

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

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and Mike St.John

# The Ecosystem Modeller's Universe

## Empiricists

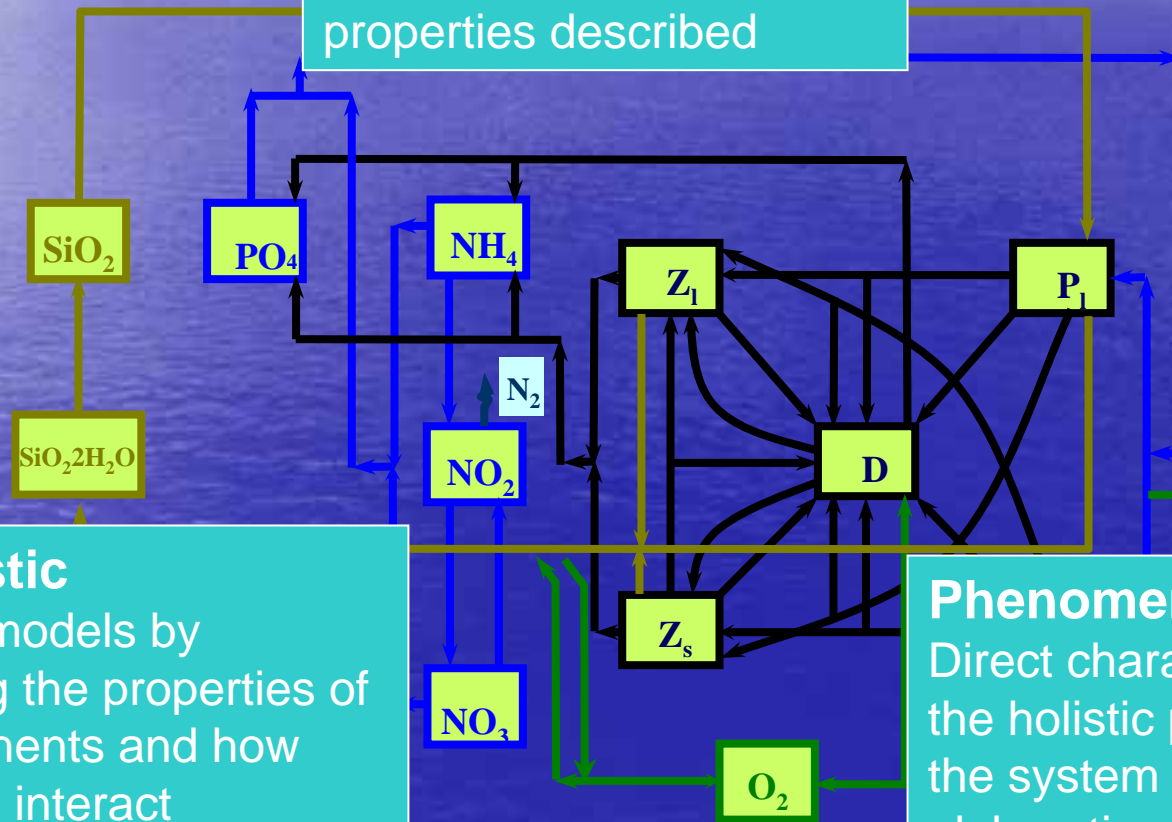
Data guide the way the processes are characterized and properties described

## 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



# 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

# 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

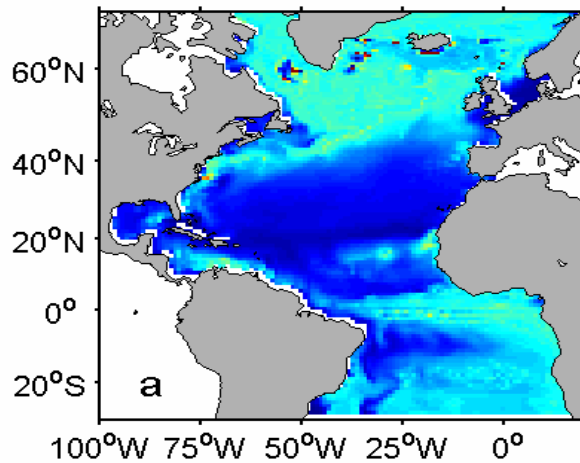
Top down approach to add complexity in an organized, systematic manner

