Marine food webs, climate change and extinction

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Basic assumptions

- Species are members of complex ecological systems
  - Biological communities and ecosystems
- Species extinctions occur in contexts of ecosystems and changing environments

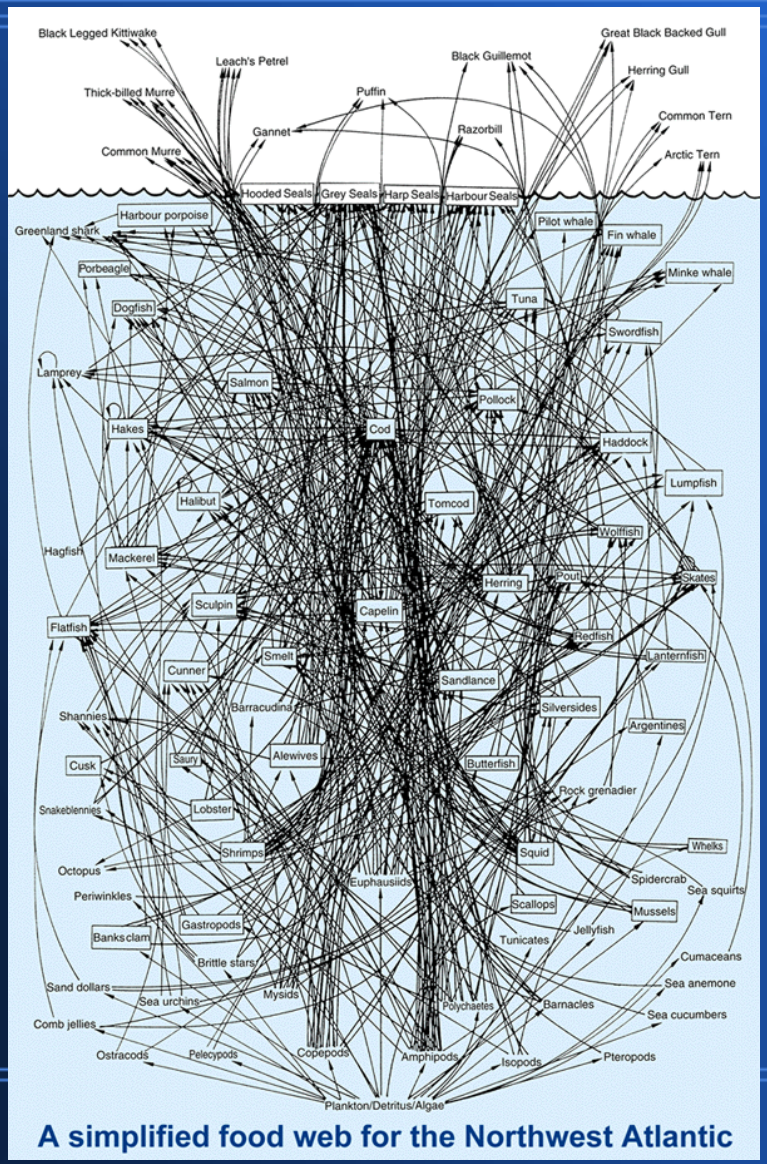
Ecosystems as CAS

- Ecosystems are Complex Adaptive Systems (CAS)
  - The whole is often not the sum of its parts
  - Species extinction may be both primary or secondary

Ecosystems as Networks

- Food webs or trophic networks
  - Patterns of energy transfer and flux
- Mutualistic networks
  - Patterns of symbiosis, commensalism, etc.
- Biogeochemical cycles and networks

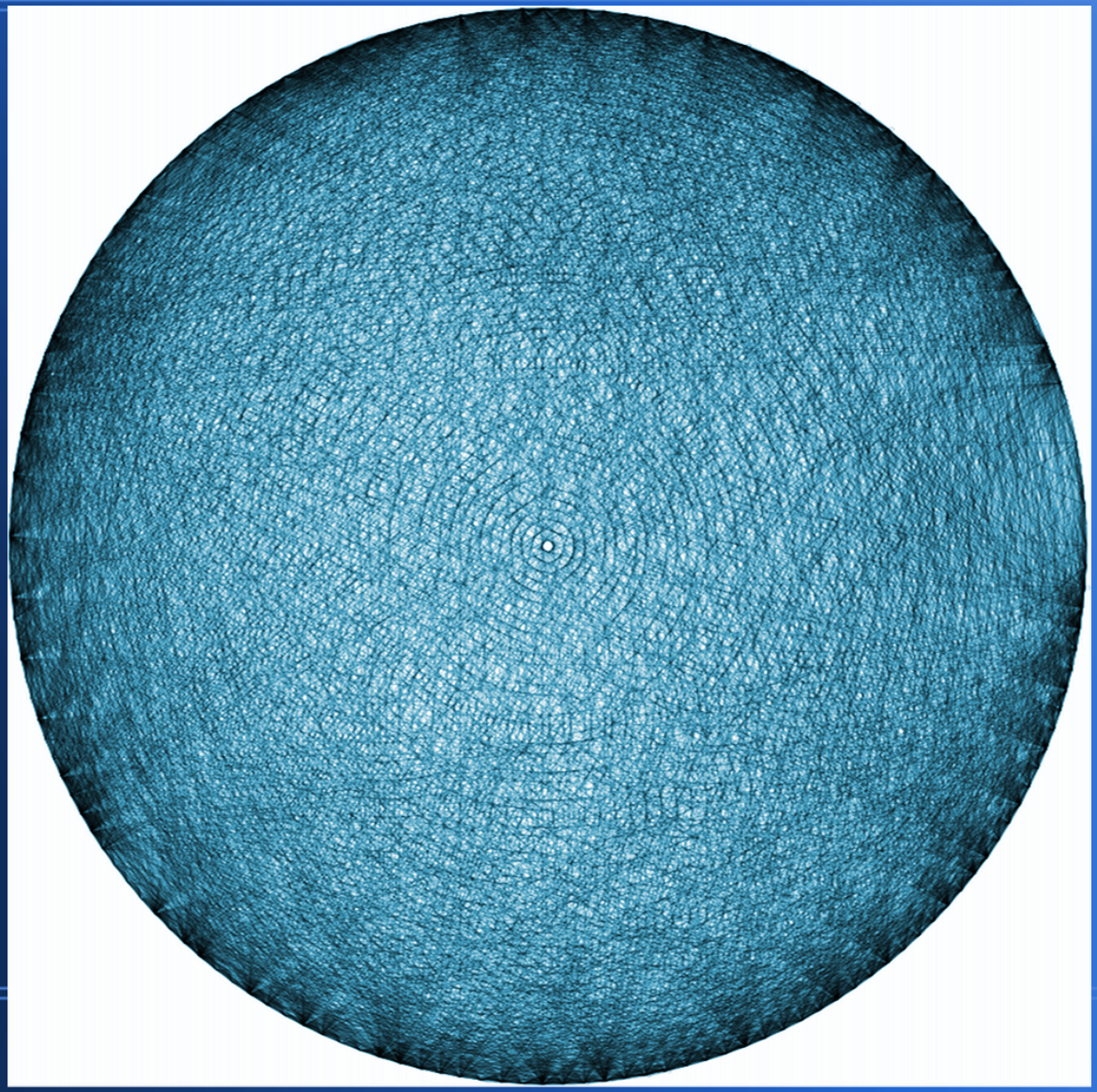
Marine food webs



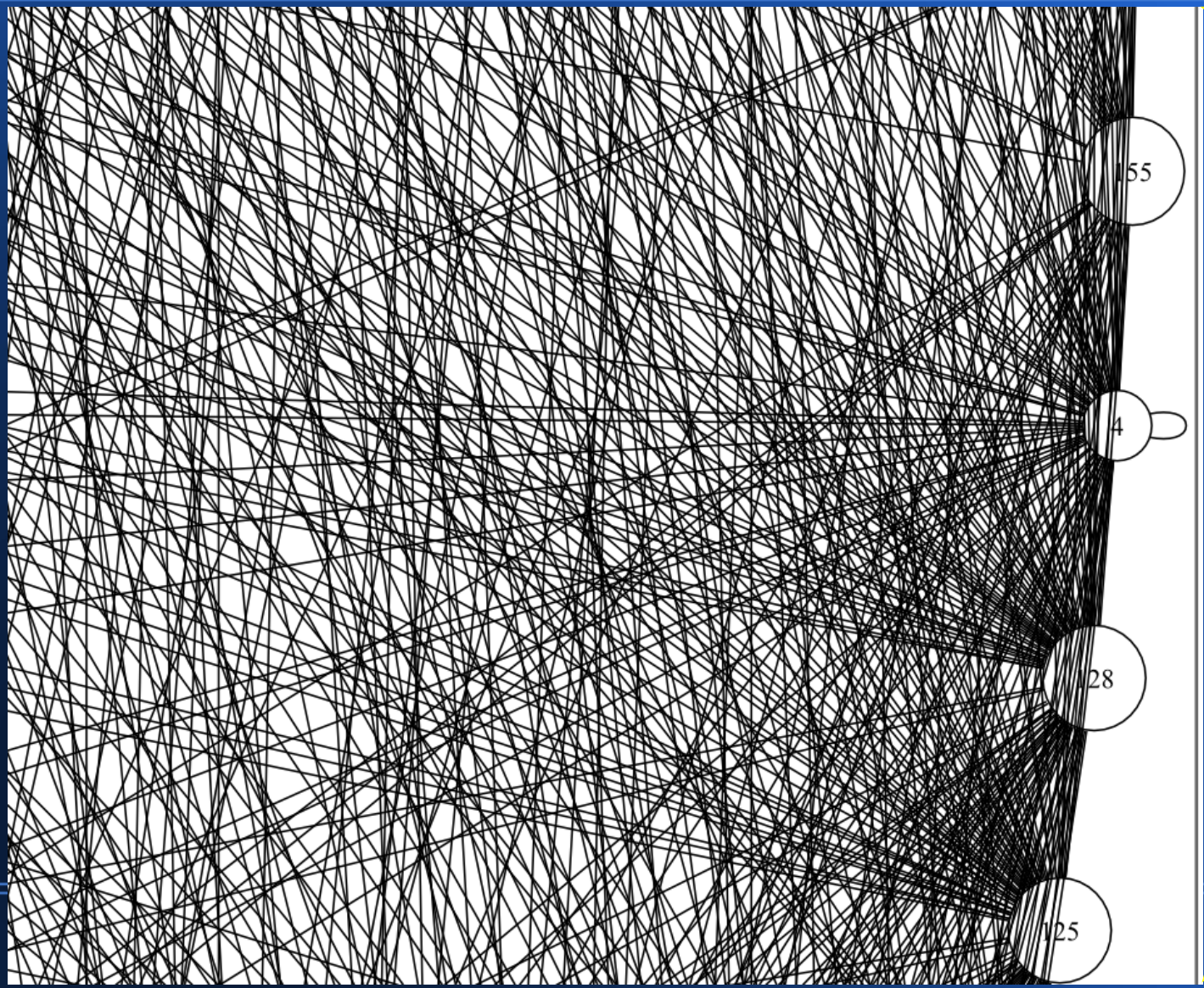
A simplified food web for the Northwest Atlantic

