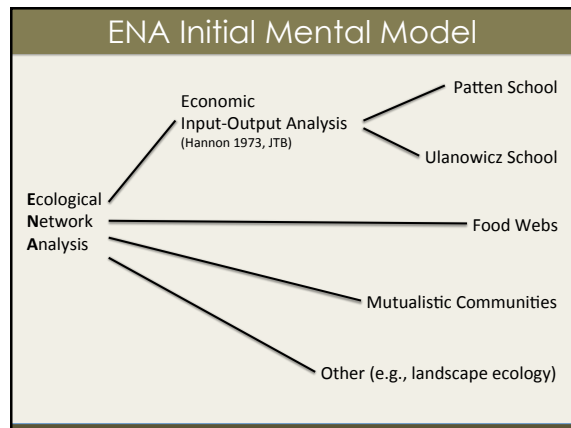
What is Network Ecology today (topics)?
Network Environ Analysis
Ecological Network Analysis (ENA)

Who are Network Ecologists?

What is the structure of the community? (sociology of science)



How has Patten influenced this domain?

Initial Mental Model = Hypothesis



Two Schools of ENA

Scharler & Fath 2009

Patten School	Ulanowicz School
	
University of Georgia	University of Maryland
Organism-Environment Focus	Trophic Focus
Diff Eqs	Phenomenological Graph
Environ Concept	Information Theory
Network Environ Analysis	Ascendency Concept
Distinct but interwoven development	

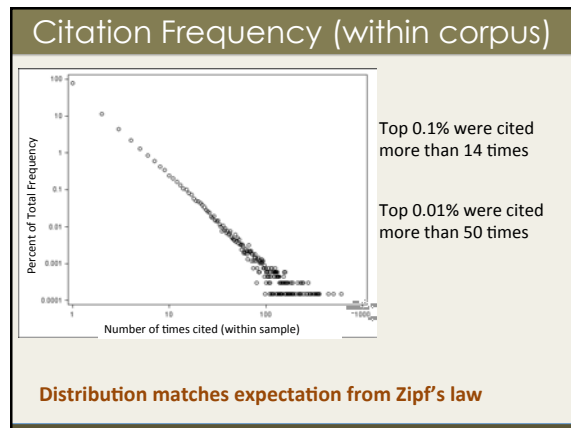
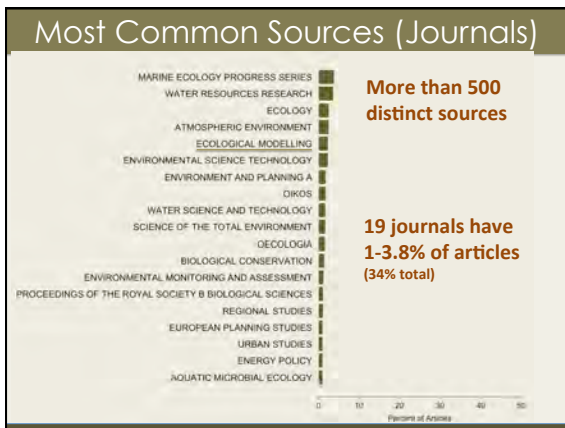
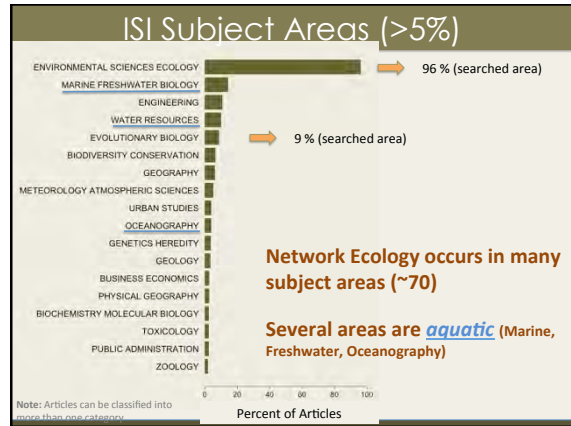
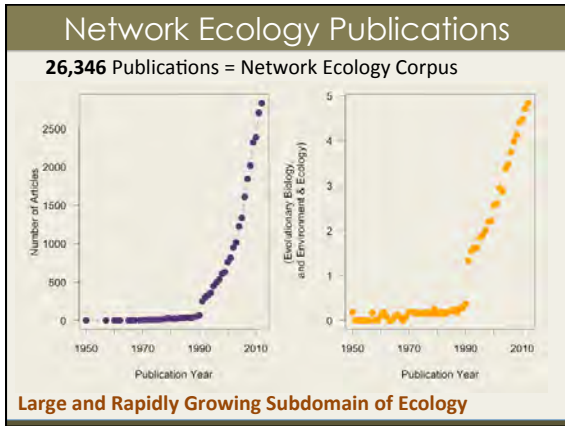
Approach & Methods