- 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

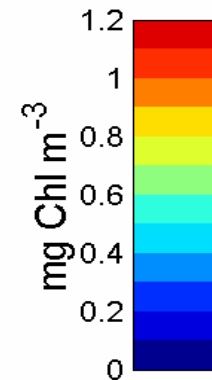
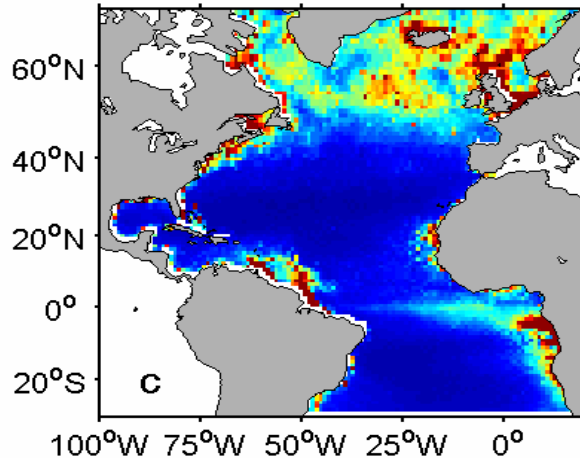
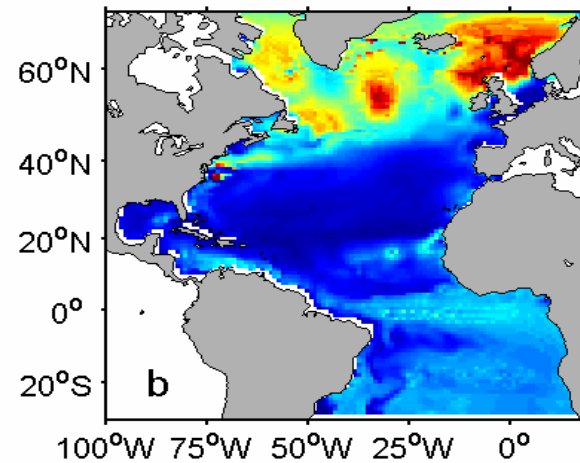
# What we can do now