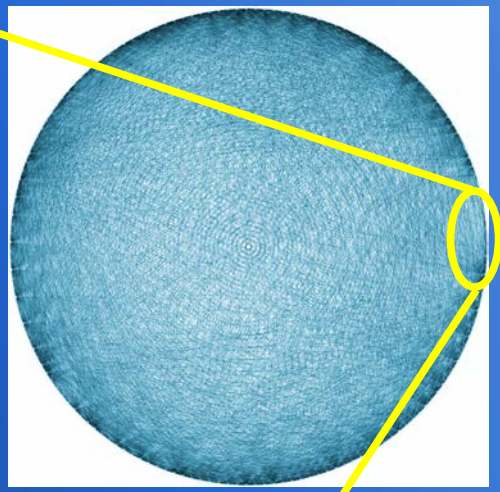
Food web - San Francisco Bay

- 1,332 species
  - 65 vertebrates
- 5,907 interactions
- ~180 vertebrate species to be added



Food web - San Francisco Bay



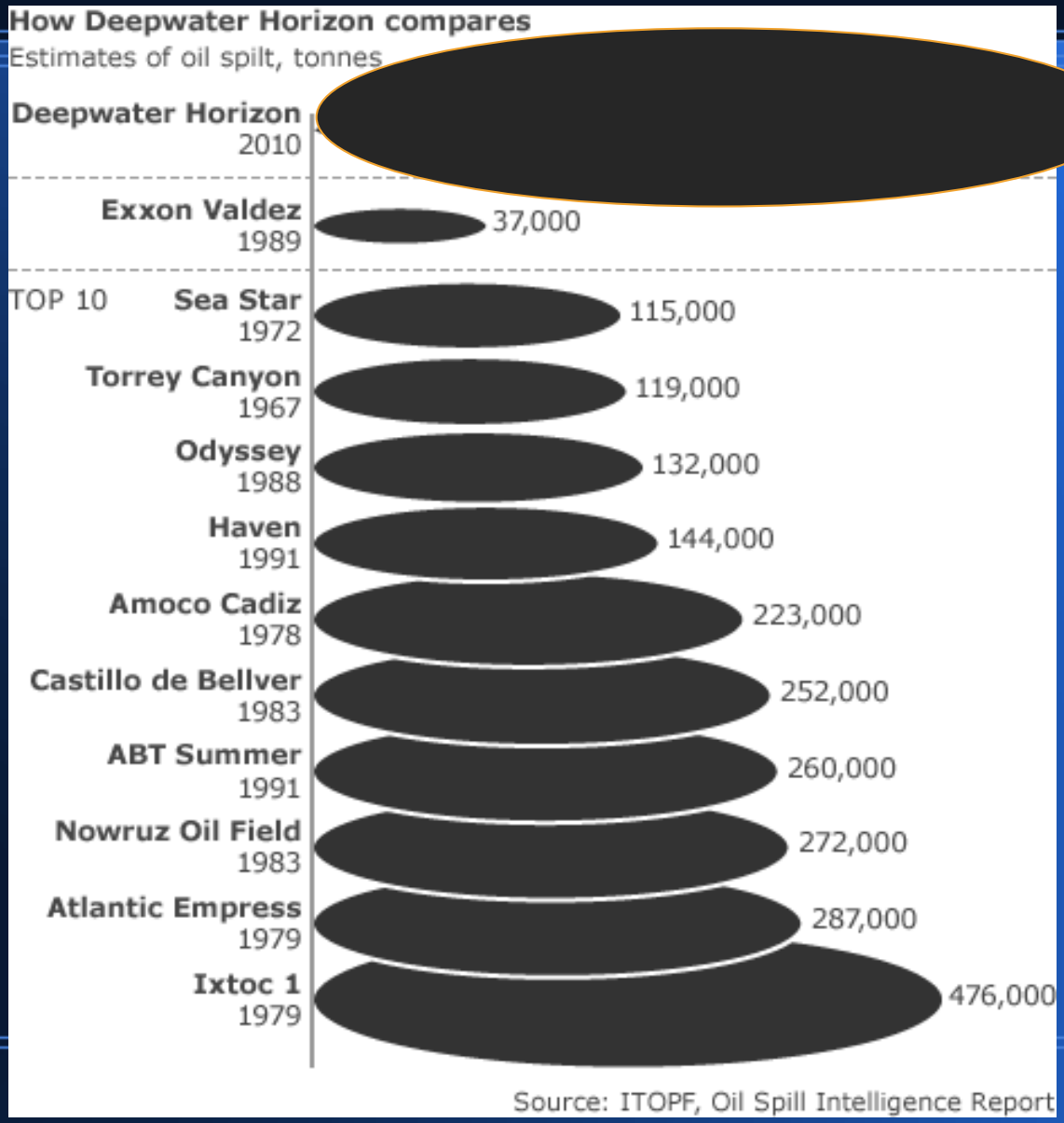


Outline

- Disturbance and structure of marine food webs
  - Gulf of Mexico and northern Caribbean reefs
- Modeling of marine food web dynamics
- San Francisco Bay, impacts of
  - Climate change
  - Loss of high trophic level species

