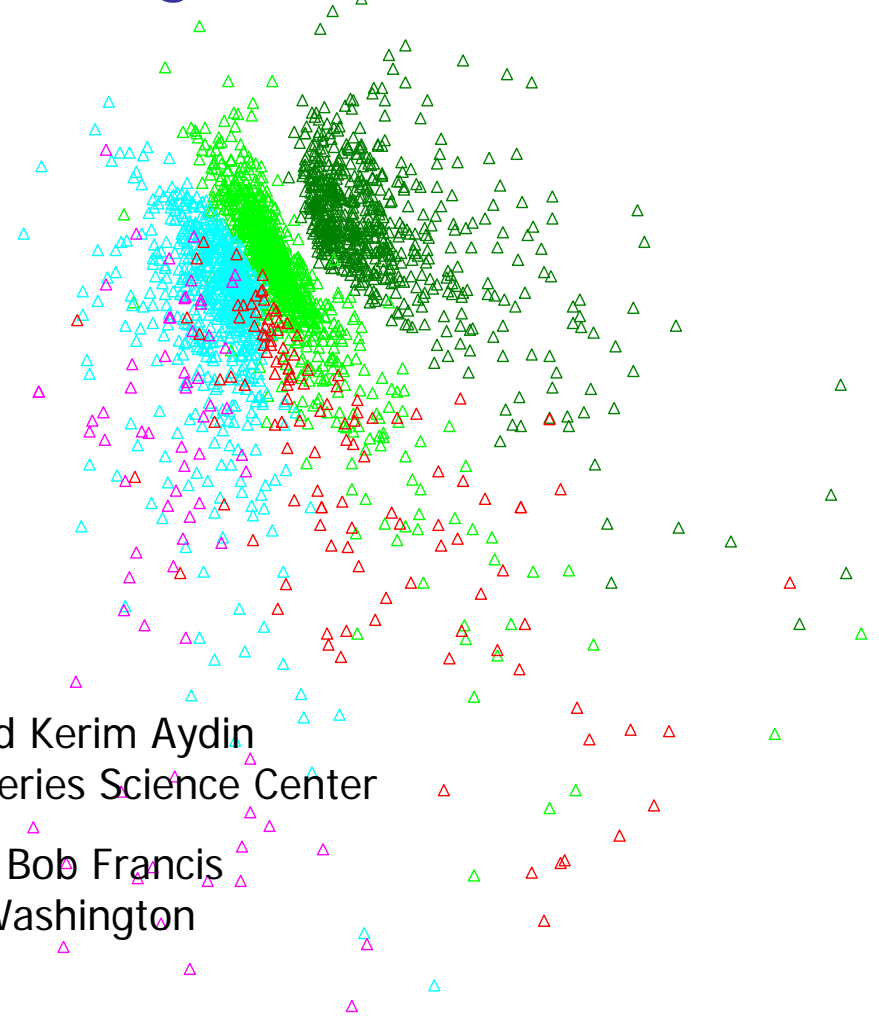
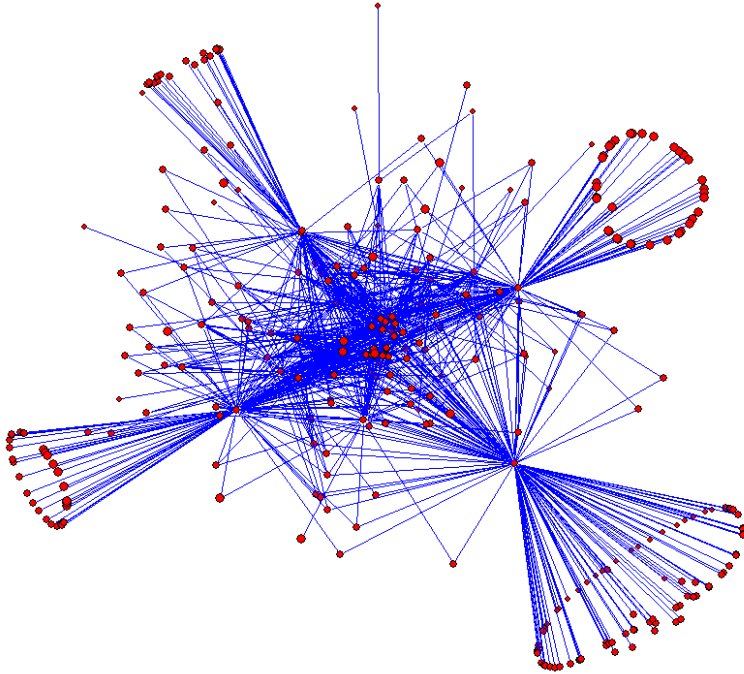
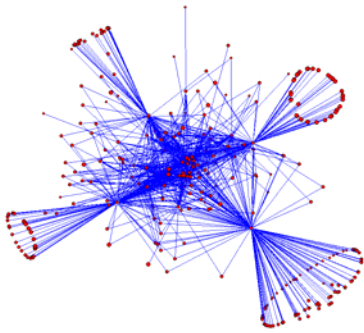


Complex systems models of trophic and fishing interactions with implications for research and management

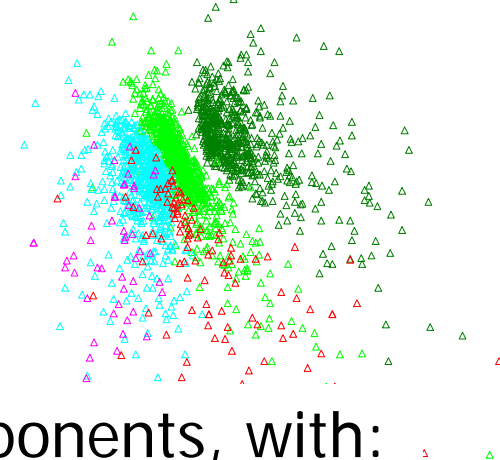


Sarah Gaichas and Kerim Aydin
NOAA NMFS Alaska Fisheries Science Center

Garry Odell and Bob Francis
University of Washington



Complex systems?



Systems of large numbers of interacting components, with:

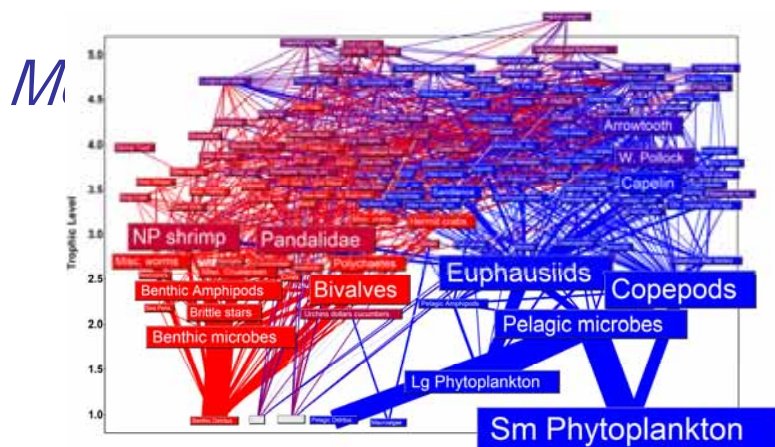
Self-organization, robustness to error and random disturbance