Flexible/adaptive grazing formulations

Constant parameters

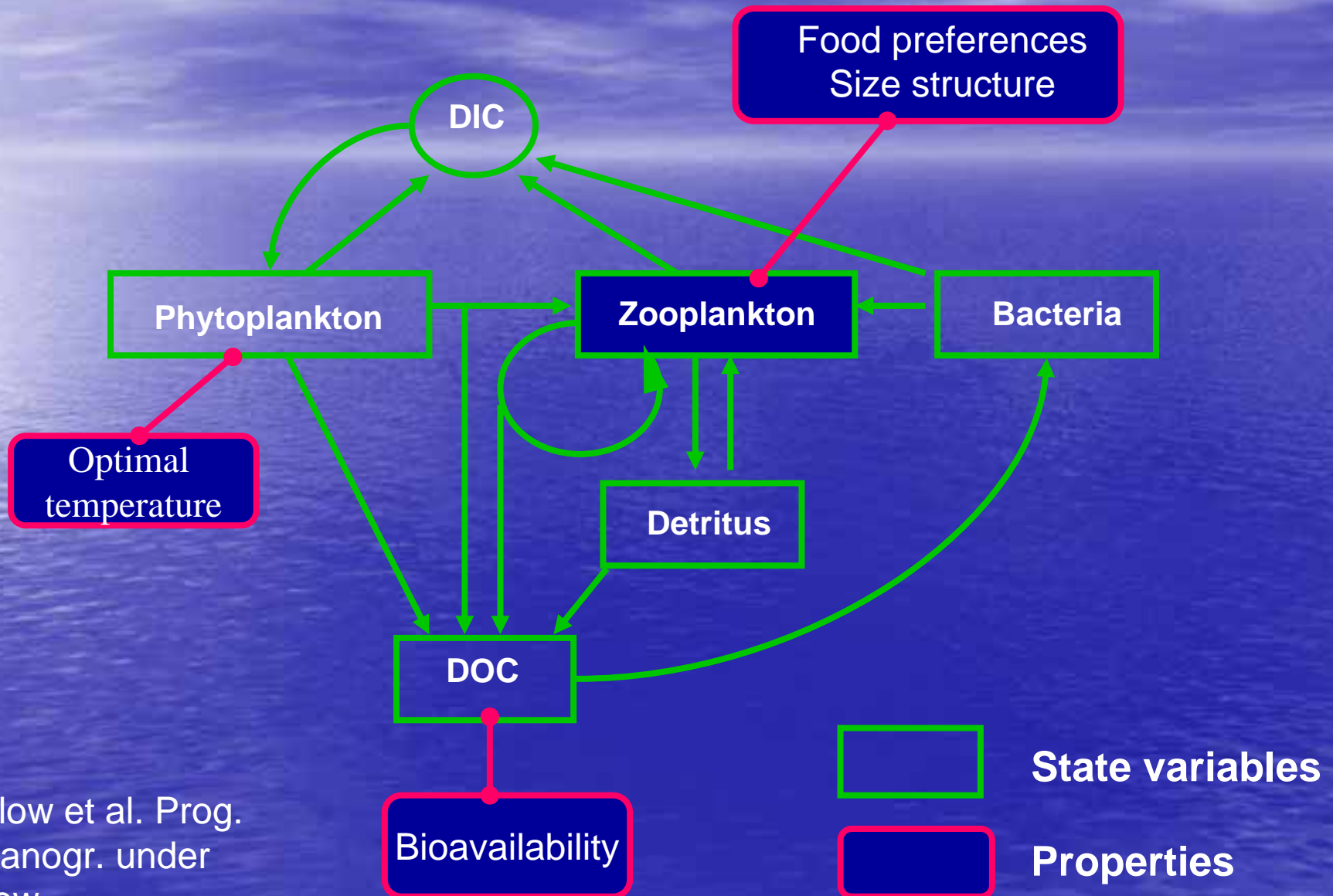


Parameters vary by BG provinces



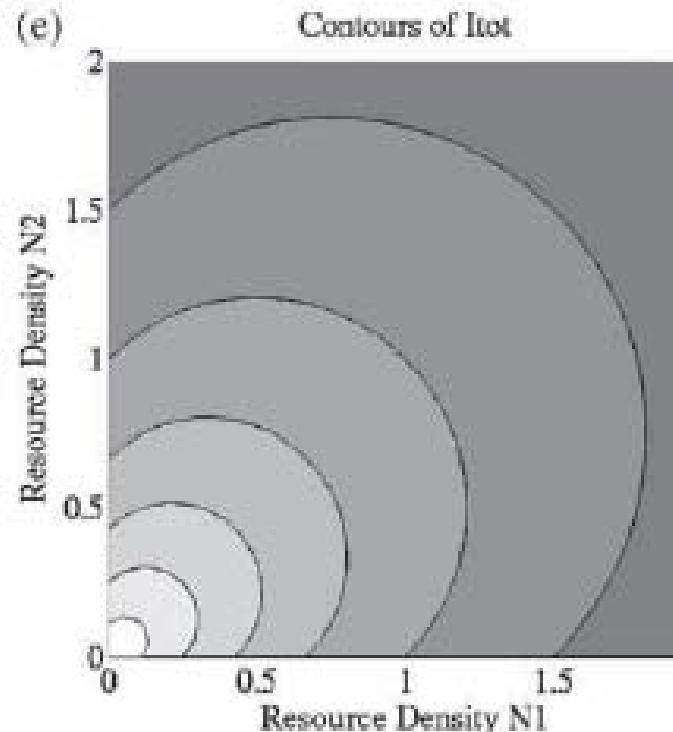
SeaWiFS climatology (97-03)

# Ecosystem model with adaptive dynamic properties



# Zooplankton: Food Preferences and