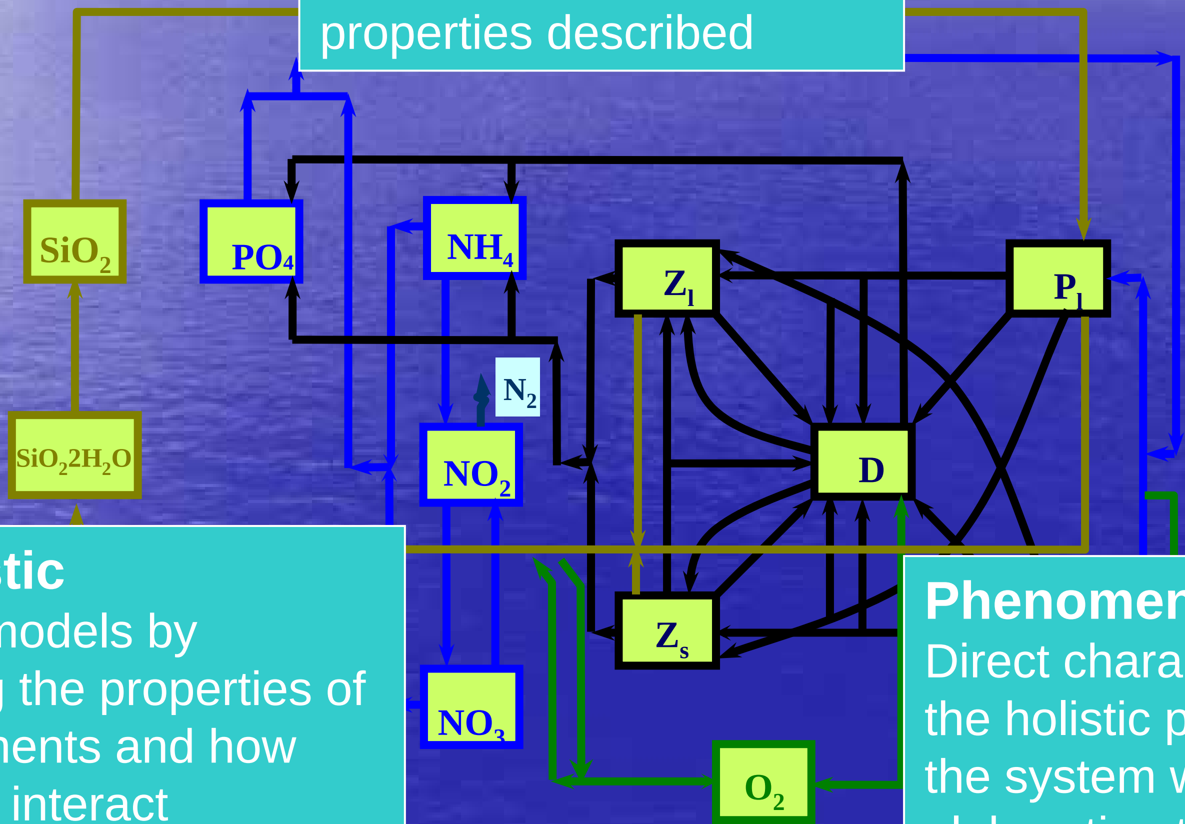
A top-down approach to modelling marine ecosystems in the context of physical-biological modelling

Alain F. Vezina, Charles Hannah and Mike St.John

The Ecosystem Modeller's Universe

Empiricists
Data guide the way the processes are characterized and properties described



Mechanistic
Construct models by considering the properties of the components and how these parts interact

Phenomenological
Direct characterization of the holistic properties of the system without elaborating the underlying mechanisms

Getz, W.M. 1998. BioScience 48, 540

Approaches to model development

Bottom up: Start by putting as many details as you can in the model and then simplify as need be.

→ Error of omission

Top down: Start with an integrated phenomenological description of the system at the lowest level of resolution that includes the structures and processes of interest

Getz, W.M. 1998. BioScience 48, 540

Increasing model complexity

'Heated' debate in the pages of J. Plankton Research

Plankton functional type modelling: running before we can walk?
THOMAS R. ANDERSON

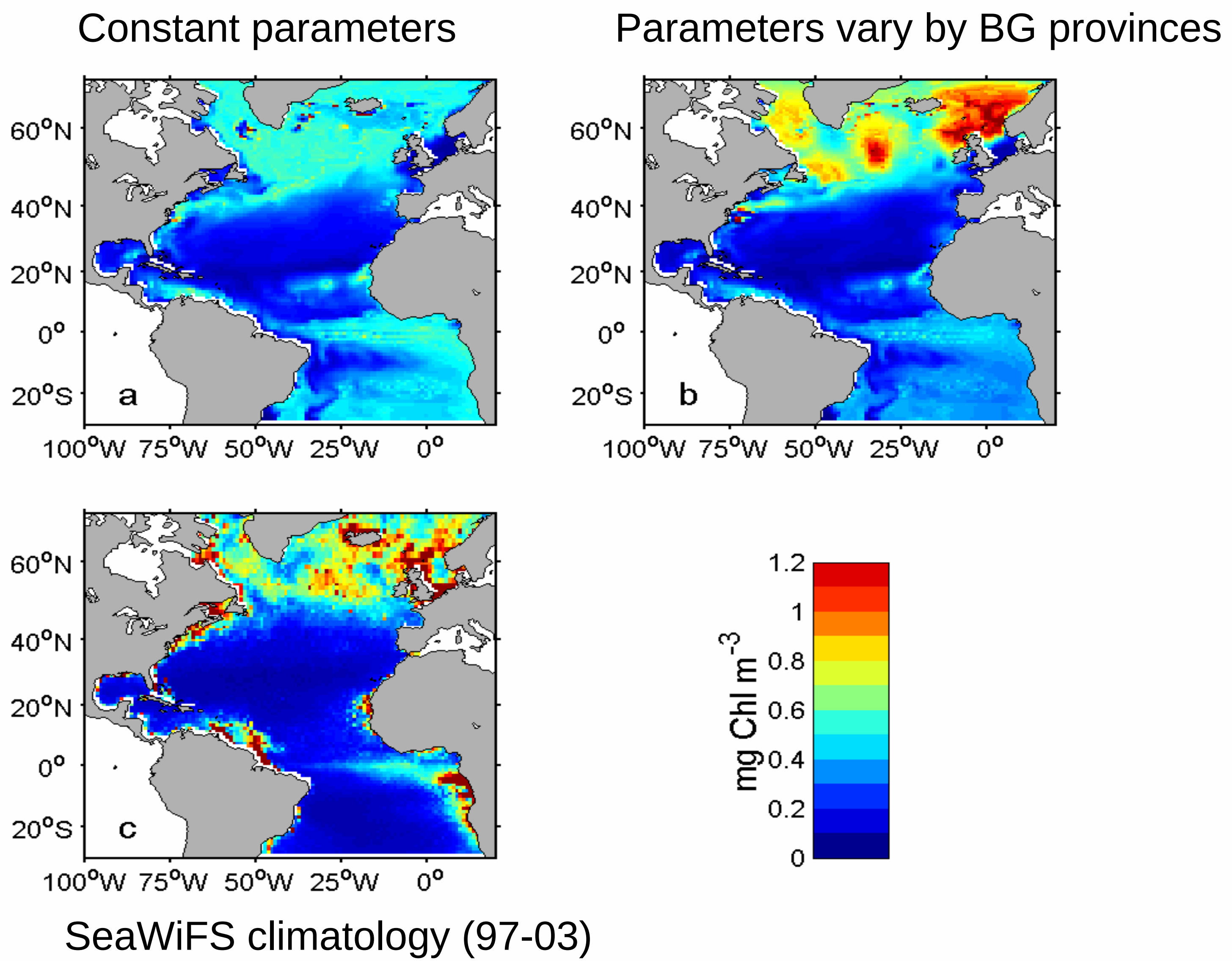
Reply to Horizons Article 'Plankton functional type modelling: running before we can walk?' Anderson (2005): I. Abrupt changes in marine ecosystems?
CORINNE LE QUERE

Top down approach to add complexity in an organized, systematic manner

- What we can do now
  - Flexible, adaptive grazing/closure terms
- What we might think about
  - Models that sacrifice process detail to increase the number of interacting components

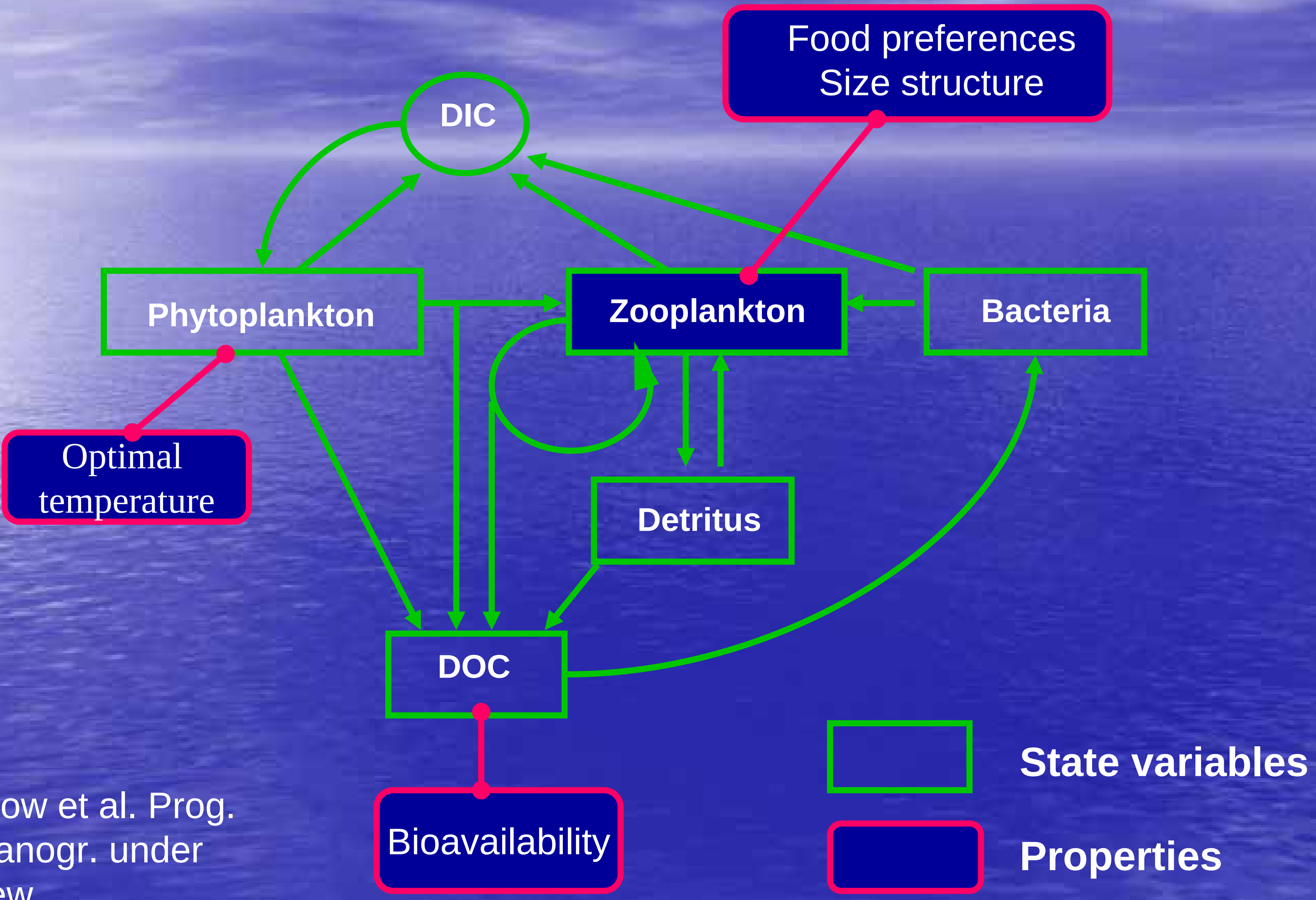
What we can do now

Flexible/adaptive grazing formulations



Losa et al. 2006. J. Mar. Syst. 61, 230

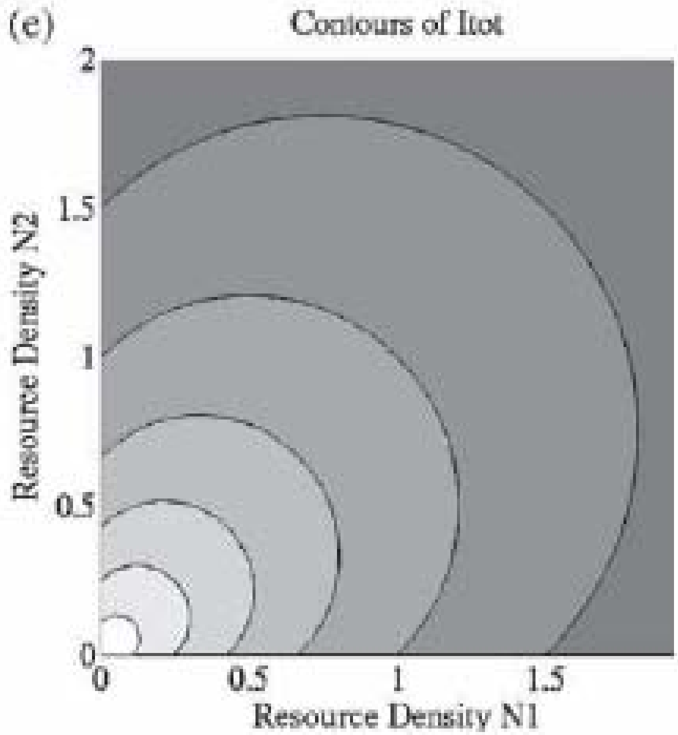
Ecosystem model with adaptive dynamic properties



Pahlow et al. Prog. Oceanogr. under review

Zooplankton: Food Preferences and Omnivory

Dilemma: variable food preferences can reduce ingestion with more prey.