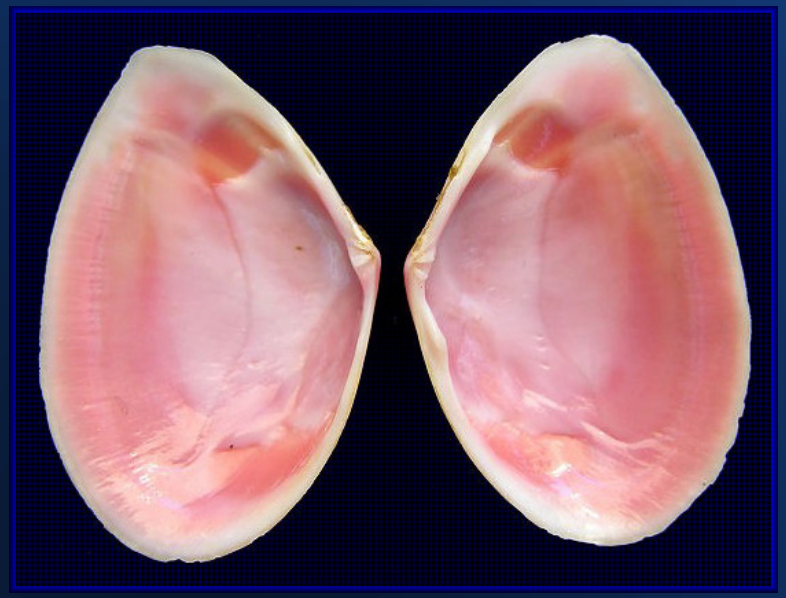
April 20, 2010

Magnitude of spill



Crassostrea virginica

Geukensia demissa

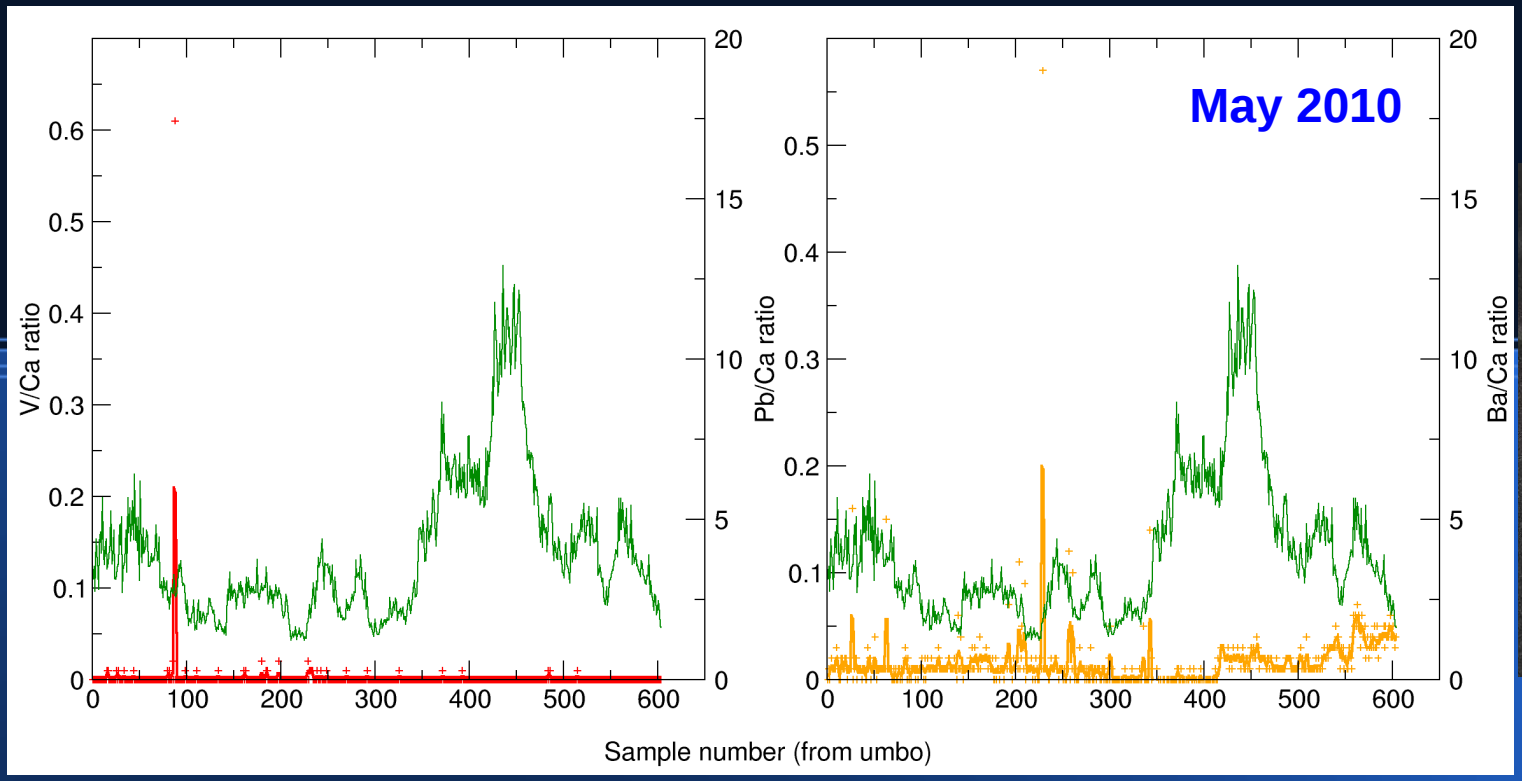


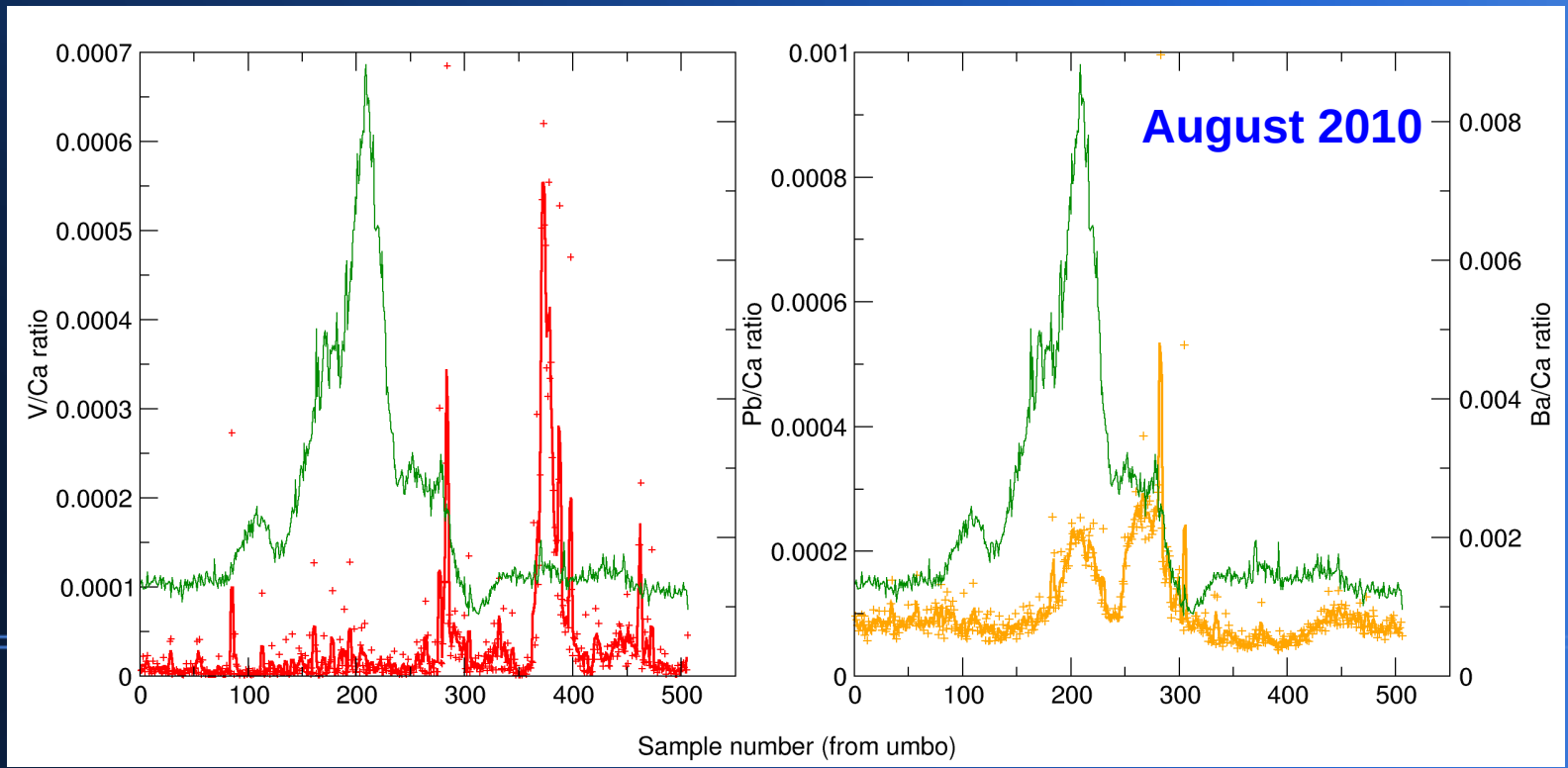
Tellina lineata

Littoraria irrorata

Deepwater Horizon contamination

- Oil-derived heavy metals
  - Shells; laser ICPMS (inductively coupled plasma mass spectrometry)
  - Tissues; ICPMS
- Oil-derived PAHs
  - Tissues; GCMS

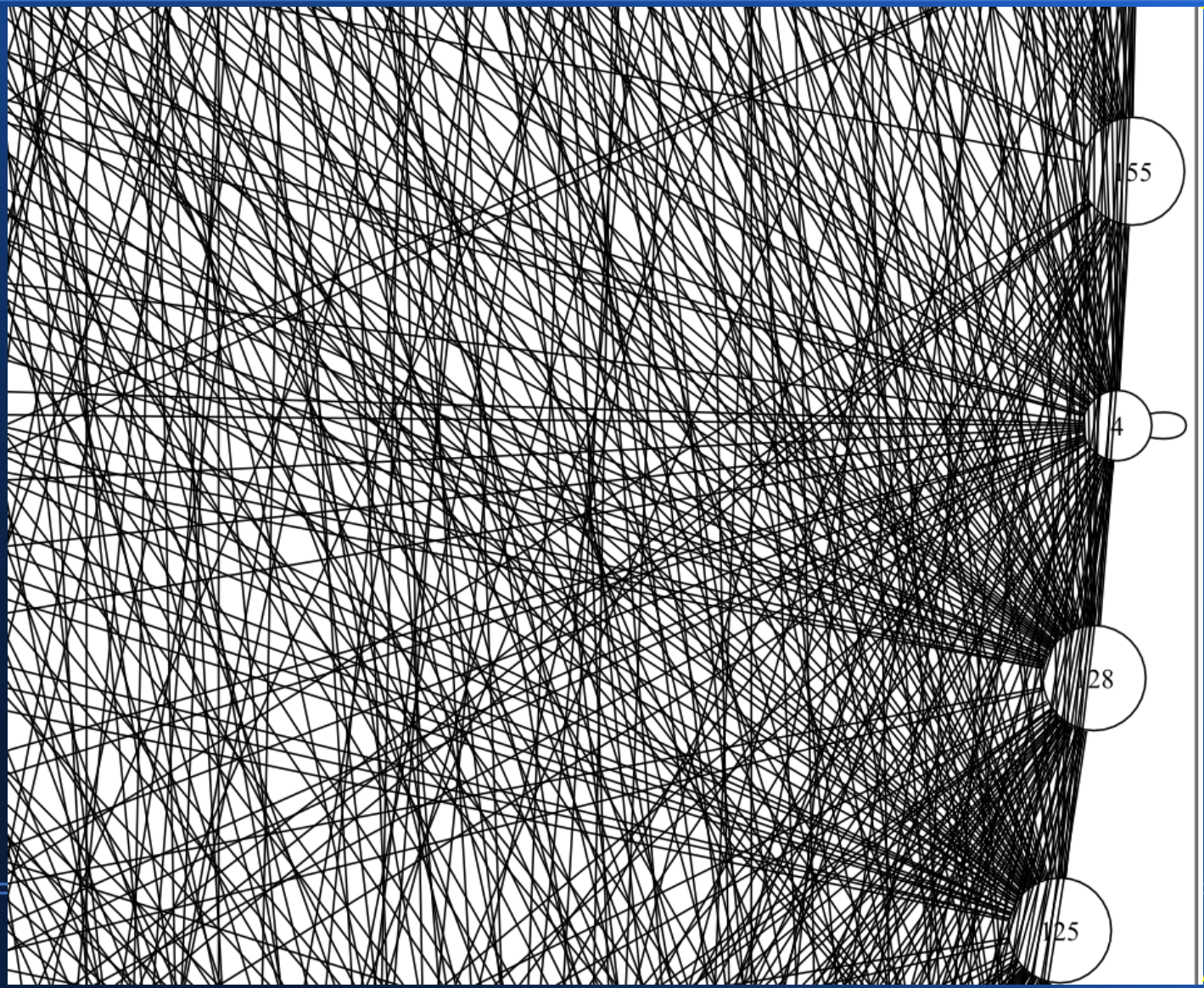

May 2010
V/Ca ratio
Pb/Ca ratio
Ba/Ca ratio
Sample number (from umbo)

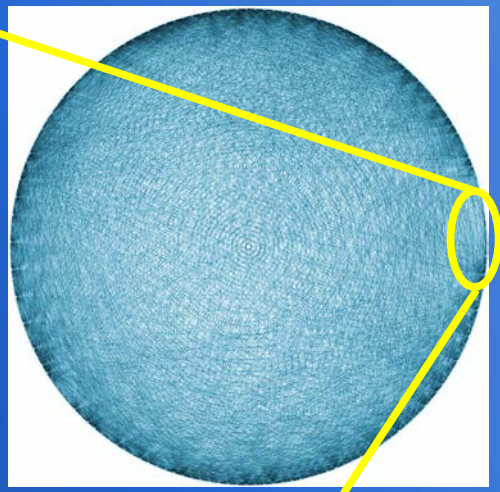

August 2010
V/Ca ratio
Pb/Ca ratio
Ba/Ca ratio
Sample number (from umbo)

Deepwater Horizon contamination

- Shells
  - Vanadium
  - Lead
  - Chromium
- Soft-tissues
  - Vanadium
  - Lead
  - Cobalt