Omnivory

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



(Gentleman et al. 2003)

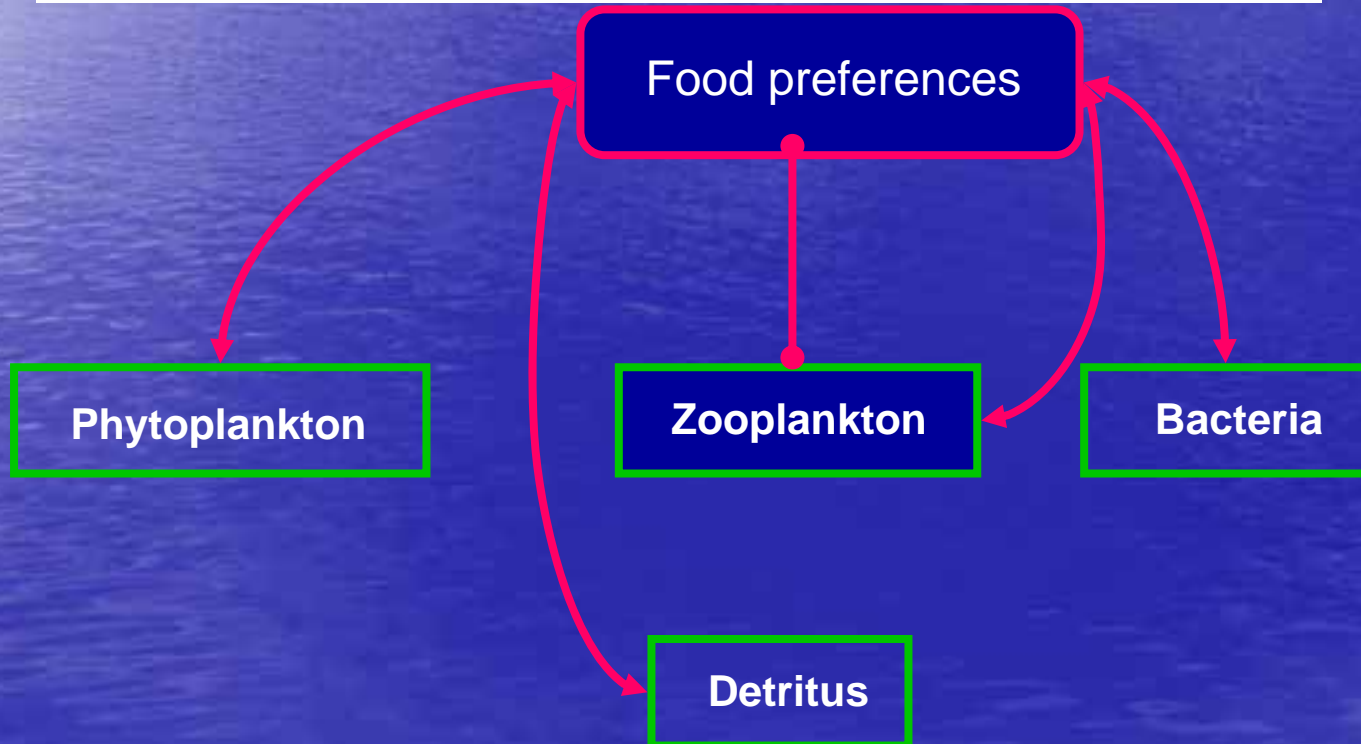
- implicit assumption: no omnivory
  - ▶ contradiction to assumption of optimal growth
- Omnivory:
  - ▶ no rejection of most abundant food
  - ▶ additive filtering rates