System reorganization at critical thresholds

Emergent properties unpredictable from components

Example 1: Network model of the food web (static)

Example 2: Fishing simulations with predation (dynamic)



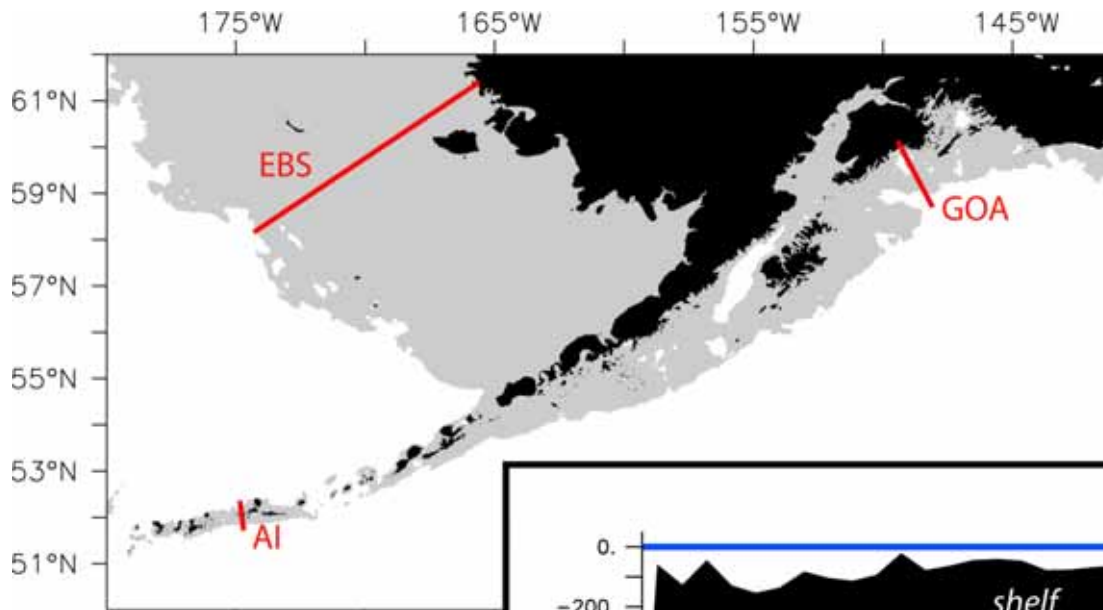
*ies some
native mc*



*results
suite*

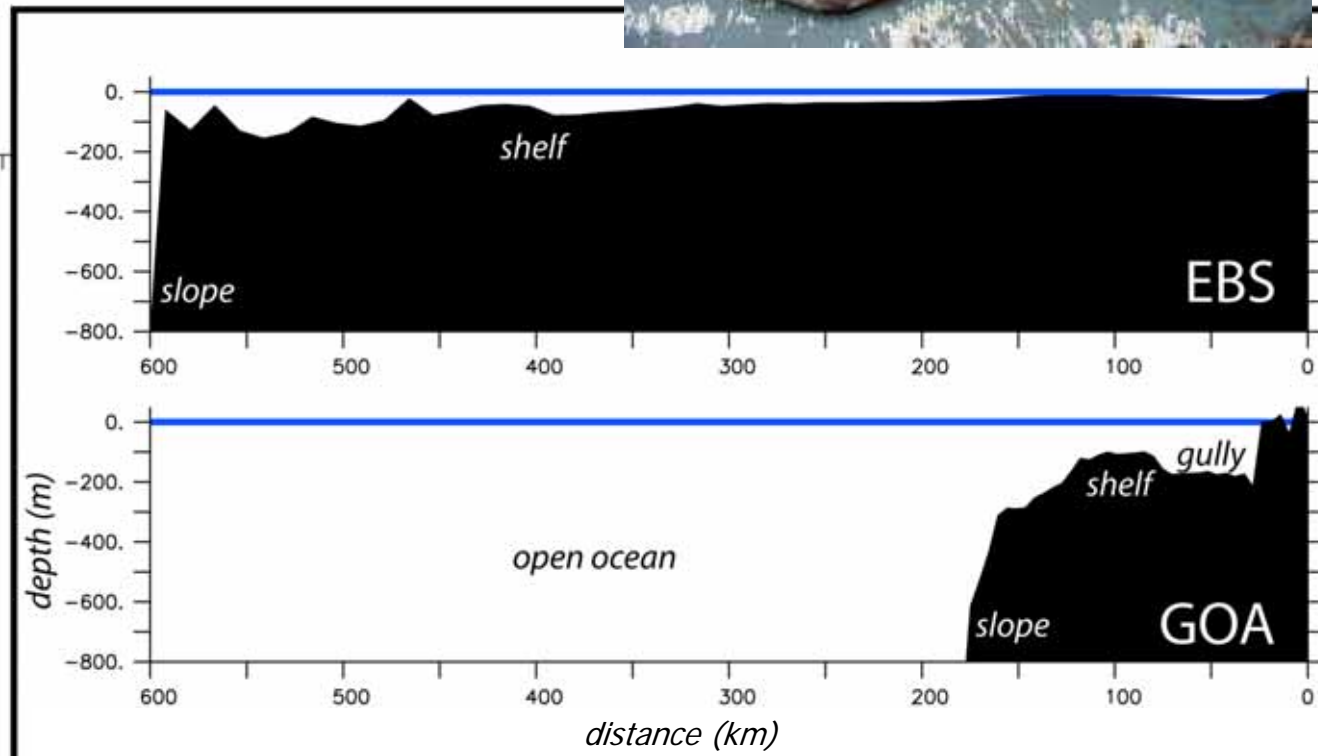


Two Alaskan shelf ecosystems



Eastern
Bering Sea

Gulf of
Alaska



I. How is the food web structured?
Network properties: "Small world"



the ONION®

VOLUME 38 ISSUE 40

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31 OCTOBER-6 NOVEMBER 2002

