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Ecological Network Structure & Dynamics

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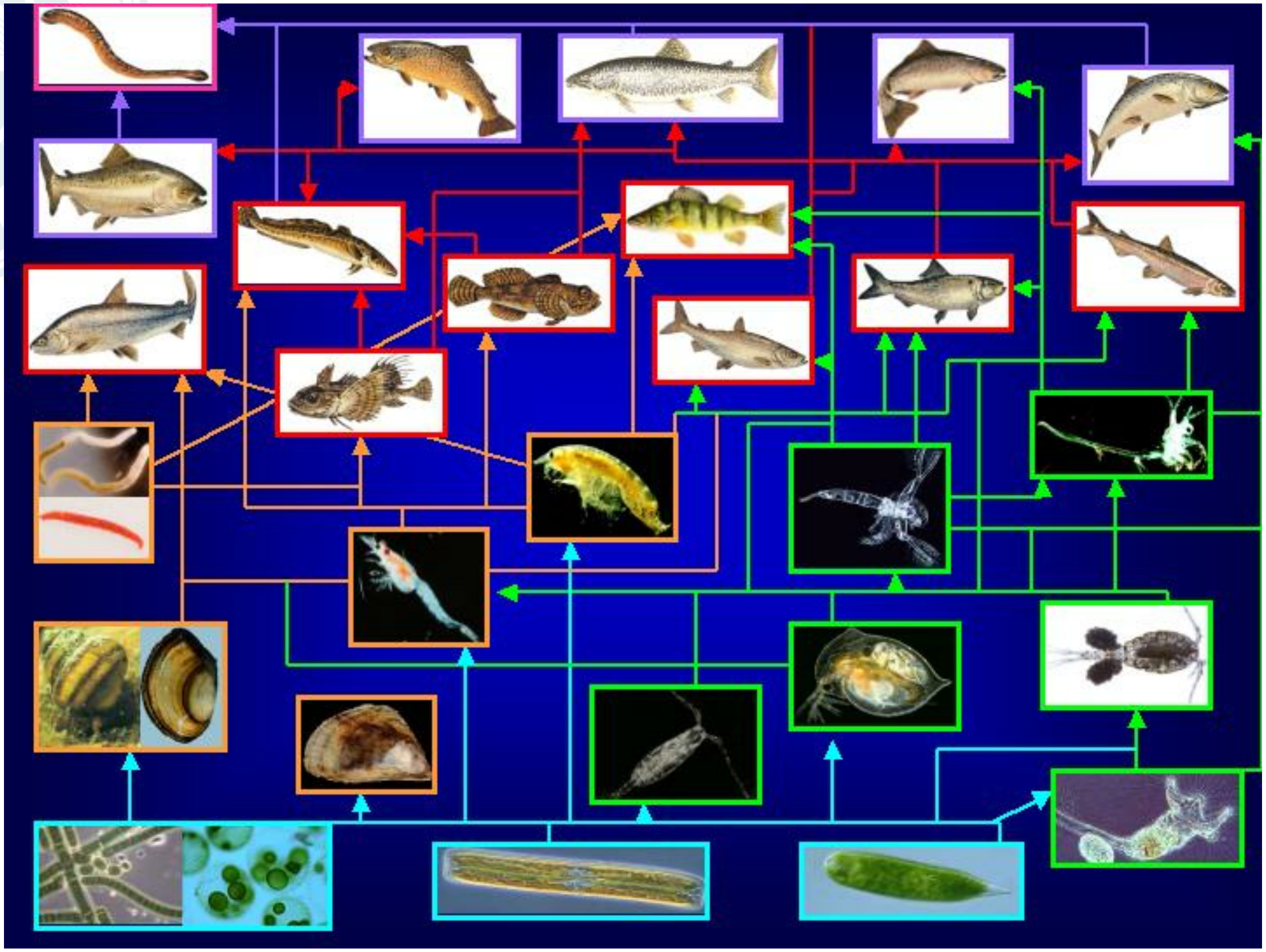
In any study of evolutionary ecology, food relations appear as one of the most important aspects of the system of animate nature. There is quite obviously much more to living communities than the raw dictum "eat or be eaten," but in order to understand the higher intricacies of any ecological system, it is most easy to start from this crudely simple point of view.

G. Evelyn Hutchinson (1959) Homage to Santa Rosalia, or Why are There so Many Kinds of Animal? *The American Naturalist* 93: 145-159.



Nodes = Taxa

- -primary producers
- -herbivores
- -detritivores
- -carnivores
- -parasites

Edges = Trophic Links

- -predation
- -herbivory
- -detritivory
- -parasitism
- -cannibalism

Ecological Network Structure

1. Generation 1/2 Data & Questions
2. Generation 1/2 Models
3. Generation 3 Data, Questions, Approaches

Ecological Network Dynamics

4. Allometric Trophic Network Model
5. Empirical Validation

Application

6. Humans in Food Webs

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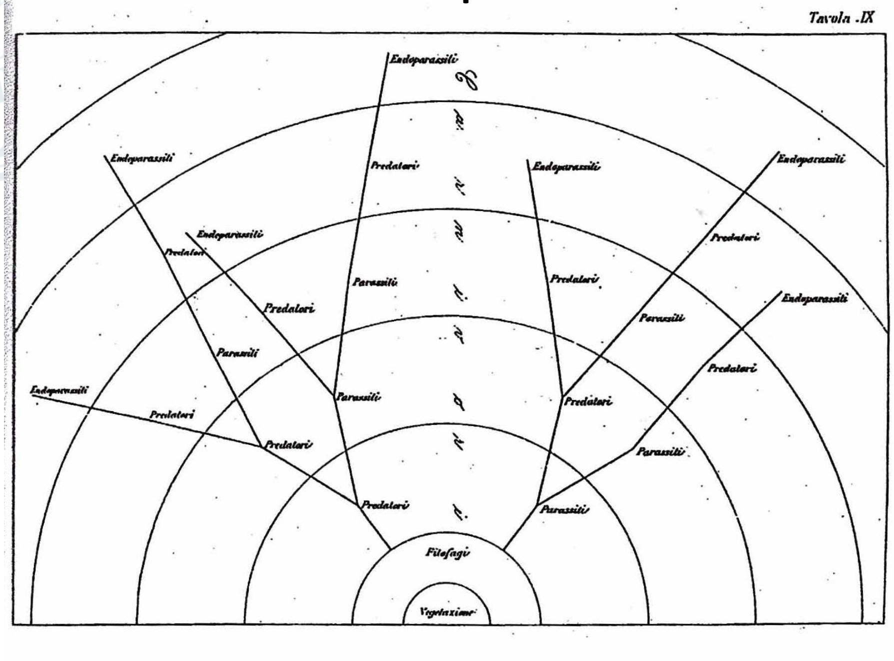
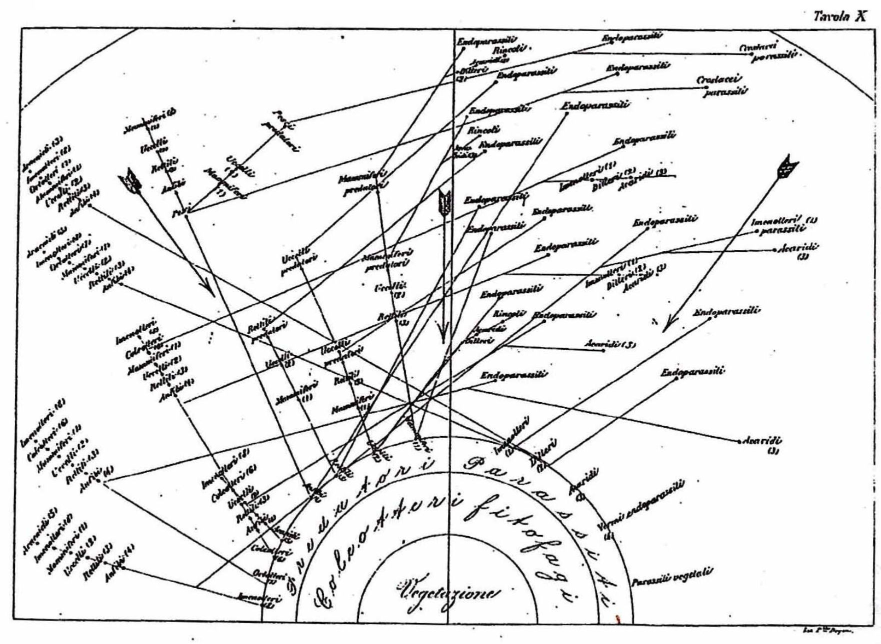
Generation 0 Data

Lorenzo Camarano (1880)

Generalized Trophic Network



Specific Trophic Network

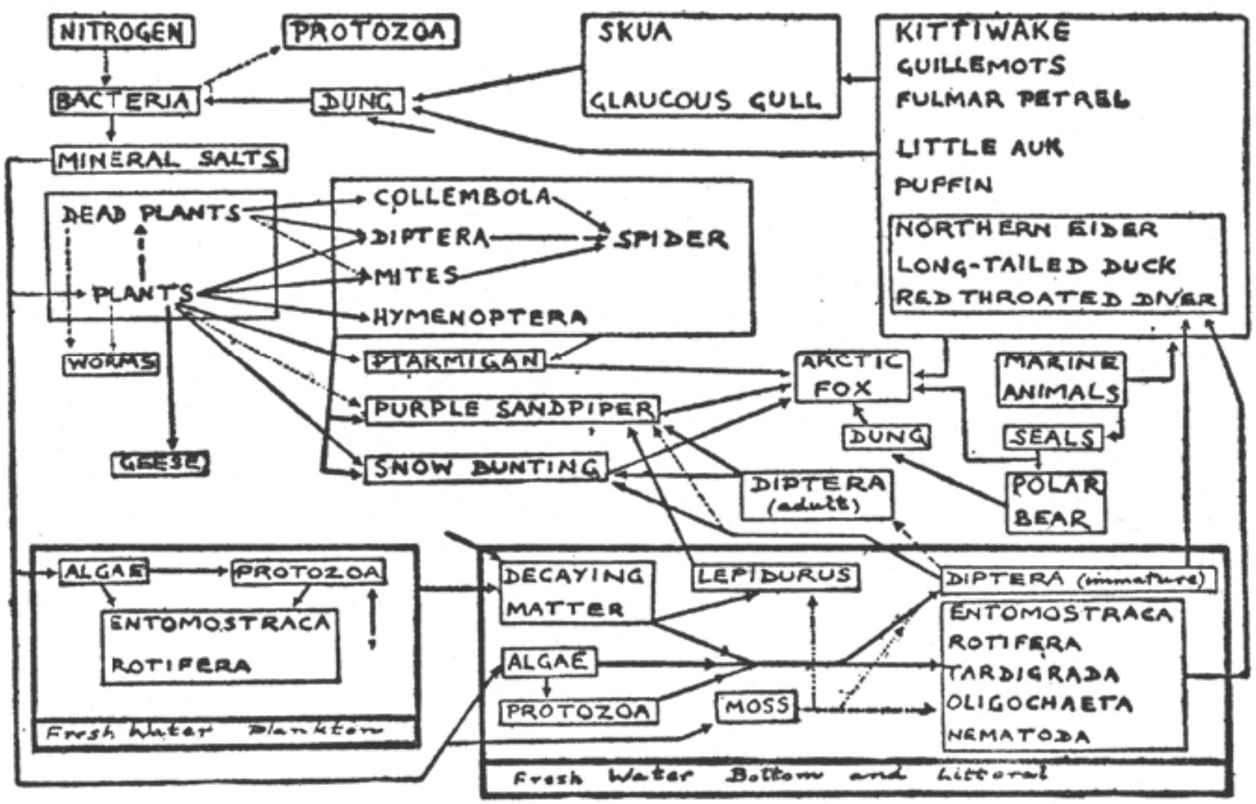


5 categories: vegetation, predators, parasites, endoparasites, carnivores

15 taxa: plants, parasitic plants, worms, amphibians, reptiles, fish, birds, mammals, crustaceans, spiders, insects

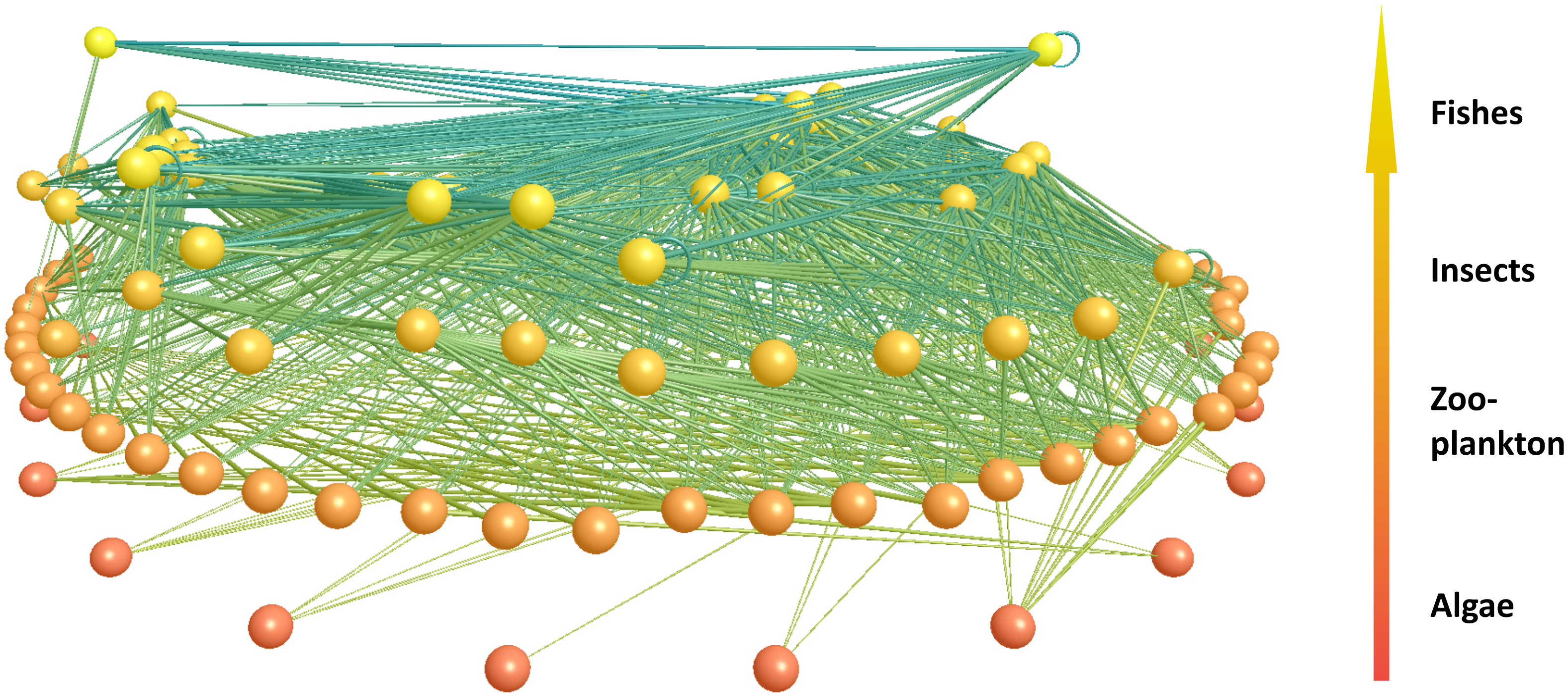
Generation 1 Data (1910s – 1980s)

Summerhayes & Elton 1923
Food Web of Bear Island



Generation 2 Data (1990s to 2010s)