Food web - San Francisco Bay



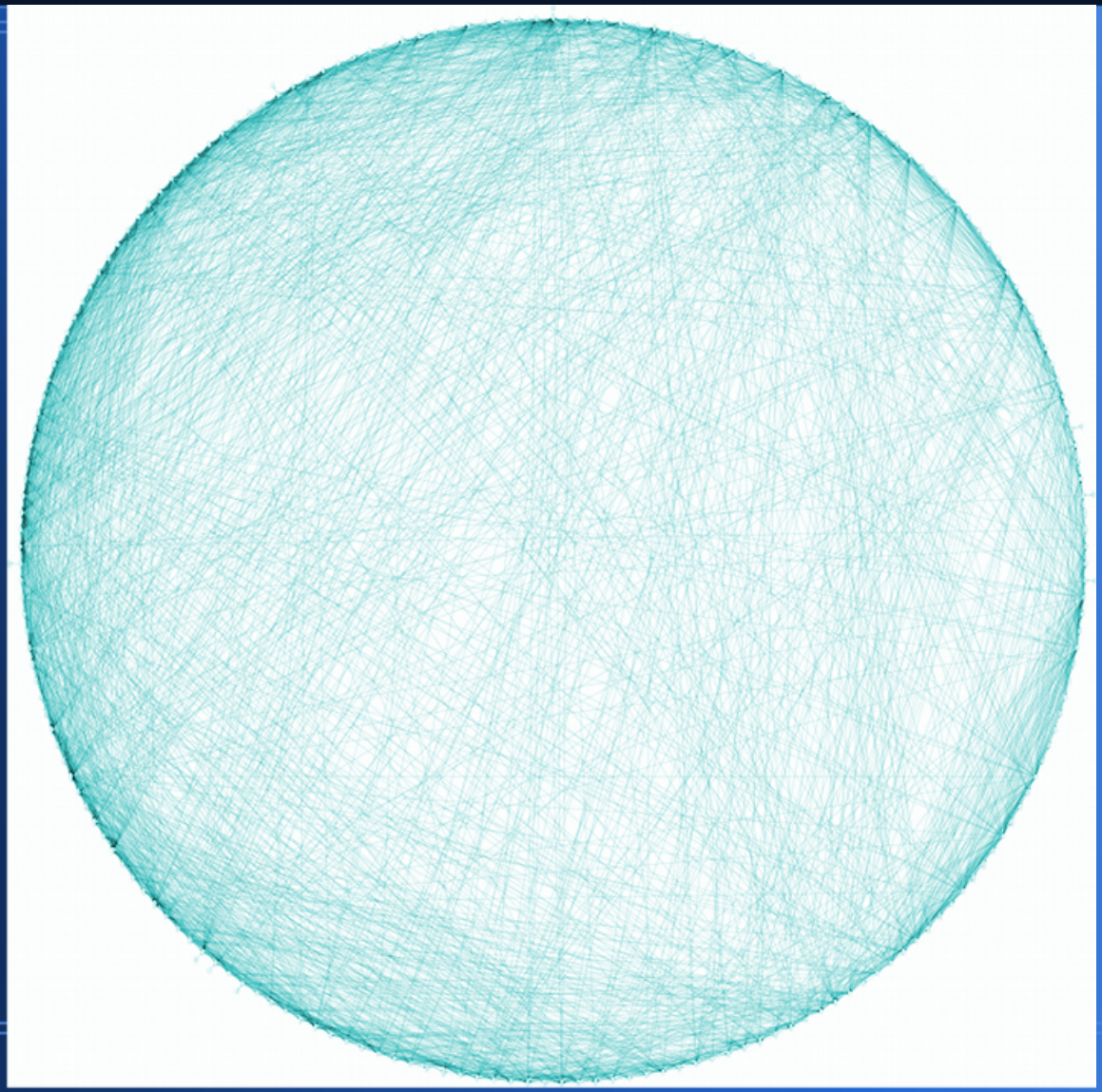


Greater Antillean coral reefs

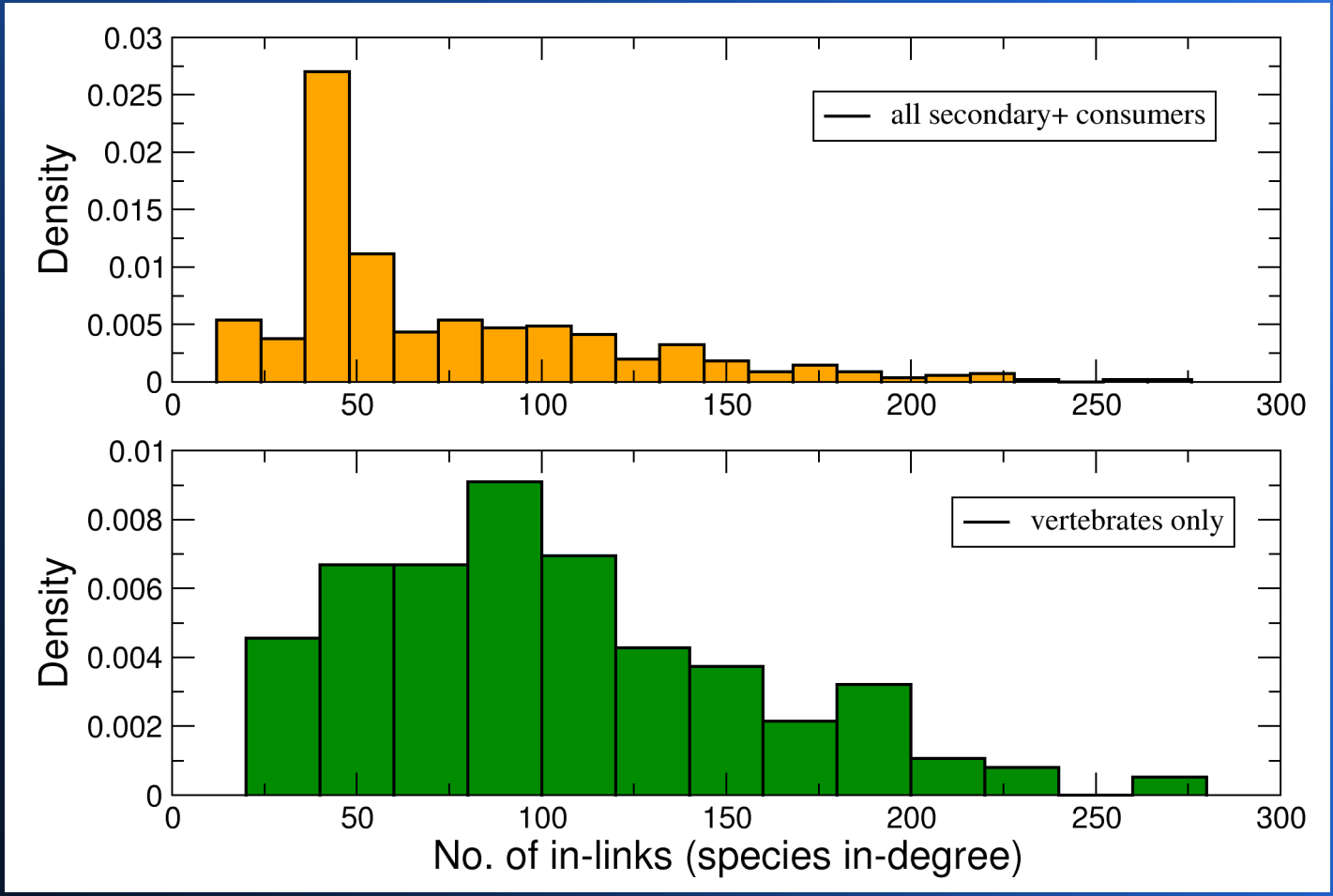
- Examine regional variation in food web structure
- Causes and implications of variation

Greater Antillean coral reefs

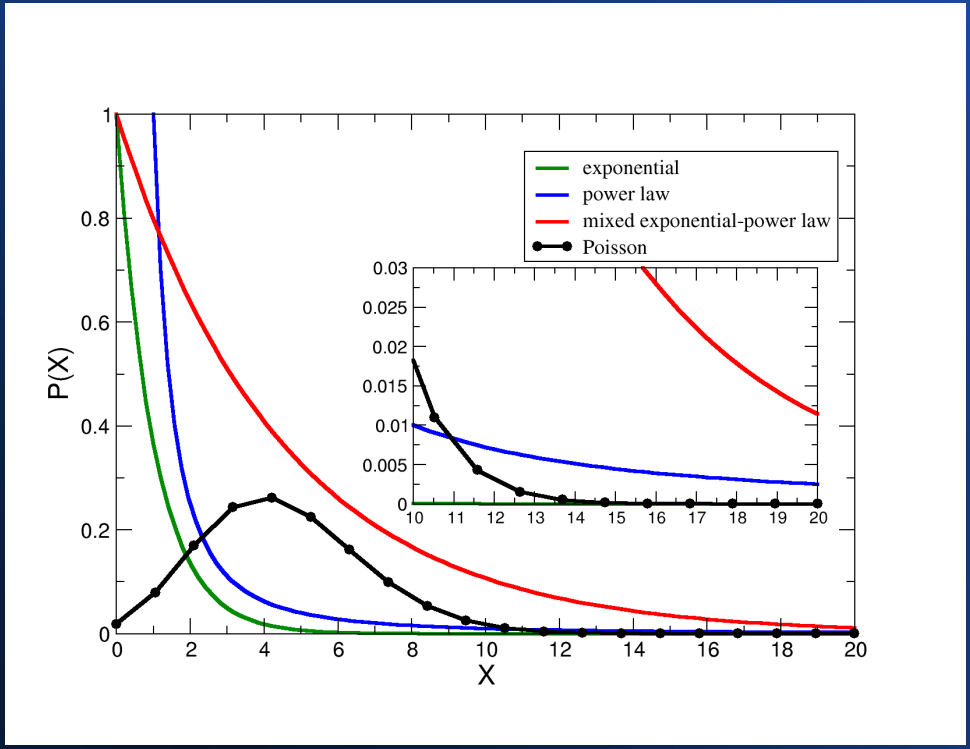
- 756 species
  - 196 vertebrates
- 4616 interactions