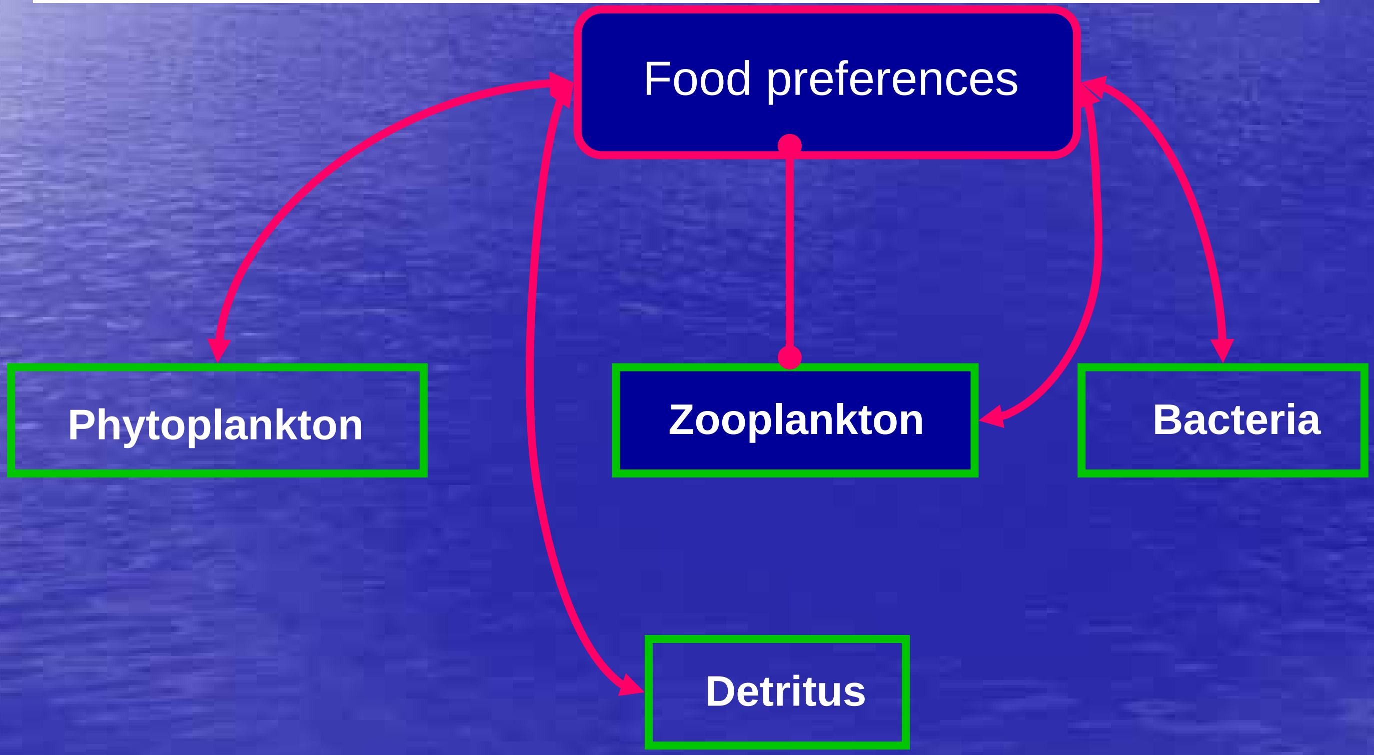
(Gentleman et al. 2003)

- implicit assumption: no omnivory
  - contradiction to assumption of optimal growth
- Omnivory:
  - no rejection of most abundant food
  - additive filtering rates

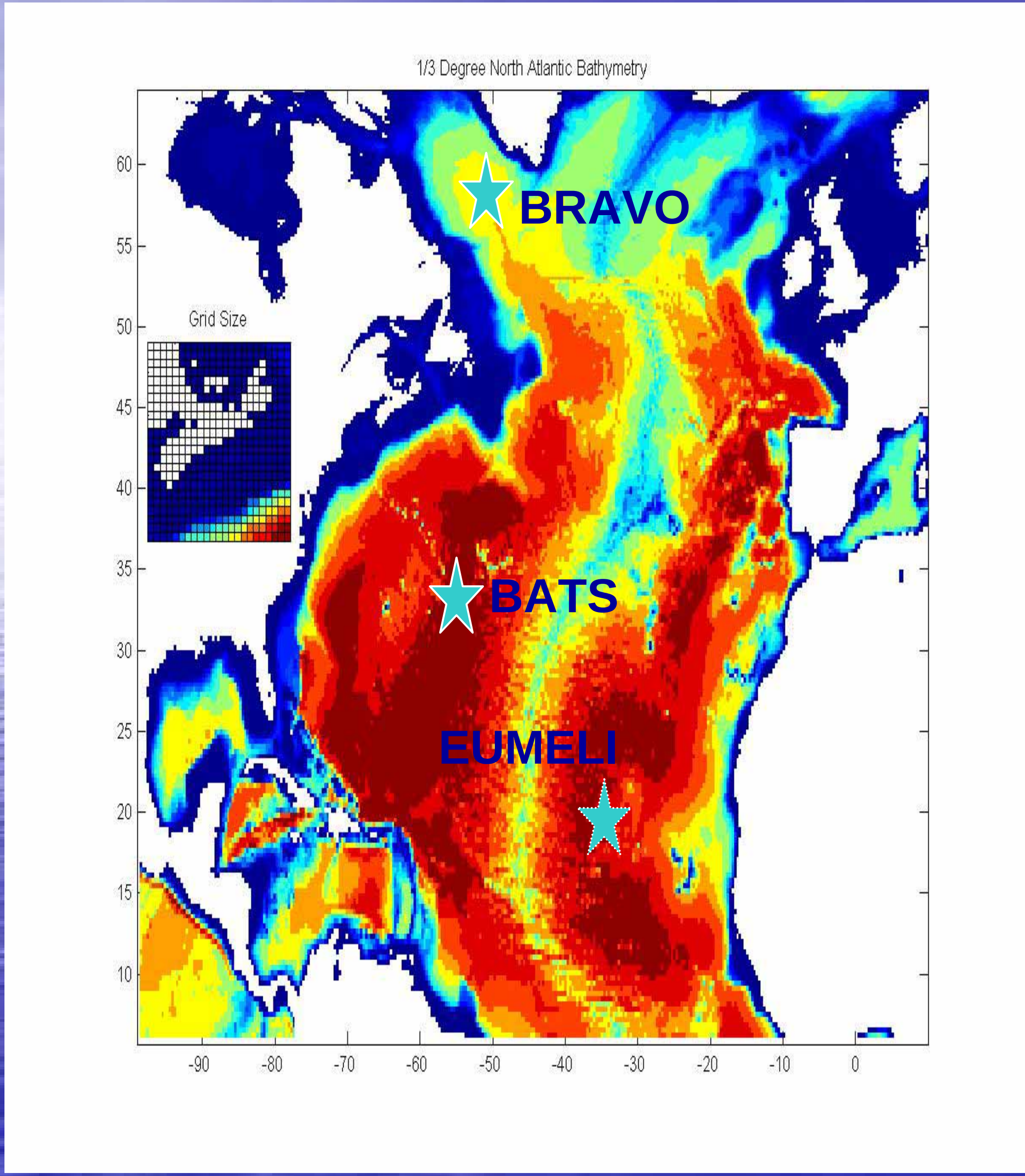
Food preference property dynamics

Ingestion/Rejection of potential prey

- Specific food preferences
- Species composition: specialists and omnivores
- Variable food preferences (active switching): flexible predators or species succession
- Food preferences optimize growth by adapting to prey-specific ingestion rates



Evaluating adaptive functions



POP model simulations provided 1D forcing at stations

Parameters of ecosystem model fitted to 'climatologies' of biogeochemical data for each station.

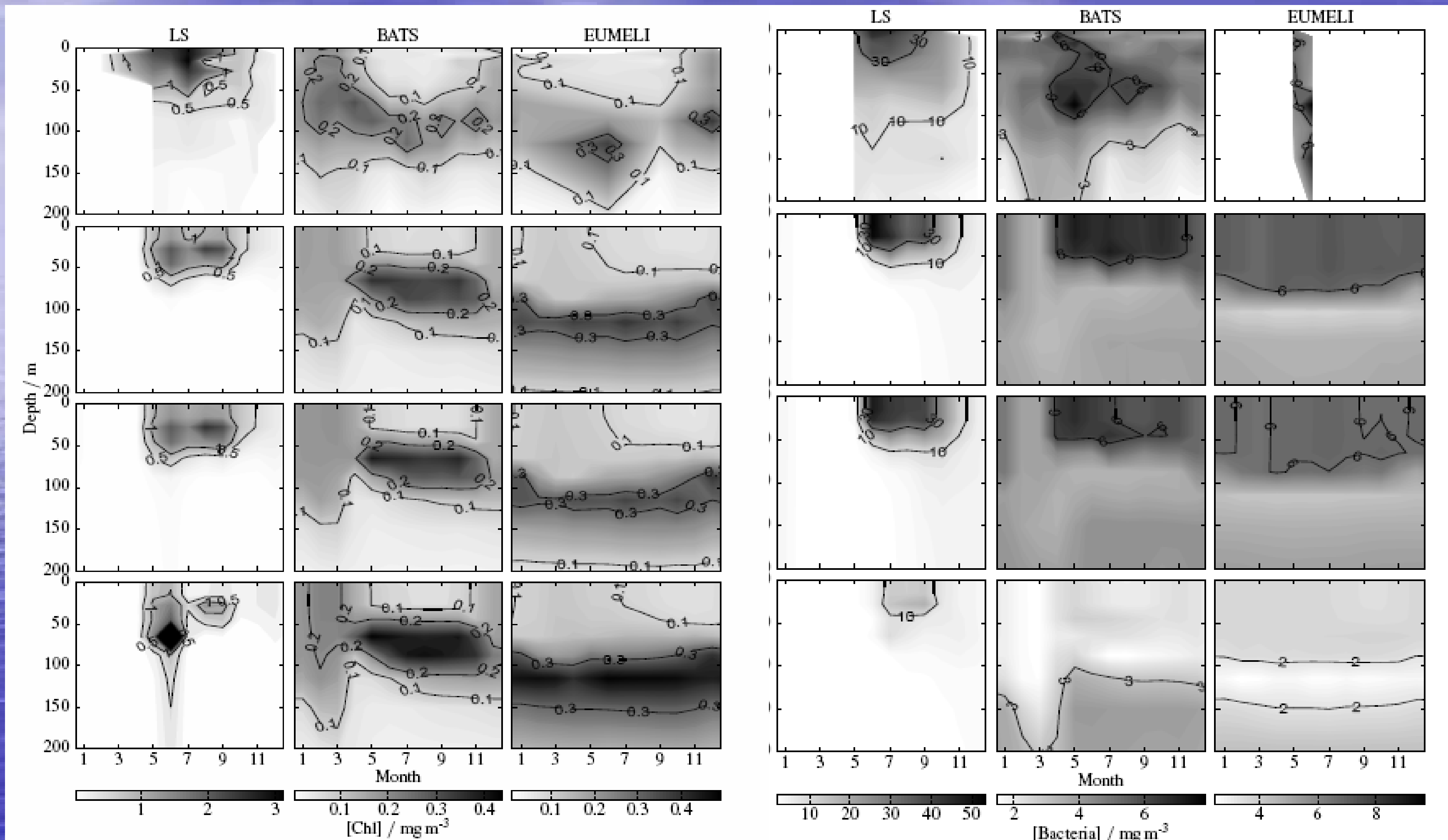
Attempted local fits (parameters adjusted separately for each station) and global fits (parameters fitted to all 3 stations) with and without adaptive functions.