Little Rock Lake, Wisconsin

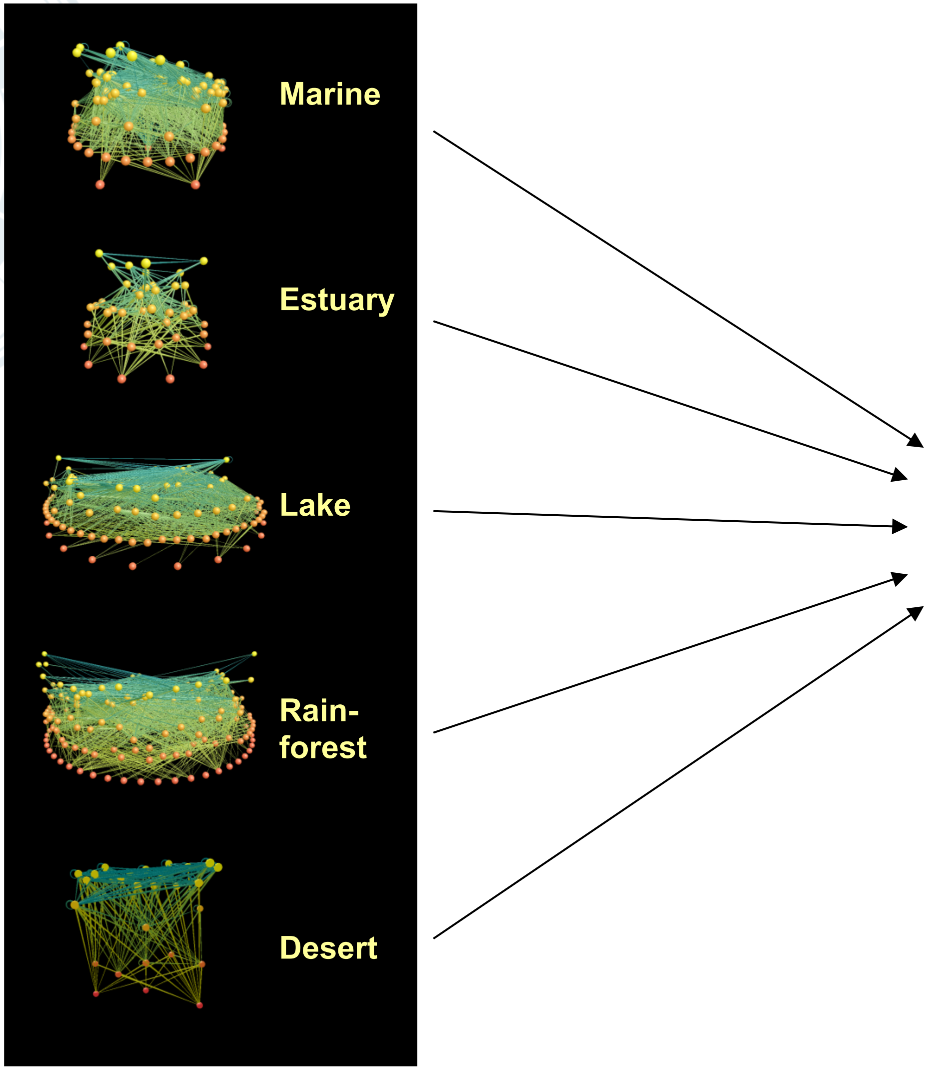


S = 92, L = 997, L/S = 11, C = 0.12, TL = 2.40

Martinez 1991 *Ecological Monographs*

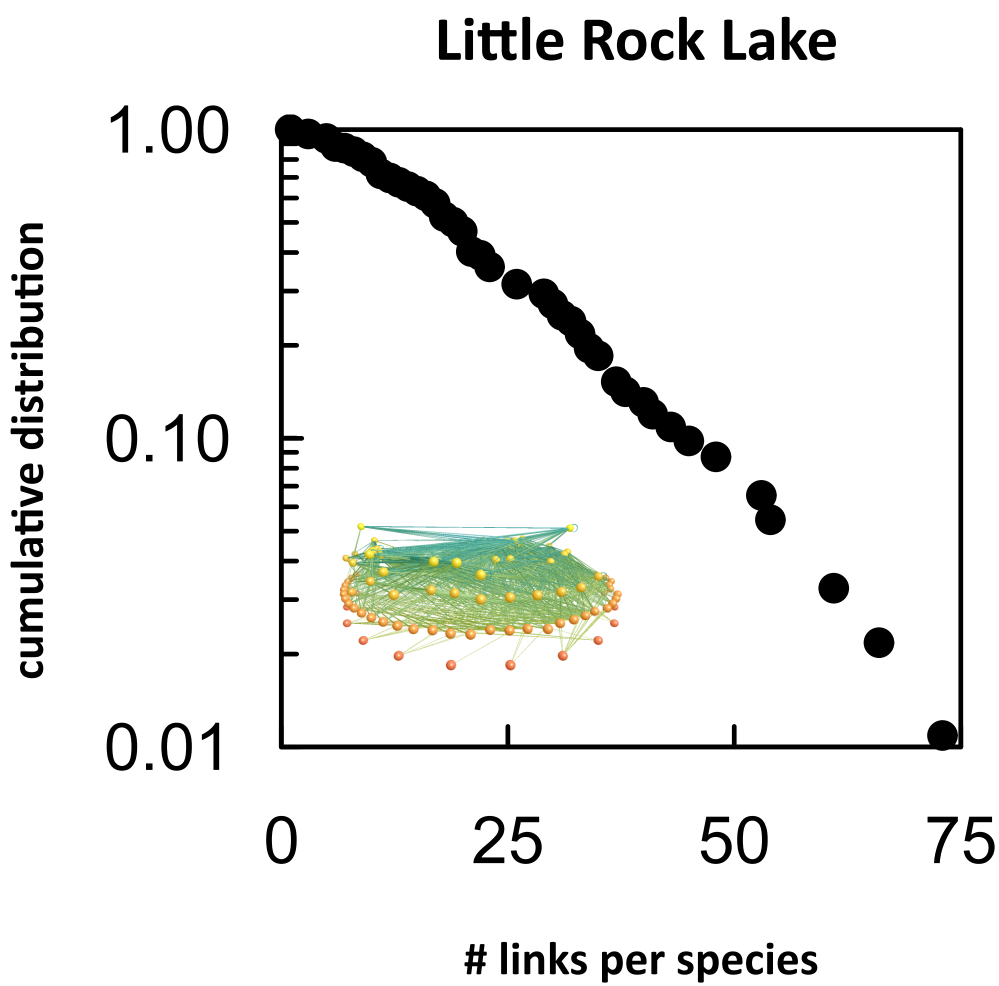
Generation 1 & 2 Questions

- **How are food webs organized?**
- **Are properties of food webs scale dependent?**
- **Do food webs from different habitats have similar structure?**
- **Are there simple models that predict food web structure?**
- **Do food webs show non-random modules, motifs, & community structure?**
- **How does food web structure influence risk of cascading extinctions?**
- **How does structure influence dynamics and stability?**



Apparent Complexity

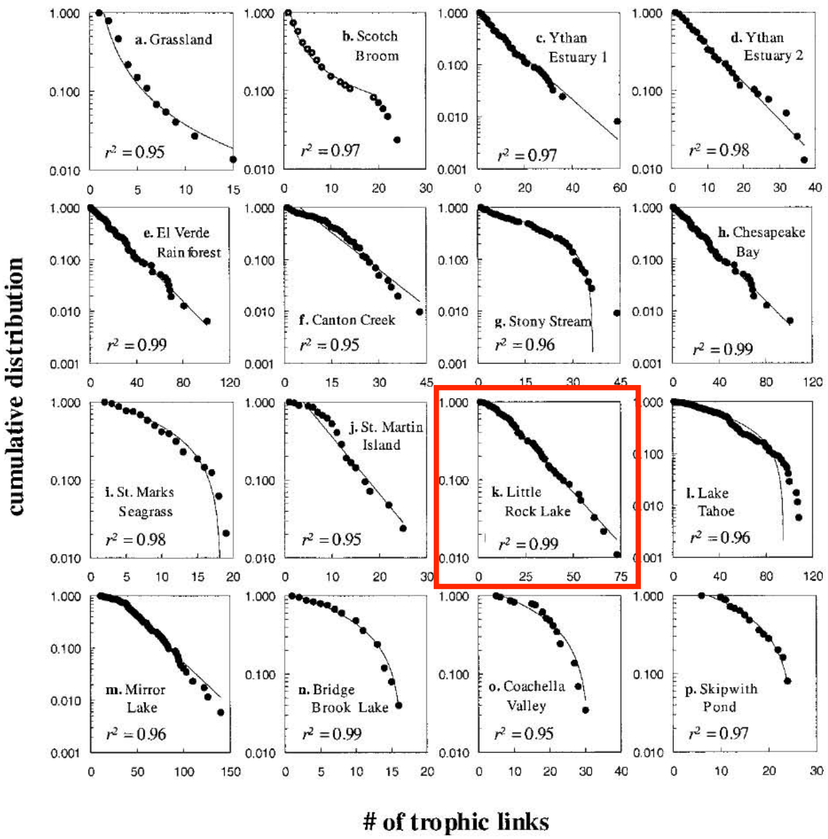
Example 1: Degree Distributions



Exponential, not Power Law

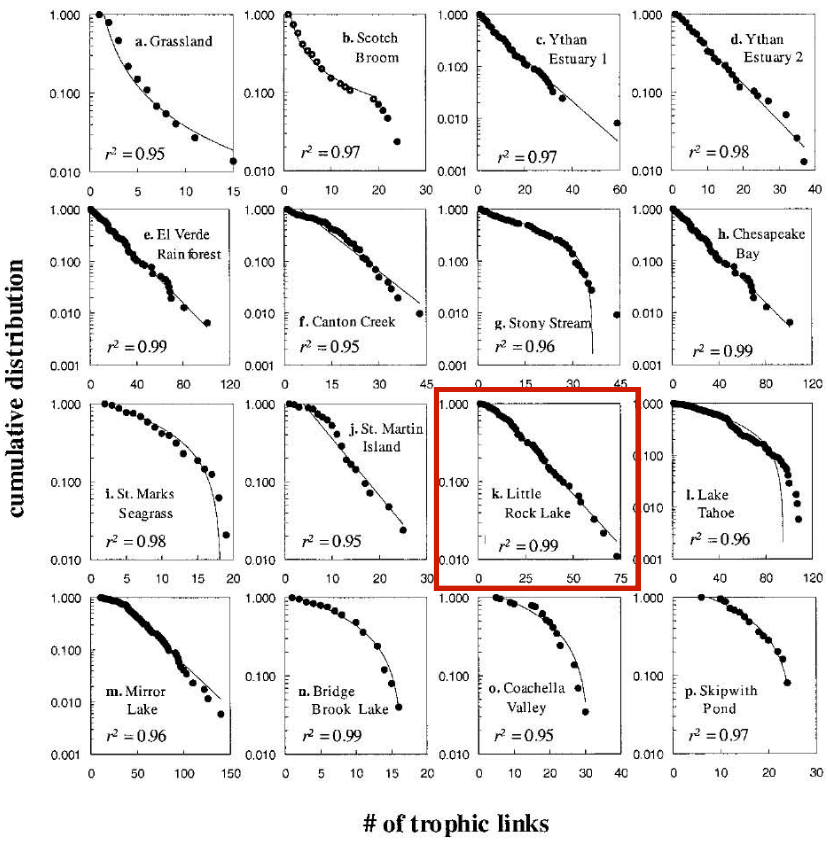
Apparent Complexity

Un-Normalized Data for 16 Webs

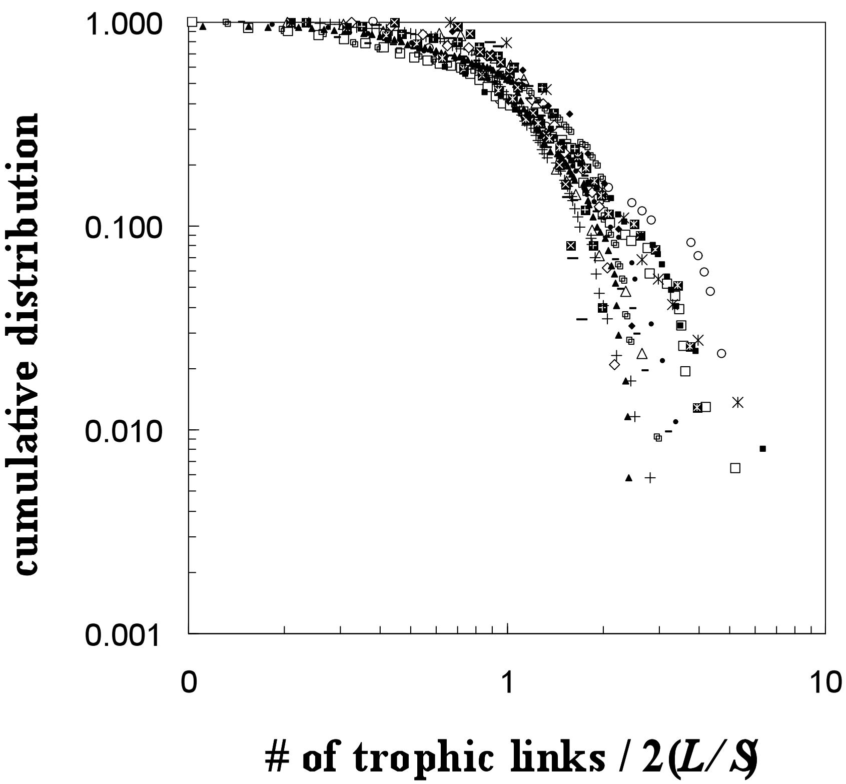


Apparent Complexity → Underlying Simplicity

Un-Normalized Data for 16 Webs



Normalized Data for 16 Webs



Dunne *et al.* 2002 *PNAS*; Camacho *et al.* 2002 *Phys Rev Lett;* Stouffer *et al.* 2005 *Ecology*

Example 2: Metrics

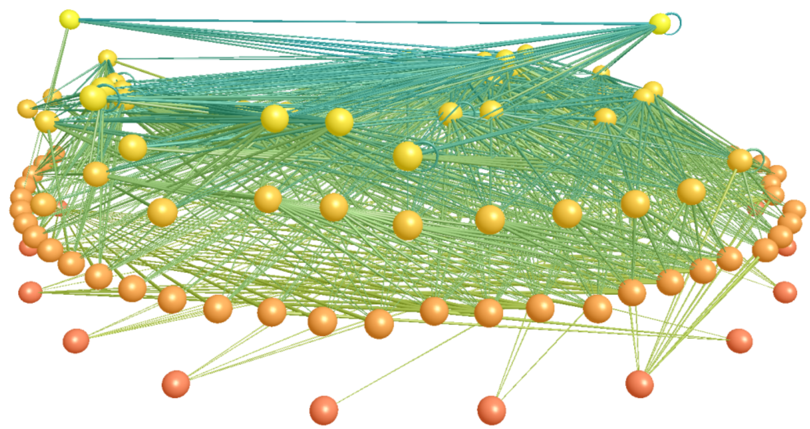
Types of Organisms:

% Top spp.	= 1.1
% Intermediate spp.	= 85.9
% Basal spp.	= 13.0
% Cannibal spp.	= 14.1
% Herbivore spp.	= 37.0
% Omnivore sp.	= 39.1
% Species in loops	= 26.1

Linkage Metrics:

Mean food chain length	= 7.28
SD food chain length	= 1.31
Log number of chains	= 5.75
Mean trophic level	= 2.40
Mean max. trophic simil.	= 0.74
SD vulnerability (#pred.)	= 0.60
SD generality (#prey)	= 1.42
SD links (#total links)	= 0.71
Mean shortest path	= 1.91
Clustering coefficient	= 0.18

Little Rock Lake Food Web



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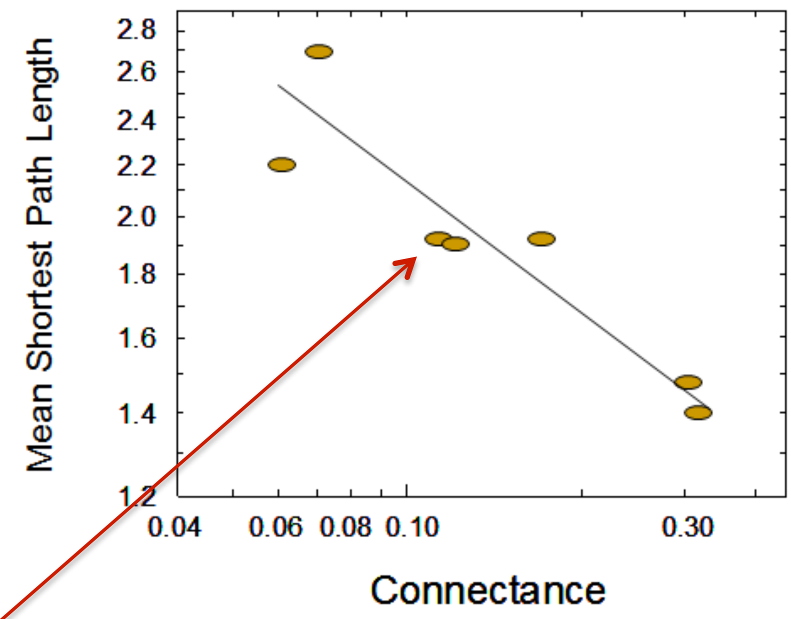
Path Length vs. C



Williams et al. 2002 *PNAS*

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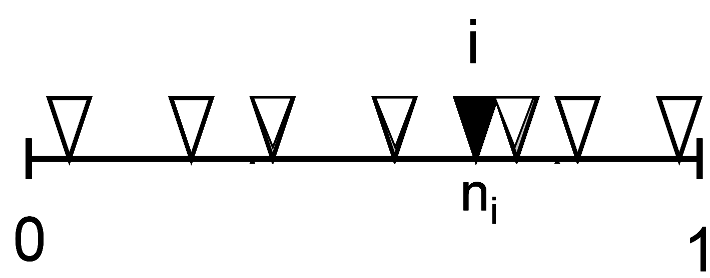
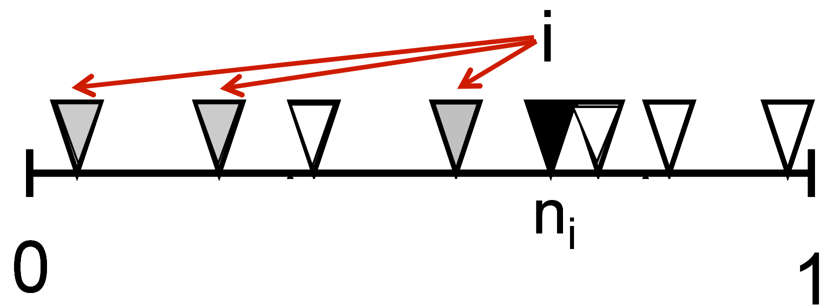
Simple, Stochastic, Single-Dimensional Models of Food-Web Structure

Explain "the phenomenology of observed food web structure, using a minimum of hypotheses"

1) **Two parameters: S (species richness) and C (connectance)**
2) **Assign each species i a uniform random "niche value" n_i of 0 to 1**
3) **Simple rules distribute links from consumers to resources**



Generation 1: Cascade Model



Link distribution rules:

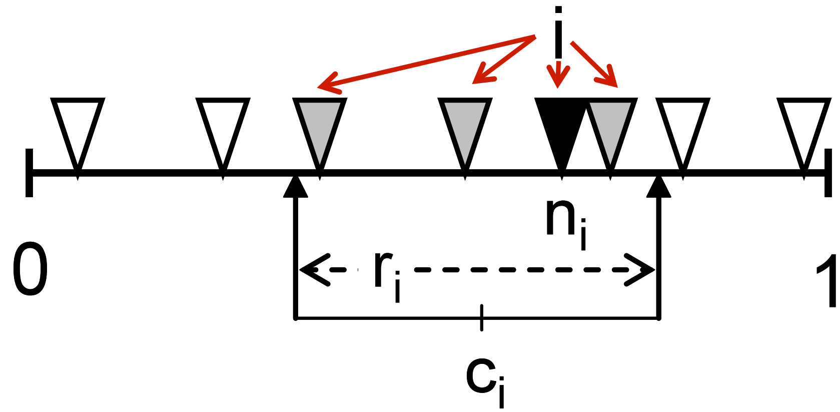
→ Each species i has probability P = 2CS/(S-1) of consuming resource species j with lower niche values ($n_j < n_i$)

Effect of rules:

→ Creates strict hierarchy of feeding (cannibalism & longer cycles prohibited)

Cohen & Newman 1985 *Proceedings of the Royal Society London B*

Generation 2: Niche Model



Link distribution rules:

→ Species i is assigned a feeding range r_i (drawn from beta distribution)

→ The center c_i of r_i is a uniform random number < n_i

→ Species i feeds on all species that fall within r_i

Effect of rules:

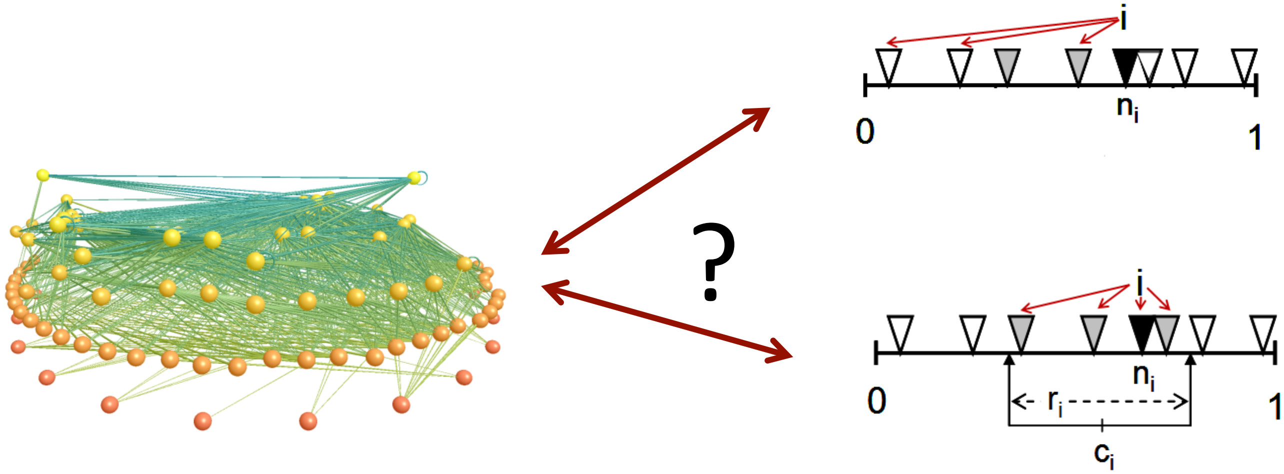
→ Beta distribution generates exponential-type degree distributions

→ The feeding hierarchy is slightly relaxed (cycles can occur)

→ Webs are "interval" (species feed on contiguous sets of species)

Williams & Martinez 2000 *Nature* (Simple rules yield complex food webs)

Fit of the Models to Data



1. **Metrics**
2. **Motifs**

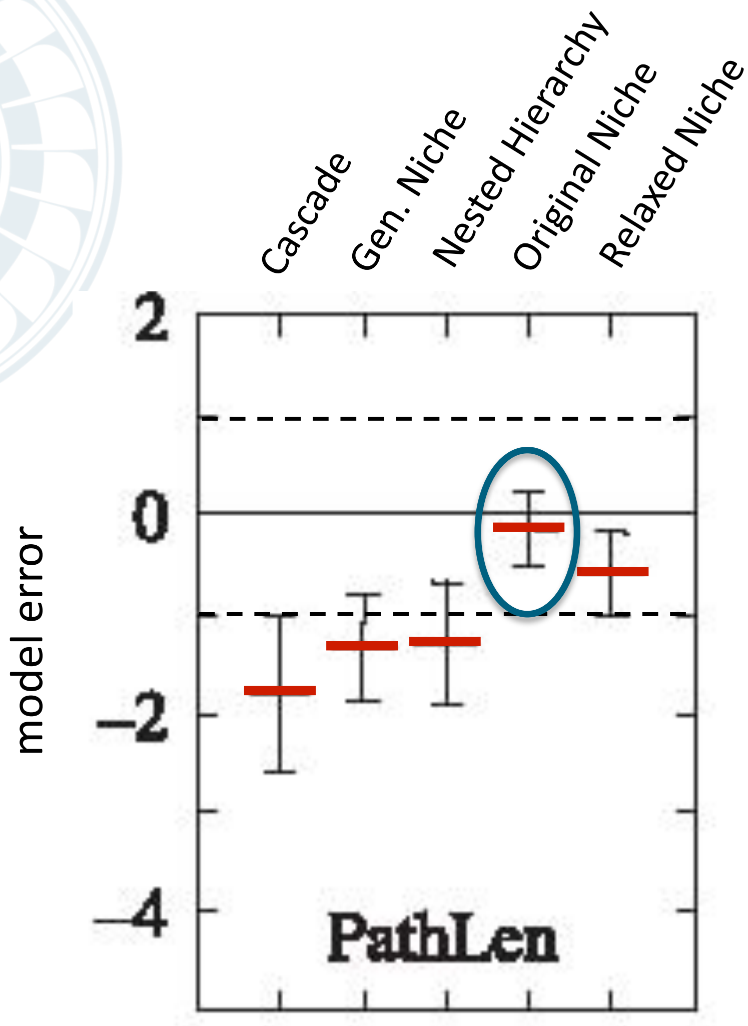
Analysis 1: Metrics

- **<u>Test:</u> Against the structure of empirical food webs**
- **<u>Assess:</u> A suite of structural properties/metrics**
- **<u>Generate:</u> 1000s model webs for each empirical web**
- **<u>Evaluate:</u> How well does the model perform?**

→ **Normalized Model Error** = (empirical value – model mean) / (model median value - value at upper or lower 95% boundary of model distribution)

→ **MEs ≤ |1|** show 'good' fit of model mean to empirical value

Williams & Martinez 2000 *Nature*; Dunne et al. 2008 *PLoS Biology*; Williams & Martinez 2008 *J Animal Ecology*



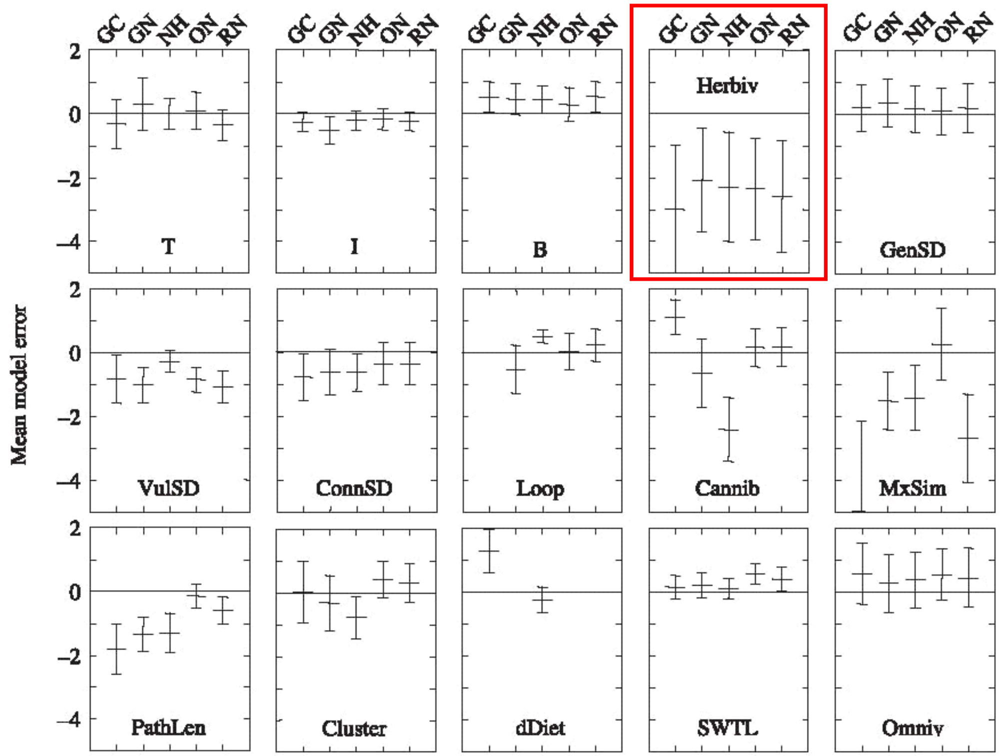
Path Length

→ 10 food webs examined

→ Most models significantly underestimate path length

→ Original Niche Model best (closest to ME = 0)

15 Metrics, 5 Models, 10 Webs



	ME mean	ME SD	% ME > |1|
Cascade	-0.57	2.37	46%
Gen Niche	-0.50	1.40	39%
Nest Hier	-0.53	1.45	26%
Niche	**-0.10**	**1.32**	**25%**
Relax Niche	-0.40	1.58	33%

1) Mean ME ≤ |1| for all models
2) Niche Model best: Lowest ME mean & SD
3) All models underestimate herbivory
4) Size effect: worse fits with increasing *S*

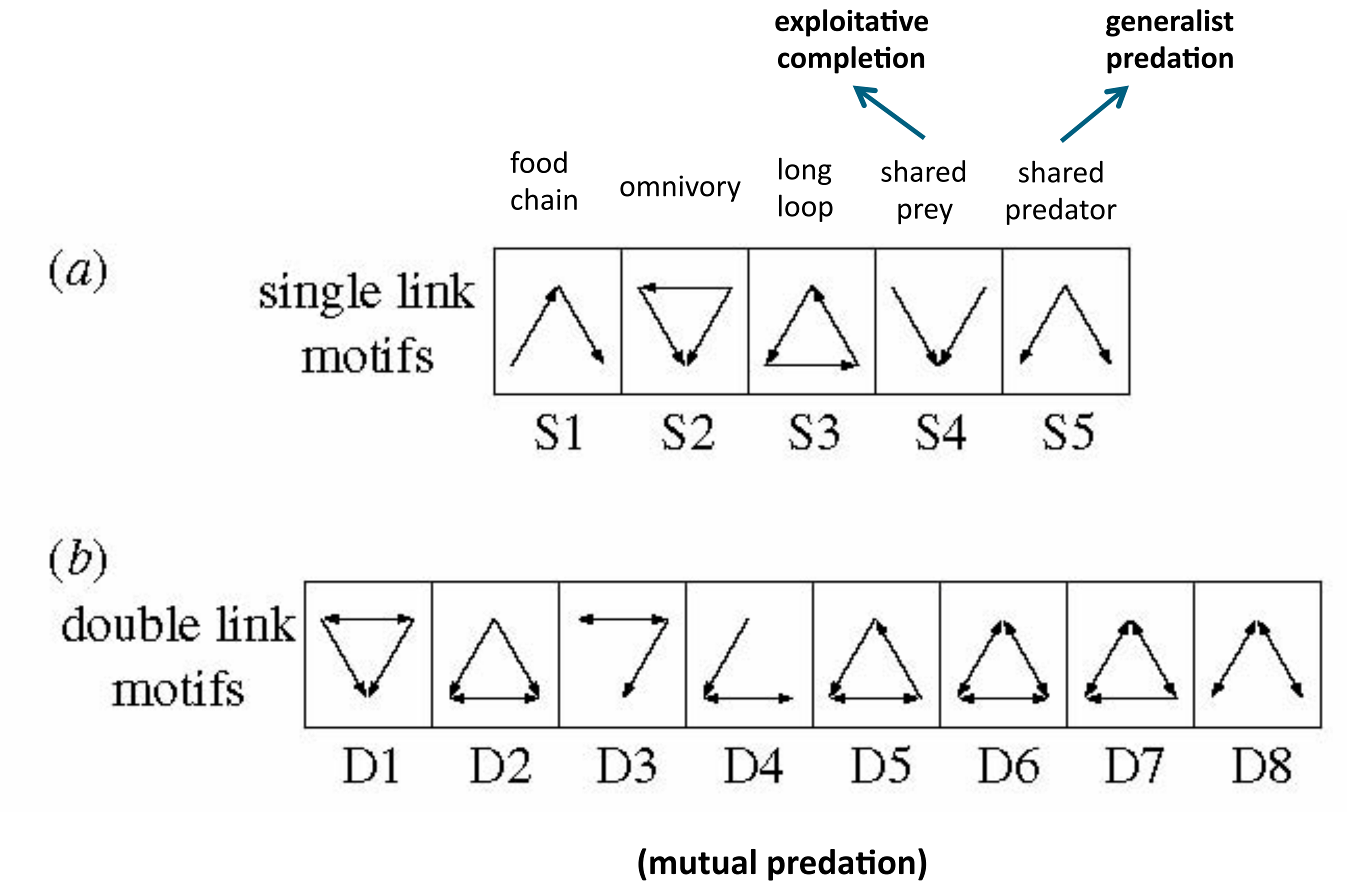
Williams & Martinez 2008 *Journal of Animal Ecology*

Analysis 2: Motifs

***n* = 3** (13 distinct motifs)

***n* = 4** (199 distinct motifs)

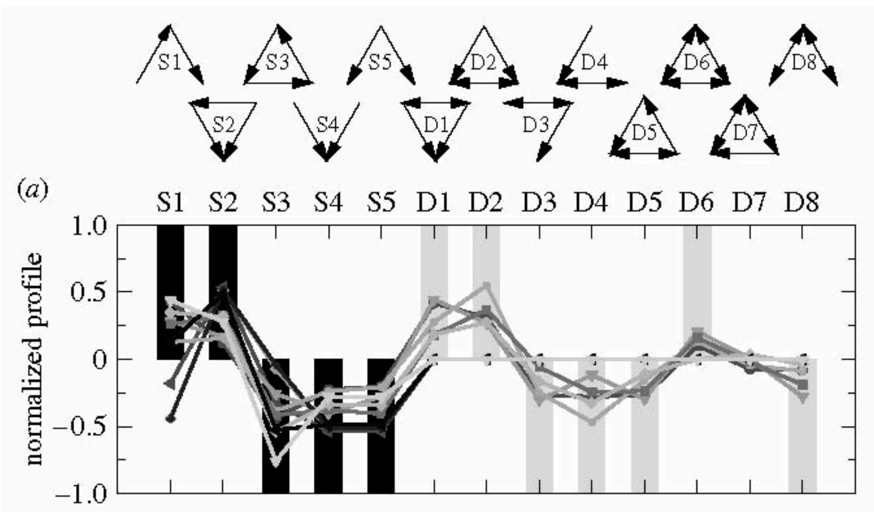
***n* = 5** (9364 distinct motifs)



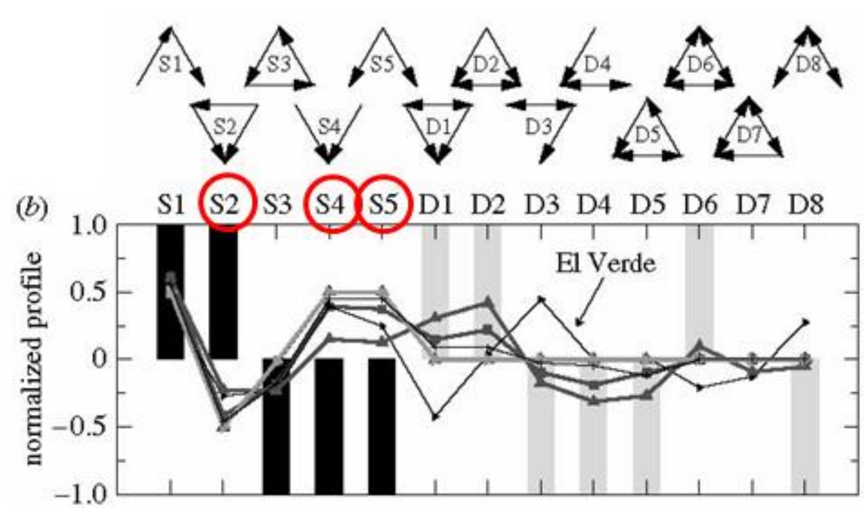
Motif Representation: Empirical Webs vs. Random Networks

→ Preserve # of prey, predator, single links, double links, and cannibals
→ Markov Chain Monte Carlo switching method used for randomization