THE WAR ON TERROR

Kevin Bacon Linked To Al-Qaeda



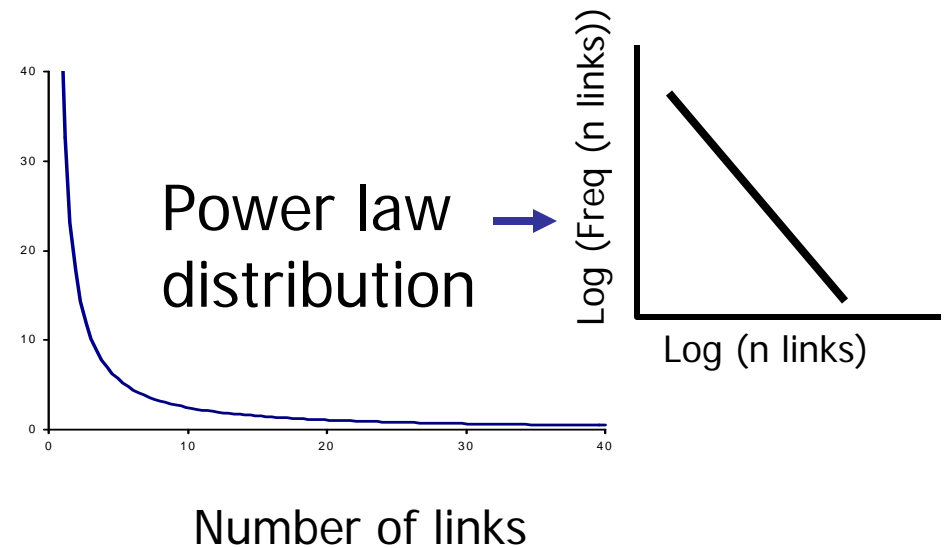
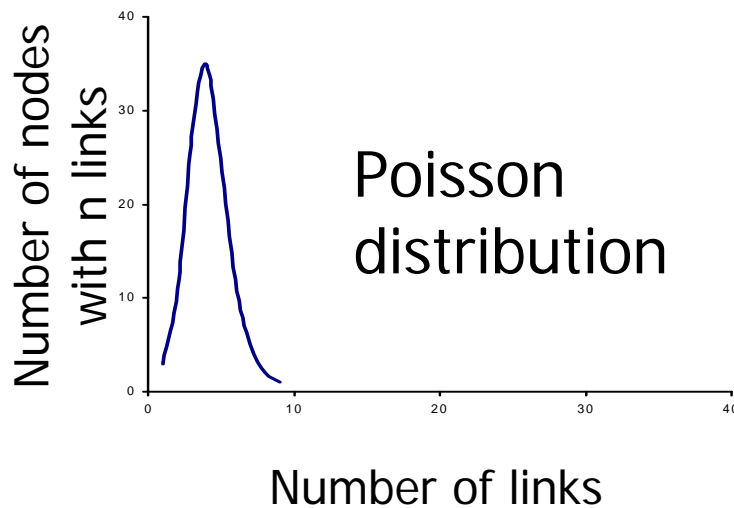
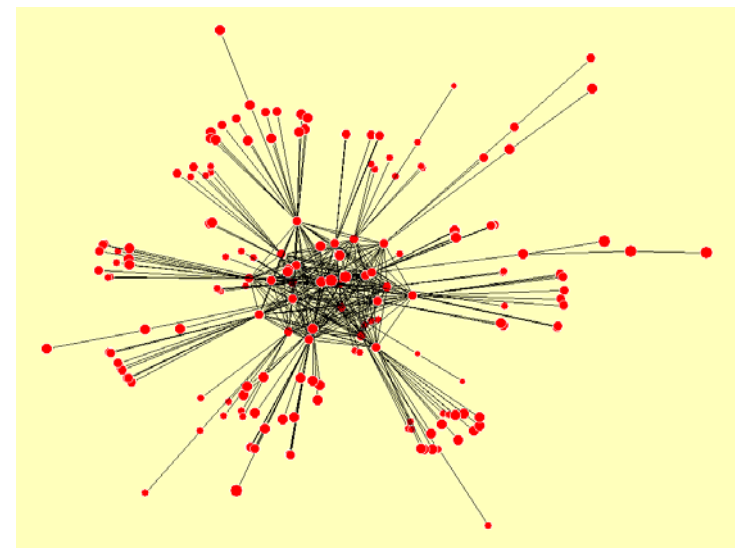
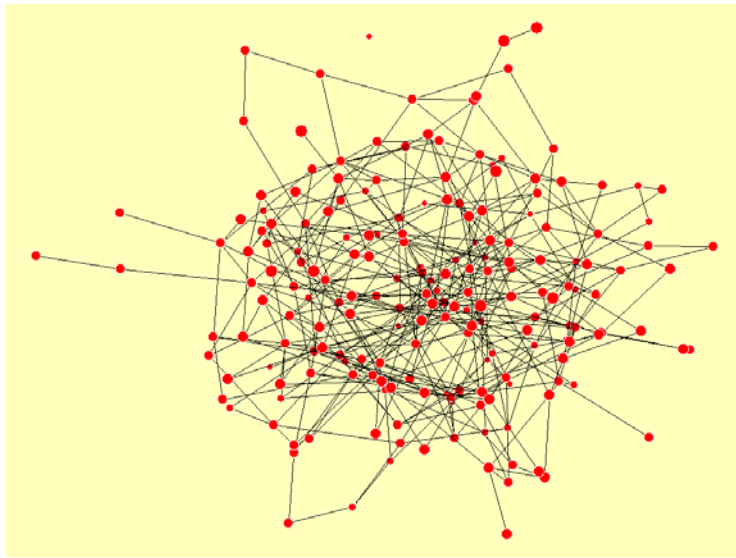
U.S. Students Lead World In Detention

UNITED NATIONS—With one in 25 students currently in detention, on

Detailed in the 922-page document is an alarming pattern of arbitrary and discip

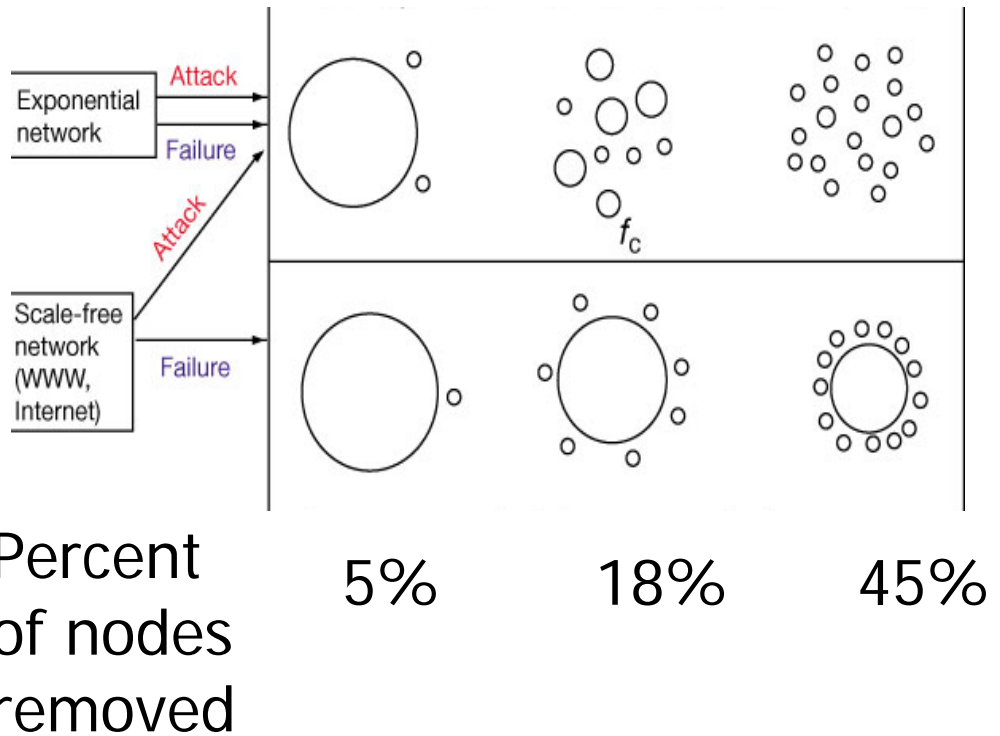
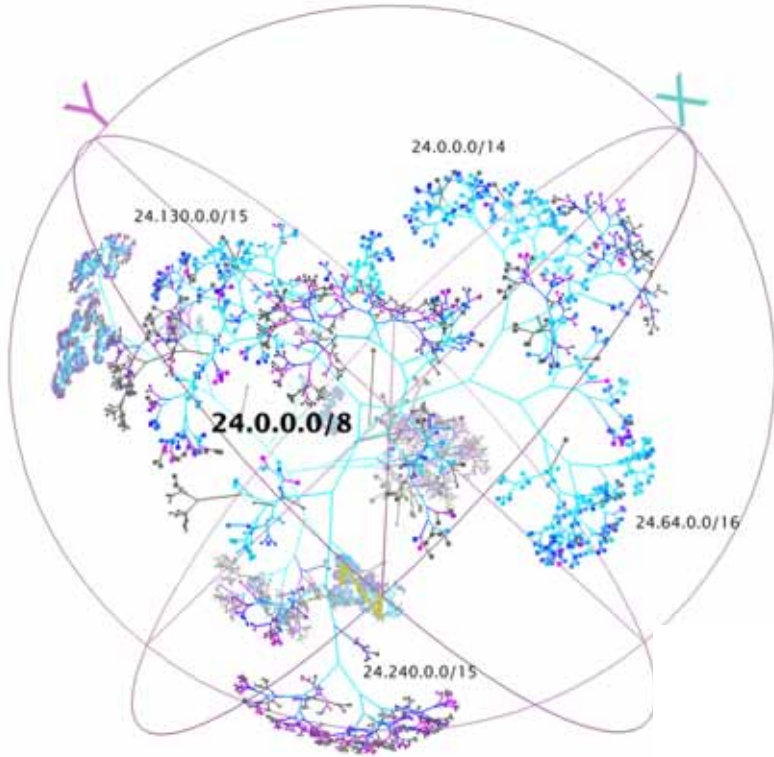
tion facilities place a far greater emphasis on isolation and punishment