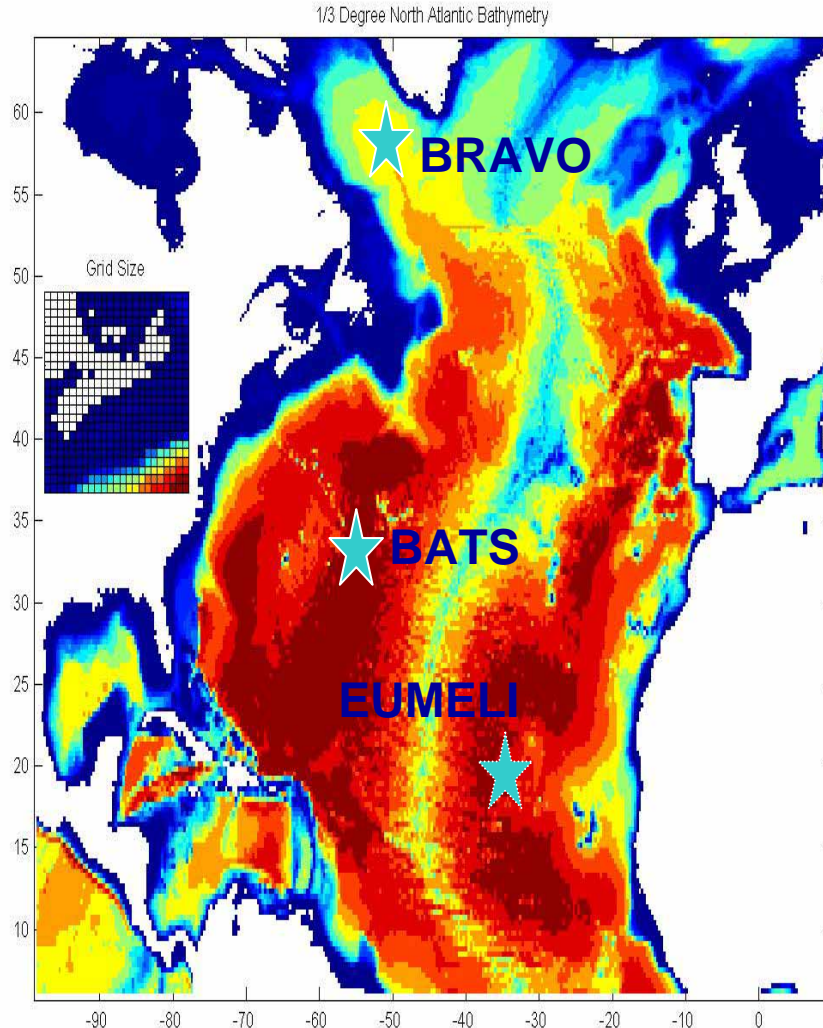
# Food preference property dynamics

## 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.

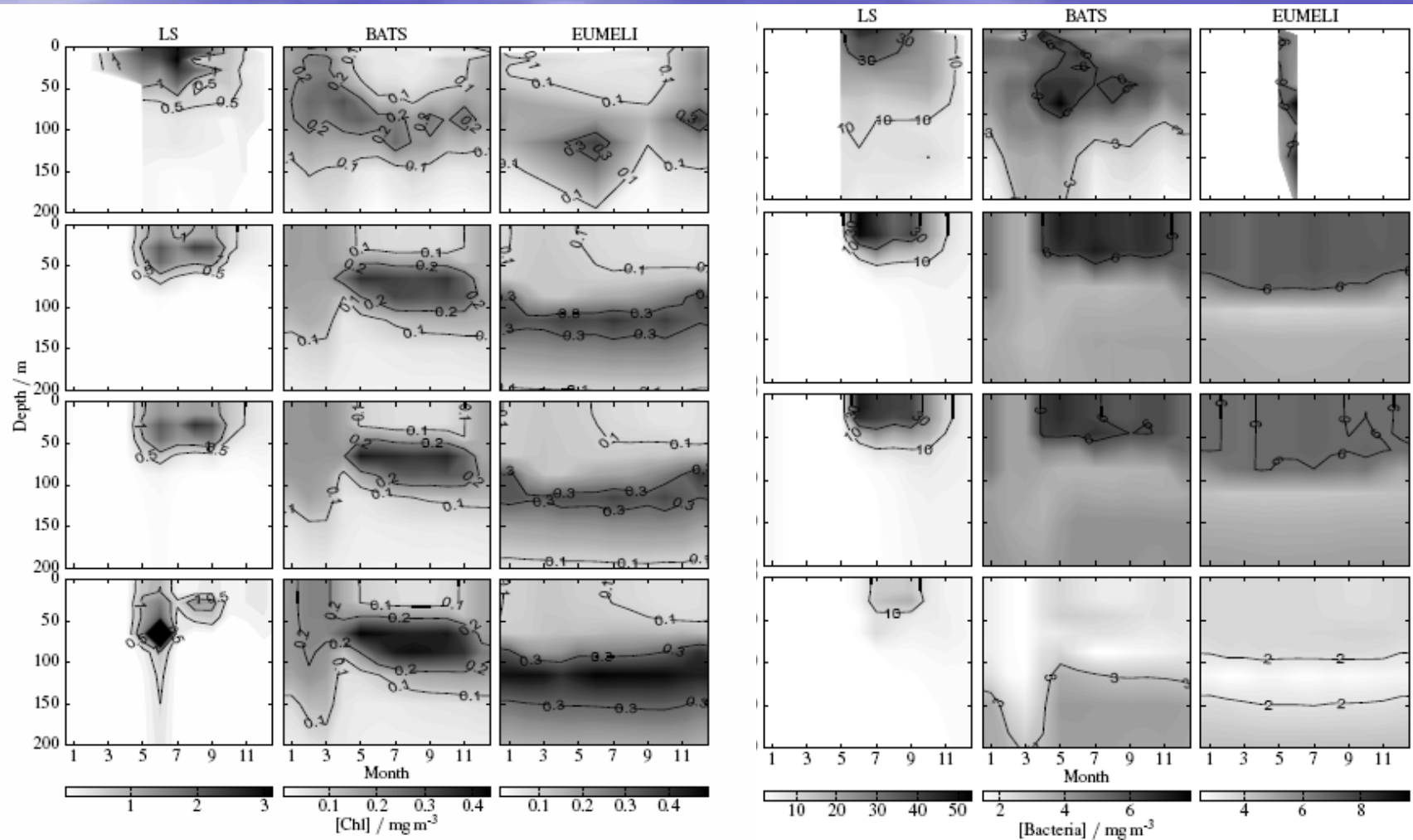
Attempted local fits (parameters adjusted separately for each station) and global fits (parameters fitted to all 3 stations) with and without adaptive functions.