Bars: Niche Model Predictions for Motif Under- or Overrepresentation

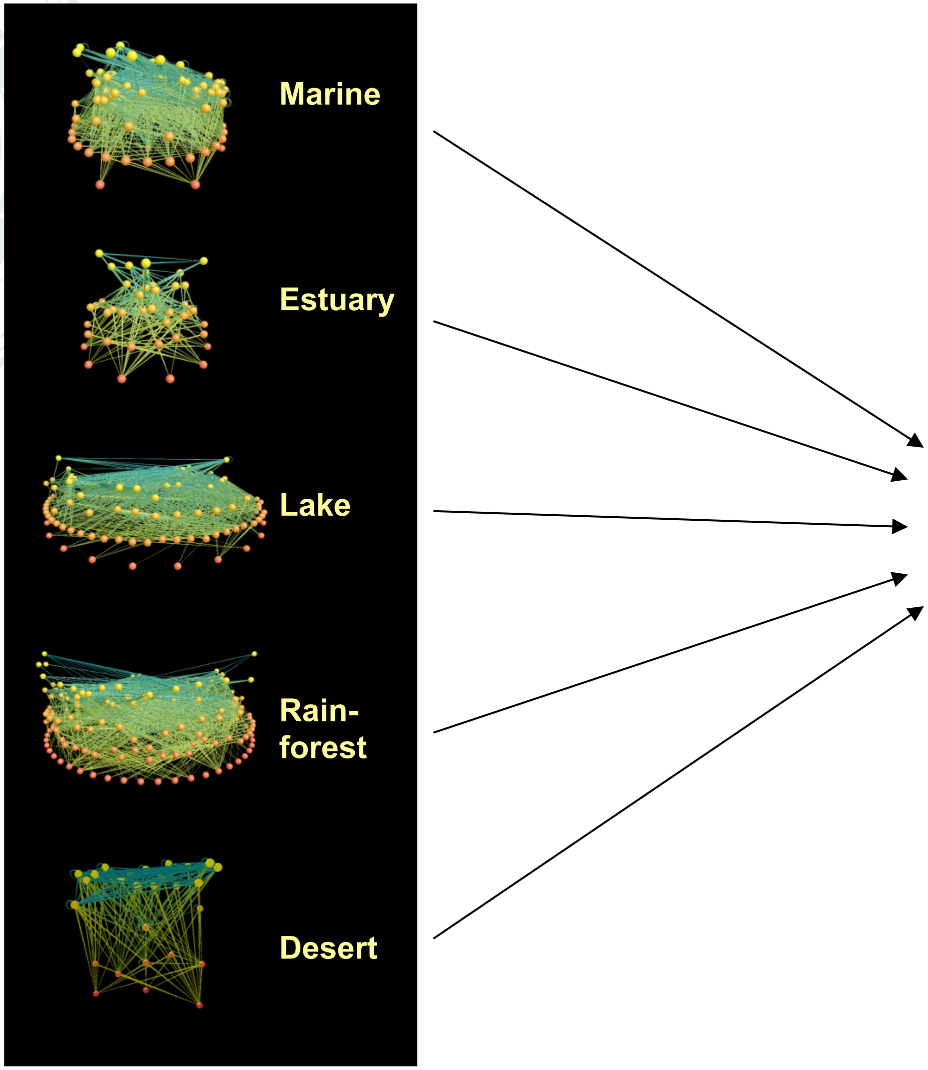


10 webs agree with Niche model

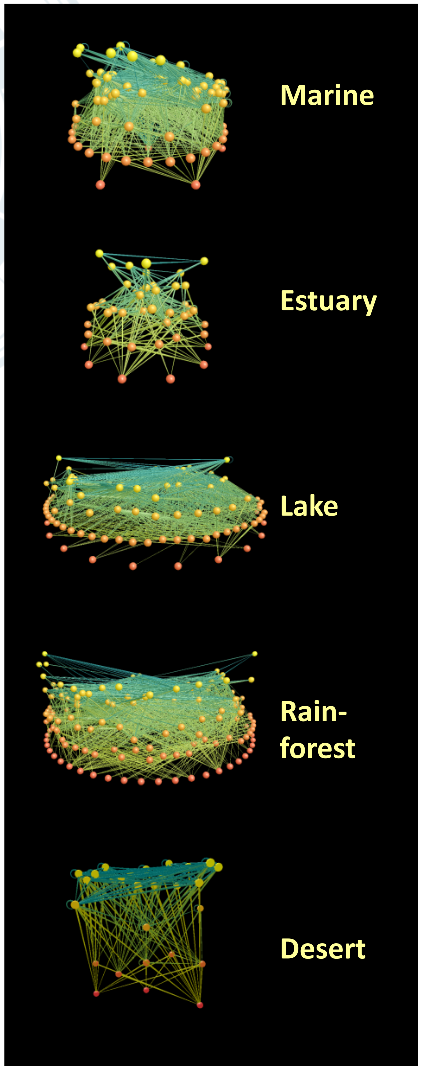


6 webs differ from Niche model

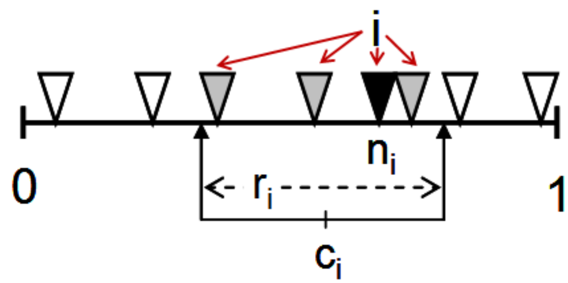
Stouffer *et al.* 2007 *Proceedings of the Royal Society B*



Apparent Complexity



Underlying Simplicity

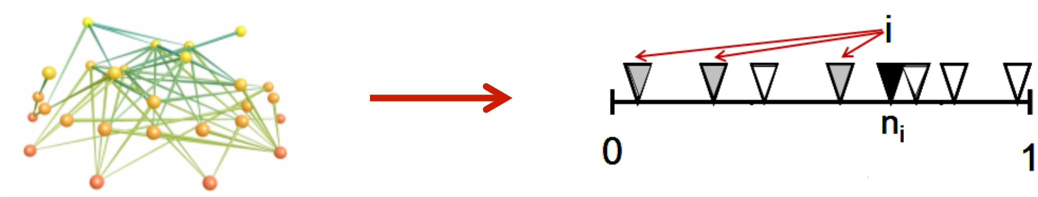


Two Parameters (C,S)

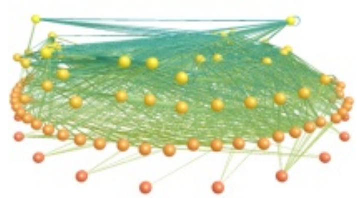
Simple Link Distribution Rules

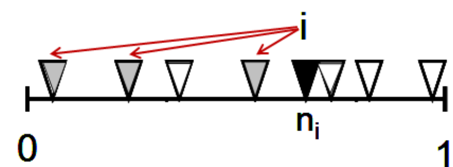
Successful Prediction of Network Structure

Gen 1 Data, Gen 1 Model: YES

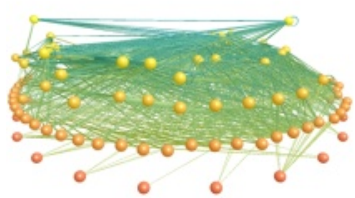


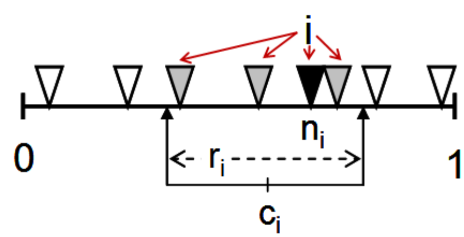
Gen 2 Data, Gen 1 Model: NO





Gen 2 Data, Gen 2 Model: YES





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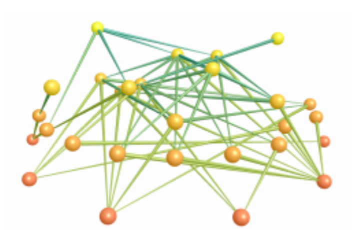
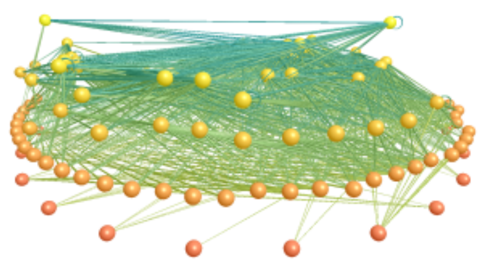
Generation 3 Data:

- More Highly & Evenly Resolved
- More Comprehensive: Parasites, Soil Biota, etc.
- Inclusion of Humans
- Replication Along Gradients
- Enriched Datasets (Traits/Abundance/etc.)
- Multiple Types of Interactions
- Individual Level Data
- Automated Data Generation

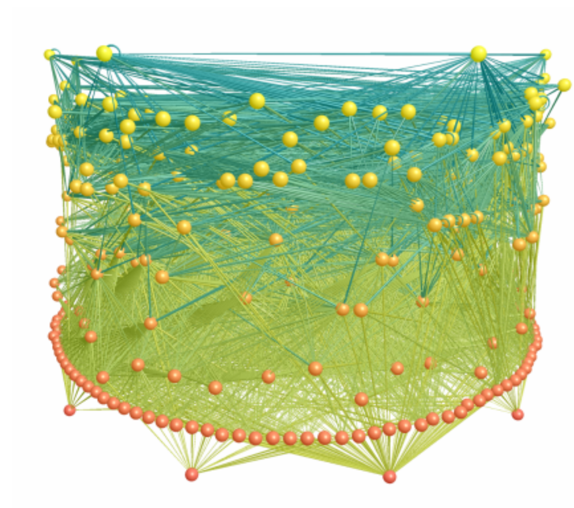
More Comprehensive & Resolved Webs



Bear Island, 1923



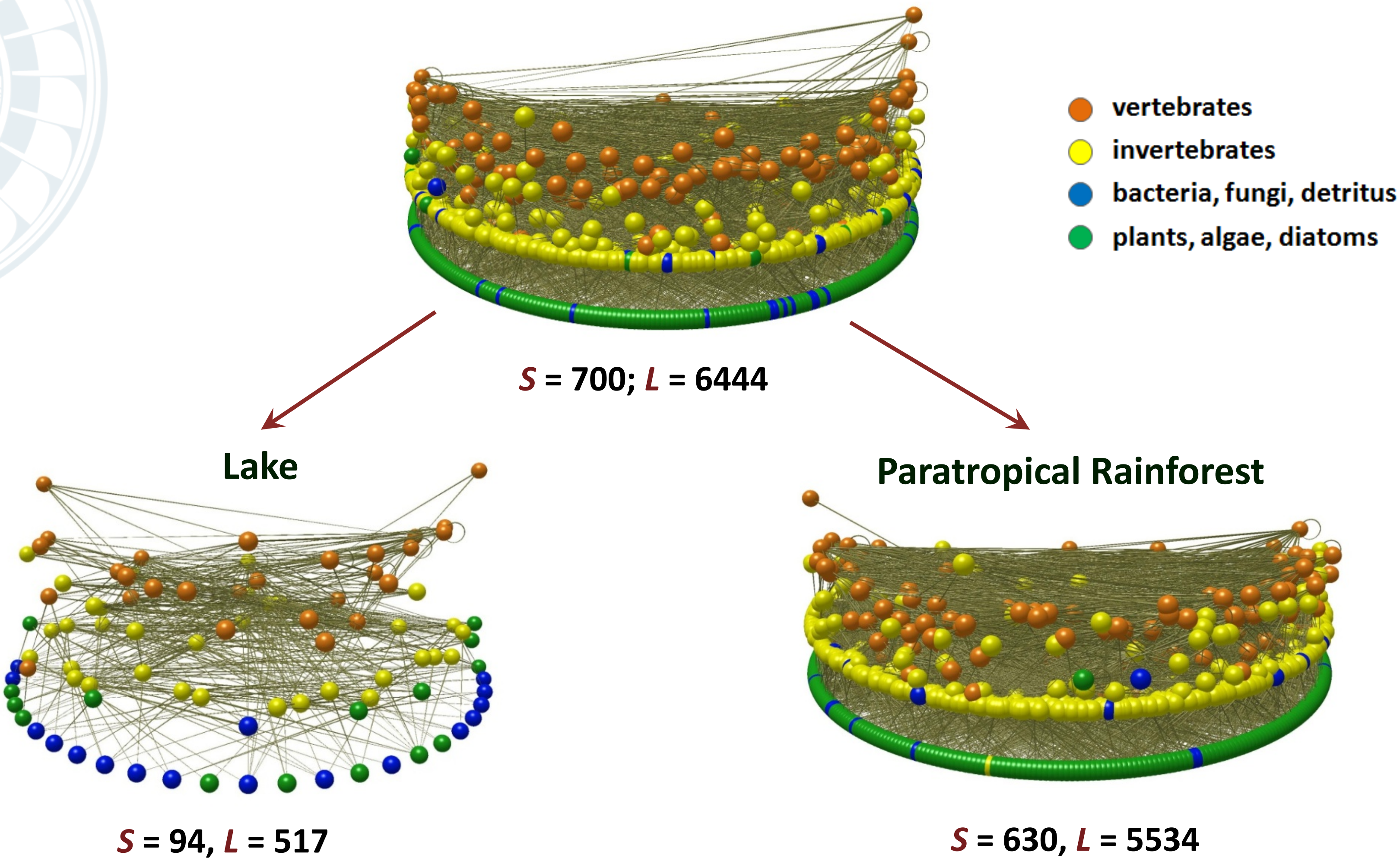
Little Rock Lake, 1991



Weddell Sea, 2011

Example 1

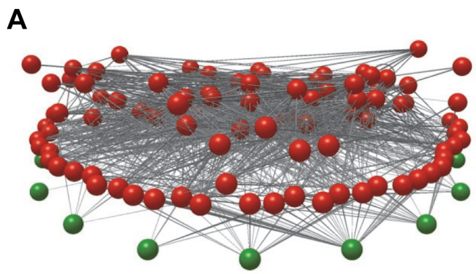
Messel Shale Food Web (47 mya)



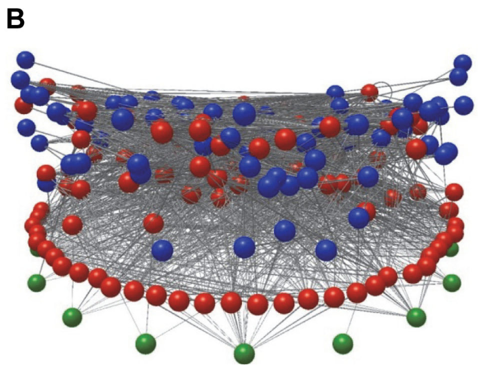
Dunne *et al.* 2013 *Proceedings of the Royal Society B*

Example 2

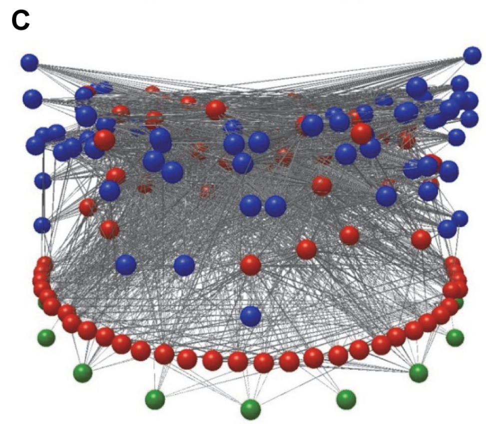
Estero de Punta Banda Food Web



Free-Living Species Only
S **= 106,** ***L*** **= 1085**



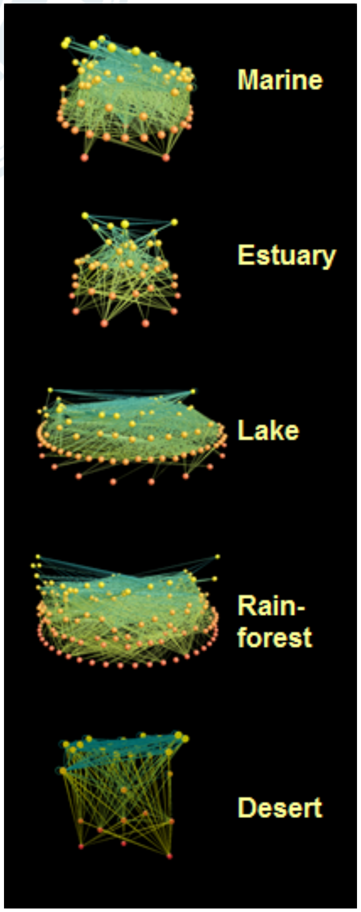
Including Parasites
S **= 185,** ***L*** **= 2838**



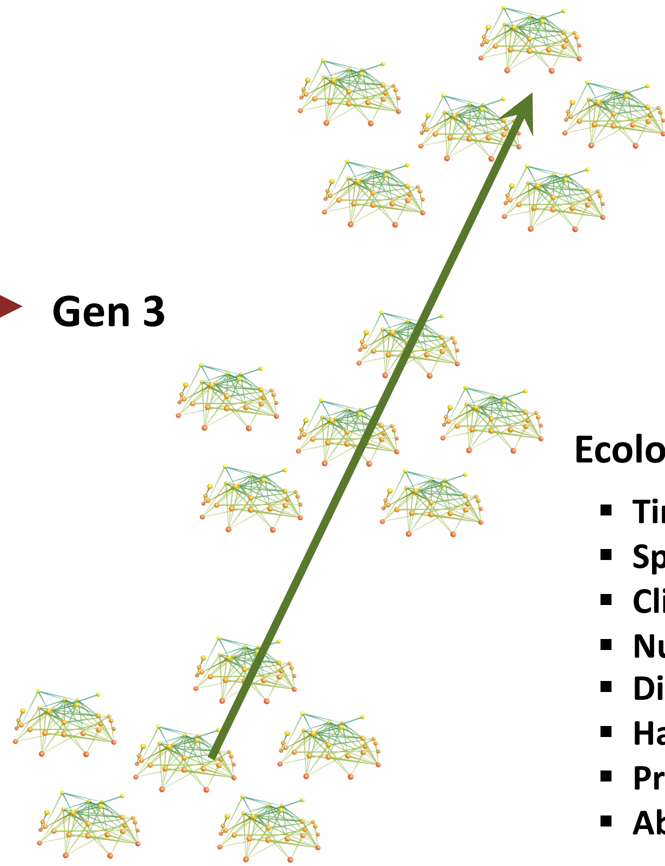
Parasites & Concomitant Links
S **= 185,** ***L*** **= 4671**