Networks II: visuals, link distributions



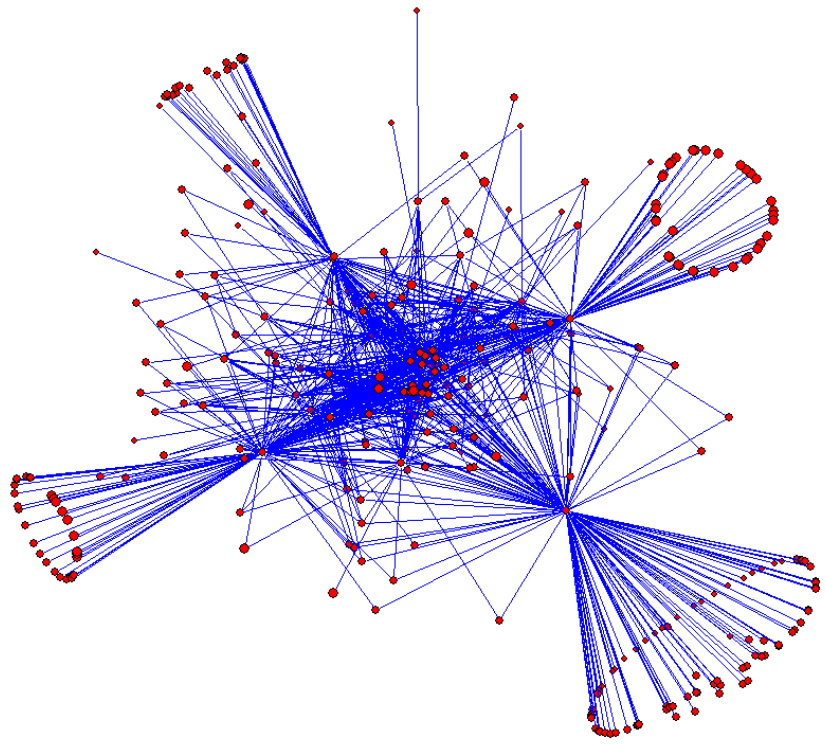
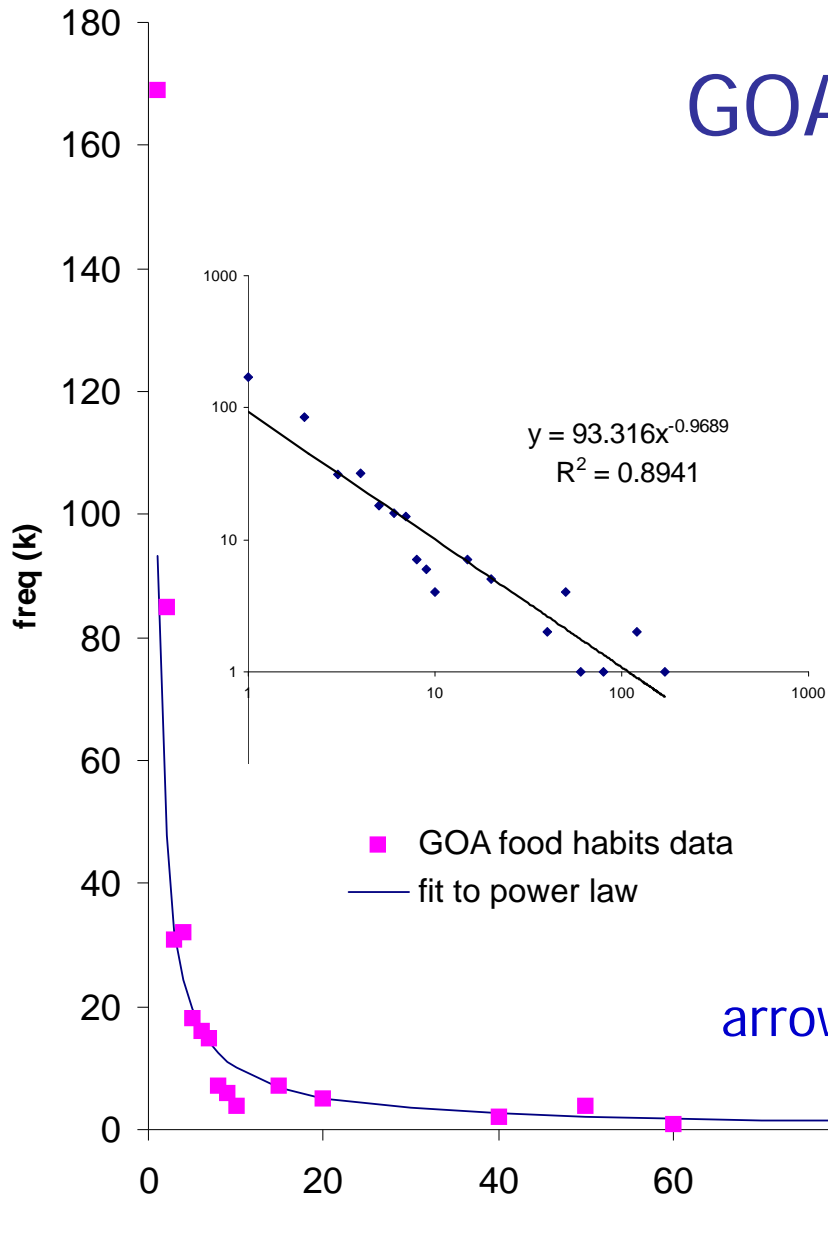
Network type implies system behavior

*Albert, Jeong & Barabasi, 2000.
Nature 406: 378-382*

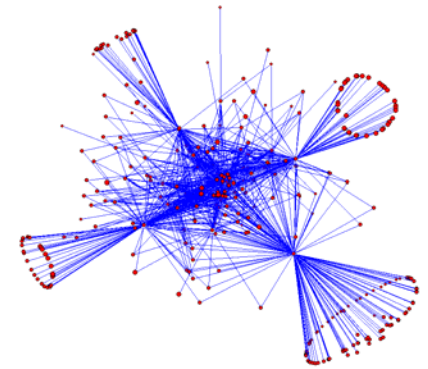


Attack = target and remove highly connected nodes
Failure = remove nodes at random

GOA results



Reorganization in the complex food web?