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

Data

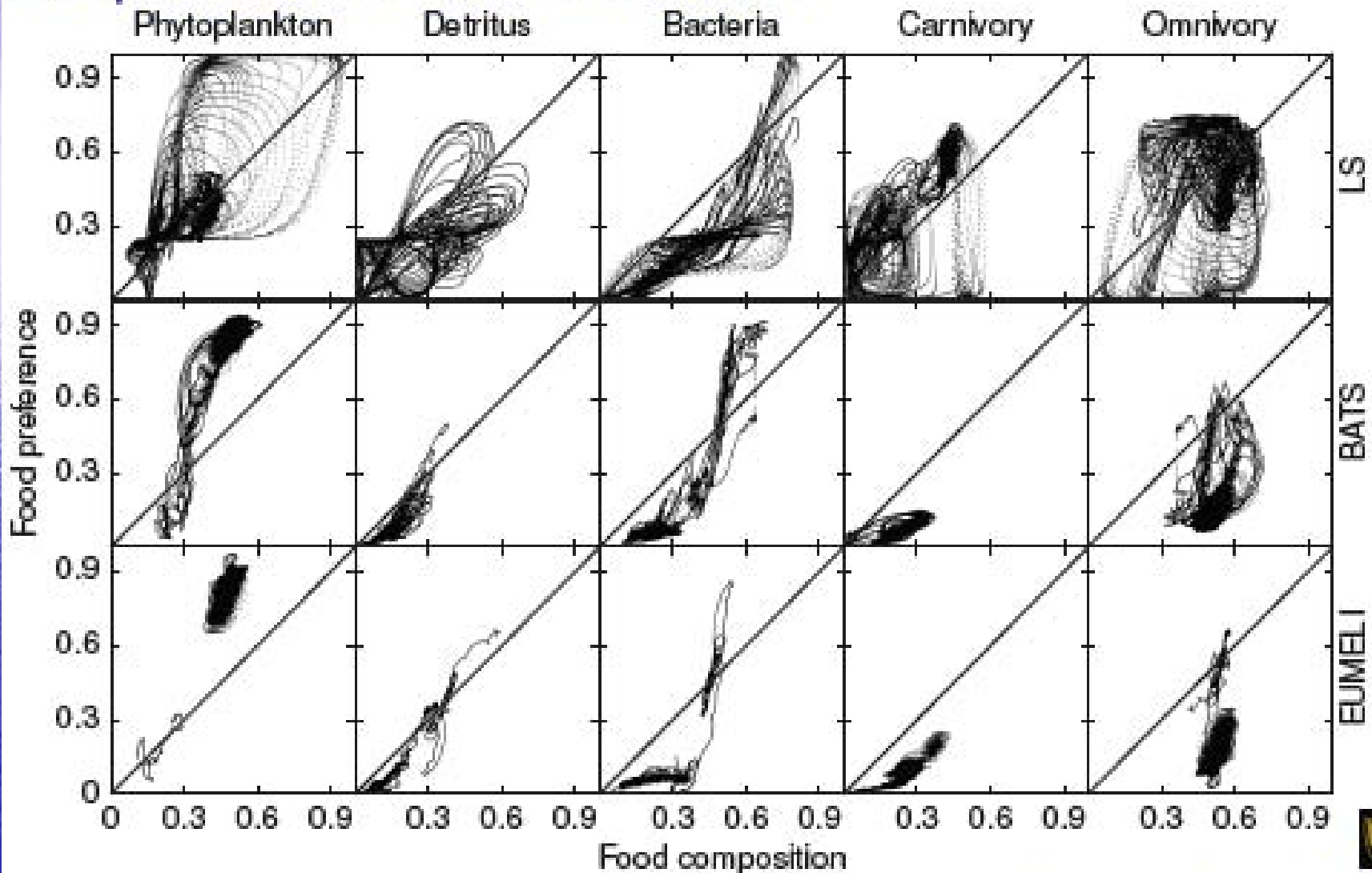
Model

Simpler

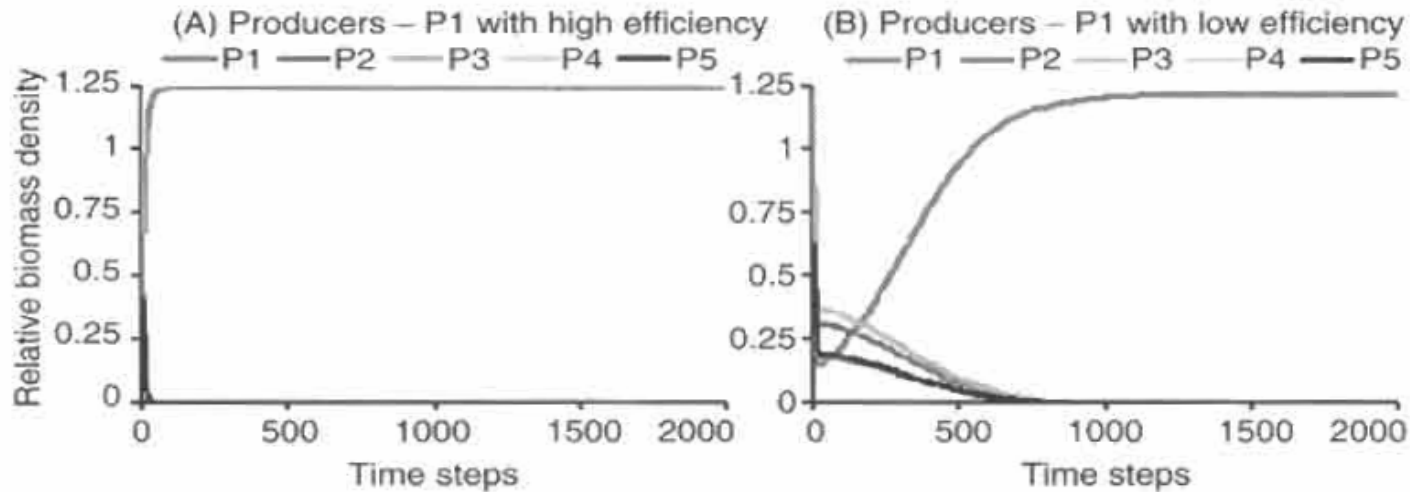


## “Emergent” functional responses for each consumer group

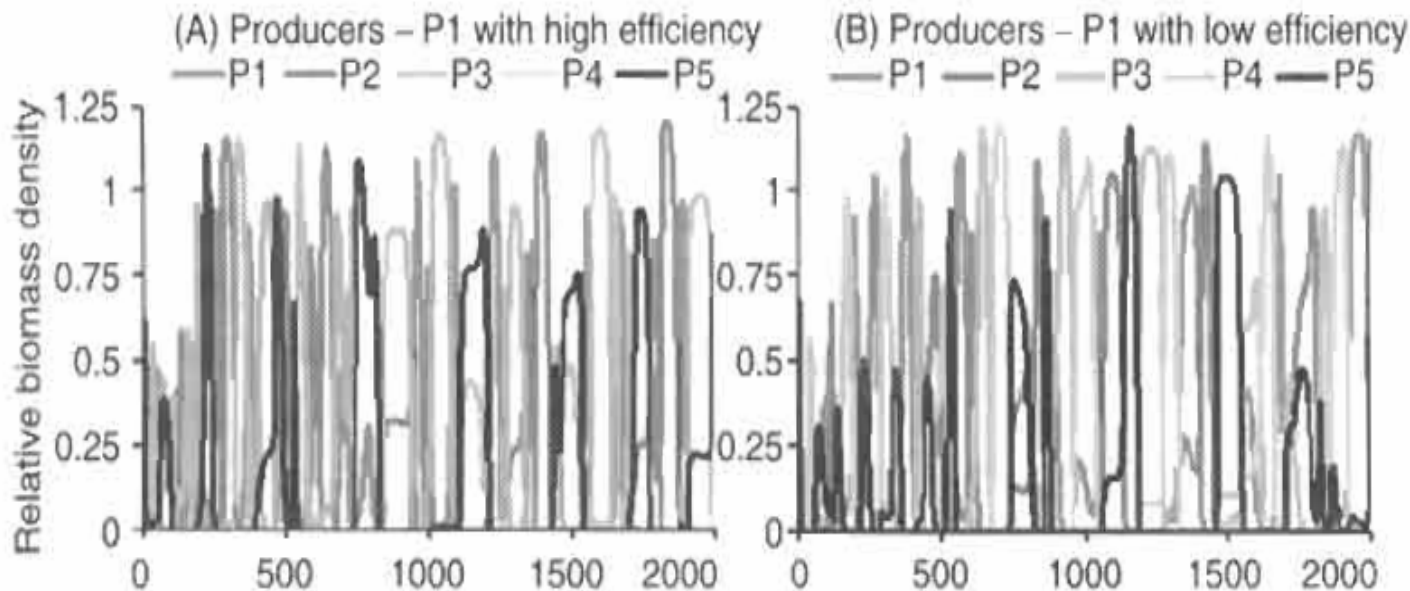