Dunne *et al.* 2013 *PLoS Biology*

Replicated Webs Along Gradients



Gen 1,2 → Gen 3

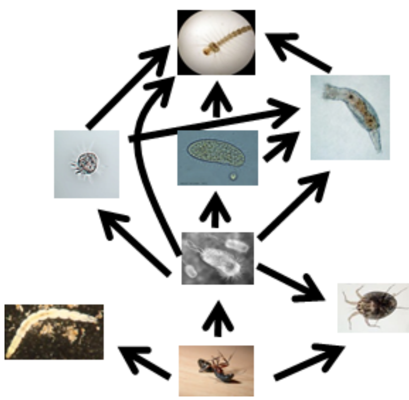


Ecological Drivers:

- Time
- Space
- Climate
- Nutrients
- Disturbance
- Habitat Size
- Productivity
- Abundance/Biomass

Example 1: Climate, Productivity, Ecosystem Size

Pitcher Plant (*Sarracenia purpurea*) Food Webs



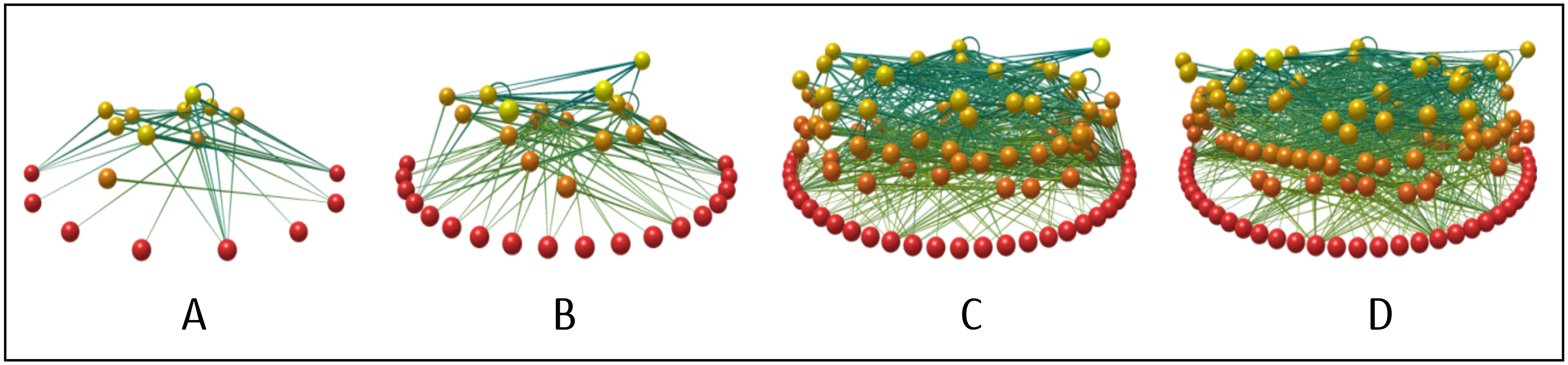
- **780 aquatic food webs: 20 reps, 39 sites**
- **Large geographic gradients**
- **75 taxa total, *S* = 2-35 per web**
- **Additional data: climate, ecosystem volume, body size, biomass & population estimates, etc.**

Baiser *et al.* 2011 *Global Ecology & Biogeography*

Example 2: Spatial Scale of Sampling

700+ Sanak Archipelago Intertidal Food Webs

Spencer Wood, Jen Dunne, *et al*.



A: Quadrat Food Web — a meter squared area (S=18)

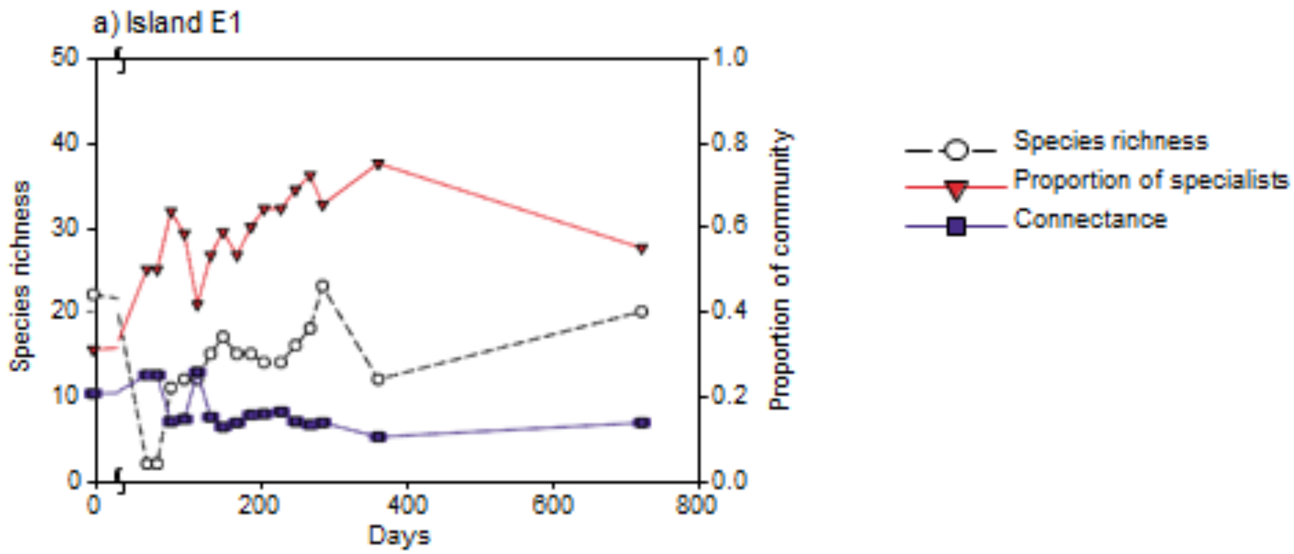
B: Transect Food Web — 10 quadrats along a transect (S=35)

C: Site Food Web — 8 neighboring transects (S=93)

D: Island Food Web — 6 sites across the island (S=120)

Example 3: Time/Ecological Assembly

Florida Mangrove Islet Food Webs



- **6 islets of varying size and distance from mainland**
- **Post-defaunation, species lists every 3 weeks for 1 year**
- **Food web data filled in 40 years later**
- **102 food webs through time**

Piechnik, Lawler, Martinez (2008) Food-web assembly during a classic biogeographic study: Species' "trophic breadth" corresponds to colonization order. *Oikos*.

Generation 3 Questions

- Simple models for high resolution data? How many dimensions?
- Do different types of taxa play unique or generic roles?
- Food web assembly through ecological & evolutionary time
- Does community organization or species roles shift along gradients?
- Does the identity of species playing particular roles change?
- How do traits and phylogeny constrain structure?
- First principles theory of constrained trophic organization at regional and local levels?
- Individual behavior → population level dynamics → ecosystem structure & function
- Roles and importance of species given different types of interactions

Generation 3 Approaches

- **Null Models: e.g., MaxEnt**
- **Probabilistic Maximum Likelihood Approaches**
- **Individual-Based Models & Analyses**
- **Phylogenetic Approaches: e.g., Coalescent Theory**
- **Machine Learning Algorithms: e.g., Trait Prediction**
- **Graph Alignment**
- **Motif Analysis/Species Role Analysis**
- **AUC (Area Under Curve) Analyses**

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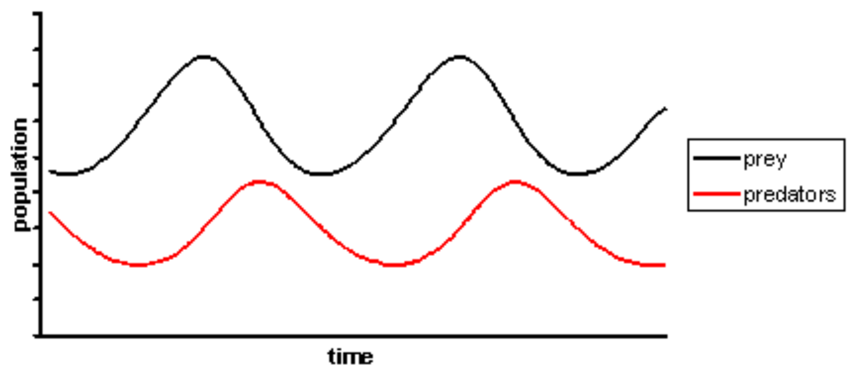
Lotka-Volterra Predator-Prey Dynamics

A pair of first order, non-linear differential equations, representing change in numbers of predator y and prey x over time t due to their interaction.

$$\frac{dx}{dt} = \alpha x - \beta x y \qquad \frac{dy}{dt} = \delta x y - \gamma y$$

αx is the intrinsic exponential growth of prey
βxy is the rate of predation of y on x, proportional to rate at which y and x meet
δxy is the growth rate of the predator
γy is the natural death rate of the predator (exponential decay)



Lotka 1925 Elements of Physical Biology, Volterra 1926 *Mem R Accad Naz dei Lincei*

Modeling Species Interactions, S > 2

1) Community Matrices: Species interaction coefficients describe the impact of species *i* on growth of species *j* at equilibrium population densities.
LOCAL STABILITY

2) Food-Web Modules: Population dynamics of *S* = 3-9 interacting species via numerical integration of linked ordinary differential equations.
POPULATION STABILITY

3) Complex Food Webs: Population dynamics of $S \geq 10$ interacting species.
POPULATION STABILITY, SPECIES PERSISTENCE, etc.

→ **Population Dynamics + Structure:** run population dynamics on complex networks

→ **Population + Evolutionary Dynamics:** evolve complex webs from a few species

→ **EcoPath with EcoSim:** Software package based on static, linear, steady-state, mass-balanced snapshots of specific systems + dynamic projections

→ **Individual-Based Models:** simple agents governed by simple rules

Allometric Trophic Network (ATN) Model

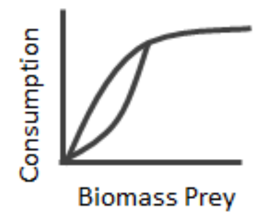
Time evolution of species' biomasses given bioenergetic constraints & interactions

- **Basal species grow via a carrying capacity, resource competition, or other models**
- **Other species grow according to feeding rates and assimilation efficiencies**
- **All species lose energy due to metabolism and consumption**
- **Functional responses determine how consumption rates vary**
- **Rates of production, metabolism, maximum consumption scale with body size—i.e. allometry reduces dimensionality**

Yodzis & Innes 1992 *Amer. Nat.*, Williams & Martinez 2004 *Eur. Phys. J. B*

Allometric Trophic Network (ATN) Model: Population Biomass Dynamics through Time

Loss to metabolism
Gain from resources
Loss to consumers



Functional Response

mass-specific metabolic rate

$$B_i' = -x_i B_i + \sum_{j=resources} x_i y B_i F_{ij} - \sum_{j=consumers} x_j y B_j F_{ji} / e_{ji}$$

Biomass$_i$ at time *t*

max metabolic-specific ingestion rate

assimilation efficiency

F: Functional Response

Predator's relative consumption rate as fraction of maximum ingestion rate

Type I

- Linear (used in Lotka-Volterra models)

Type II

- Saturating curve (dominates non-linear modeling)

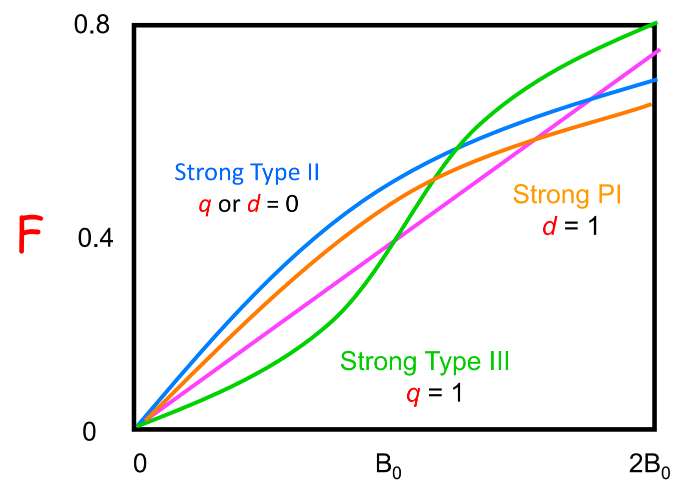
Type III (parameter *q*)

- S curve

Predator Interference (parameter *d*)

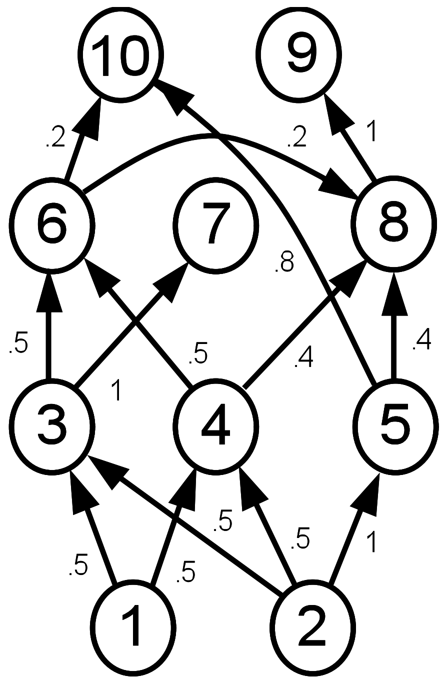
-Similar to Type II shape

Functional Response Forms

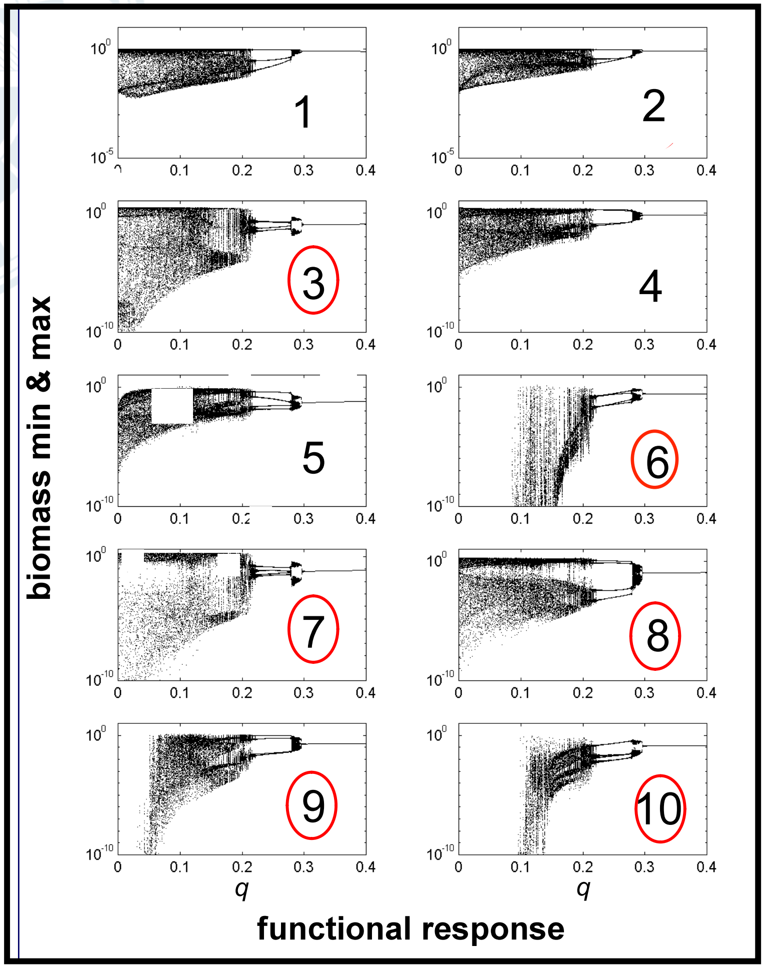


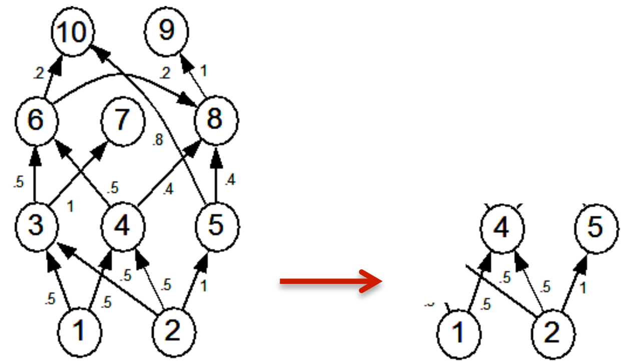
biomass of resource species

Functional Response: Impacts on Species Stability & Persistence



- On S=10 web, run dynamics altering only the shape of the FR
- Go from Strong Type II (*q* = 0) to weak Type III (*q* = 0.4)