Link or degree distributions



Link or degree distributions



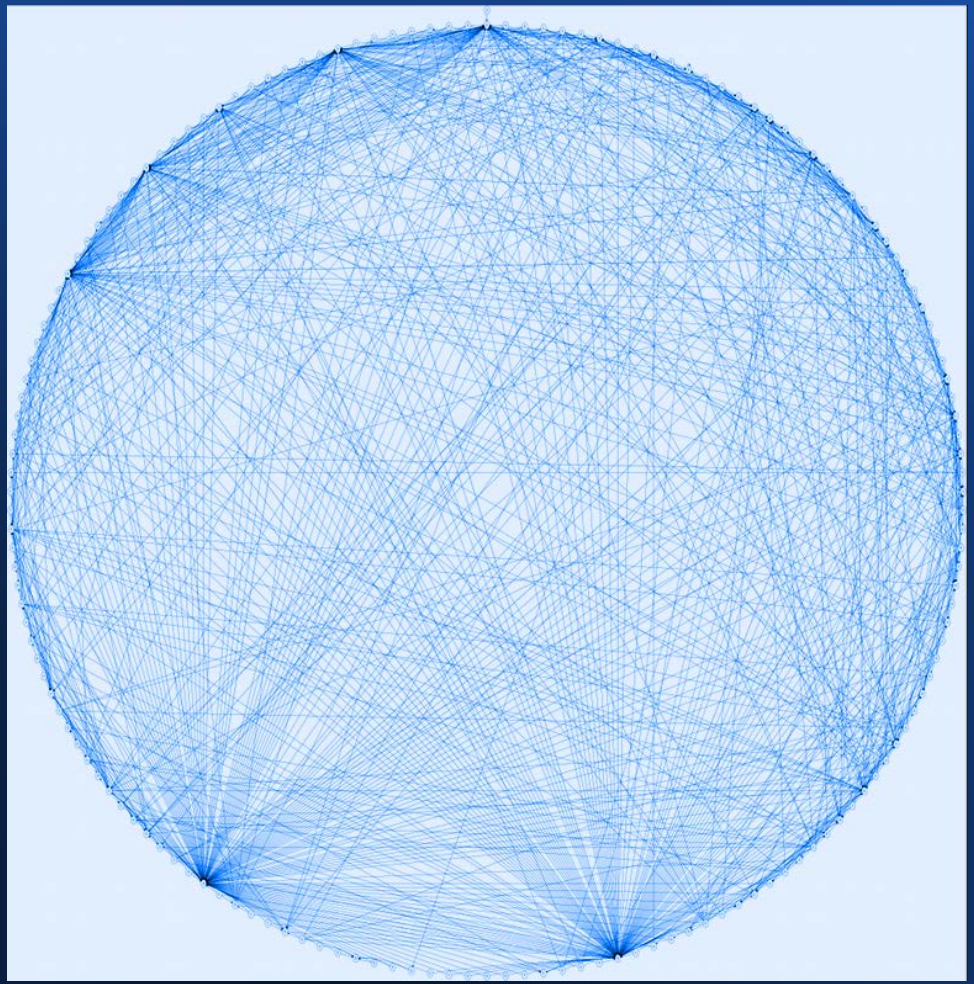
$$p(r) = e^{-z}\frac{z^r}{r!}$$

$$p(r) = ce^{-r}$$

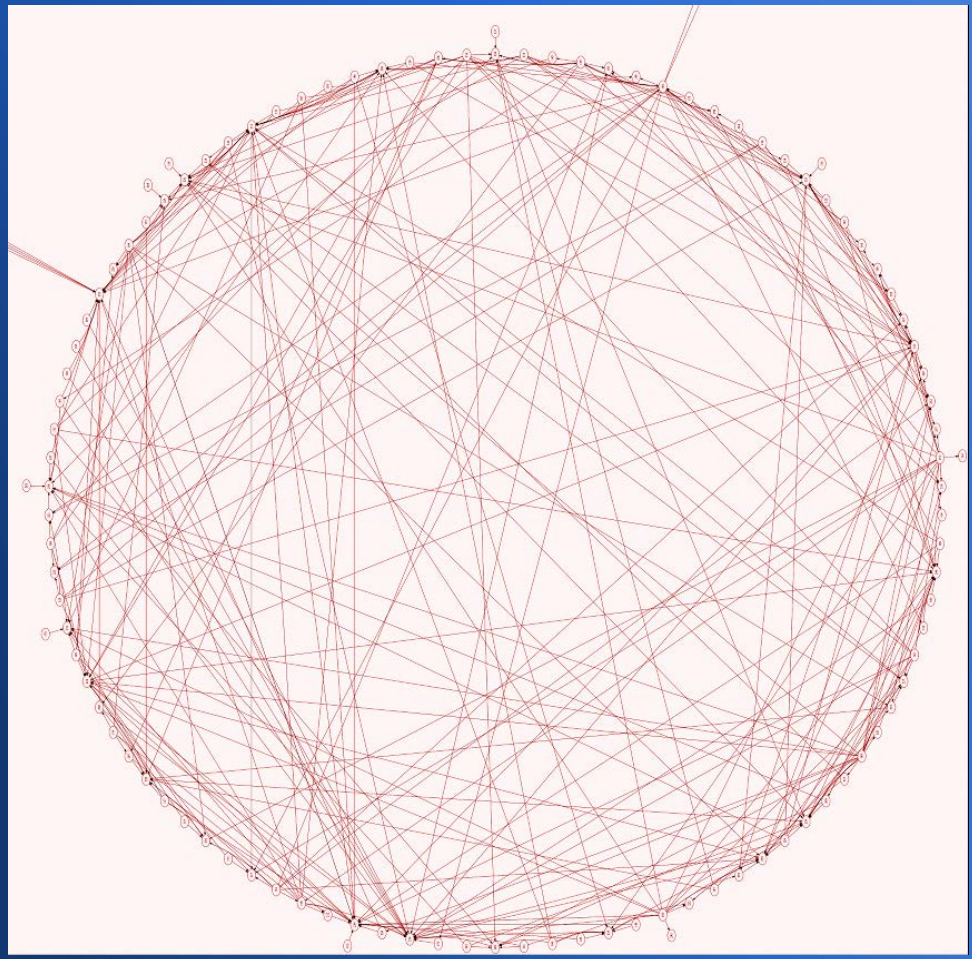
$$p(r) = Mr^{-\gamma}$$


Gulf of Mexico
Key West
New Providence
Eleuthera
The Bahamas
Cat Island
San Salvador
Andros Island
Great Exuma
Rum Island
Long Island
Samana Cay
Cay Sal Bank
Crooked Is.
Ragged Island Range
Mayaguana
Acklins Is.
Turks & Caicos
Great Inagua
Guinchos Cay
Matanzas
Santa Clara
Cienfuegos
Cay Lobos
Isla de la Juventud
Camagüey
Holguín
Santiago de Cuba
Cuba
Cayman Islands
Haiti / Dominican Republic
Santiago
DOMINICAN REPUBLIC
Mona
San Juan
US / British Virgin Islands
Culebra
Tortola
Anegada
Virgin Gorda
Anguilla
St Thomas
St Martin
Saba
St Eustatius
St Barts
St Croix
St Kitts
Nevis
Montserrat
Dominica
Kingston
Navassa Island
Jamaica
Puerto Rico
Greater Antilles
Cancún
Cozumel
Belize
Swan Islands
Islas de la Bahia
La Ceiba
Puerto Lempira
Honduras
Tegucigalpa
Cayos Miskitos
Nicaragua
Matagalpa
NICARAGUA
León
Managua
Bluefields
Mosquito Coast
Isla de la Providencia
Isla de San Andres
Islas del Maiz
Caribbean Sea
Aruba
Curacao
Bonaire
St Lucia
St Vincent
The Grenadines
Grenada
North Atlantic Ocean

Vertebrate-only networks



Regional pool



Jamaica

Food web - San Francisco Bay

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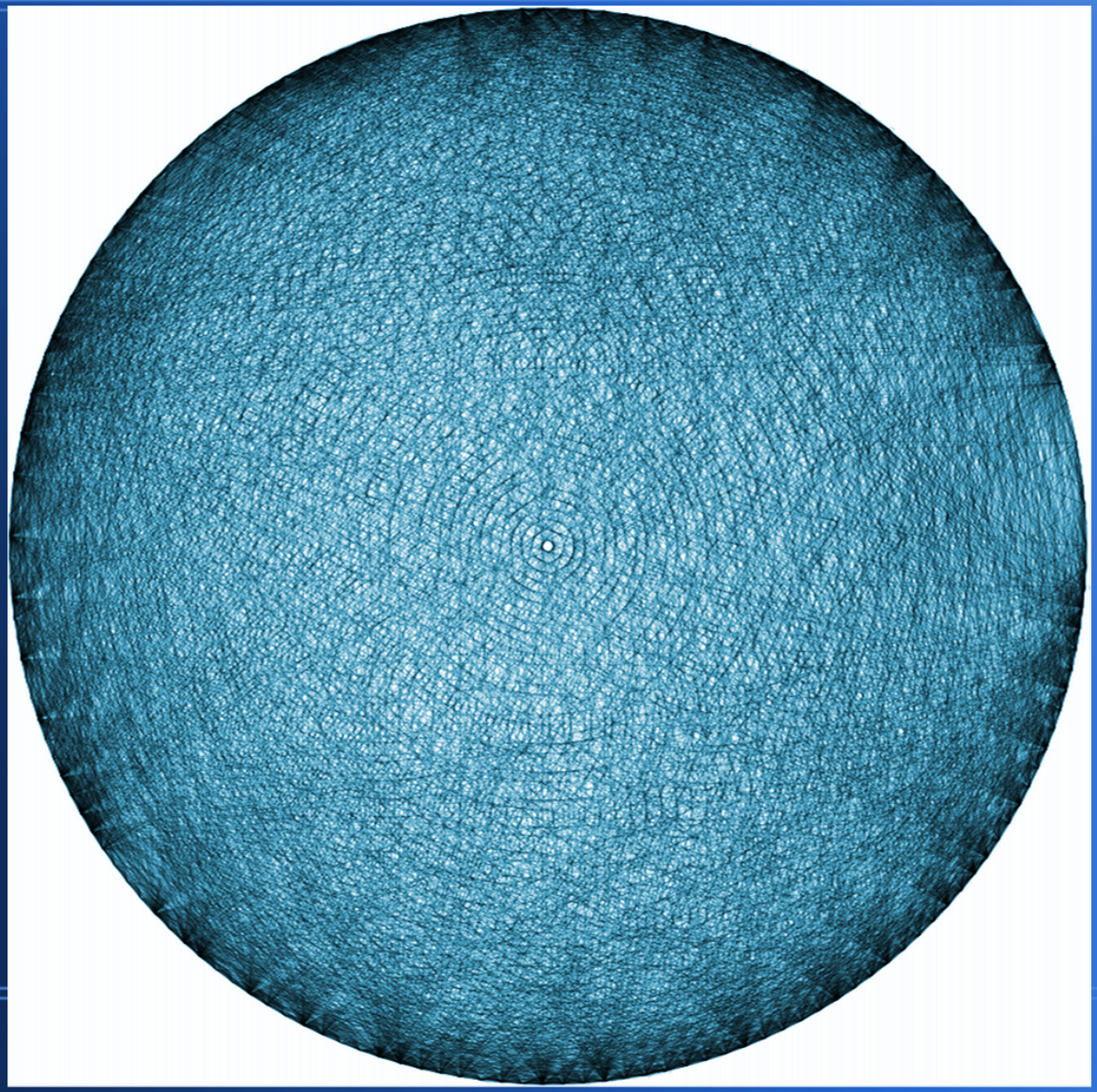
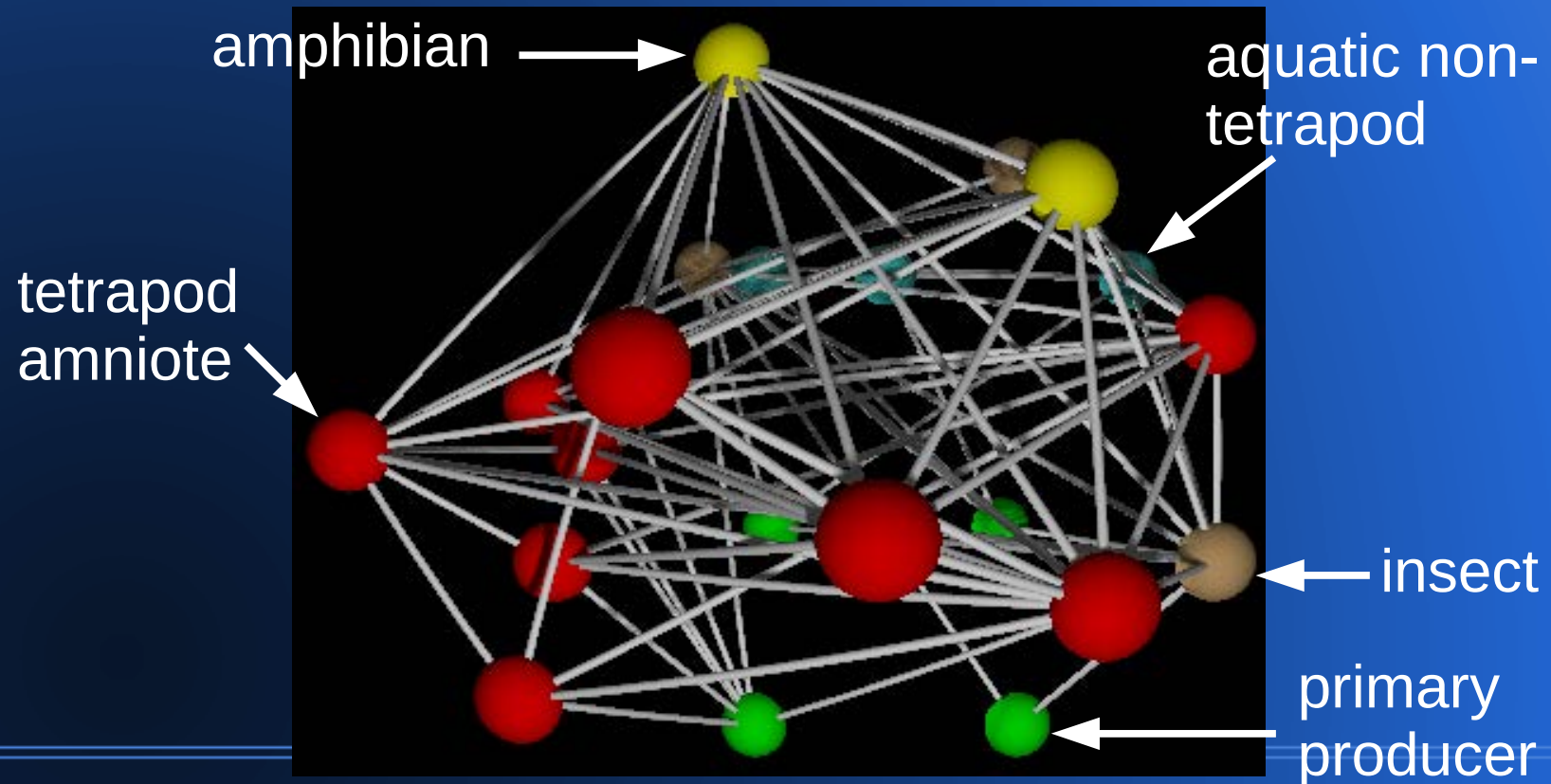