“Scale free” food web network is robust to random species losses, but

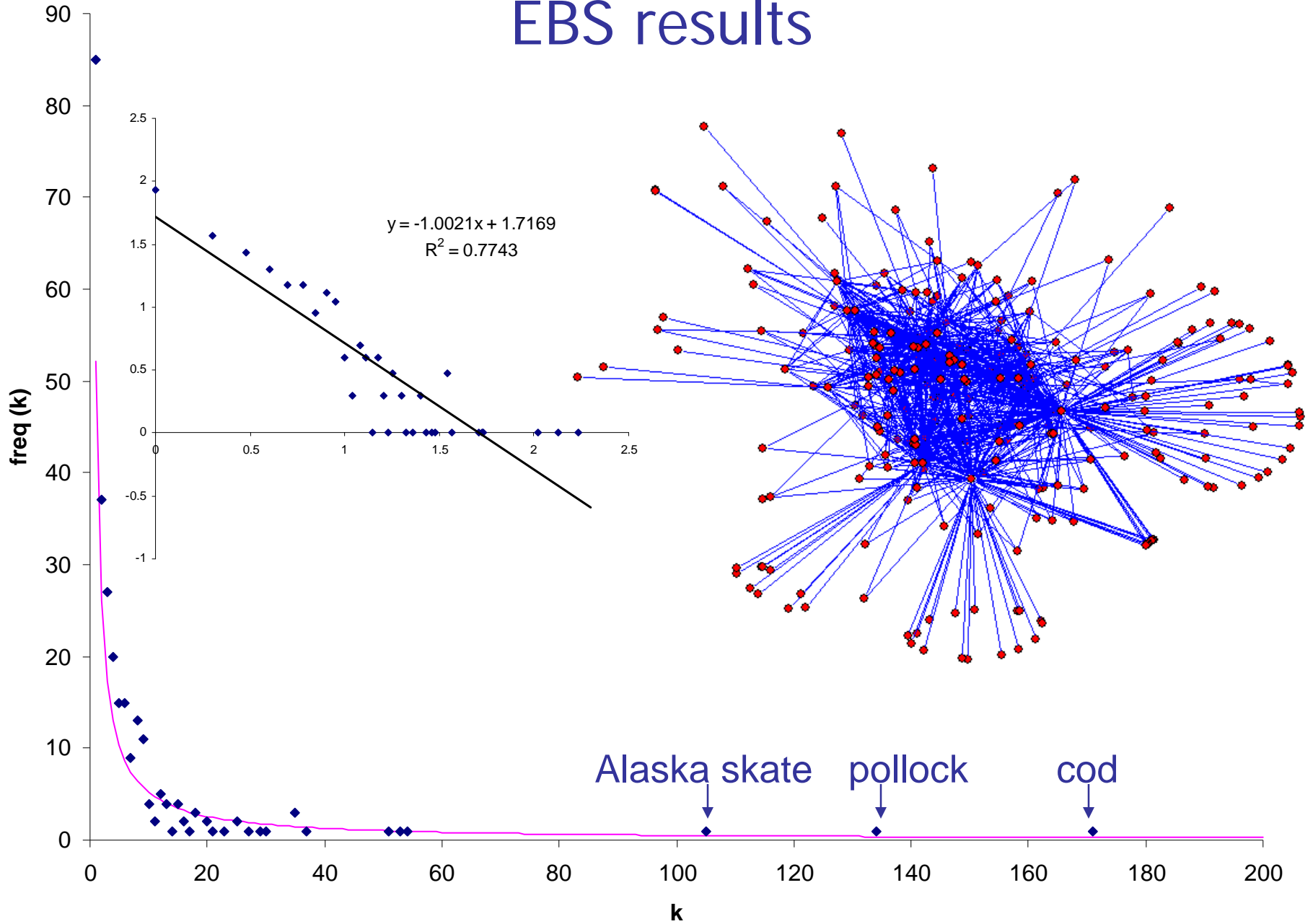
Small world property means impacts to one species can transmit rapidly, and

“Attack” on highly connected species (cod, pollock, arrowtooth, halibut) may fragment the network

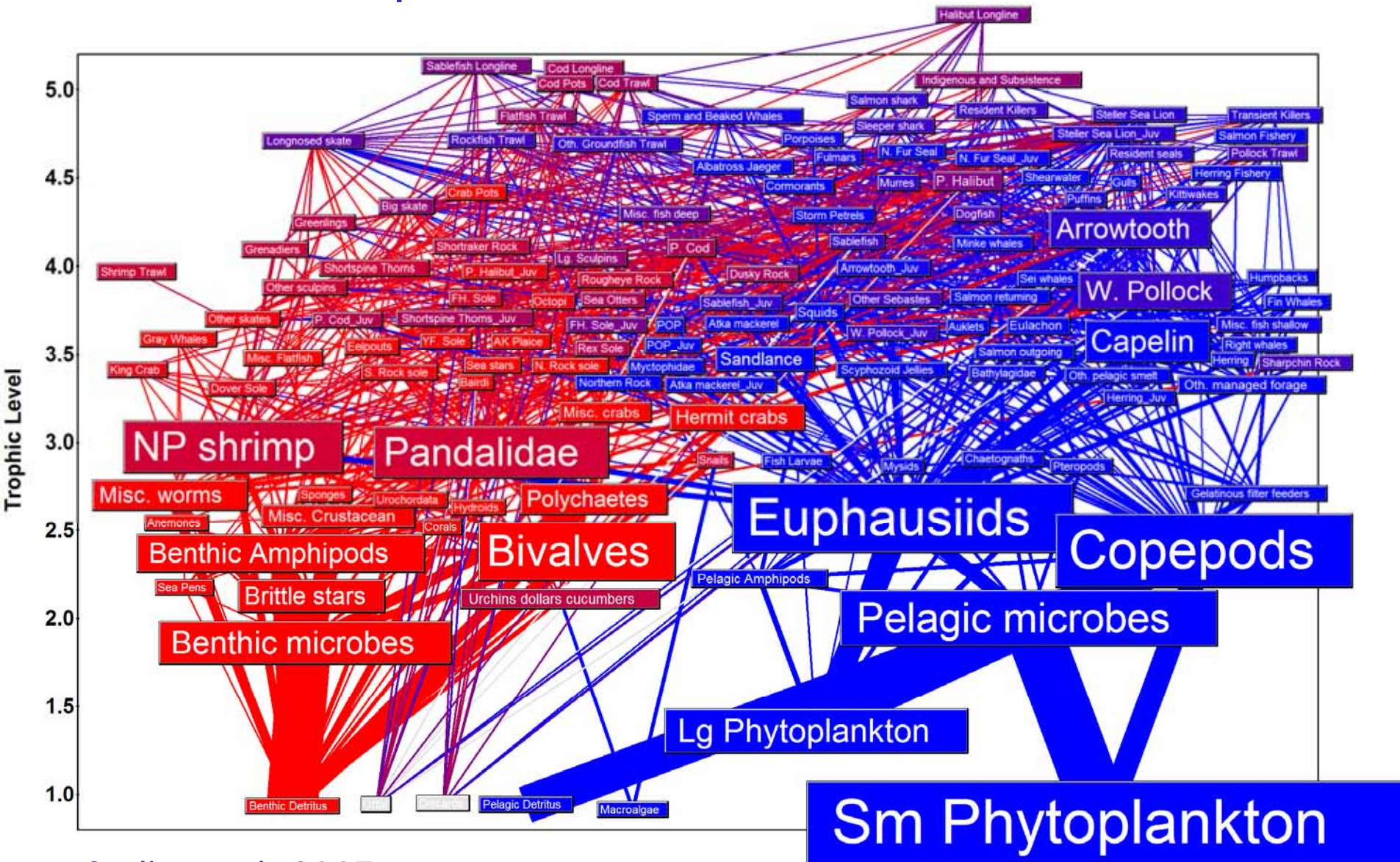
What is “attack”? Overfishing? More? Less?