- **Red circles: 6 species that go extinct with strong Type 2 (*q* = 0) FR**
- **Weak Type III FR (e.g., *q* = 0.1-0.3) stabilizes dynamics for any given species and increases overall species persistence.**
- **Why? By decreasing feeding on low abundance species, allows them to recover.**

Williams & Martinez 2004 *Eur. Physics Journal B*

Ecological Network Structure

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2. Generation 1/2 Models
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Ecological Network Dynamics

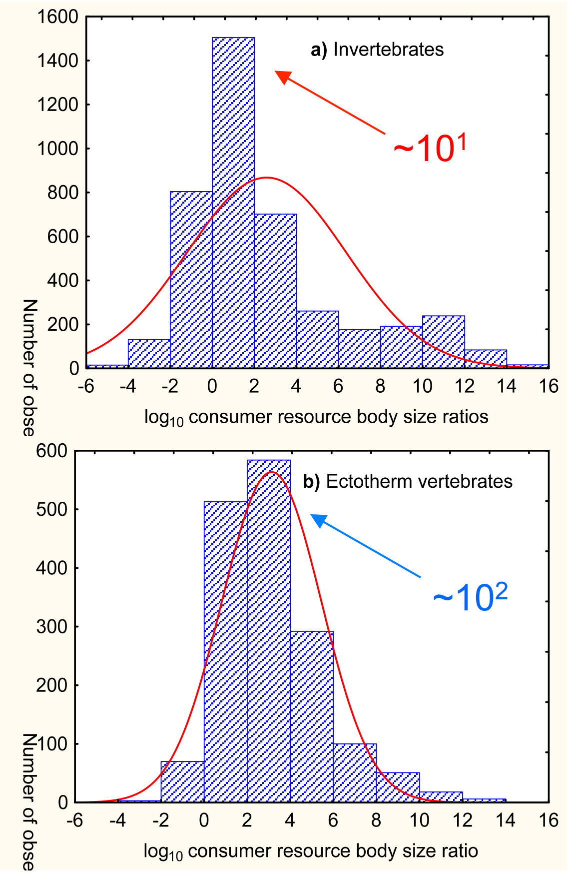
4. Allometric Trophic Network Model
5. **Empirical Validation**

Application

6. Humans in Food Webs

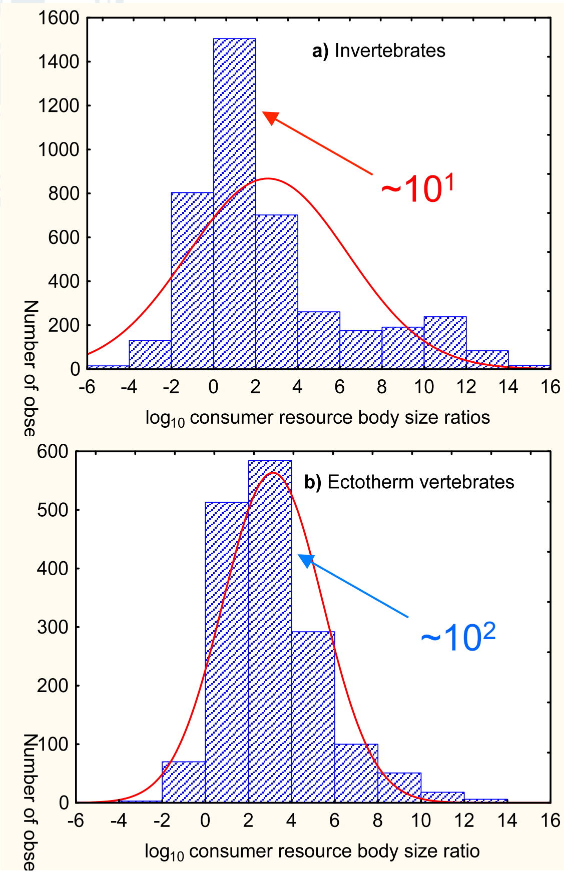
Example 1: Consumer-Resource Body-Size Ratios

Empirical Body-Size Ratios

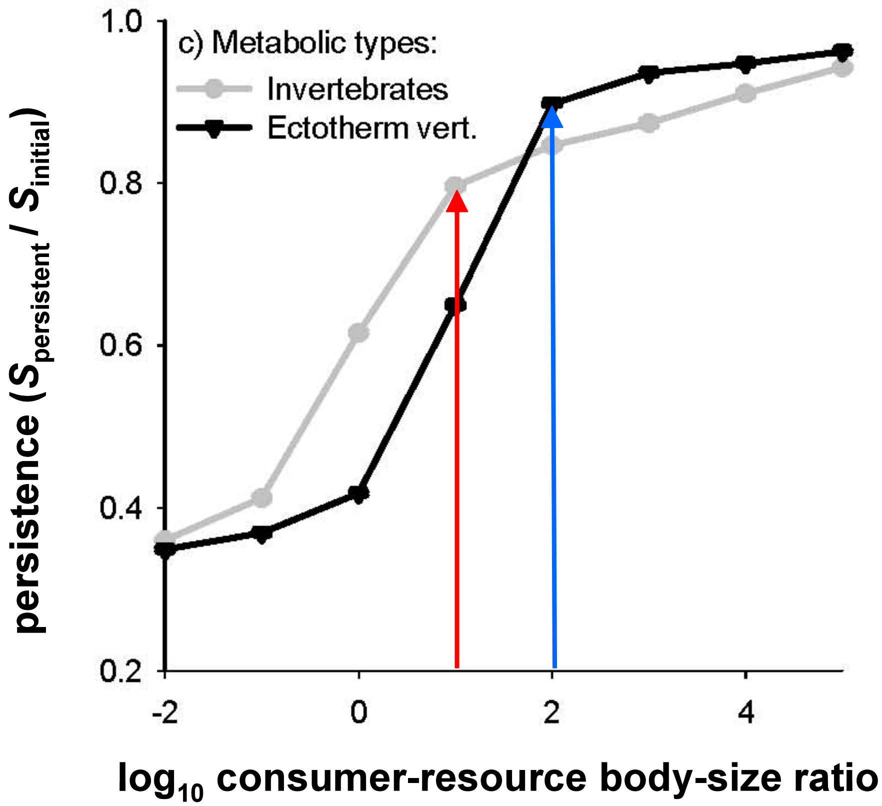


Brose *et al.* 2006. Body sizes of consumers and their resources. *Ecology*

Empirical Body-Size Ratios



ATN Model: Persistence as *f* (Ratios)



Brose et al. 2006 Allometric scaling enhances stability in complex food webs. *Ecology Letters*

Example 2: Interaction Strength

Measure effect of each "Removed Species" *R* on the biomass of every other species *T*, "Target Species"

1) For 100s of niche model webs with persistent ATN dynamics, do every 1-species removal
2) After removal, mean biomass & densities for time steps 50-200 used to calculate interaction strengths (**IS**)
2) Vary S, C, consumer metabolism, max. consumption, initial biomass, functional response, plant nutrient uptake across webs, etc.
3) For each of >250K possible ***R*** & ***T*** interactions, record 90 species, link, and network structure attributes
4) Assess which attributes best explains variation in **IS** using a Classification and Regression Tree (CART) algorithm (a nonlinear modeling algorithm)

Berlow et al. 2009. Simple prediction of interaction strengths in complex food webs. *PNAS*

90 Attributes

1) Global Structure

-S_i, S_f, C_i, C_f
-# & prop. of T, I, B, Herb, Carn, Omn
-# links TI, TB, II
-# links, L/S
-mean, max, sd of TL (resource average, shortest chain)
-clustering coefficient

2) Local Structure around R & T

-TL, #, total biomass, and mean # of consumer & resource spp. 1, 2, 3 degrees from R & T

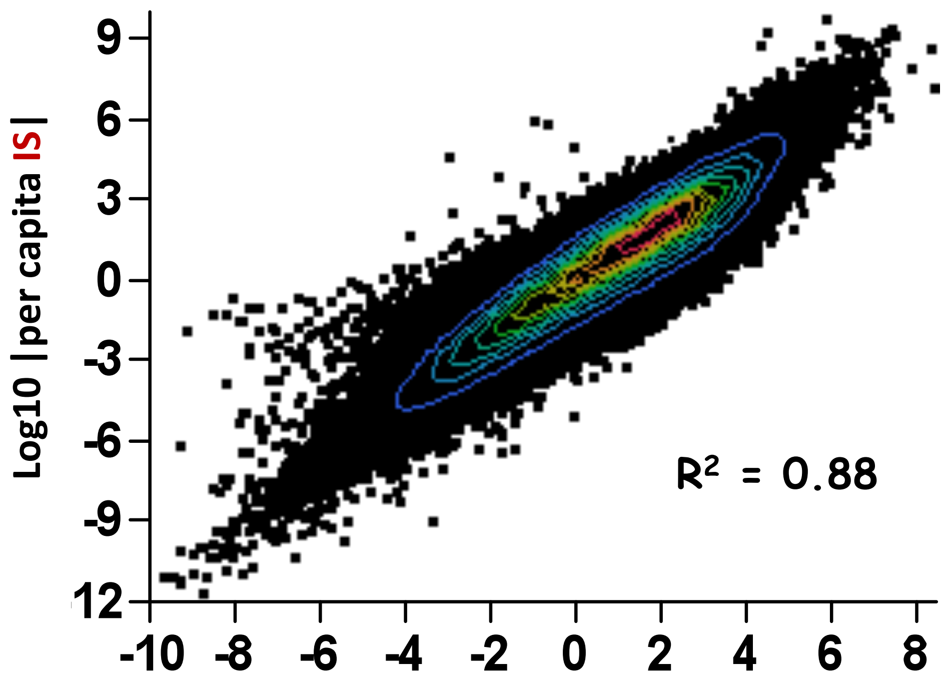
3) R & T Attributes

-mean biomass before R removed
-mean body mass
-functional response shape
-consumer interference
-half-sat. conc. of nutrient uptake for producers

4) Attributes of R-T Pair

-degrees of separation
-single vs. multiple paths from R to T
-net sign of all shortest paths and next-shortest
-sum of those, weighted sum of those

Per Capita IS: Best Prediction



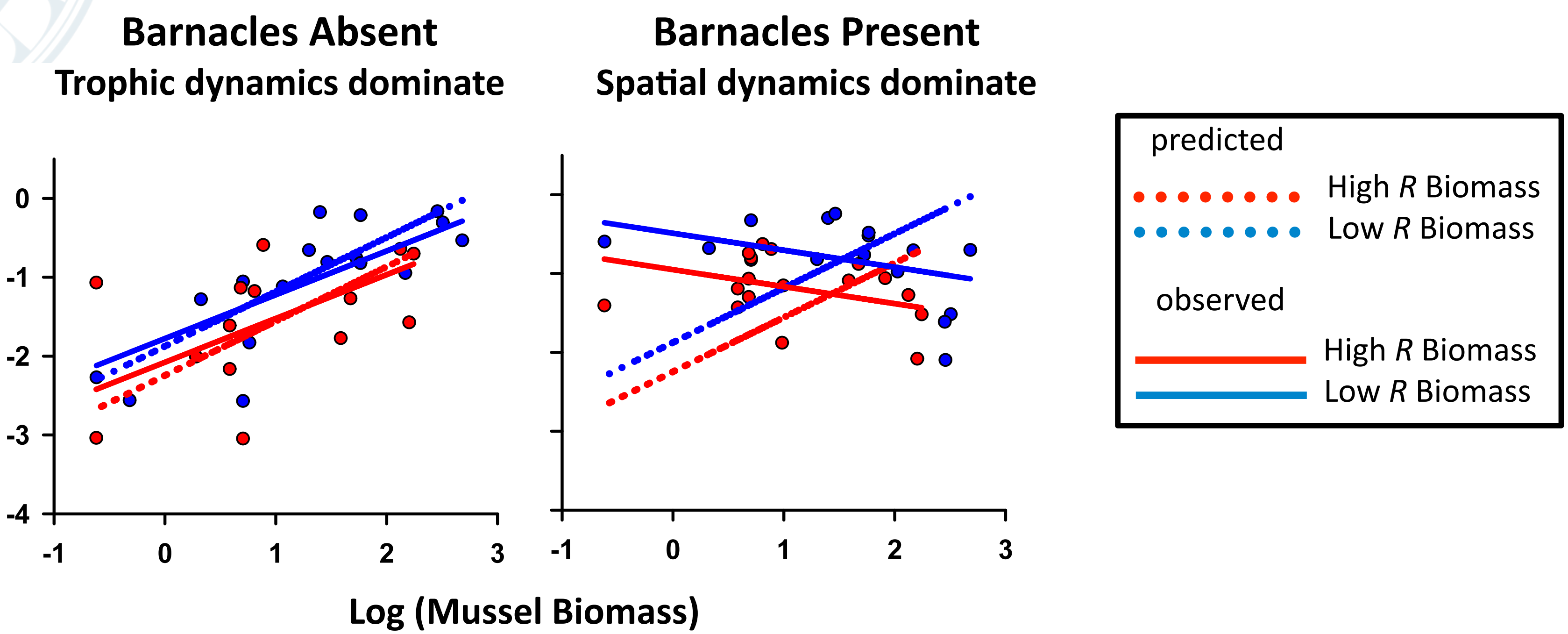
3 Easy to Measure Attributes:
Log (*T* biomass) + Log (*R* biomass) + Log (*R* body mass)

Empirical Test: An Experimental Intertidal Field System

1) Small intertidal habitats, S ~ 30
2) 3 species manipulated: R = predatory whelk; T = mussels; & barnacles
3) Barnacles mediate non-trophic effects of whelks on mussels, since whelks eat barnacles and barnacles facilitate mussel recruitment.
4) Measurements: IS of whelks on mussels; B^{+}_{T} (biomass of mussels with whelk present), B_r (biomass of whelk), M_R (body mass of mussels)

Berlow 1999. Strong effects of weak interaction in ecological communities. *Nature*

ATN Interaction Strength Predictions vs. Data



Example 3: Seasonal Planktonic Food Web Dynamics

ECOLOGY LETTERS

Ecology Letters, (2012) doi: 10.1111/j.1461-0248.2012.01777.x

LETTER

Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

Alice Boit,[1]* Neo D. Martinez,[2] Richard J. Williams[3,4] and Ursula Gaedke[1]

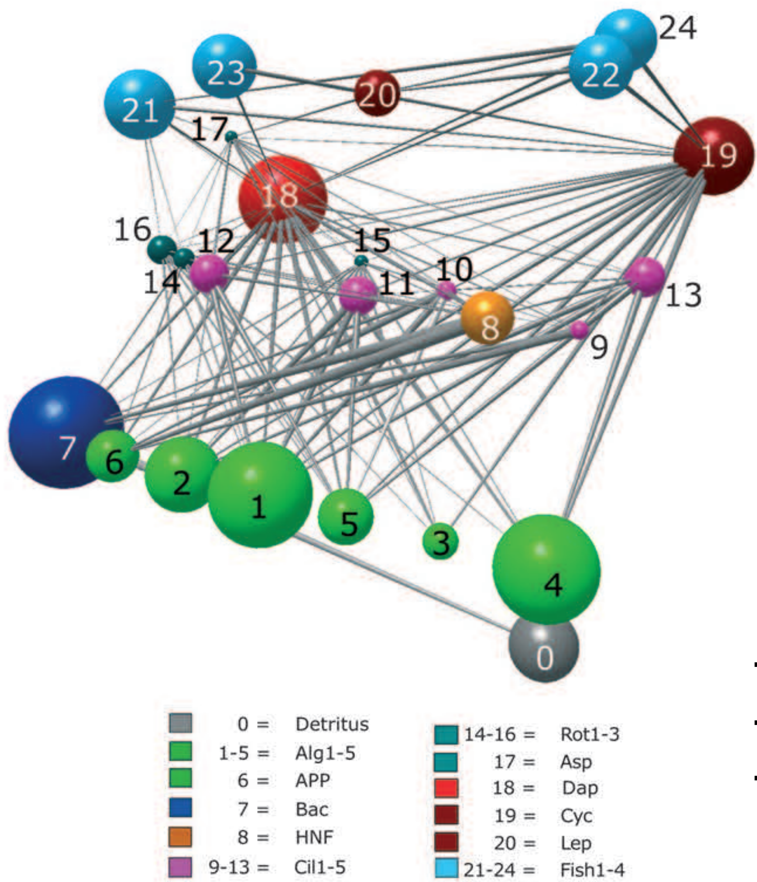
Abstract

Mechanistic understanding of consumer-resource dynamics is critical to predicting the effects of global change on ecosystem structure, function and services. Such understanding is severely limited by mechanistic models' inability to reproduce the dynamics of multiple populations interacting in the field. We surpass this limitation here by extending general consumer-resource network theory to the complex dynamics of a specific ecosystem comprised by the seasonal biomass and production patterns in a pelagic food web of a large, well-studied lake. We parameterised our allometric trophic network model of 24 guilds and 107 feeding relationships using the lake's food web structure, initial spring biomasses and body-masses. Adding activity respiration, the detrital loop, minimal abiotic forcing, prey resistance and several empirically observed rates substantially increased the model's fit to the observed seasonal dynamics and the size-abundance distribution. This process illuminates a promising approach towards improving food-web theory and dynamic models of specific habitats.

Keywords

Allometric Trophic Network model, community ecology, food web, multi-trophic dynamics, seasonal plankton succession.