San Francisco Bay

- Acidification and increasing water temperatures
  - Disruptions of planktonic primary productivity
  - Loss of calcified species
- Unsustainable species harvesting
  - Loss of high trophic level species

Modeling network disruption

- Summarize community's trophic structure with greatest accuracy available

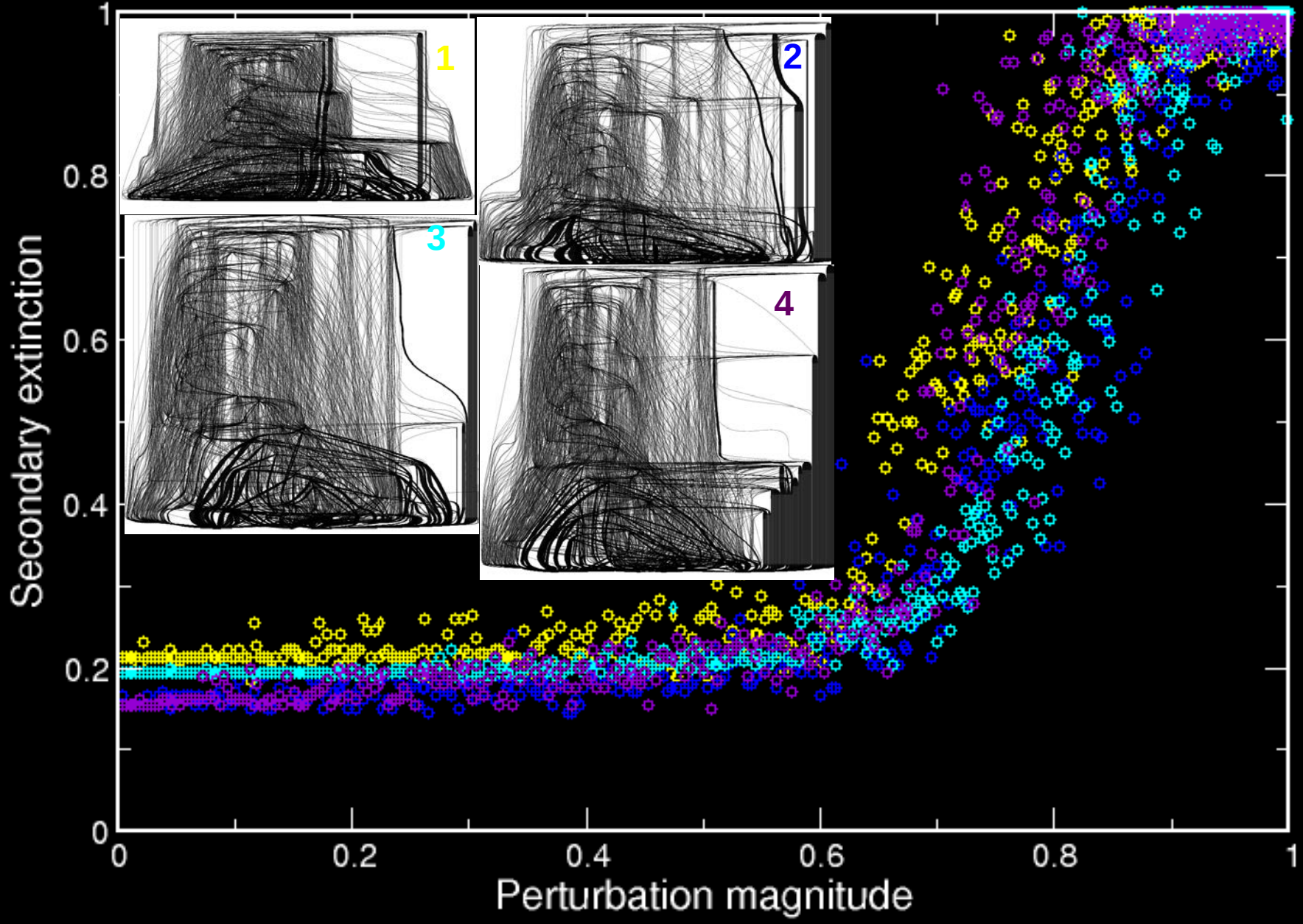


But...

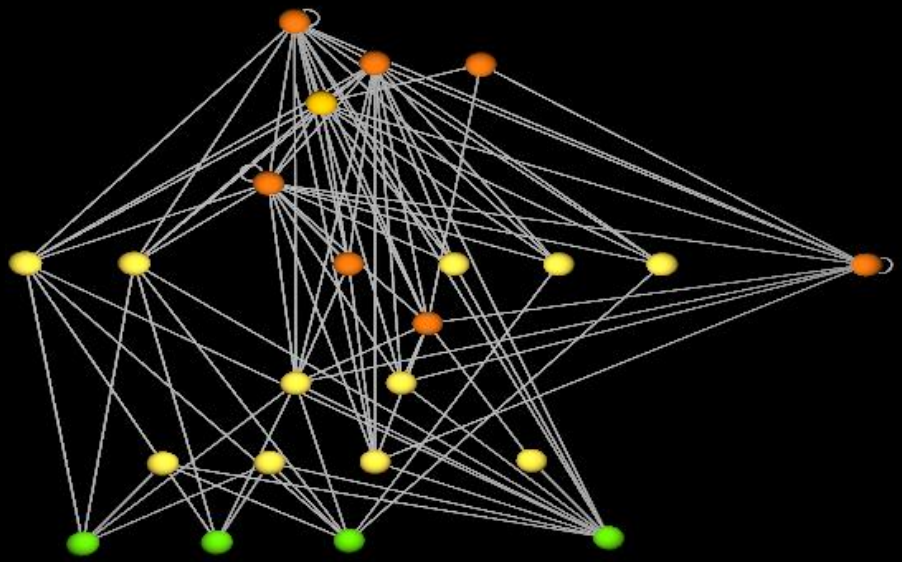
- Secondary extinction propagates in bottom-up directions only
  - No top-down trophic cascades
- Species interactions are all equal and equivalent
  - All equal in strength
- Species are demographically neutral

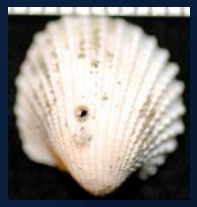
Dynamic difference equation

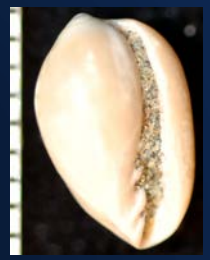
$$N_i^x(t) = \frac{1}{N_i^x(0)} \left[\sum_{j=1}^{r_i^x} s_x N_j^y(t) - \sum_{k=1}^{p_i^x} s_k N_k^s(t) \right]$$