Management can focus on protecting the few highly connected species to avoid rapid reorganization

EBS results



Simplified Gulf of Alaska food web

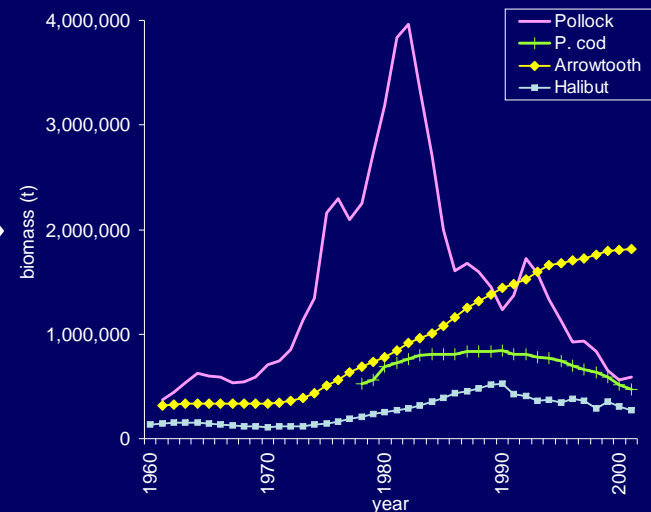
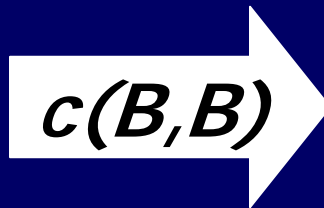
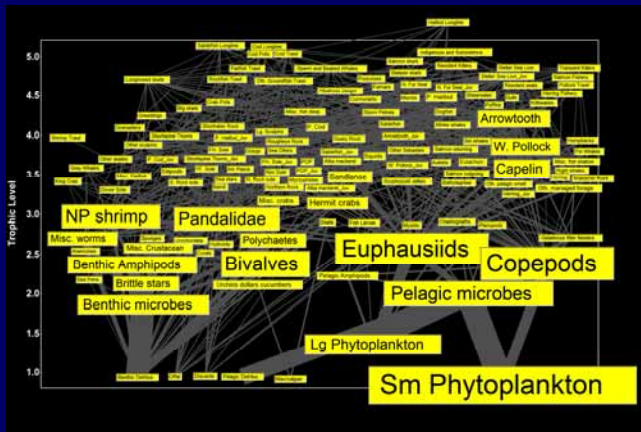


Aydin et al. 2007

II. How much fishing is too much?

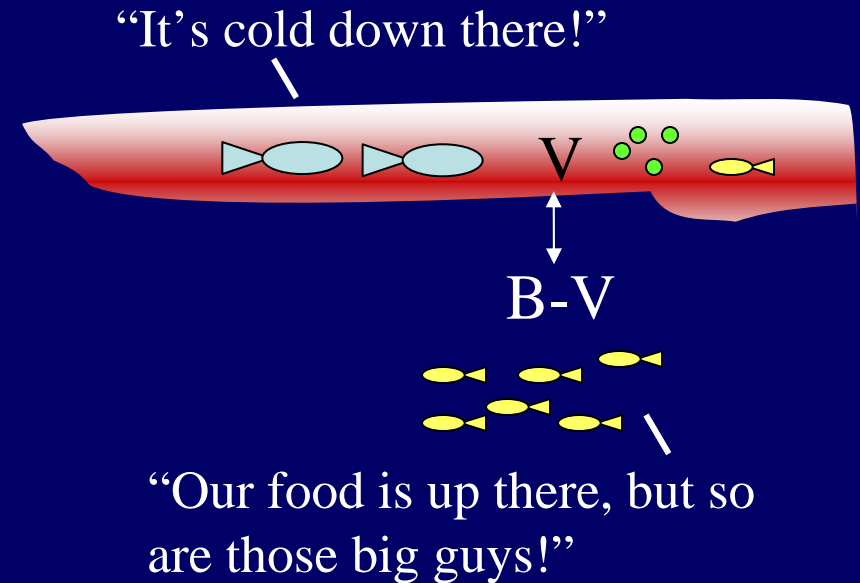
- Current view: overfishing of a single species is a loss of yield, so an economic loss, but that's all. Its reversible.
- Is that true if many species are fished heavily and simultaneously in a full ecosystem context? Or even just one group?

$$\frac{dB_i}{dt} = GE \cdot \sum_{prey} c(B_i, B_{prey}) - M_0 B - FB - \sum_{pred} c(B_{pred}, B_i)$$

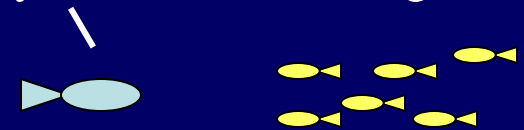


Functional response parameters

- Vulnerability:
how much prey biomass is available to predators?
- Foraging Time:
if I'm hungry, should I spend more time vulnerable?
- Handling Time:
at some point, my consumption is limited even if there are more prey

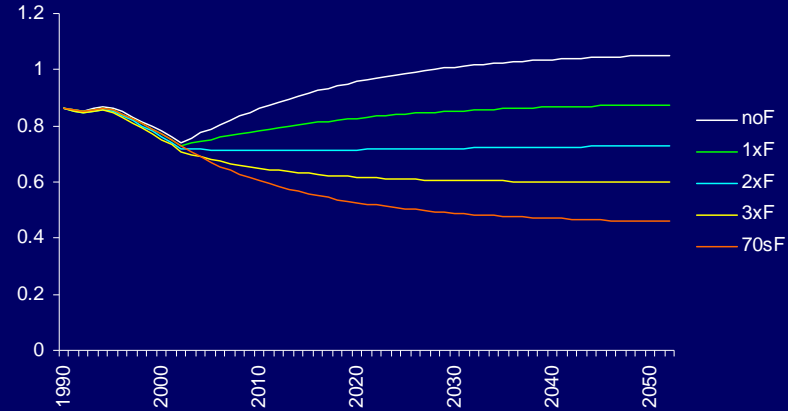
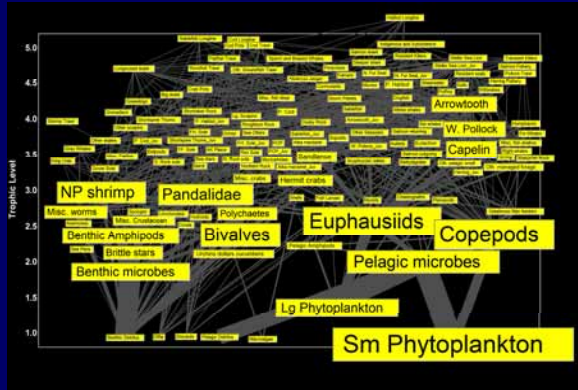