Food Web of Lake Constance



Node size = mean biomass
Link size = mean carbon flow

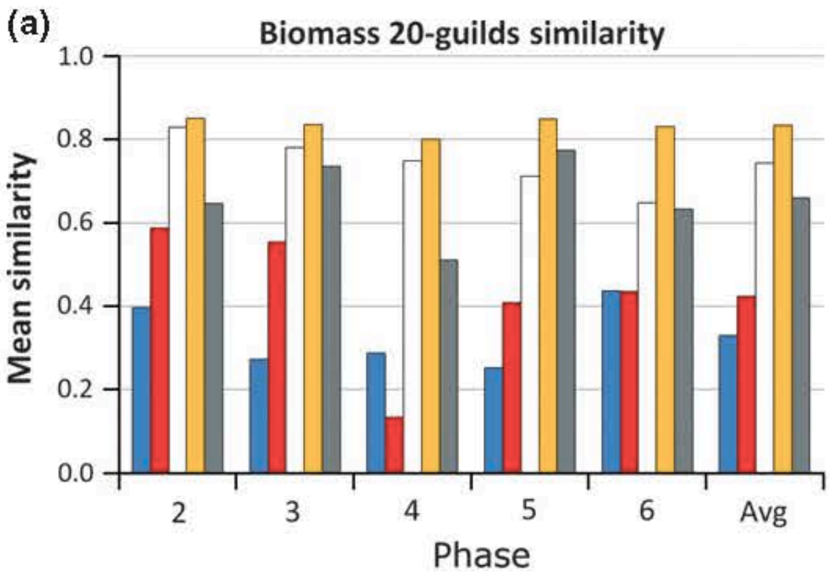
24 guilds, 107 links:

1 bacteria category
6 phytoplankton guilds
13 zooplankton guilds
4 fish guilds

→ **10 years of seasonal biomass data**
→ **Focus on 5 non-winter active phases**
→ **Average biomasses in each phase across years**

Seasonal Planktonic Biomass Dynamics:

Similarity of Model Predictions to Data For 20 Guilds



5 Cumulative Model Variants:

M0: Standard ATN model with detrital loop

M1: Lower prokaryote rates; active respiration

M2: Higher planktonic prey resistance

M3: Simple seasonal abiotic forcing

M4: Eliminates 17% of links (weak, poor doc)

Higher Similarity = Greater Fit of Model Output to Data

Figure 2 Summary of M0-M4 models' fit to relative biomass and relative production within each temporal phase. Phases are 2, early spring; 3, late spring; 4, CWP; 5, summer; 6, autumn. Mean percentage similarity between modelled and empirical biomass (a) and production (b) percentages in each phase and averaged across seasons.

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Ecological Network Dynamics

4. Allometric Trophic Network Model
5. Empirical Validation

Application

6. **Humans in Food Webs**

The Sanak Biocomplexity Project

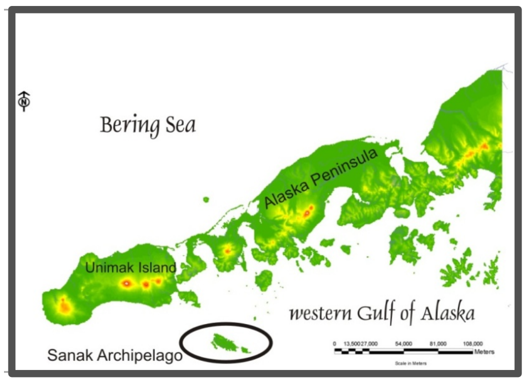
Maschner *et al.* (2009) An introduction to the biocomplexity of Sanak Island, Western Gulf of Alaska. *Pacific Science* 63:673-709

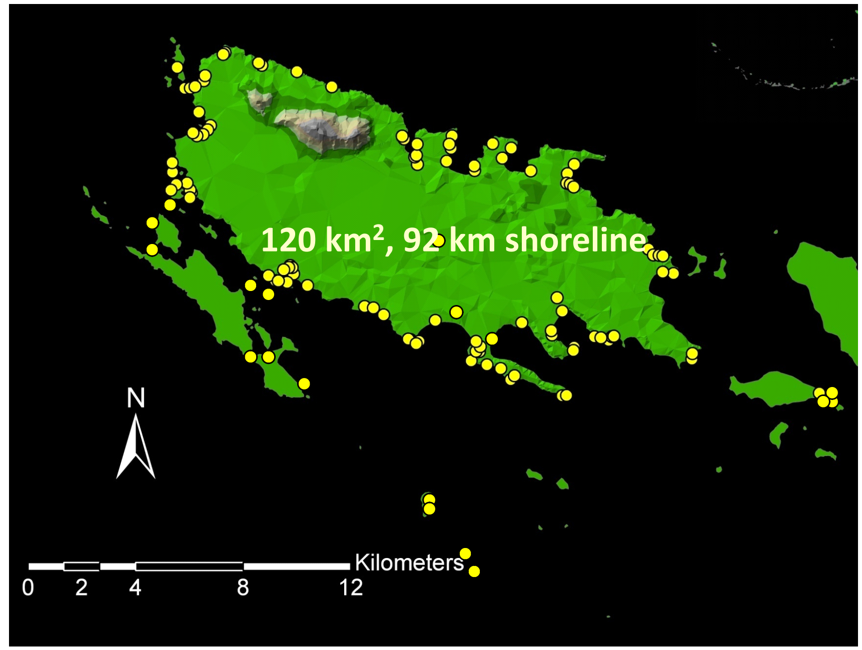
- What roles did humans play in North Pacific food webs?
- How do human hunter-gatherers compare to other species?
- What can we learn about sustainability from how pre-industrial humans interacted with other species?

The Aleut/Unangan

- Crossed Beringia 8,000-10,000 years ago
- 15,000-25,000 peak population
- Hunter-gatherers: marine, freshwater, terrestrial

Sanak Archipelago, Alaska





- Far-eastern end of Aleutian archipelago
- 50 km south of tip of Alaska peninsula, Western Gulf of Alaska
- 6000 year record of human occupation
- 128 known occupation sites

How do humans help or hurt ecological sustainability?

- Humans can be included explicitly in ecological models
- Use ecological analyses to understand ancient, historical & contemporary human roles
- Unangan/Aleut: ~6000 years of sustainable culture & habitation
- A local economy tied directly to ecosystem goods and services
- This work focuses on human roles & dynamics prior to commercial harvesting

Consumer-Resource Interactions

- Ecological Observations
- Shell & Bone Middens
- Literature Searches
- Ethnographic Data
- Interviews

Anemone (Anthopleura)

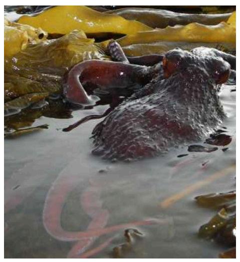
White Acorn Barnacle

Giant Acorn Barnacle

Nuttall’s Cockel

Northwest Ugly Clam

Giant Octopus



Sea Lettuce
(Green Algae)

Sea Otter

Crab

Whelk

Macoma

Neptune Whelk

File Dogwinkle

Coastal Shrimp

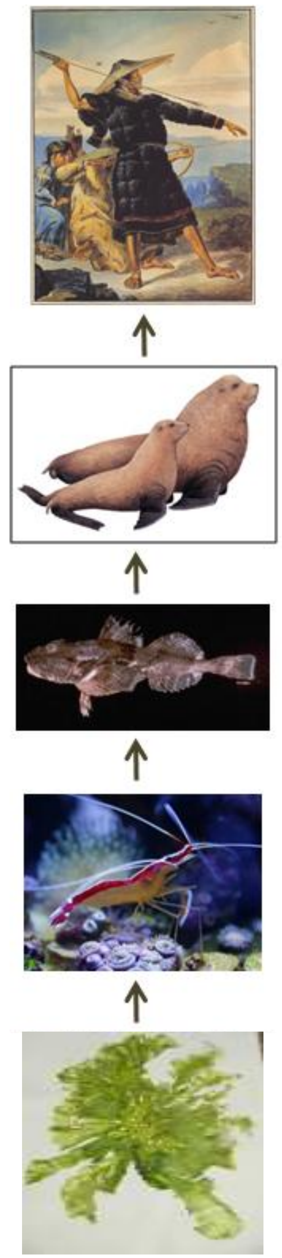
Brooding Anemone

Rock Weed (Brown Algae)

Gumboot Chiton

Sea Cucumber

Sitka Periwinkle



Humans

↑

Steller Sea Lion

↑

Great Sculpin

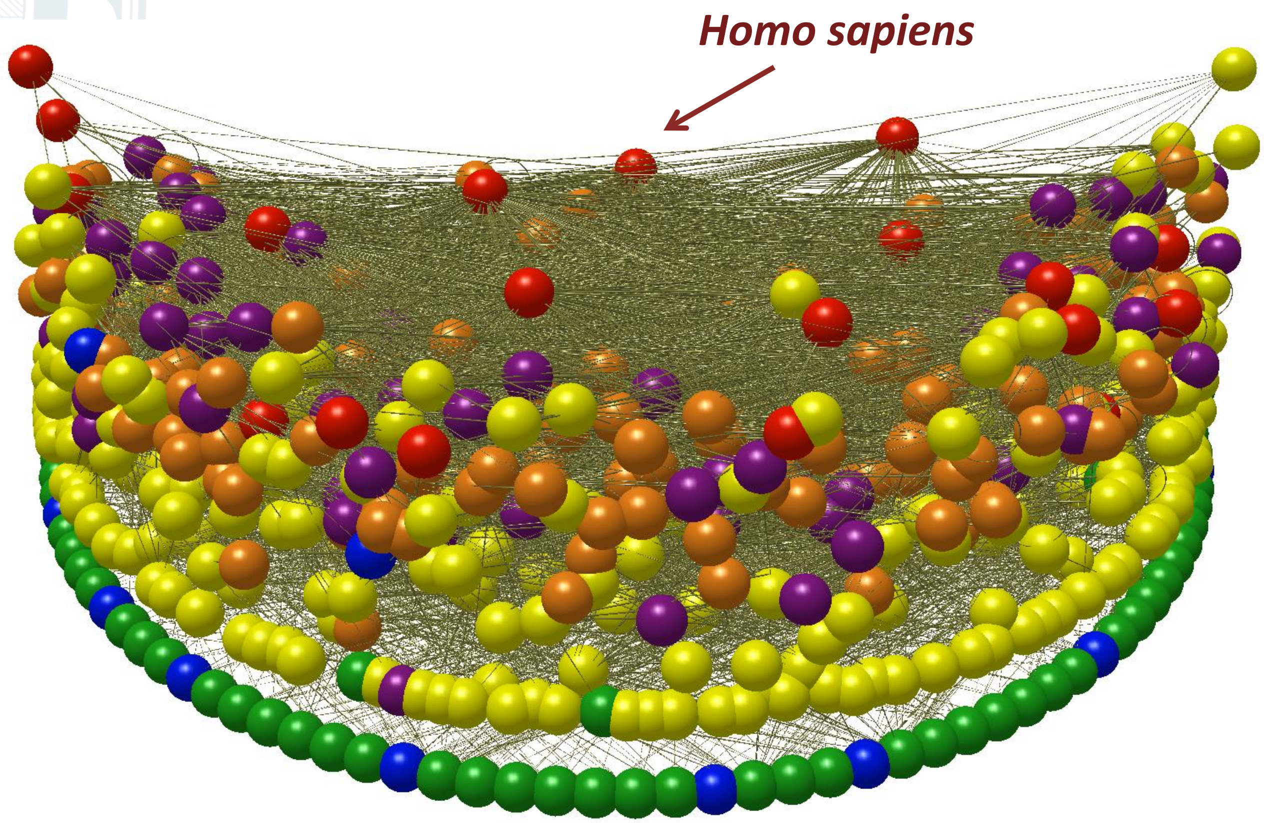
↑

Shrimp

↑

Green Algae

Sanak Nearshore Marine Food Web

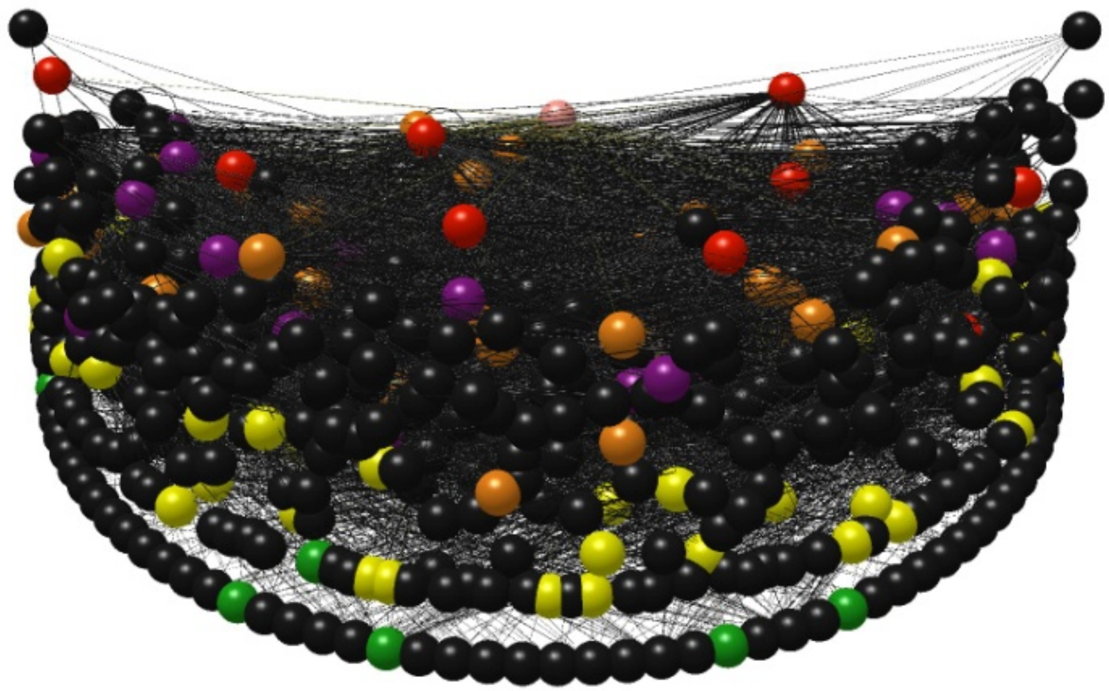


- Birds (64)
- Mammals (21)
- Fish (139)
- Invertebrates (222)
- Algae (55)
- Misc (12)
  - -detritus
  - -protozoa
  - -bacteria
  - -biofilm
  - -lichen
  - -seagrass

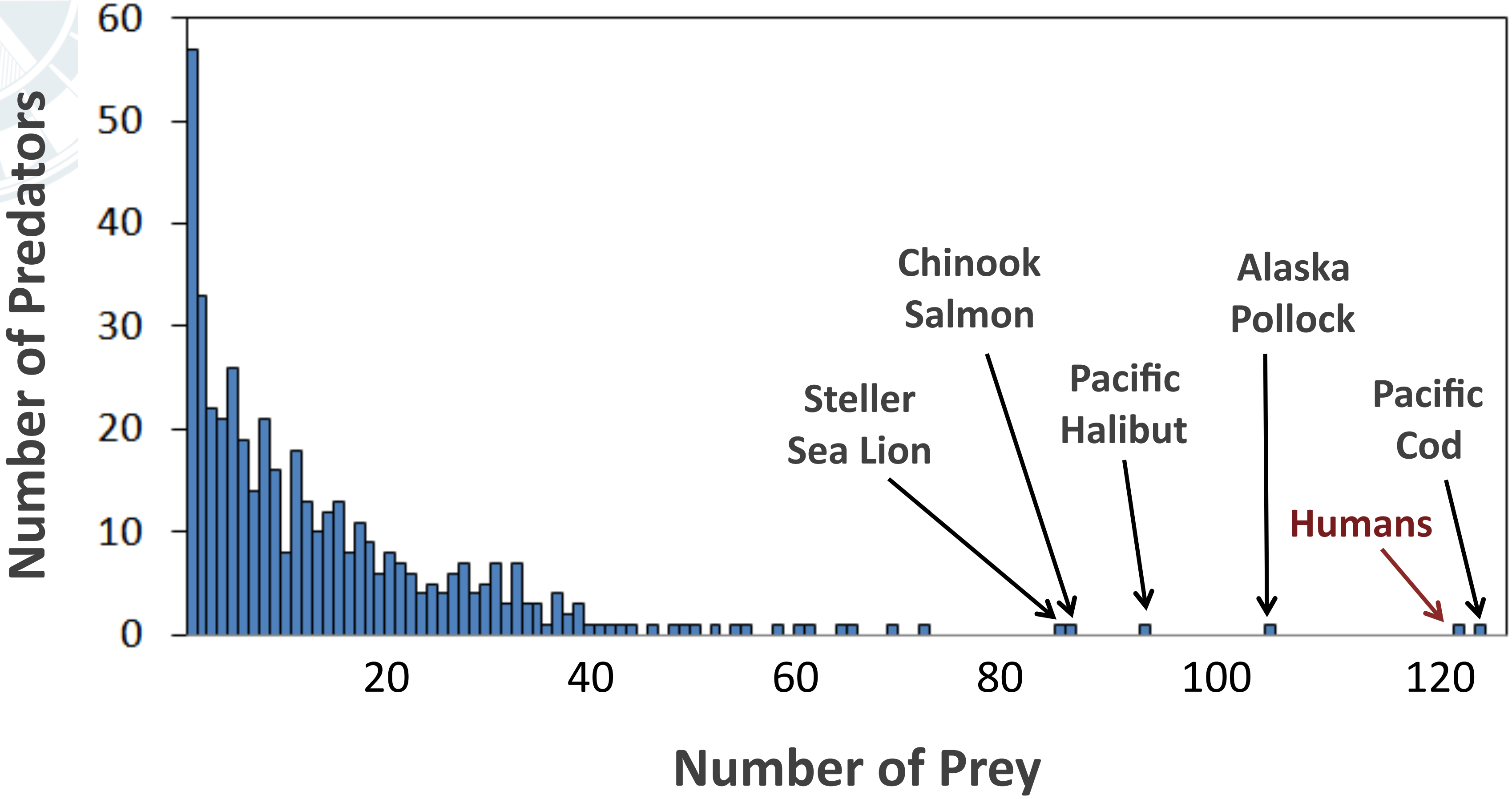
513 taxa, 6774 feeding links, 13.2 links per species