Impact of model complexity depends on the location and the ecosystem component

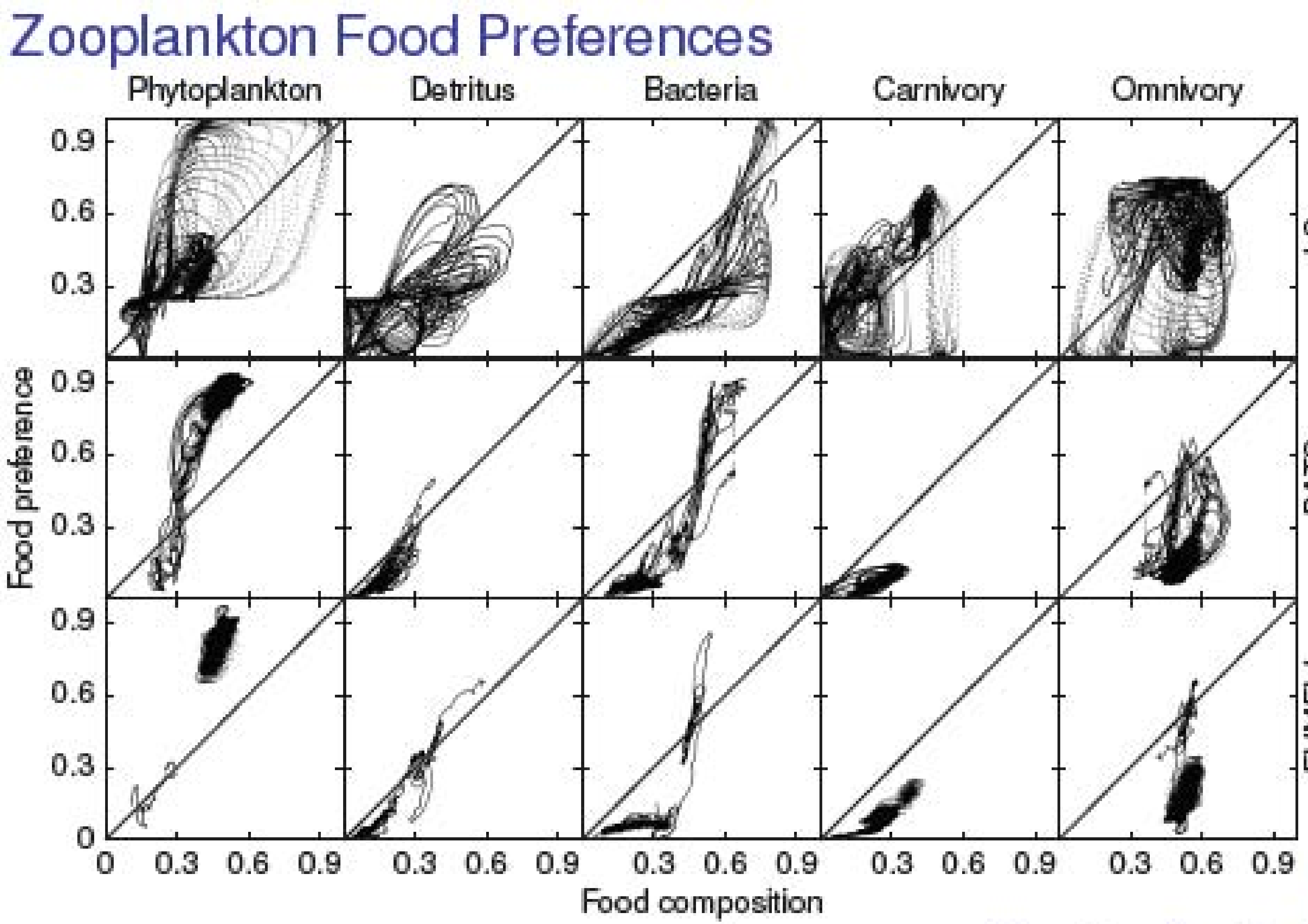
Data

Model

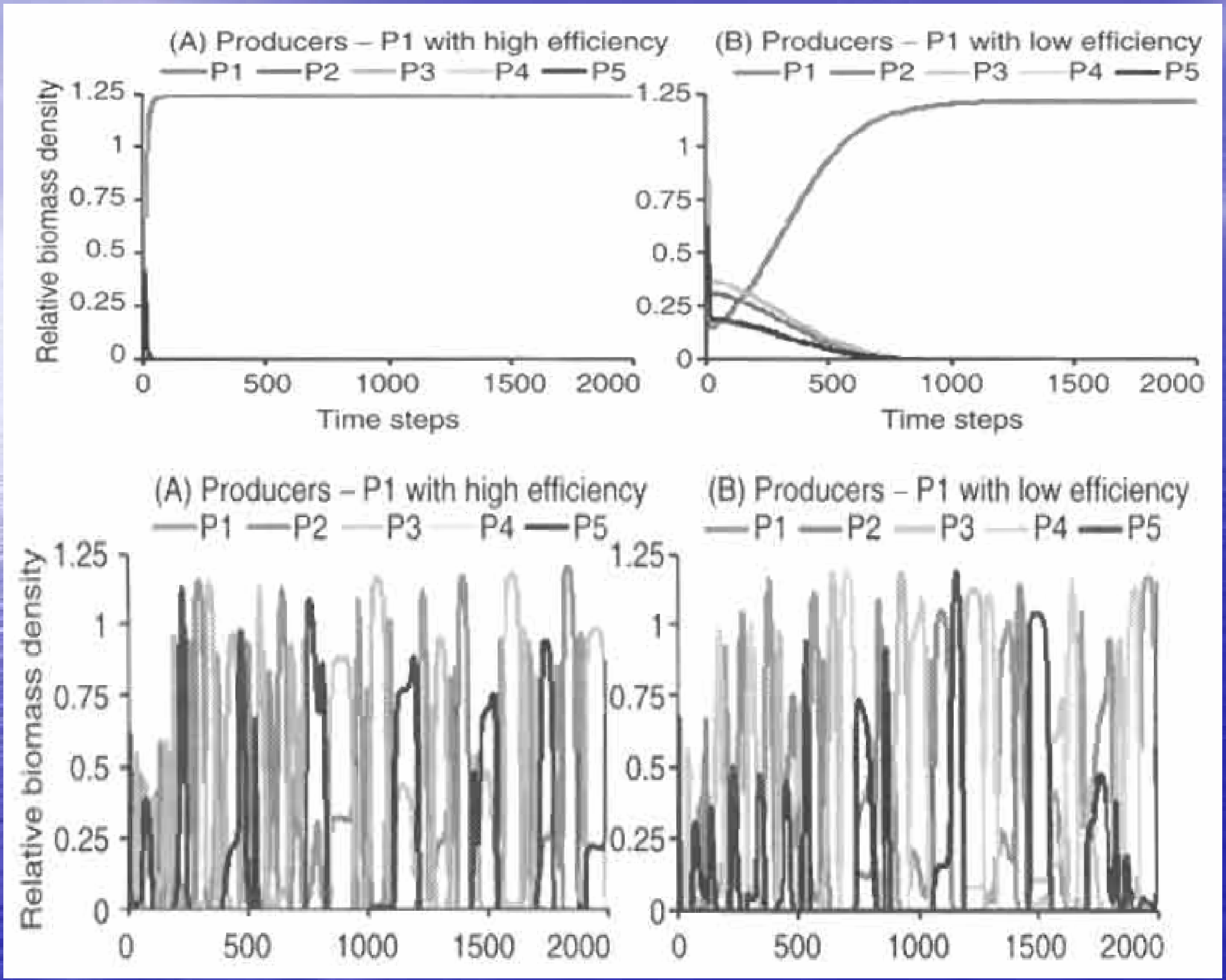
Simpler



“Emergent” functional responses for each consumer group



Linking competition among producers with trophic interactions

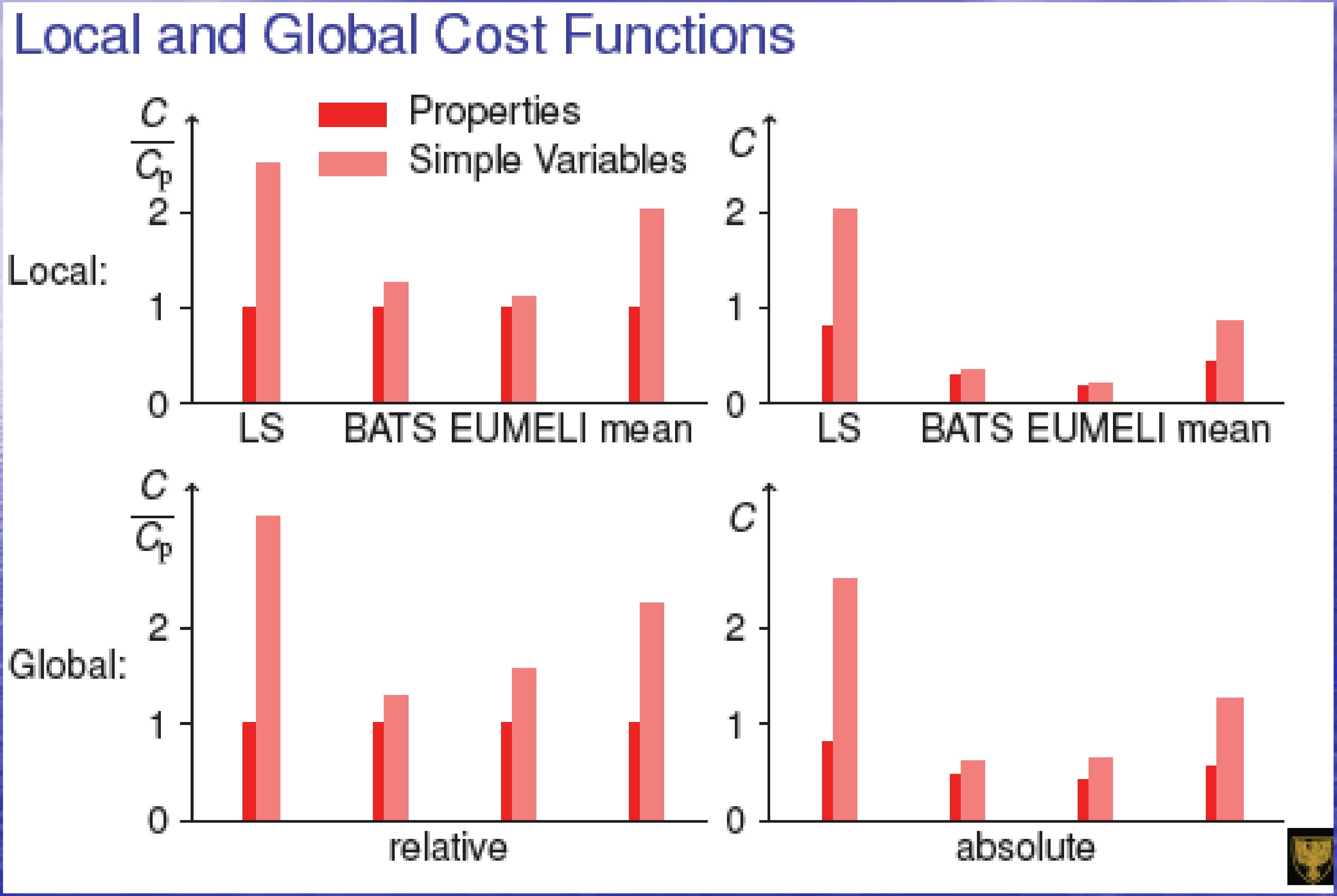


Without specialist grazers

With specialist grazers

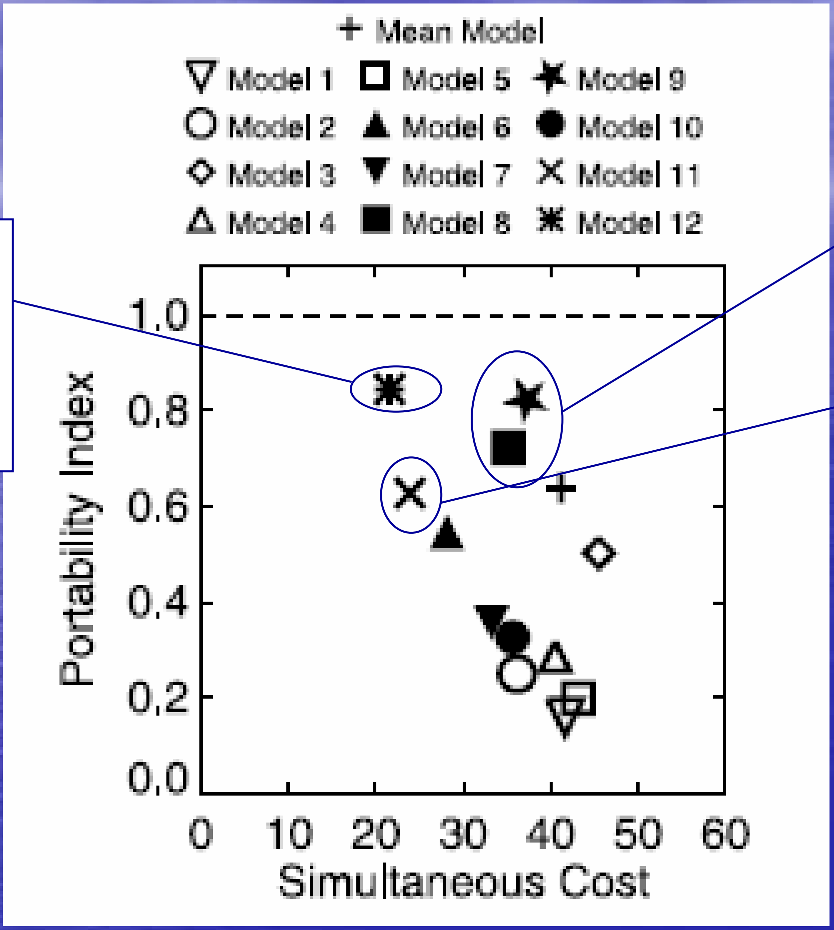
Brose, U., E.L. Berlow, and N.D. Martinez. 2005. in Dynamic Food Webs: Multispecies Assemblages, Ecosystem Development and Environmental Change.
P.C. de Ruiter, V. Wolters, and J.C. Moore, eds. Academic Press

Increasing complexity buys you more portability



Increasing resolution at the phytoplankton level buys you more portability

Size-dependent
Empirical grazing
‘closure’
Dunne et al. 2005



2-4 zooplankton groups

Single size adaptable
Zooplankton pool
Moore et al. 2004

… but increasing resolution at zooplankton level does not!