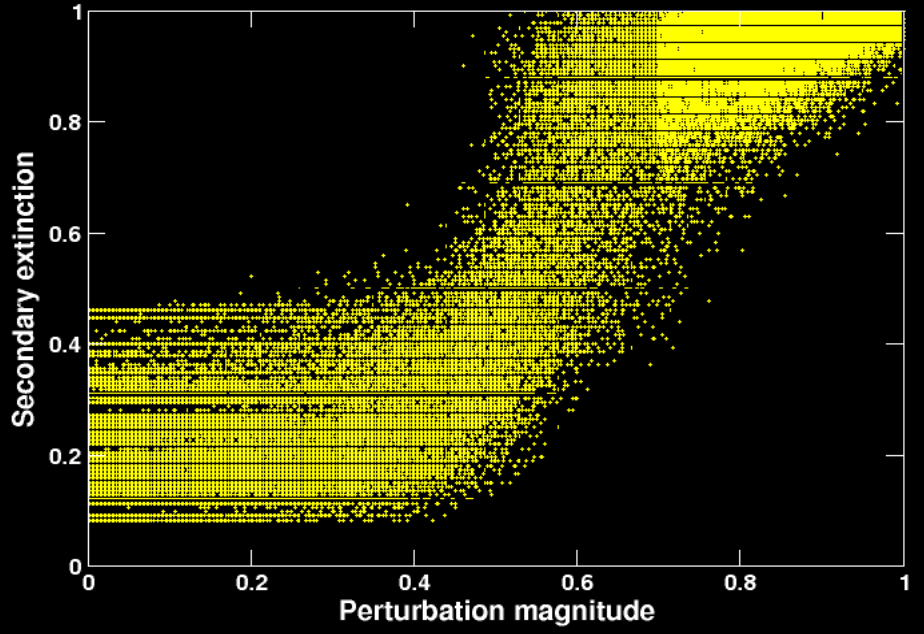

1
2
3
4
Secondary extinction
Perturbation magnitude
0
0.2
0.4
0.6
0.8
1

Sample 607 – Dominican Republic

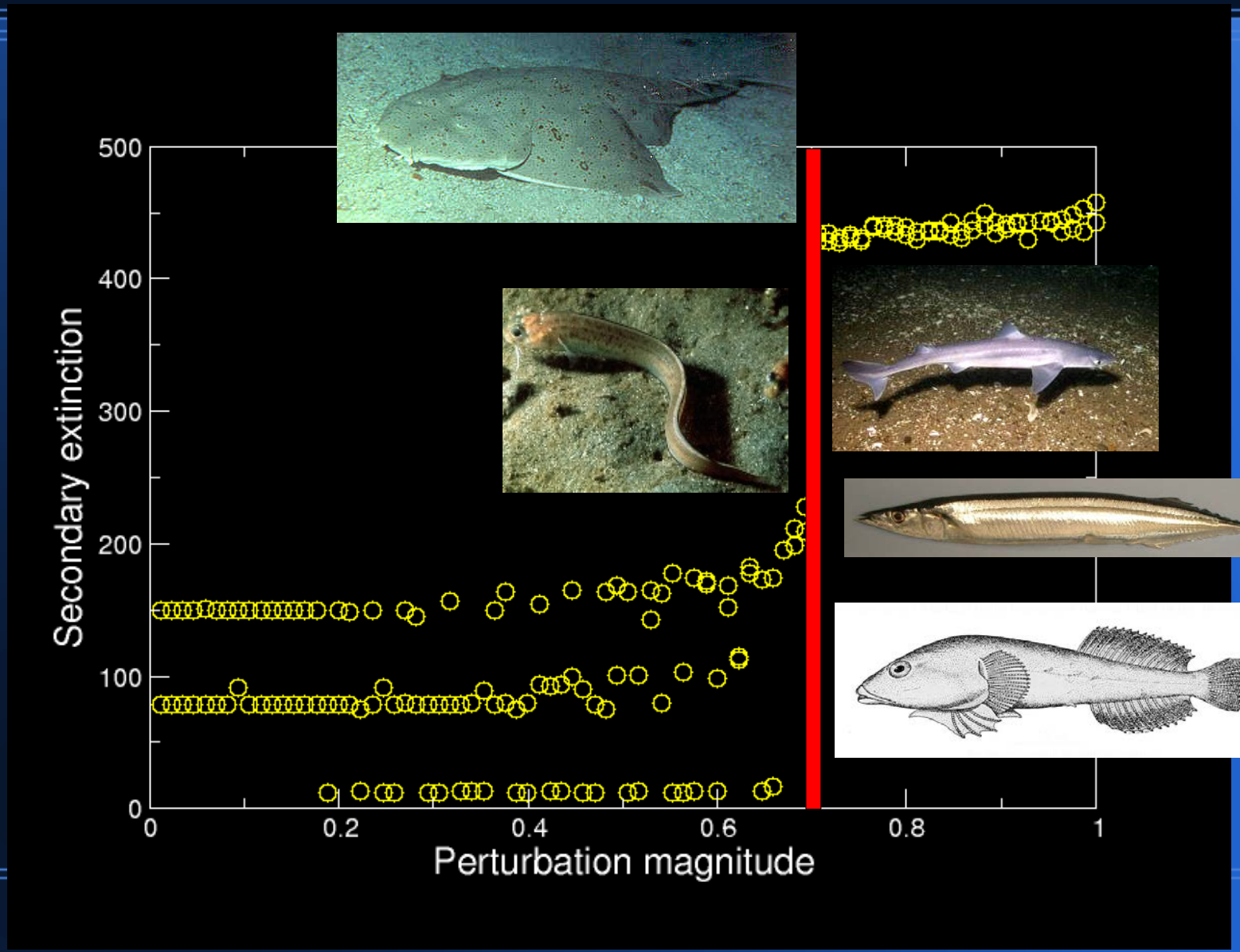








San Francisco Bay



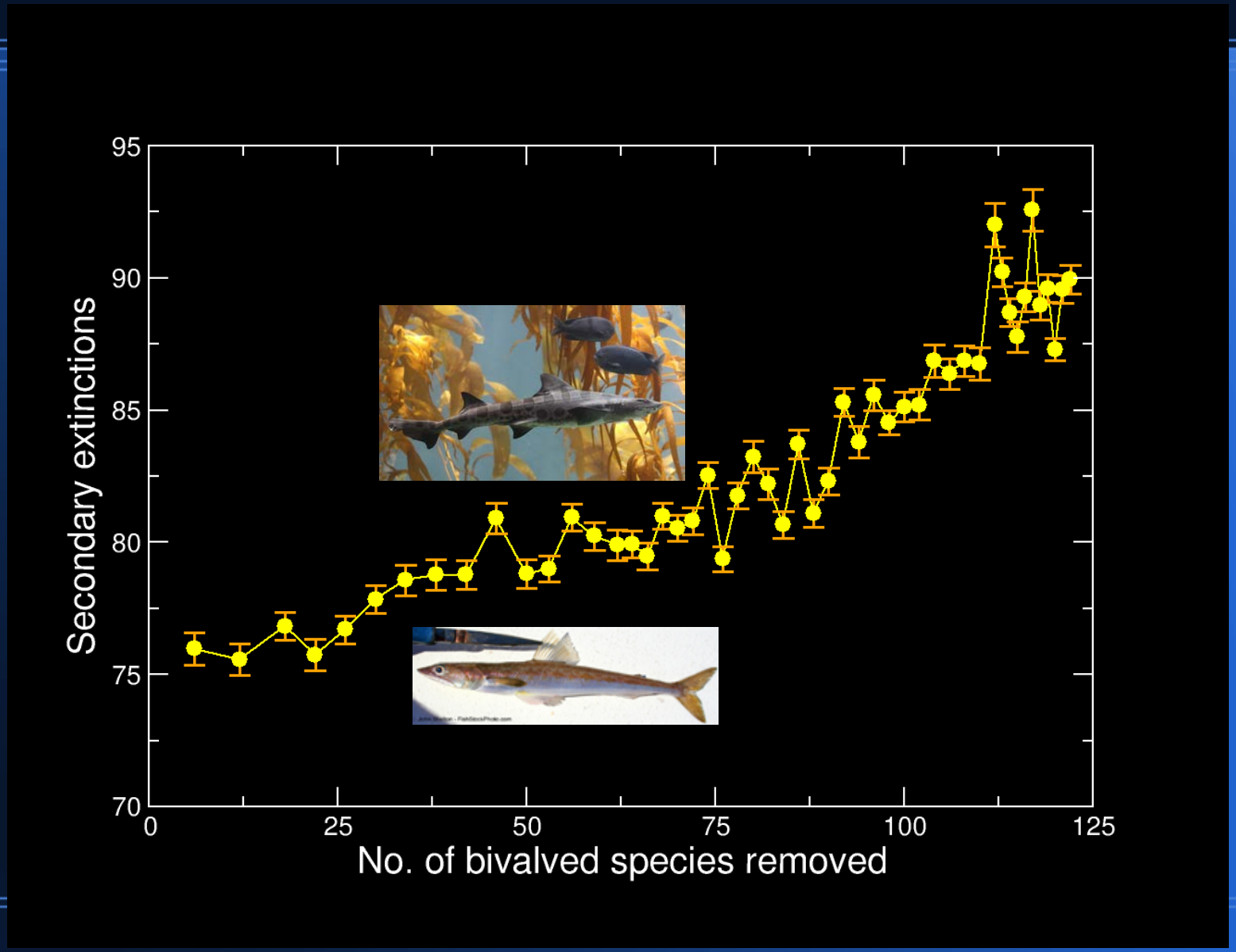
Two general rules

- Systems are robust against disruptions of primary production
- Susceptibility is highly nonlinear and catastrophic
  - Signaled by increases variability and sensitivity

Acidification

- Decline and possible loss of calcifying species
- Model
  - Remove up to 122 bivalved molluscan species

Acidification

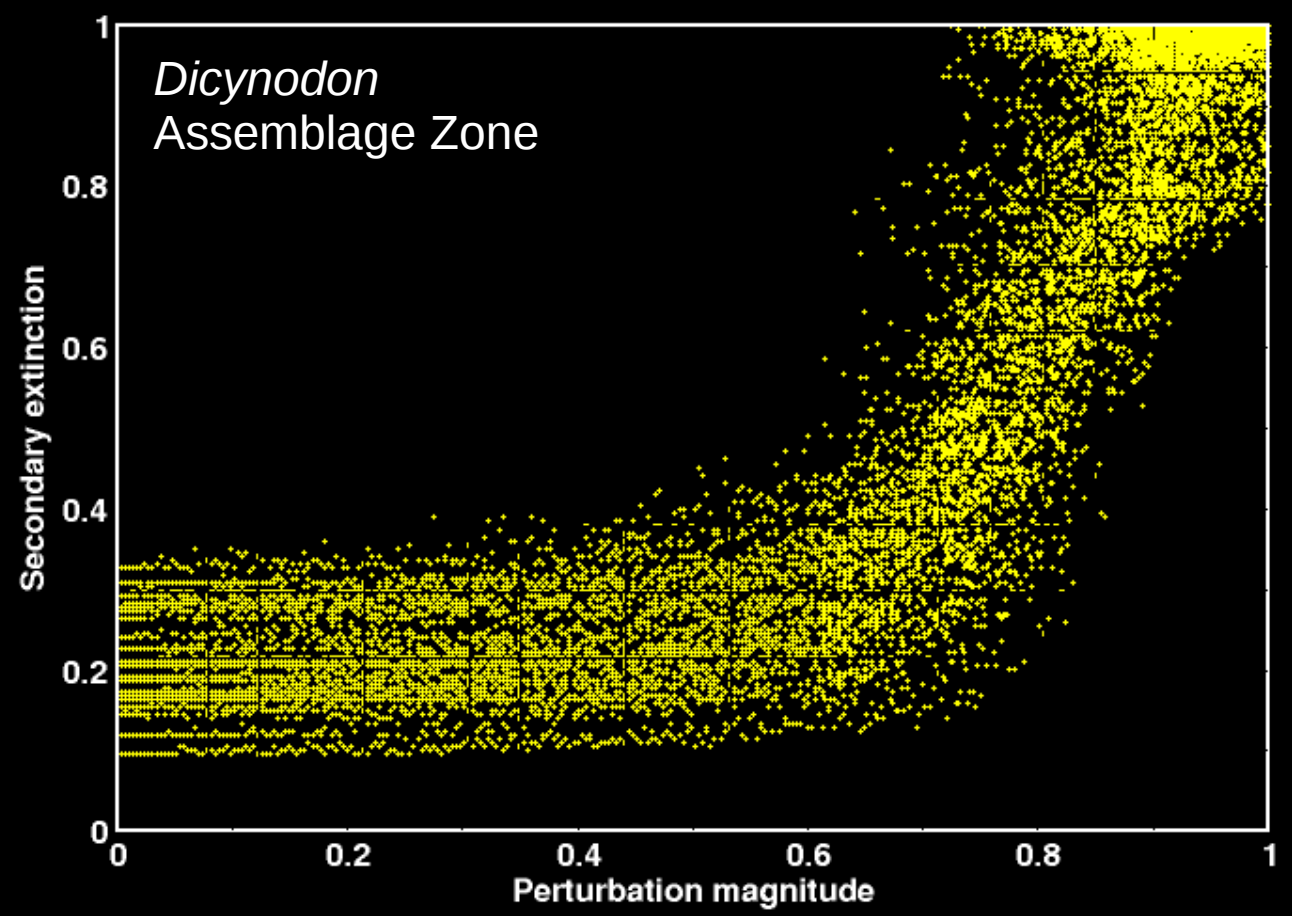


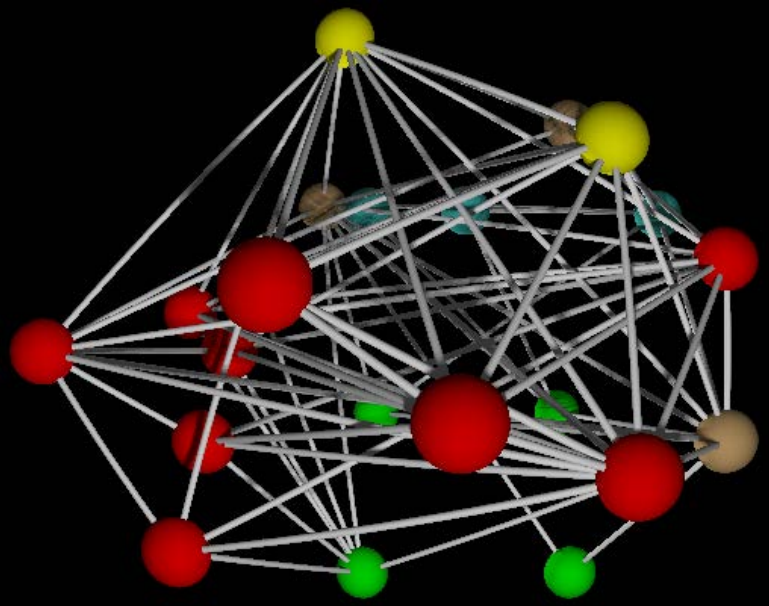
Species exploitation

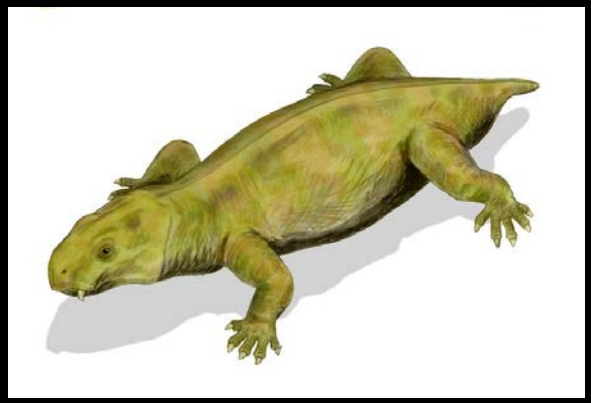
- Removal of seven elasmobranch species
  - High trophic level
  - Trophic cascades