“Don’t worry, I’m still chewing.”



$$c(B_{pred}, B_{prey}) = Q_{link}^* \left(\frac{X_{link} \cdot Y_{pred}}{X_{link} - 1 + Y_{pred}} \right) \left(\frac{D_{link} \cdot Y_{prey}^{\theta_{link}}}{D_{link} - 1 + Y_{prey}^{\theta_{link}}} \right) \quad Y = TB_t / B^*$$

Fishing sensitivity simulations

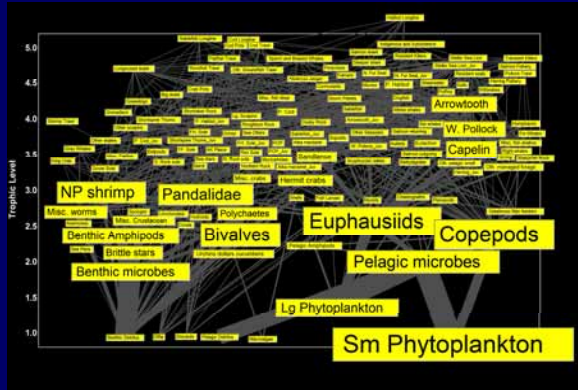


Default functional response:

Vulnerability=2.0
Foraging Time=0
Handling Time=0



Fishing sensitivity simulations



Generate randomized functional responses and test each with fishing:

Vulnerability:

$$\text{Exp}(9.0 * U [0,1] - .5)$$

by link *or* by species

Foraging Time: $U [0,1]$

Handling Time: $U [0,1]$



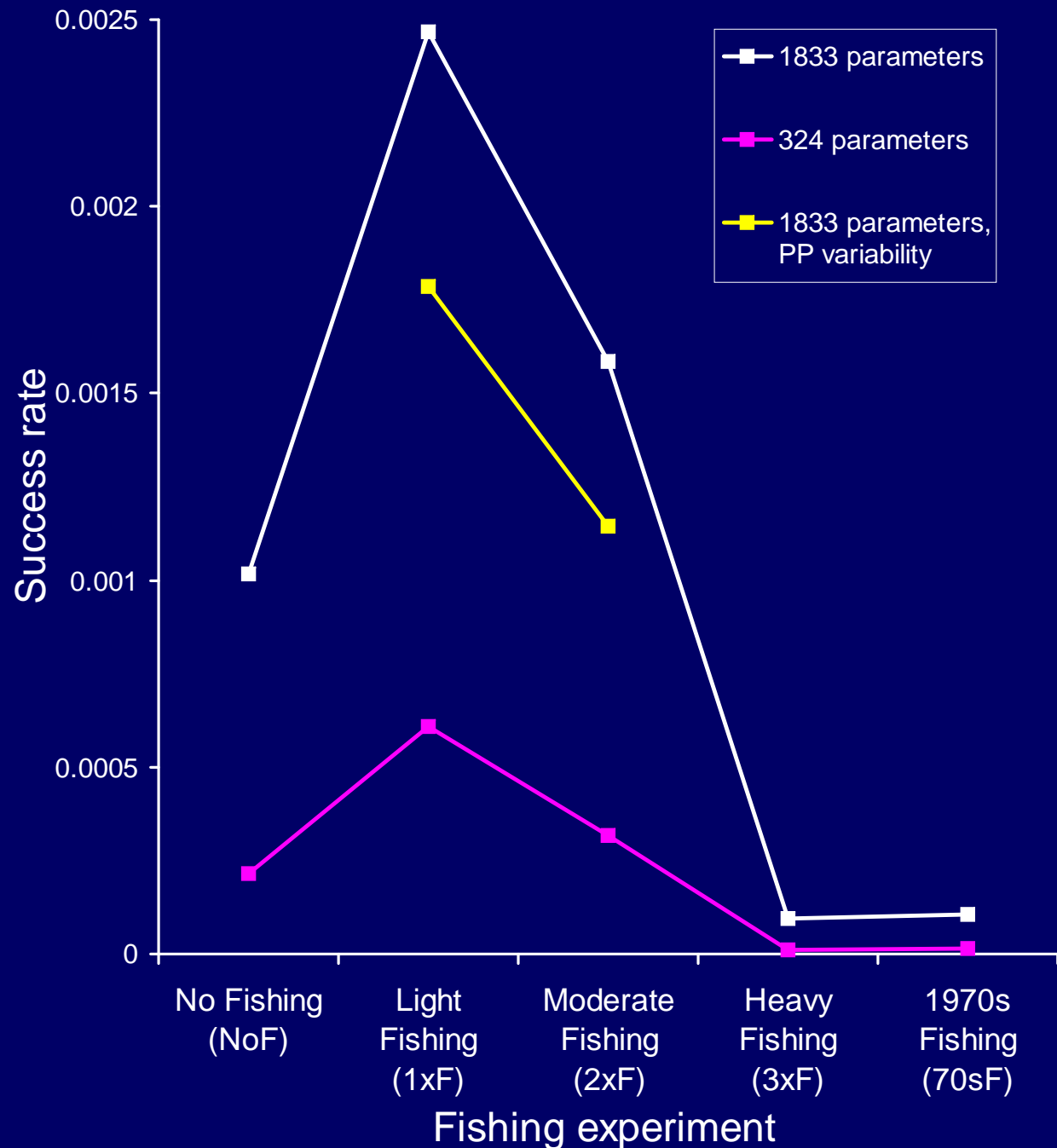
➤ *How many systems survive 50 years in each fishing scenario?*

➤ *How do surviving systems compare to base?*

➤ *Are special parameters required for system survival?*

Ecosystem success rate:

Clear threshold between moderate and heavy fishing, whether system wide or for a single fishery