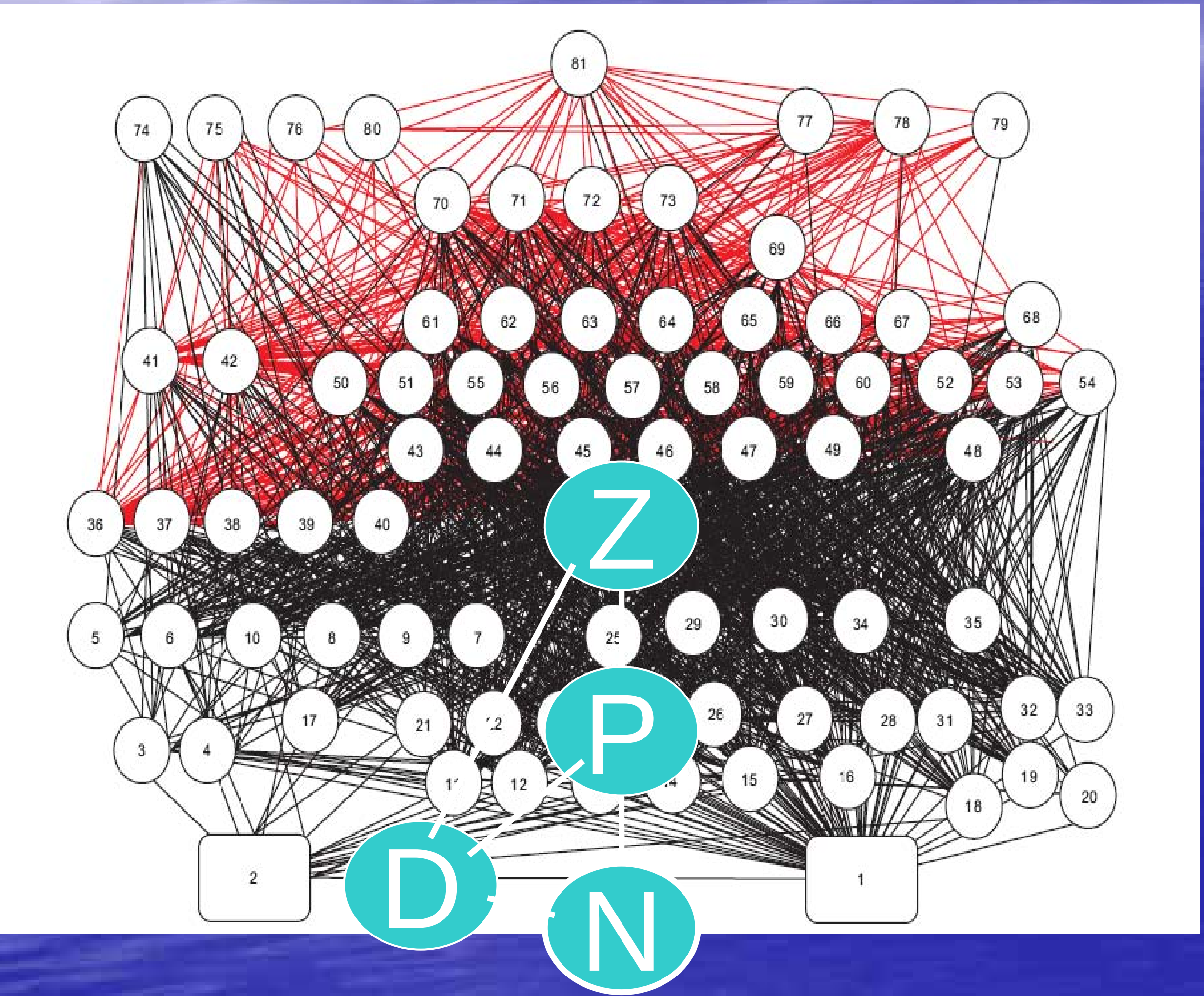
Friedrichs et al. 2007. J. Geophys. Res. 112, 10.1029/2006JC003852

What we might think about

More complexity but less detail

Hannah, Vezina and St. John. Complexity Theory, Foodweb Theory, and Marine Ecosystem Modelling: A view from 30,000 feet. JGR, submitted

What we do now: the view from food web theory



PZND models are modules extracted from the complete food web

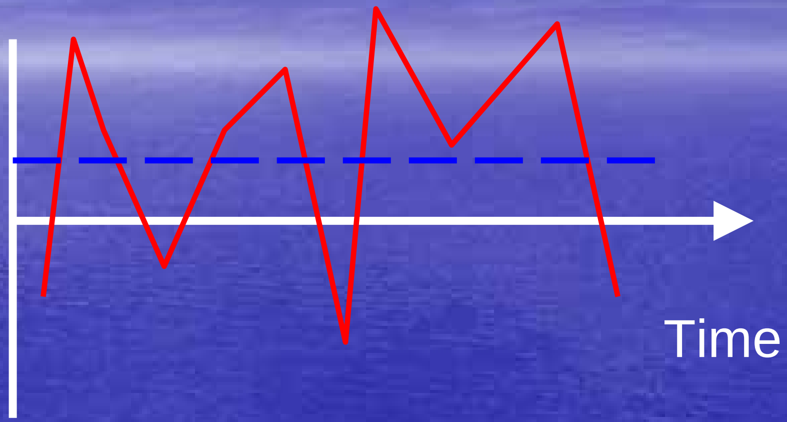
They are inherently unstable: cut-off the feedback loops

Compensate with functional response and closure terms

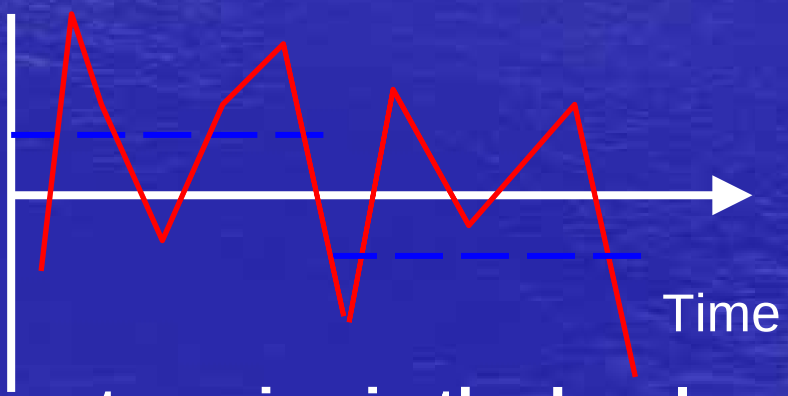
But are these fixes capture the dynamics in the whole system?

Prognostic – What will be the future state of the system (prognosis)?

2a) Weather prediction
Predict the wiggles about an observed or mean state.



2b) Climate prediction –
Predict the mean state and the statistics of the wiggles.



The difference between the categories is the level of feedback in the model.