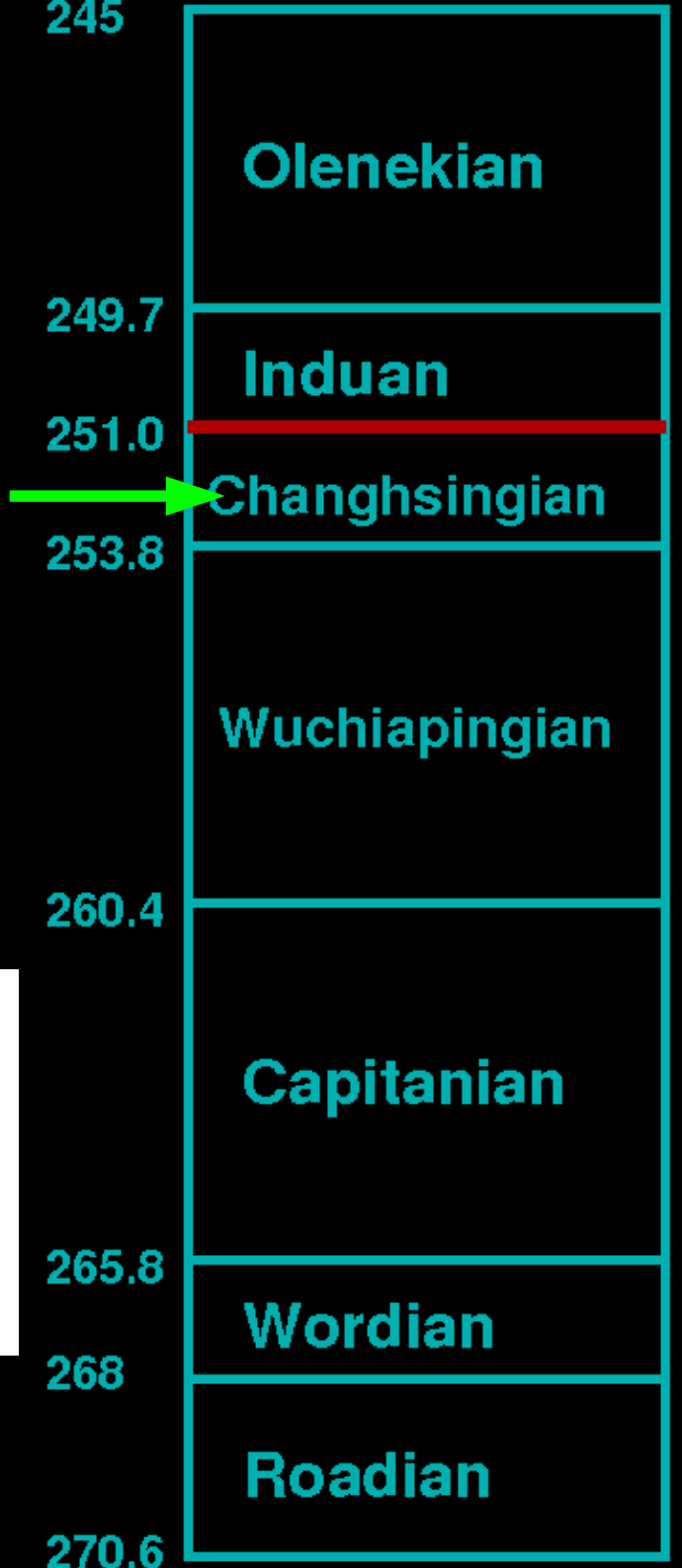
Secondary extinctions

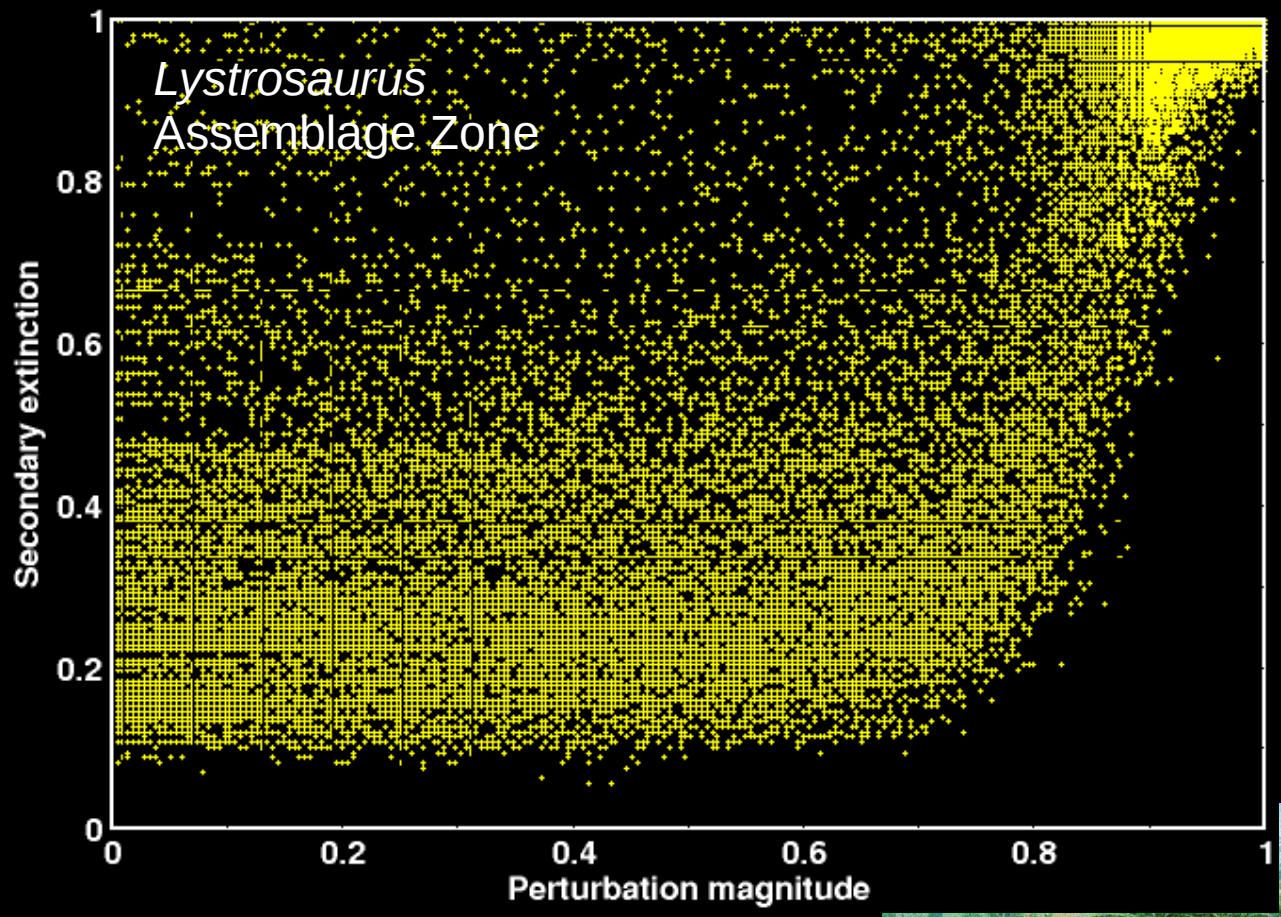
- 12 species
  - *Urticina crassicornis*
  - *Synodus lucioceps*
  - *Hemilepidotus spinosus*
  - *Tritonia gilberti*

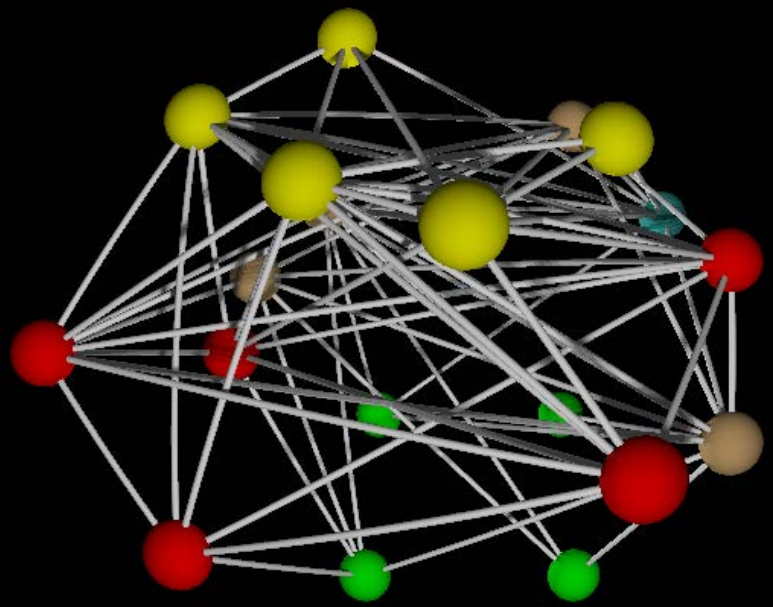

Dicynodon
Assemblage Zone
Secondary extinction
Perturbation magnitude
0
0.2
0.4
0.6
0.8
1

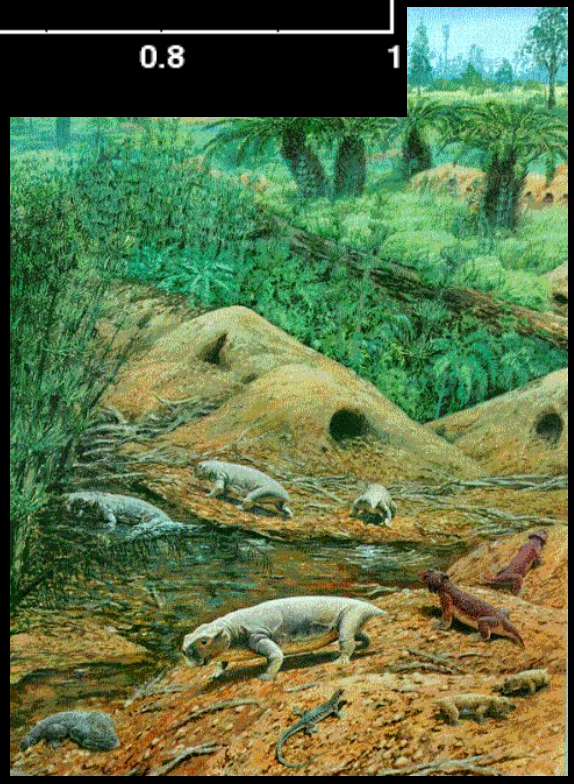





245
Olenekian
249.7
Induan
251.0
Changhsingian
253.8
Wuchiapingian
260.4
Capitanian
265.8
Wordian
268
Roadian
270.6


Lystrosaurus
Assemblage Zone
Secondary extinction
Perturbation magnitude
0
0.2
0.4
0.6
0.8
1






245
Olenekian
249.7
Induan
251.0
Changhsingian
253.8
Wuchiapingian
260.4
Capitanian
265.8
Wordian
268
Roadian
270.6

A Third rule

- Conserving functional diversity is at least as important as maintaining species richness.
- Transformation of ecosystems, or formation of new communities in the near future could yield ecologically unstable and evolutionarily short-lived systems.

Acknowledgments

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