Humans fed on…

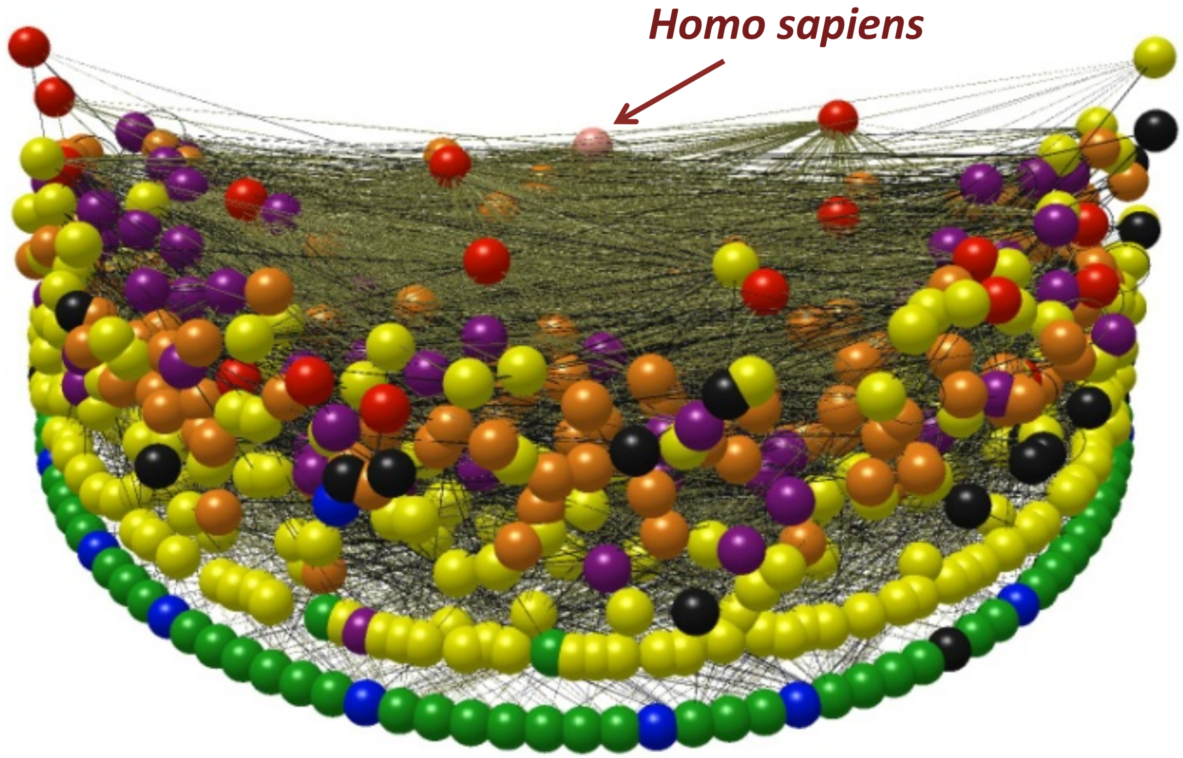
122 species (24%)



How does this compare to other species?

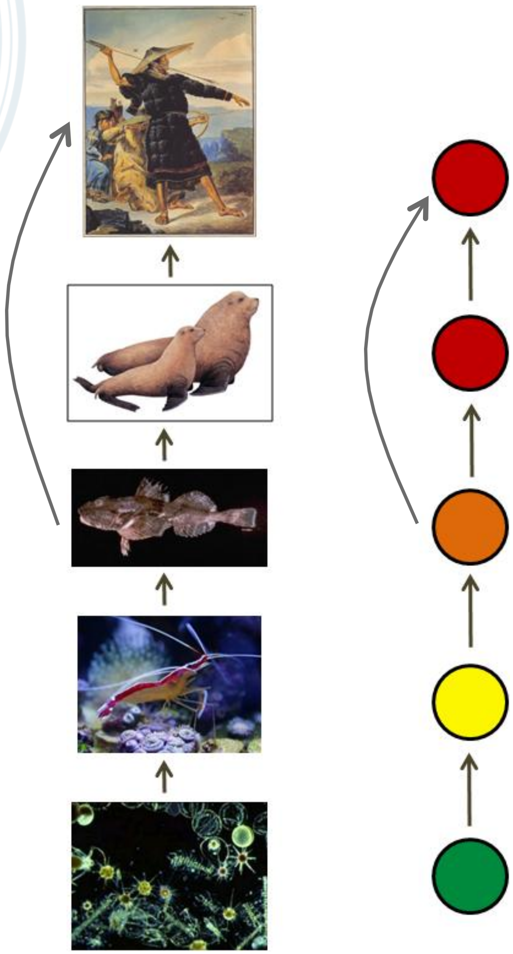

Number of Predators
60
50
40
30
20
10
0
20
40
60
80
100
120
Number of Prey
Chinook Salmon
Alaska Pollock
Steller Sea Lion
Pacific Halibut
Pacific Cod
Humans

96% of Marine Web Species within 2 Links of Humans



491 of 513 species

Human have 5th shortest mean path length



Omnivory

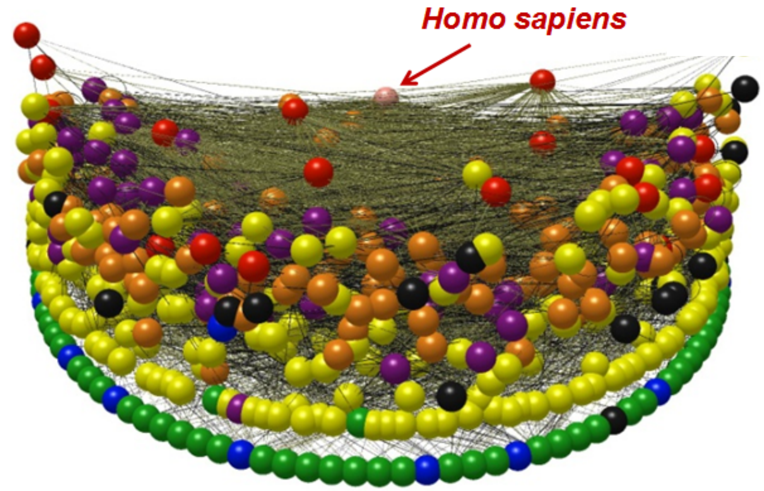
Variability of prey trophic levels

S.D. of (4,3) = 0.71

Aleut: 15th most omnivorous

The Unangan/Aleut were:

- **Super generalists**
- **Extremely connected**
- **Highly omnivorous**
- **Users of hunting technology**

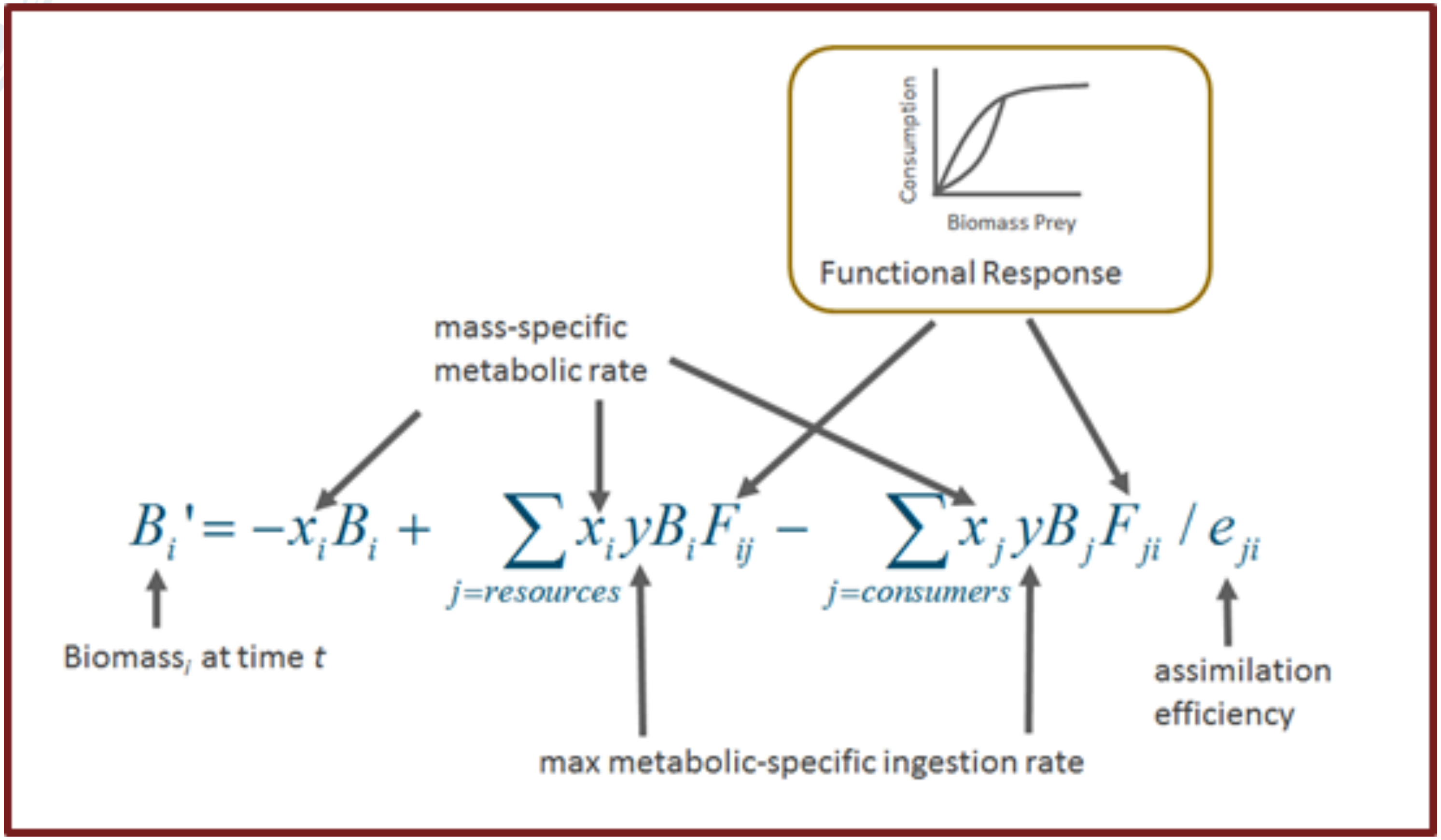


→ Humans were positioned to greatly affect local diversity.

→ But, no apparent long-term extinctions due to human foraging/subsistence.

→ What might explain the sustainability of the system after human invasion 6000 years ago?

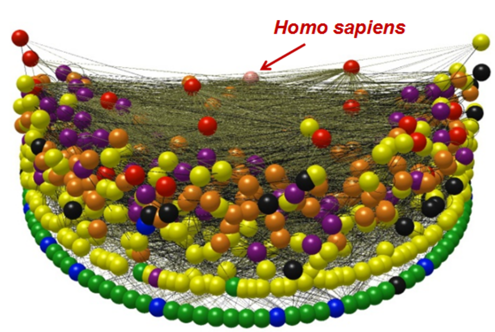
Allometric Trophic Network (ATN) Model



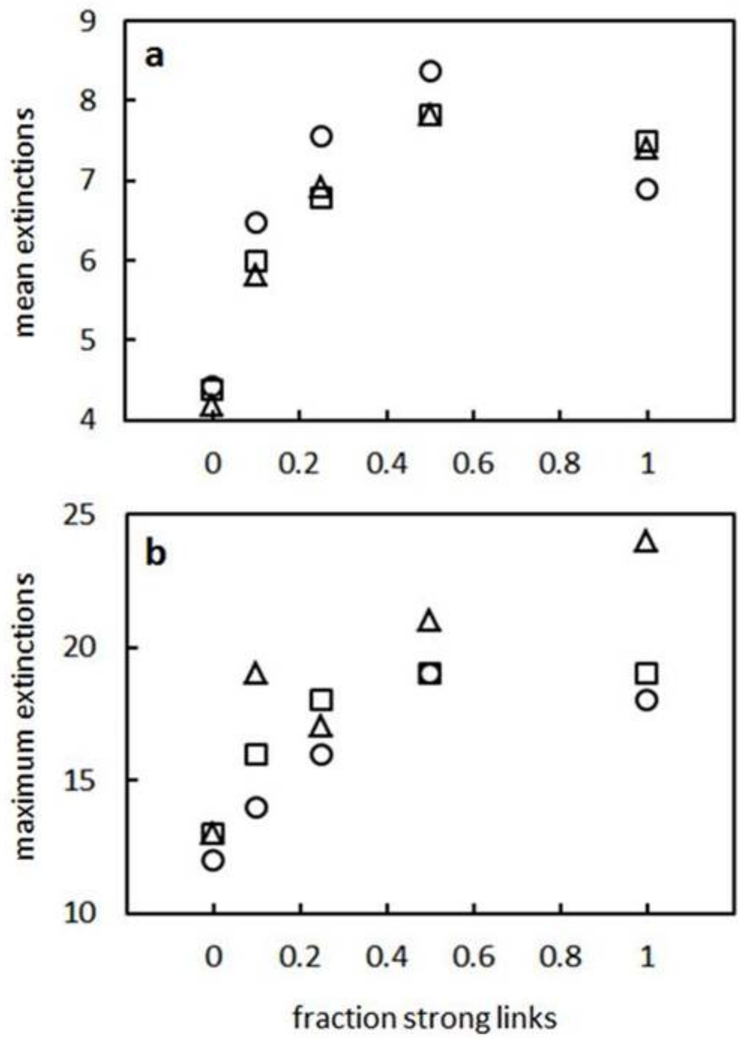
An “*In Silico*” Experiment:

<u>Impact of invasion by human-like species on ecological stability</u>

- Create a “zoo” of many model food webs.
- Include prey-switching by generalist species.
- Invade each web with an omnivorous super-generalist species.
- Vary the fraction of the invader's links that are strong to account for use of hunting technology by humans.
- Quantify how many species persist after “invasion”



Extinctions as Function of “Strong Feeding” By Invader



Fraction of taxa fed on by invader:

- ○ 25%
- □ 50%
- △ 75%

- When a super-generalist invader switches among prey, and focuses strongly on a few prey at a time, fewer extinctions.
- The ecological value of a resource decreases with rarity, which leads naturally to prey-switching by generalist predators.
- Unangan/Aleut prey-switched across habitats, seasons, body-size, and trophic levels: an ecologically normal behavior stabilizing for the whole food web.

In contrast…

- Extraction driven by global luxury economic markets
- Rarity increases value, increases extraction pressure
- Drives the species towards extinction
- **Can potentially destabilize the system**

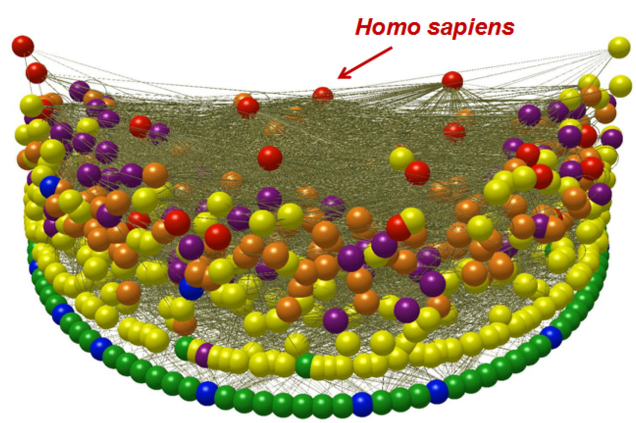
Increased Pressure on Rare Taxa: Destabilizing

(Global Luxury Economic Dynamics)

versus

Prey-Switching: Stabilizing

(Local Ecological Dynamics)



Were the Aleut just another predator?

NO: They had special structural roles, and make use of technology.

YES: They engaged in ecologically "normal" dynamics.

Acknowledgements

- National Science Foundation grants OPP-8912981, 9630072, 9714926, 9814086, 0137756; BE/CNH-0119743; ARC-0508101; DBI-0850373
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- Pauloff Harbor Tribe
- Sanak Corporation
- King Cove Corporation
- Agdaagux Tribal Council of King Cove
- The Aleut Corporation
- The Aleutians East Borough
- Izembek National Wildlife Refuge
- National Marine Mammal Lab
- NOAA Fisheries
- Peter Pan Seafoods

Socio-Ecosystem Dynamics of Natural-Human Networks on Polynesian Islands

System: Four well-studied south Pacific islands before and after a millennium of human occupation. The still-occupied islands have had different ecological and cultural development trajectories, including different balances of three types of resource extraction by humans: foraging, agricultural, economic.

Question: What are the interactions among the ecological context, the environment/climate, and human cultural development?

Why: We need to develop quantitative, general models of feedbacks between human behavior and natural processes to inform future decision-making related to sustainability of coupled natural-human systems.

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