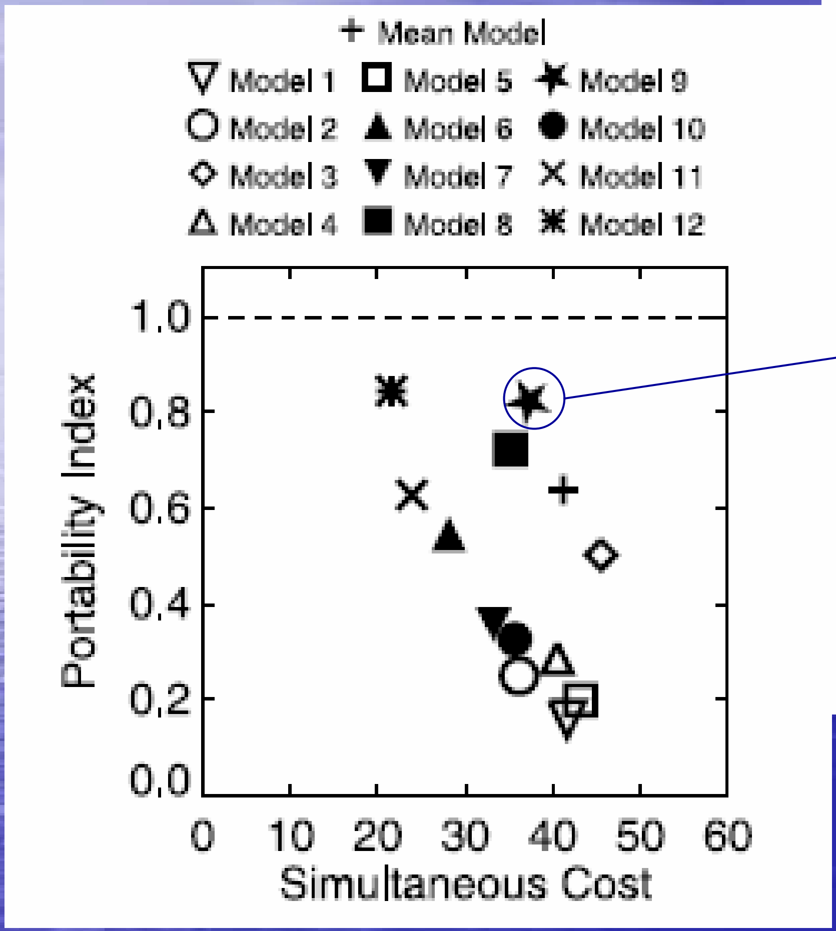
Assembly rules for ecosystems

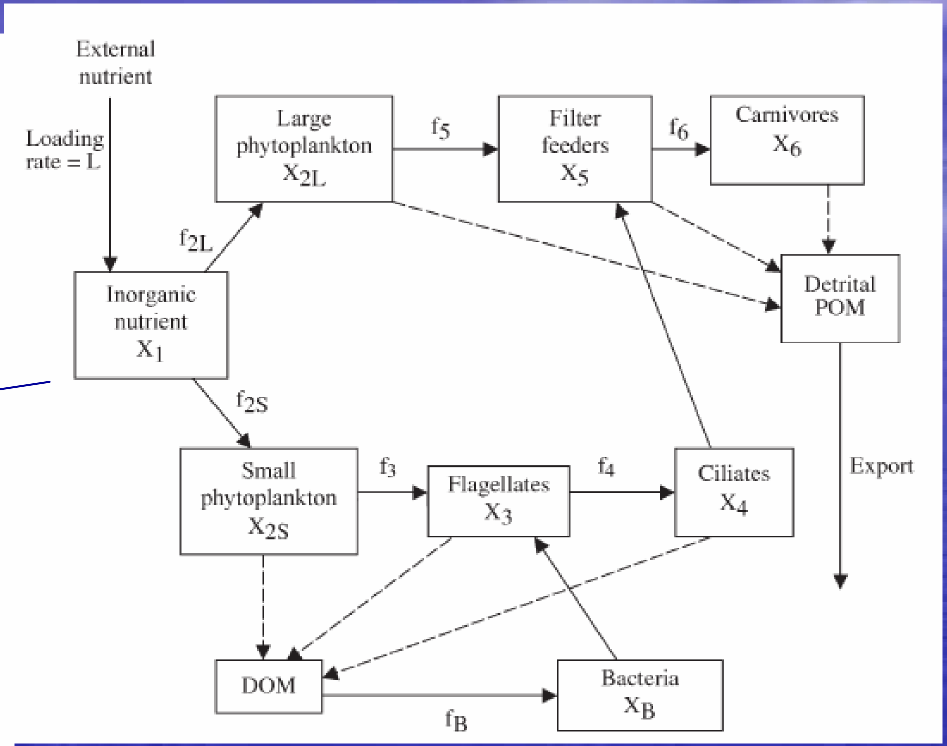
30+ years of food web ecology.

Search for the rules that govern stability and persistence in complex ecological networks.

Emphasis on interactions among ecological agents rather than on the details of the agents themselves

http://www.foodwebs.org



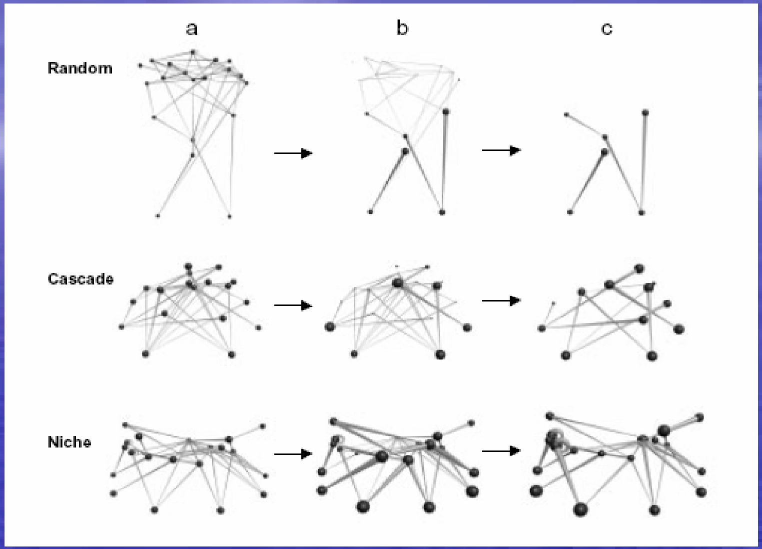


Laws et al. (2000) model
Complex structure
Simple rules
'Tuned' for max. stability

Friedrichs et al. 2007. J. Geophys. Res. 112, 10.1029/2006JC003852

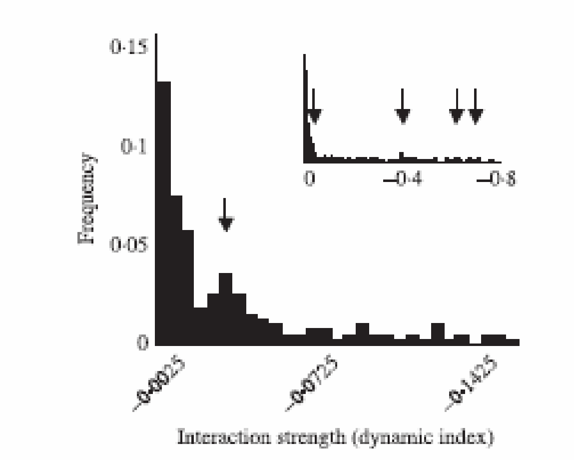
Assembly rules for ecosystems

Certain types of topology promote ecosystem stability more than others

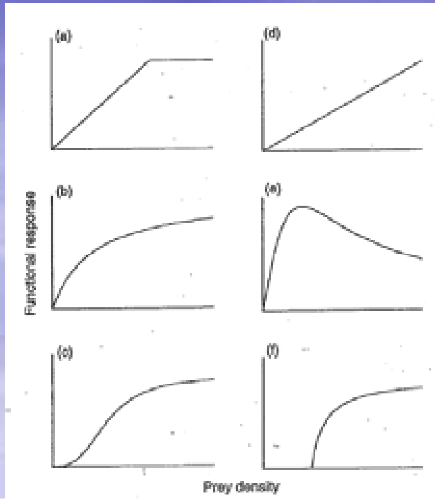


Martinez et al. 2006.

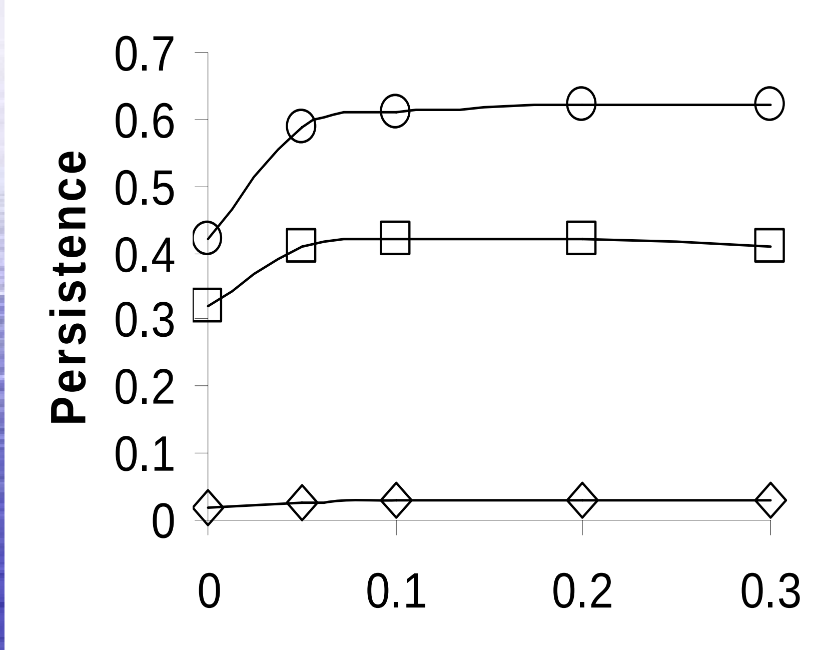
Most interactions in ecosystems are weak, but are crucial to maintaining stable networks

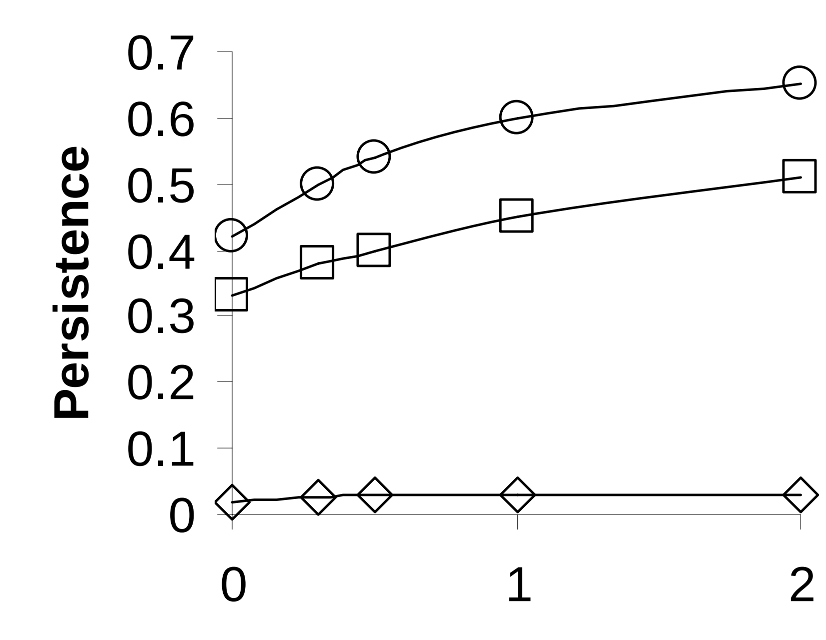


Emmerson and Raffaelli. 2004. J. Anim. Ecol. 73: 399-409



Relative impacts of structure and functional response in complex food web models (ca. 30 species)





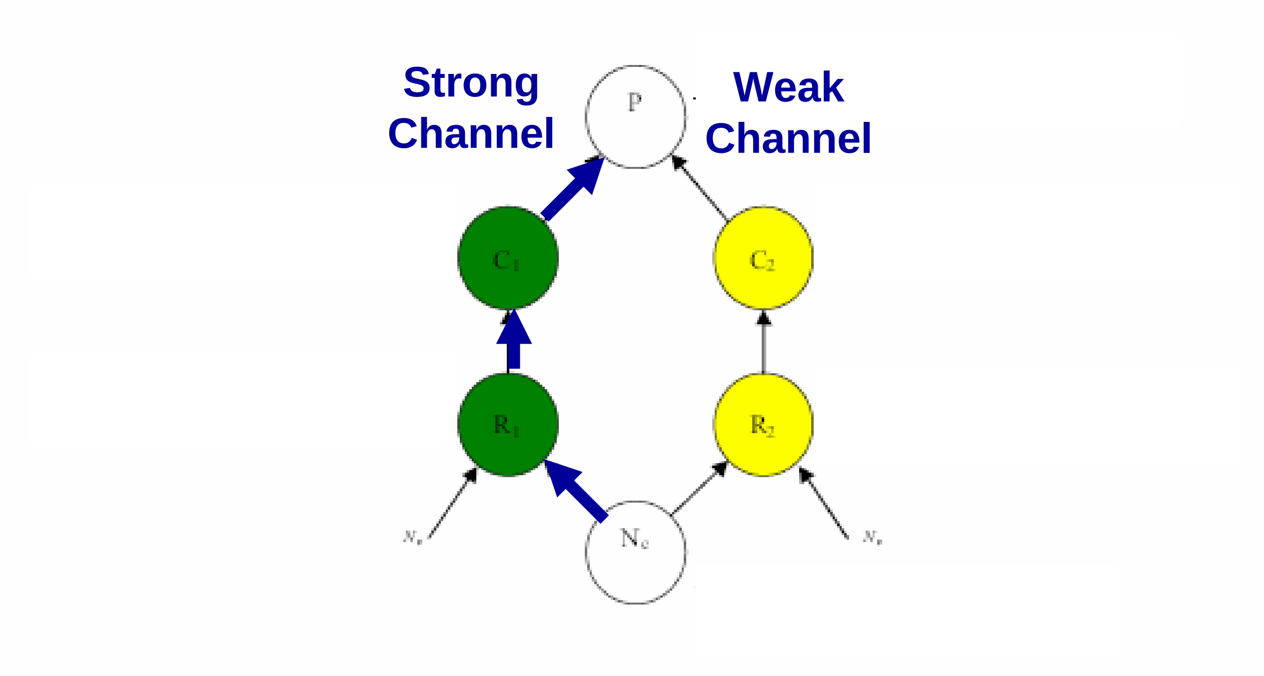
Type II —— q ——→ Type III   Type II —— c ——→ P.I.

q=0   q=1   c=0

Martinez, N.D., R.J. Williams, and J.A. Dunne. 2006. in Ecological Networks: Linking Structure to Dynamics in Food Webs. M. Pascual and J.A. Dunne, eds. Oxford University Press.