### Zooplankton Food Preferences



# Linking competition among producers with trophic interactions



Without specialist grazers



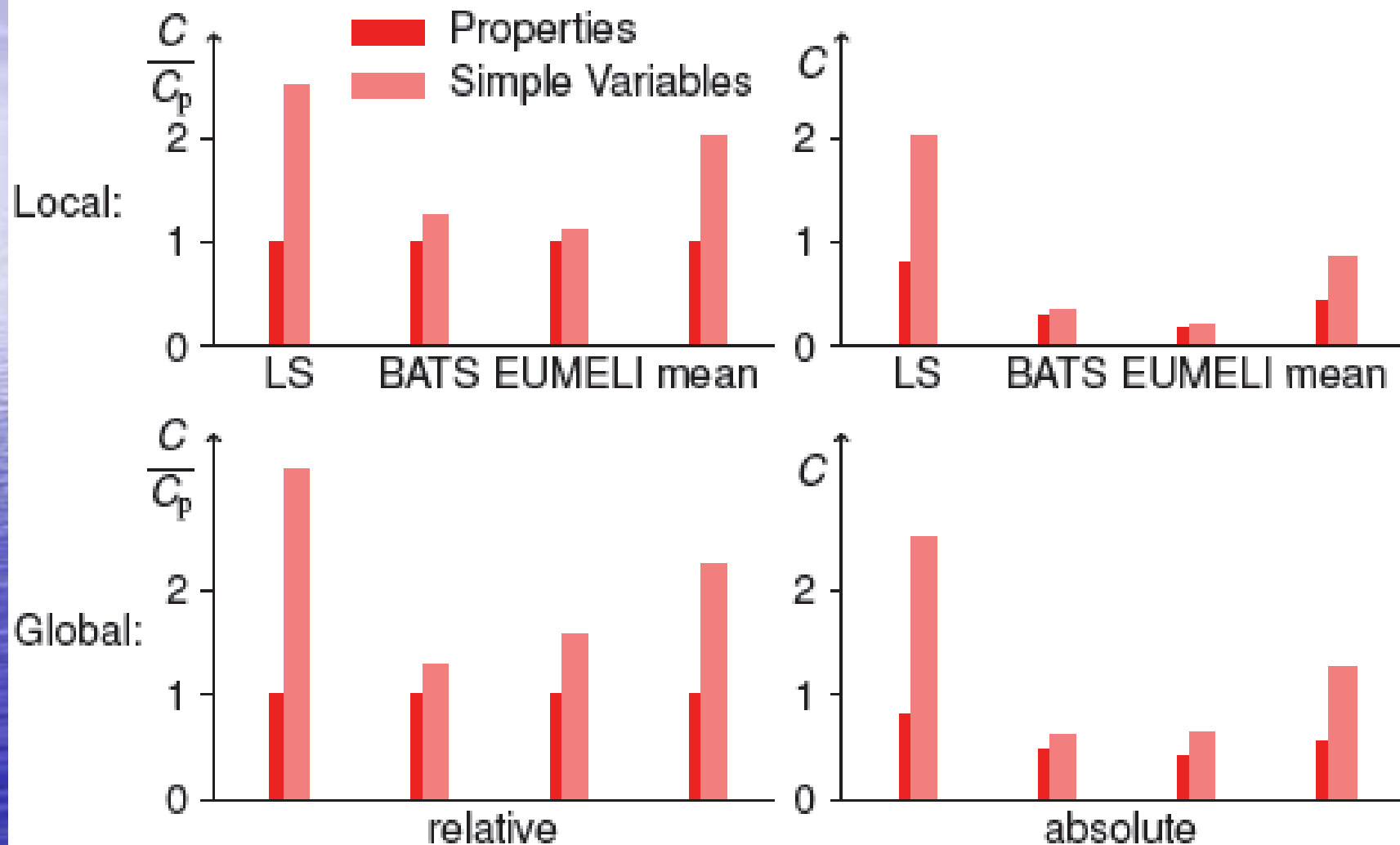
With specialist grazers

Brose, U., E.L. Berlow, and N.D. Martinez. 2005. in *Dynamic Food Webs: Multispecies Assemblages, Ecosystem Development and Environmental Change*.