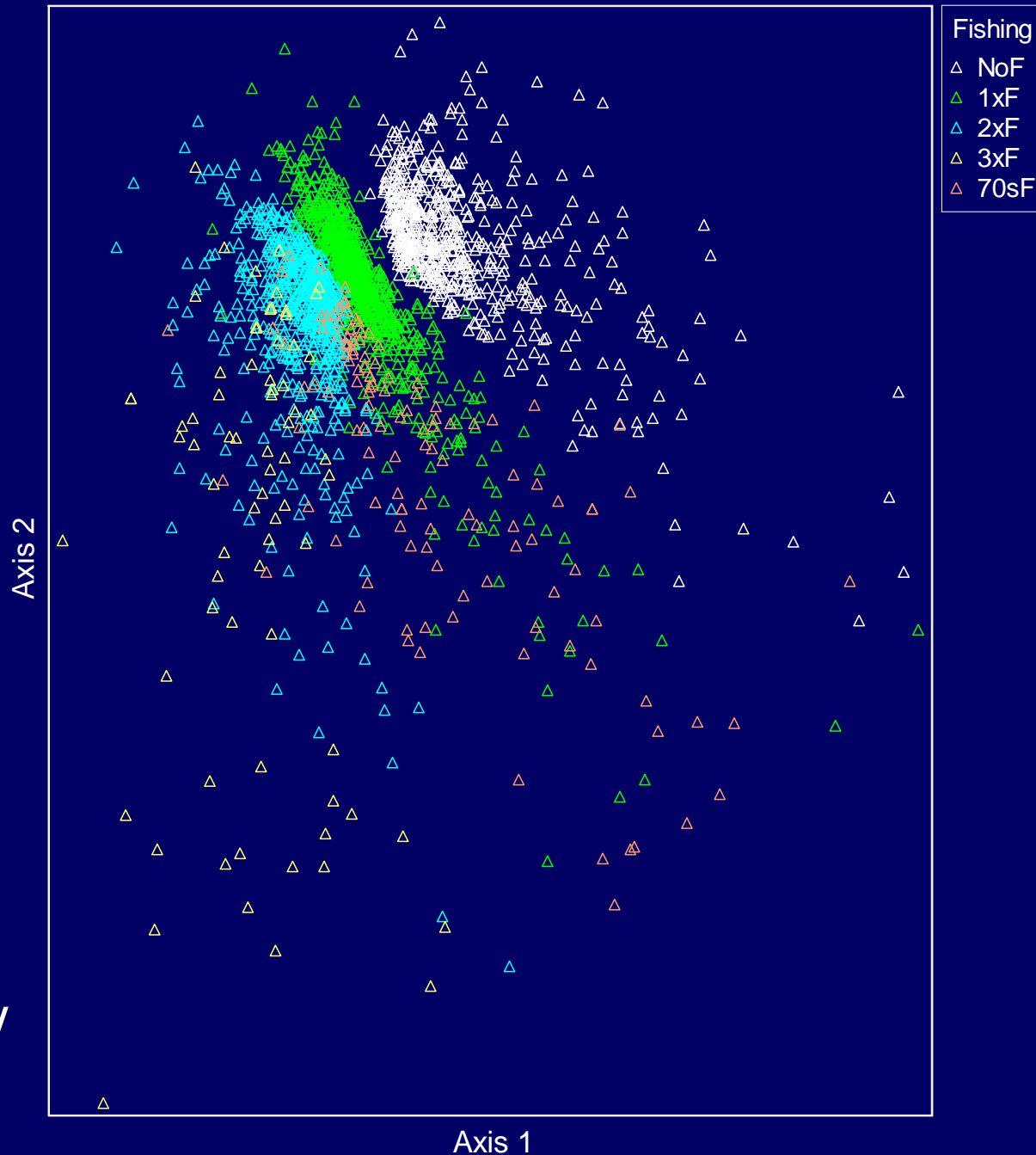
All successful ecosystems

Unfished systems different from fished systems

No, light, and moderate fishing produce mostly similar ecosystems

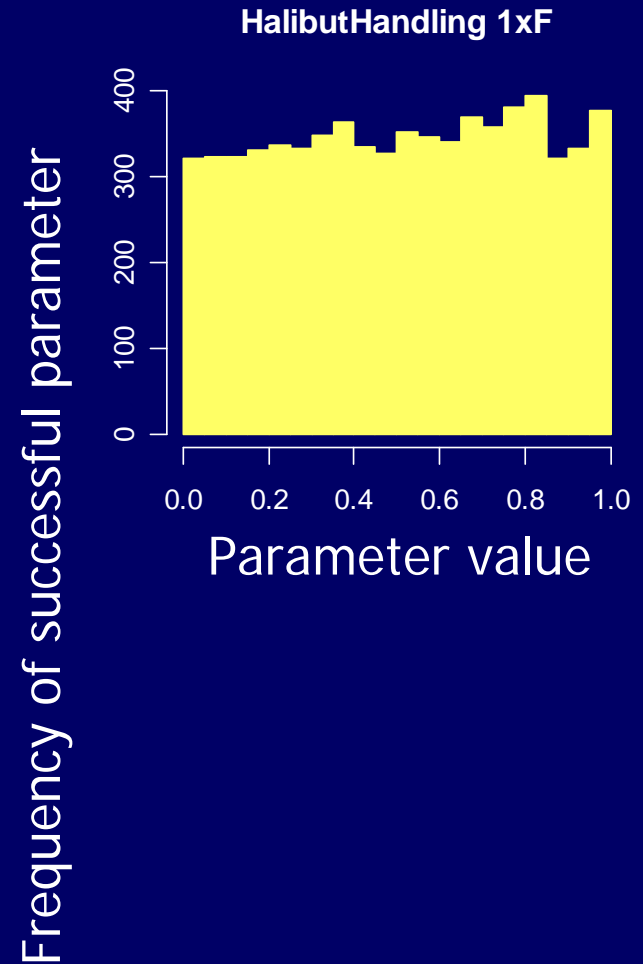
Heavy system wide fishing and heavy rockfish fishing produce mostly different, *reorganized* ecosystems

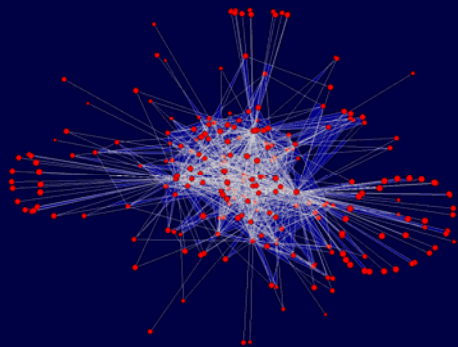
NMDS Ordination of all biomass



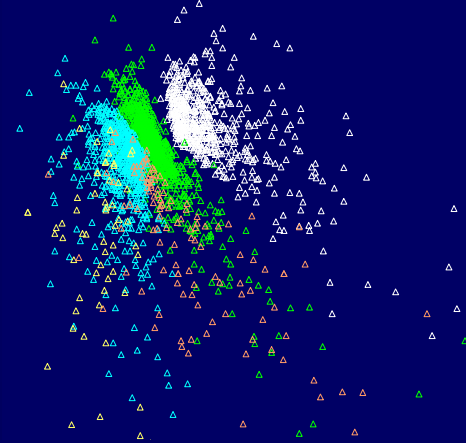
Range of successful parameters: 2 types

- Most parameters can be anything at all
 - Nearly all groups, all fishing experiments
- Some handling time parameters can't be high
 - Pollock, cod, salmon in all fishing experiments
 - Rockfish in heavy rockfish fishing experiment
 - Sharks and skates in heavy fishing experiment





Did complexity help?



Good news and bad news:

robustness to random species disturbances and uncertainty in predator prey functional response

BUT critical and or sensitive species identified, and clear threshold effect with heavy fishing

Bad news is still good news for fishery management
protect cod, pollock, large flatfish, *skates*
ecosystem level fishing thresholds exist

Modeling many interacting components is necessary

Reorganization happens...