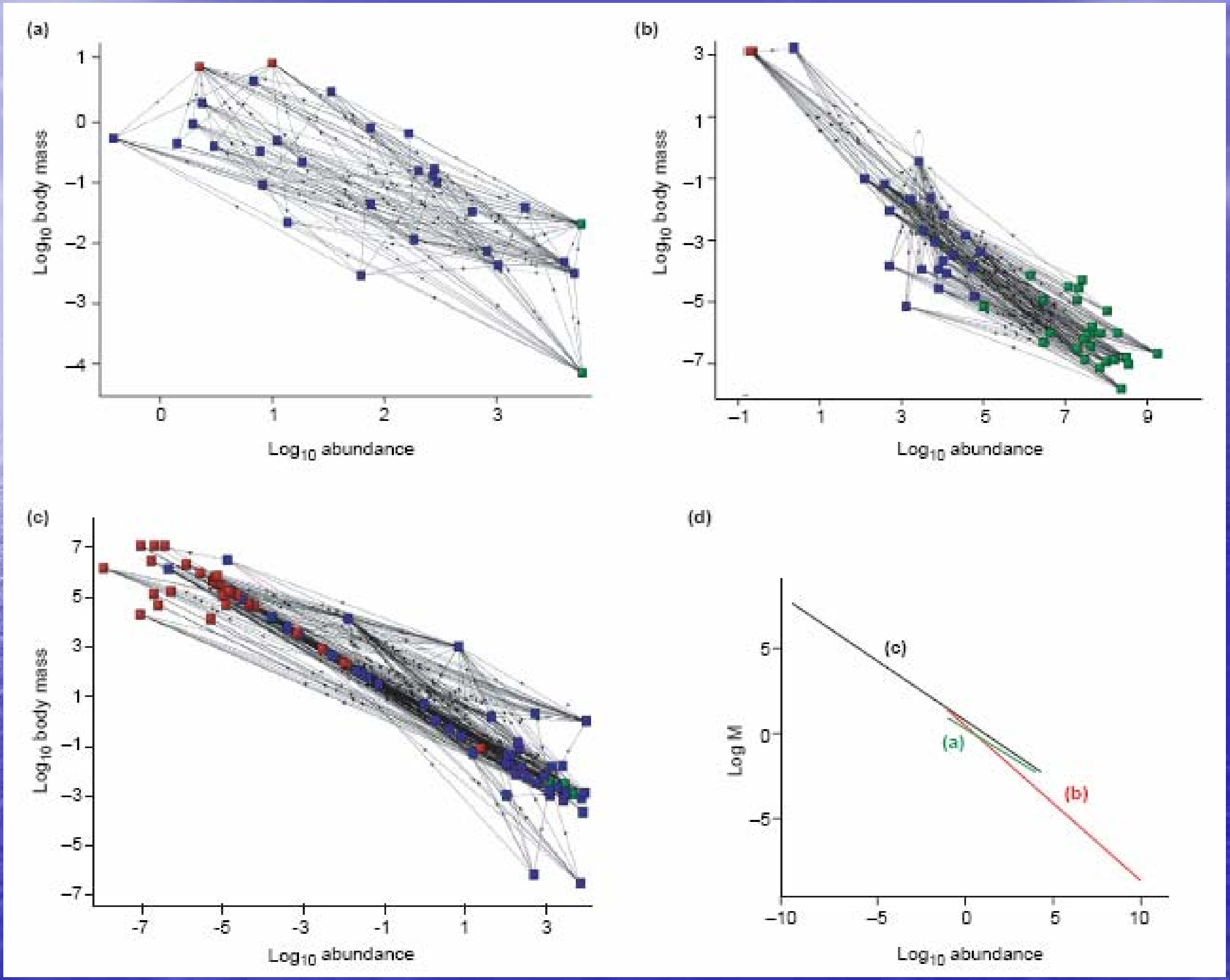
Compartmentalized food webs

Food web stability is promoted by coupling weak and strong interactions through a 'top predator'



Rooney et al. 2006. Nature 442: 265-269

Body size is a powerful constraint



Woodward et al. 2005. Trends Ecol. Evol. 20, 402

Conclusion

- Two views of intermediate complexity ecosystem models
  - Multiple groups at low trophic levels coupled through a single, flexible top “predator”
    - Sensible way to build a module
    - Agrees with ecological theory
  - Ecological networks
    - Way out of modules
    - Keep as many feedbacks as possible
    - Willingness to sacrifice process detail
    - Use high level rules about stability, persistence, or other global property of network
    - Metabolic ecology (allometry, temperature effects) helps with parameterizations
- Both give more room to a phenomenological “top down” approach to model design

END OF TALK

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Effect of complexity on marine ecosystem models

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- Explicit physiological detail of every trophic group is not always necessary.
- Simplifying a model web (which represents the food web of an entire system aggregated to the level of functional groups) to less than 20 to 25% of its original size is rarely beneficial.

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Mortality and predation in ecosystem models: is it important how these are expressed?

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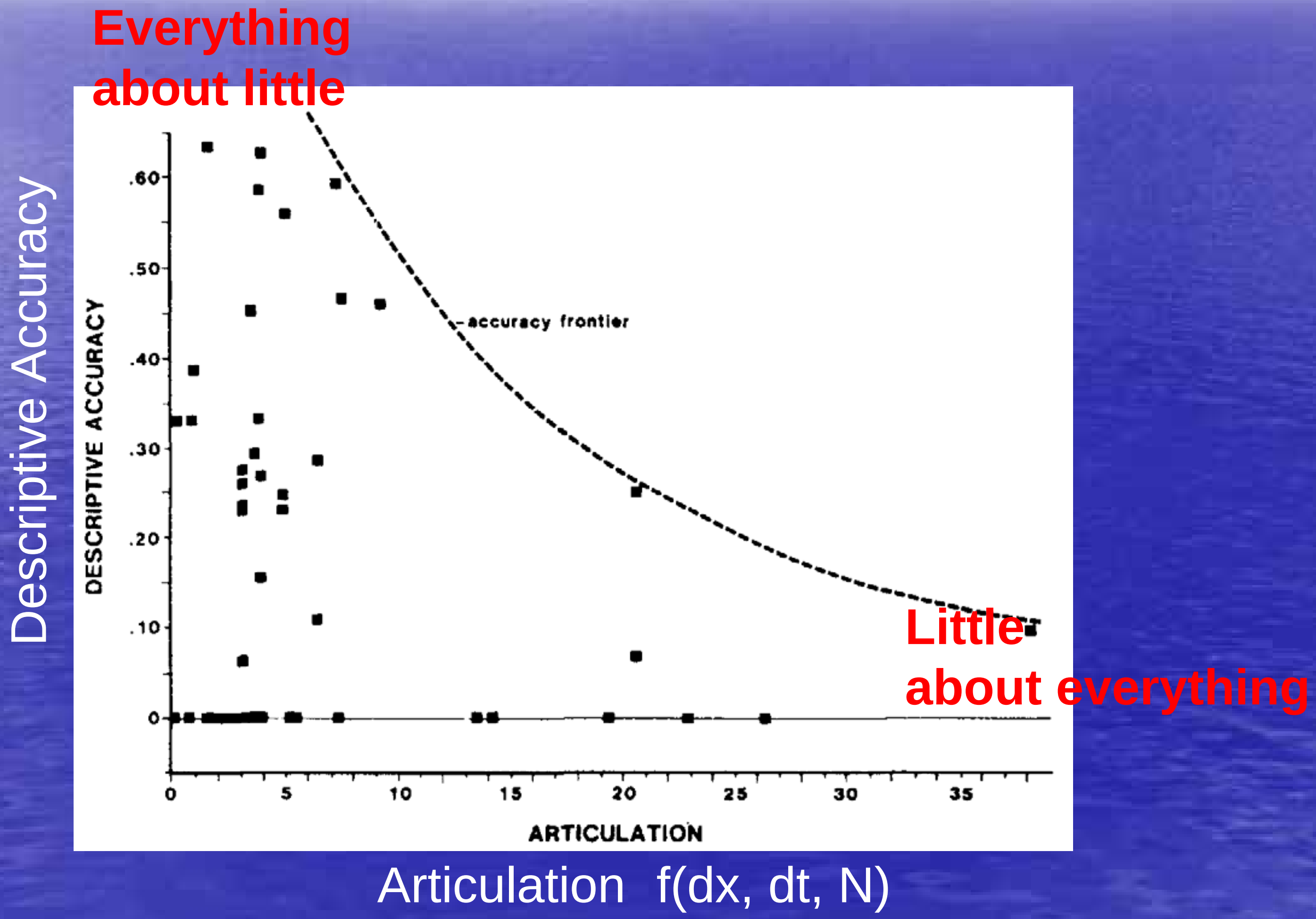
… the most dynamic and sophisticated functional responses describing grazing require more parameters and validation than the simpler Holling disk equation, but usually still lead to the same general conclusions about the system state and the effects of changes in forcing.