Given: publications are core of scientific production
Approach: **INFER** the field from publication records
Search

- ISI Web of Science (SCI-EXPANDED, SSCI), 1900 – 2012 (112 yrs)
- Subject Areas
SU = (Evolutionary Biology \wedge Environmental Sciences & Ecology)
- Search Terms
 $TS = (network \wedge graph\ theory \wedge food\ web \wedge Ecopath \wedge ascendency)$
 Exclude $TS=(neural)$

Construct network models of terms and coauthorship
Apply (Social) Network Analysis

- Identify topic clusters
- Characterize community of scholars



Discussion

Network ecology – A field defined by a methodology?

Definition of a Network

$G = \{V, E\}$

Definition of a System (Reductionist)

A partially interconnected (C) set of component parts (P).

$S = \{P, C\}$

Newman 2003 SIAM | Patten, Course Notes

Summary

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Suggested References

- Proulx, S.R., DEL Promislow, PC Phillips. 2005. **Network thinking in ecology and evolution**. TREE 20:345-353
- Newman, MEJ. 2003. **The structure and function of complex networks**. SIAM review. 45: 167-256.
- Fath BD and BC Patten. 1999. **Review of the foundations of network environ analysis**. Ecosystems 2:167-179.
- Borrett, SR, RR Christian, RE Ulanowicz. 2012. **Network Ecology** (Revised). In: A.H. El-Shaarawi and W.H. Piegorsch (Eds.). **Encyclopedia of Environmetrics** (2nd edition). John Wiley and Sons: Chinchester, pp. 1767-1772.
[doi:10.1002/9780470057339.van011.pub2](https://doi.org/10.1002/9780470057339.van011.pub2) [PDF]

Where to learn more ...

Mark Newman's papers and website
<http://www.personal.umich.edu/~mein/>

Albert-Laszlo Barabasi
<http://nd.edu/~alb/>

SAMSI Complex Networks Tutorial
<http://legacy.samsi.info/workshops/2010cn-opening201008.shtml>

International Network for Social Network Analysis
<http://www.insna.org/>

Robert Ulanowicz (Ecological Network Analysis)
<http://www.cbl.umces.edu/~ulan/>
Growth and Development: Ecosystem Phenomenology

Brian Fath's work (Ecological Network Analysis)
<http://pages.towson.edu/bfath/>

Working Syllabus

- Sunday - Foundations
- Introduction to Systems Ecology
 - Introduction to Thermodynamics for Ecology, Part 1
 - Systems Concepts
- Monday - Networks & Energy
- Thermodynamics for Ecology, Part 2
 - Network Models
 - Energy & Information with Examples
 - Ecological Network Analysis
 - Big Picture
 - ENA Software - enaR, EcoNet
- Tuesday
- Ecosystem Growth and Development
 - Water Resource Applications of ENA
 - Introduce Class Project & Homework
- Wednesday
- Working with enaR
 - Work on Project
- Thursday
- Project Summaries & Synthesis
 - Additional Examples of Systems Ecology
 - Throughflow Centrality
 - Agricultural Energy Flows
 - Indirect Effects