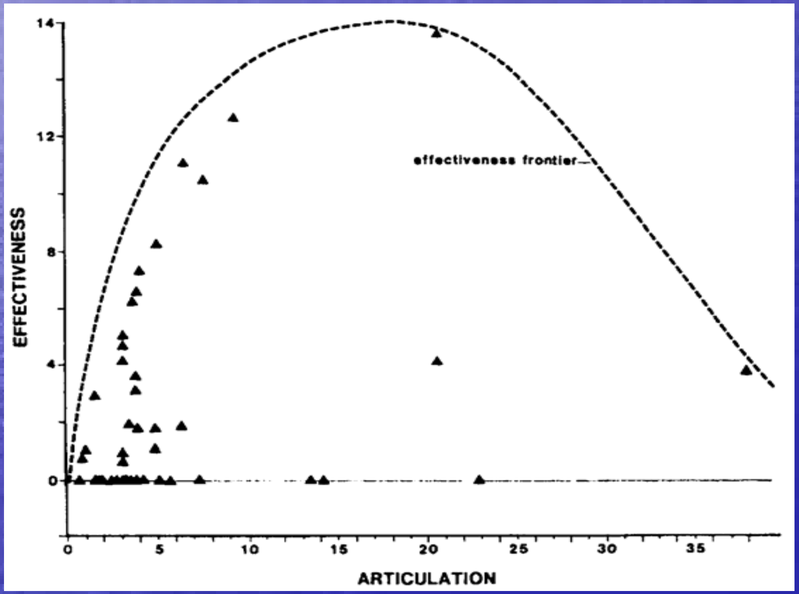
Costanza and Sklar 1985



Intermediate complexity

Effectiveness frontier

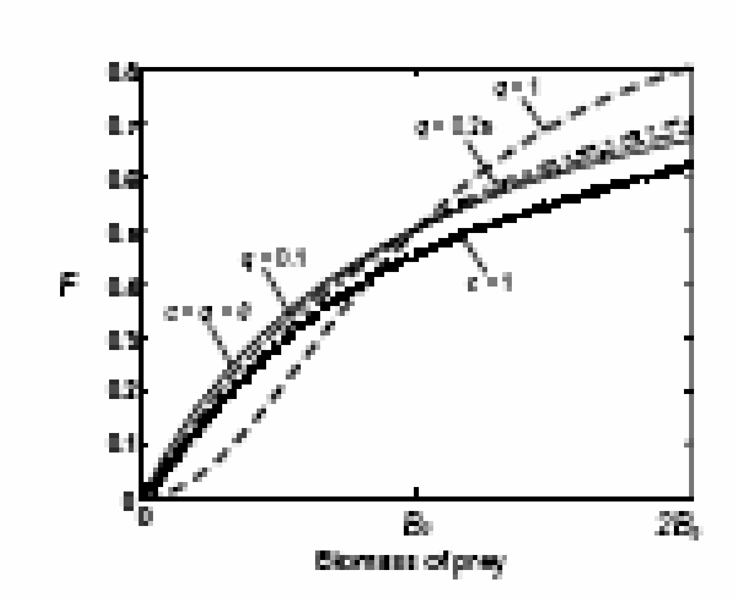
Effectiveness



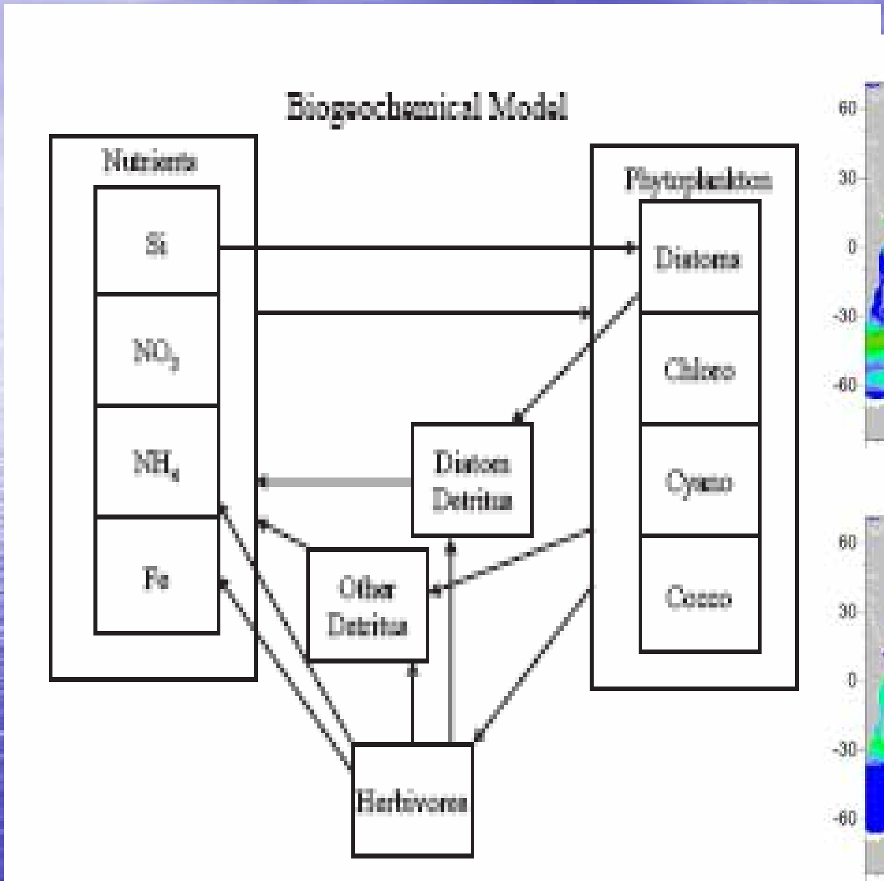
Effectiveness:
A function of descriptive accuracy and articulation (complexity)

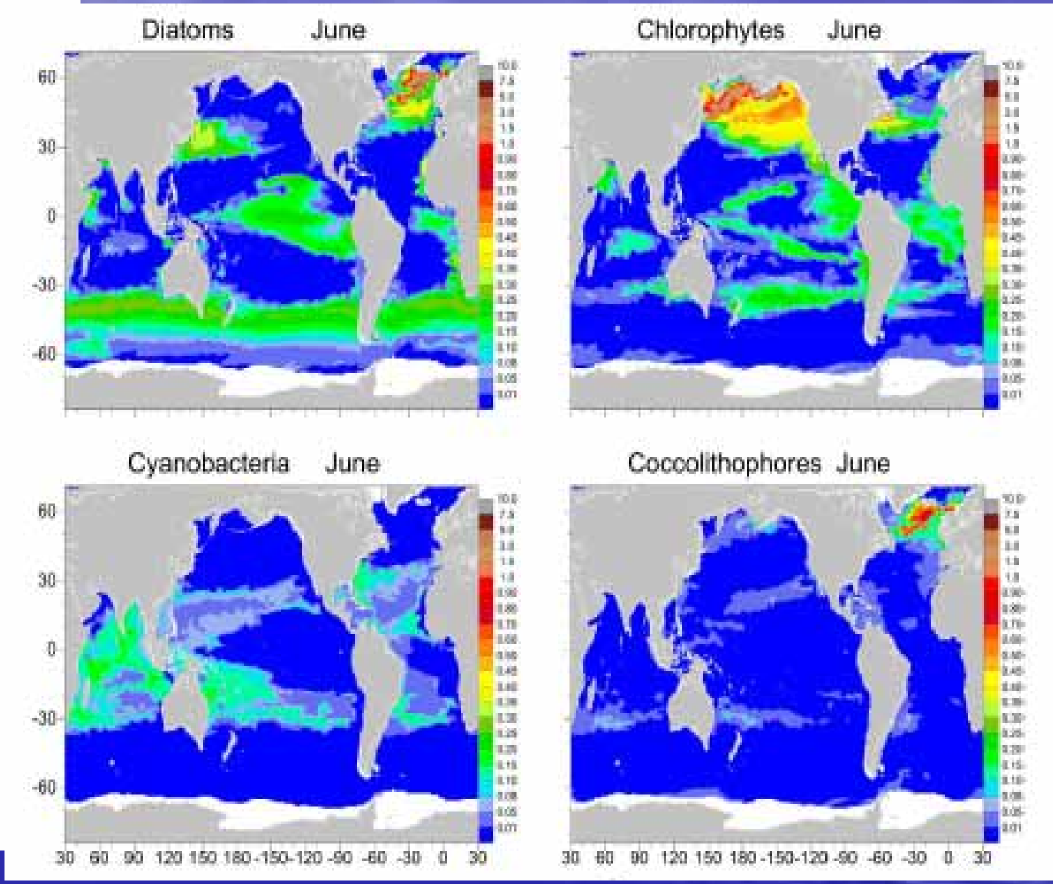
Articulation f(dx, dt, N)

Measure of complexity

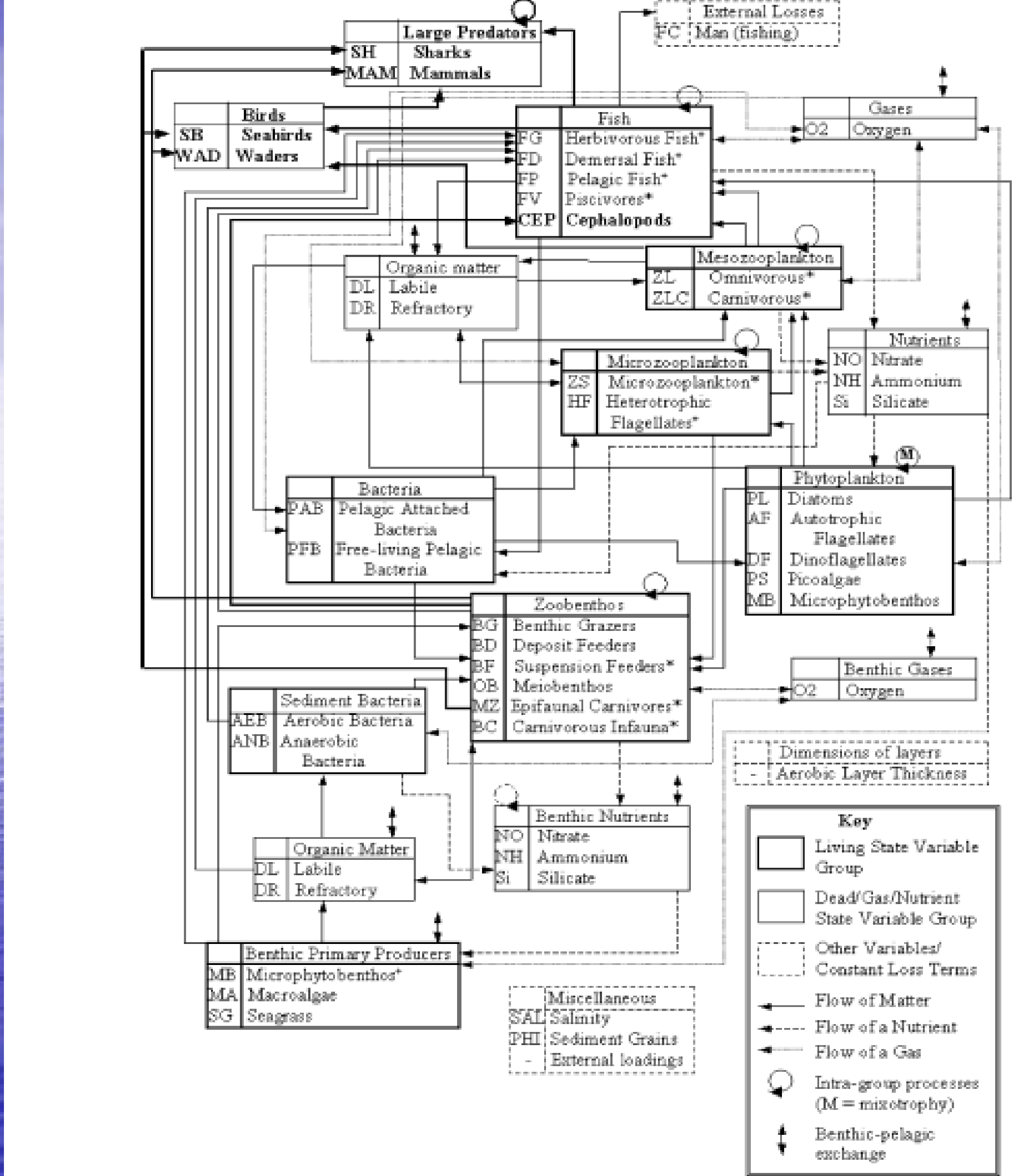


F
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
Biomass of prey
q = 1
q = 0.1
c = q = 0
c = 1

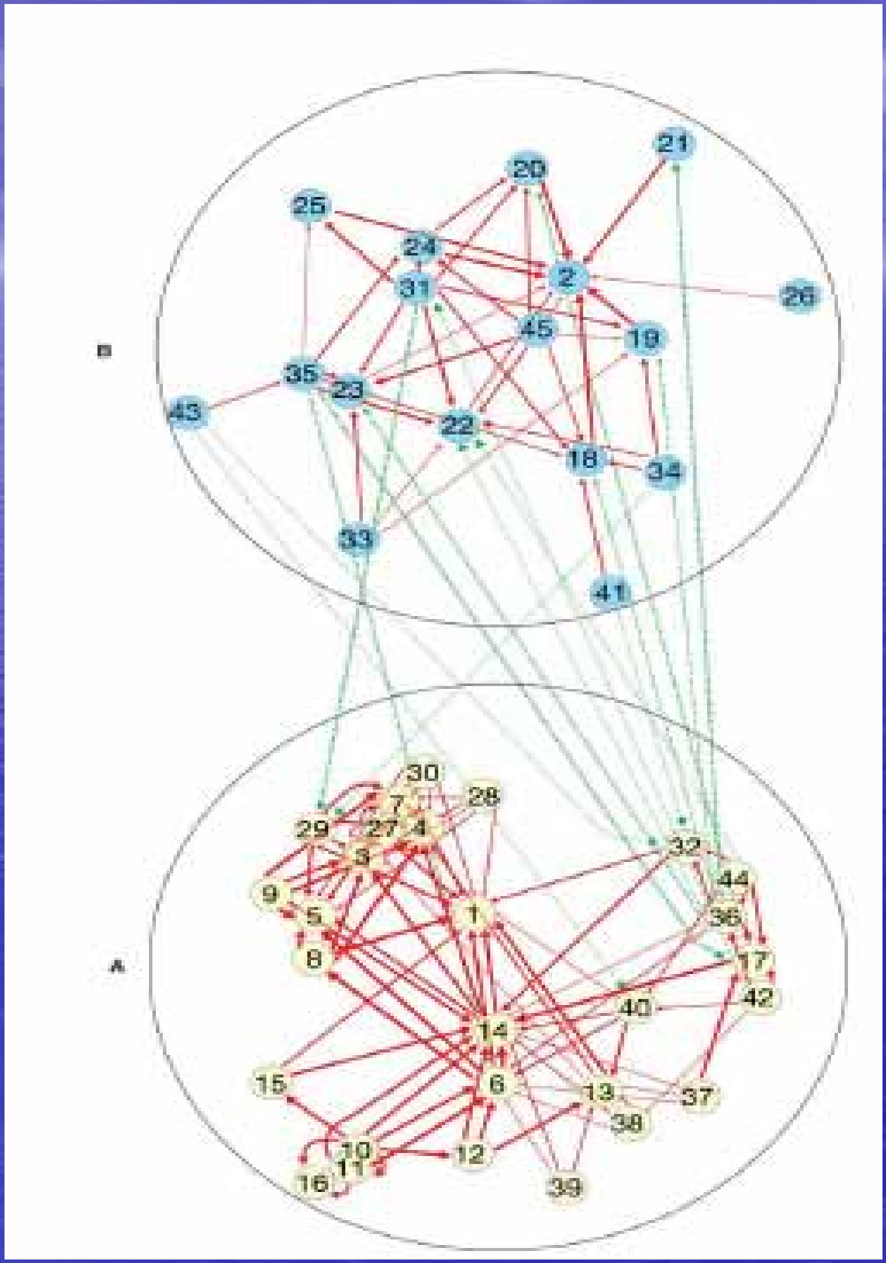




Gregg et al. 2003. Deep-Sea Res. 50, 3143



External Losses
FC Man (fishing)
Large Predators
SH Sharks
MAM Mammals
Birds
SB Seabirds
WAD Waders
Fish
FG Herbivorous Fish*
FD Demersal Fish*
FP Pelagic Fish*
FV Piscivores*
CEP Cephalopods
Gases
O2 Oxygen
Organic matter
DL Labile
DR Refractory
Mesozooplankton
ZL Omnivorous*
ZLC Carnivorous*
Microzooplankton
ZS Microzooplankton*
HF Heterotrophic Flagellates*
Nutrients
NO Nitrate
NH Ammonium
Si Silicate
Bacteria
PAB Pelagic Attached Bacteria
PFB Free-living Pelagic Bacteria
Phytoplankton
PL Diatoms
AF Autotrophic Flagellates
DF Dinoflagellates
PS Picoalgae
MB Microphytobenthos
Zoobenthos
BG Benthic Grazers
BD Deposit Feeders
BF Suspension Feeders*
OB Meiobenthos
MZ Epifaunal Carnivores*
BC Carnivorous Infauna*
Benthic Gases
O2 Oxygen
Sediment Bacteria
AEB Aerobic Bacteria
ANB Anaerobic Bacteria
Dimensions of layers
- Aerobic Layer Thickness
Benthic Nutrients
NO Nitrate
NH Ammonium
Si Silicate
Organic Matter
DL Labile
DR Refractory
Benthic Primary Producers
MB Microphytobenthos*
MA Macroalgae
SG Seagrass
Miscellaneous
SAL Salinity
PHI Sediment Grains
- External loadings
Key
Living State Variable Group
Dead/Gas/Nutrient State Variable Group
Other Variables/ Constant Loss Terms
Flow of Matter
Flow of a Nutrient
Flow of a Gas
Intra-group processes (M = mixotrophy)
Benthic-pelagic exchange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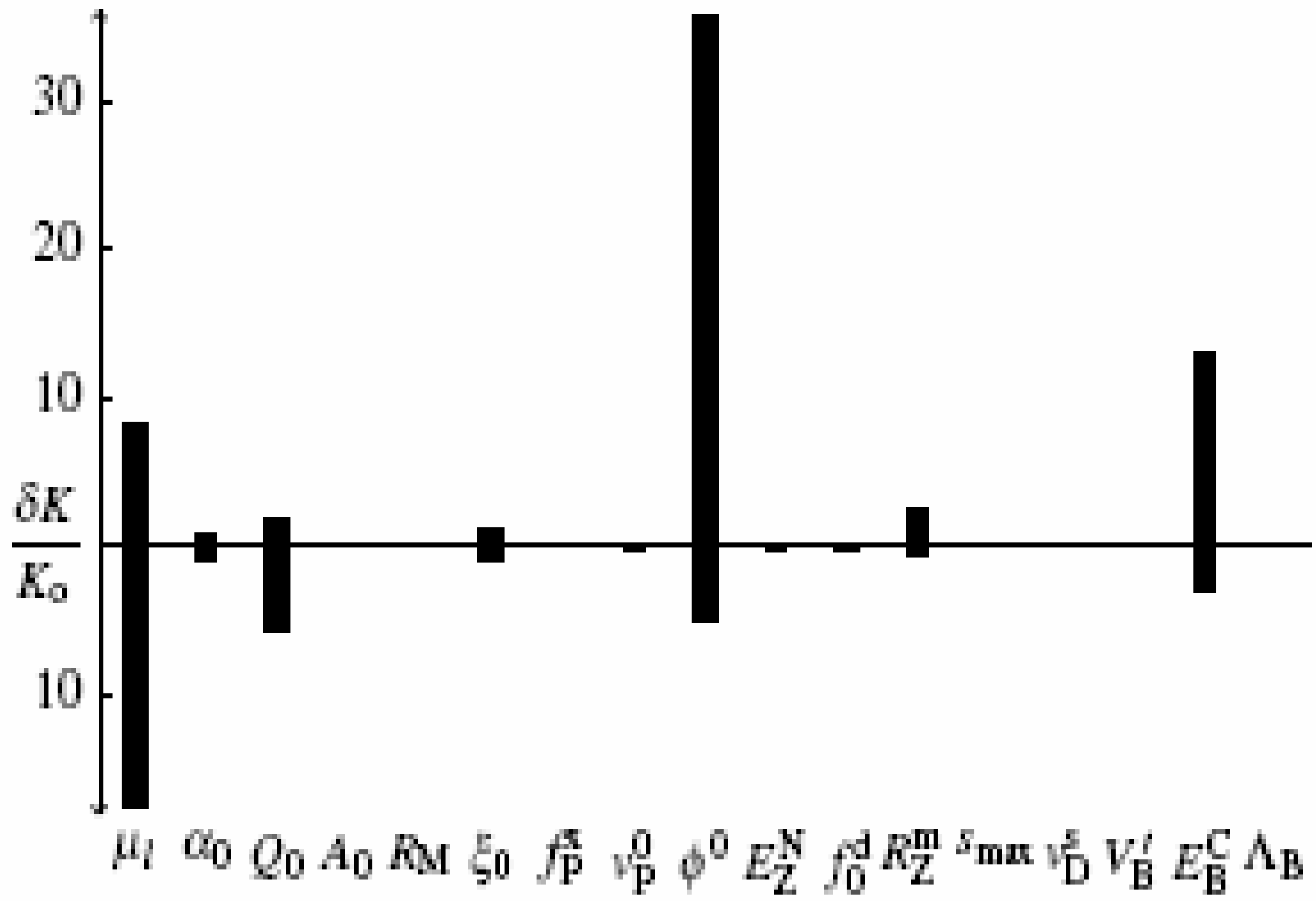
… and less sensitivity to model parameters



Scheffer and Carpenter 2003

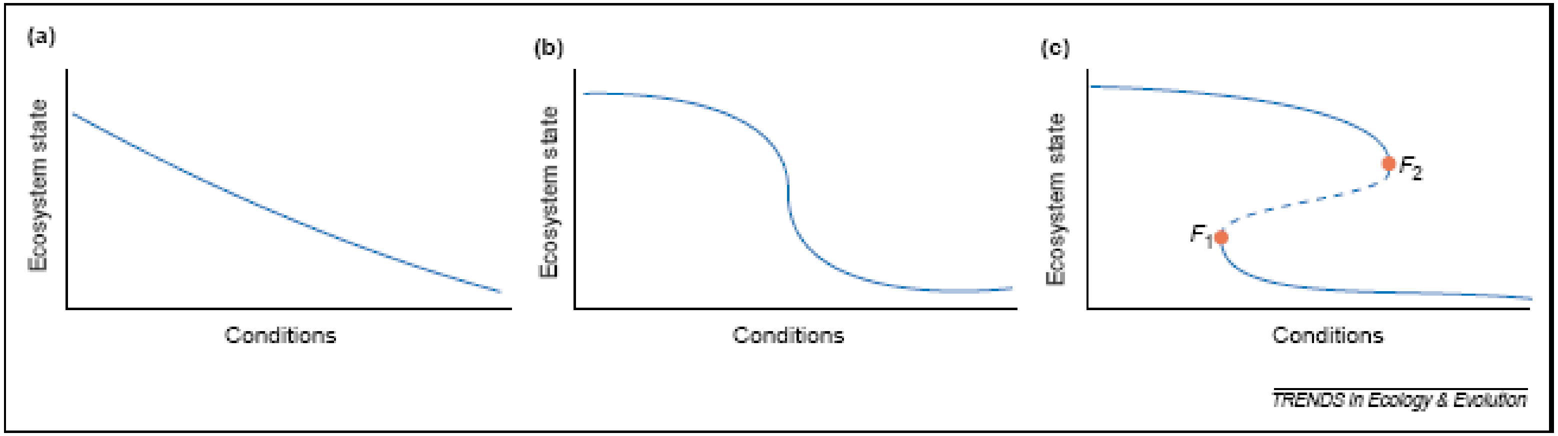
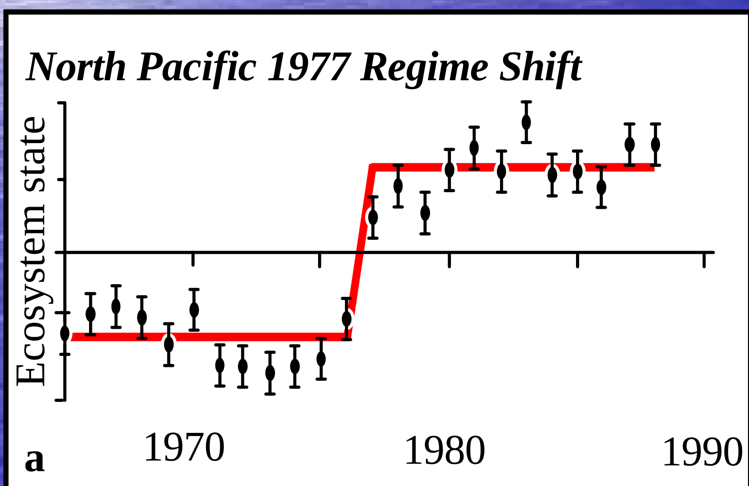
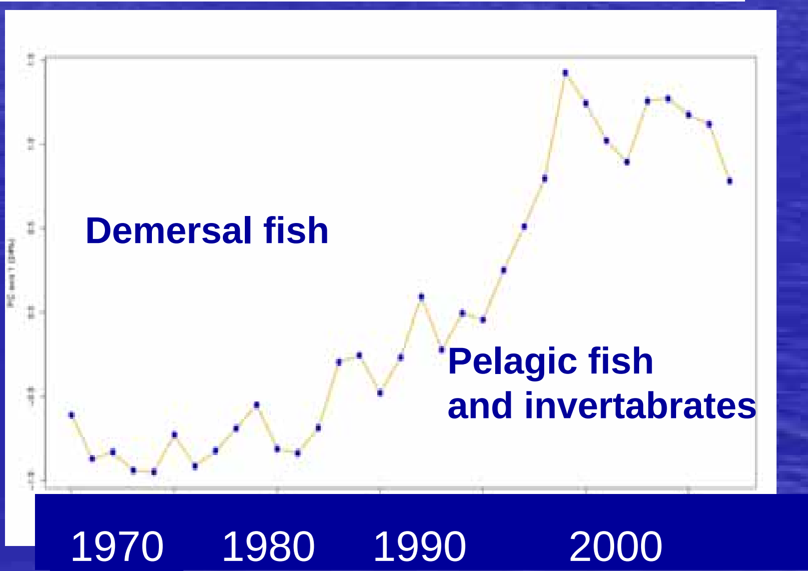


Figure 2. Different ways in which an ecosystem can respond to change in conditions. Although dynamic systems can respond smoothly to change in external conditions (a), they can sometimes change profoundly when conditions approach a critical level (b) or have more than one stable state over a range of conditions (hysteresis) (c). Although some systems tend to respond in a more non-linear way than do others, the response is not a fixed property of a system. For instance, depending on the depth of the lake, its turbidity can respond in either way to increased nutrient loading. Modified with permission from [1].

http://tree.trends.com





Hare and Manthua 1999

Frank et al. 2005