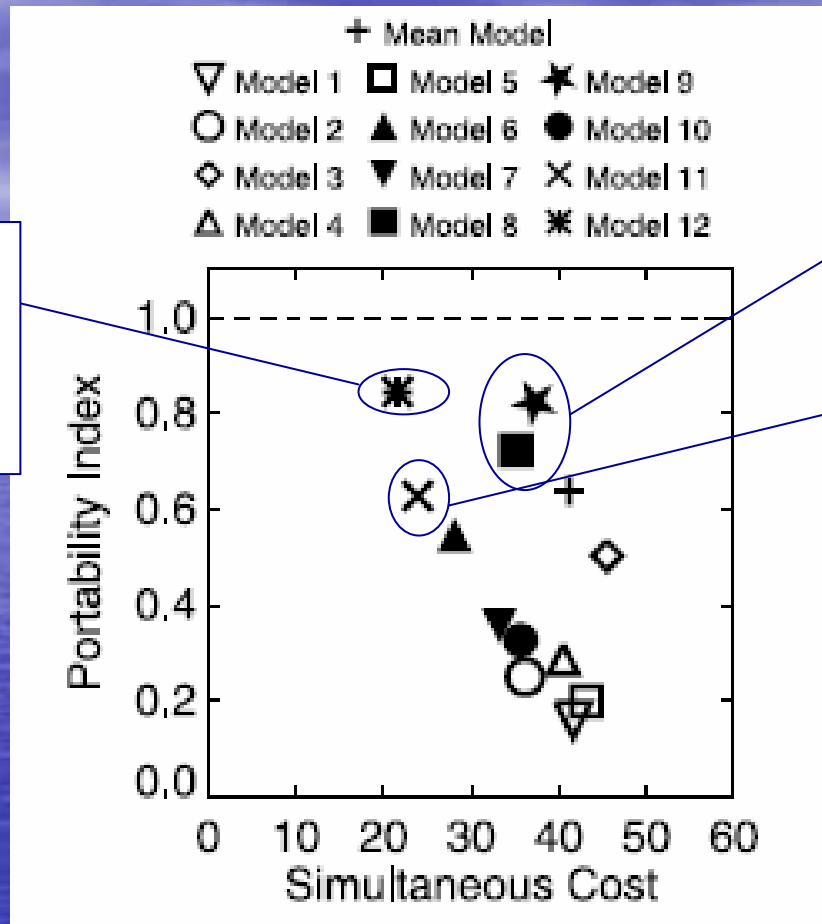
P.C. de Ruiter, V. Wolters, and J.C. Moore, eds. Academic Press

# Increasing complexity buys you more portability

## Local and Global Cost Functions



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!

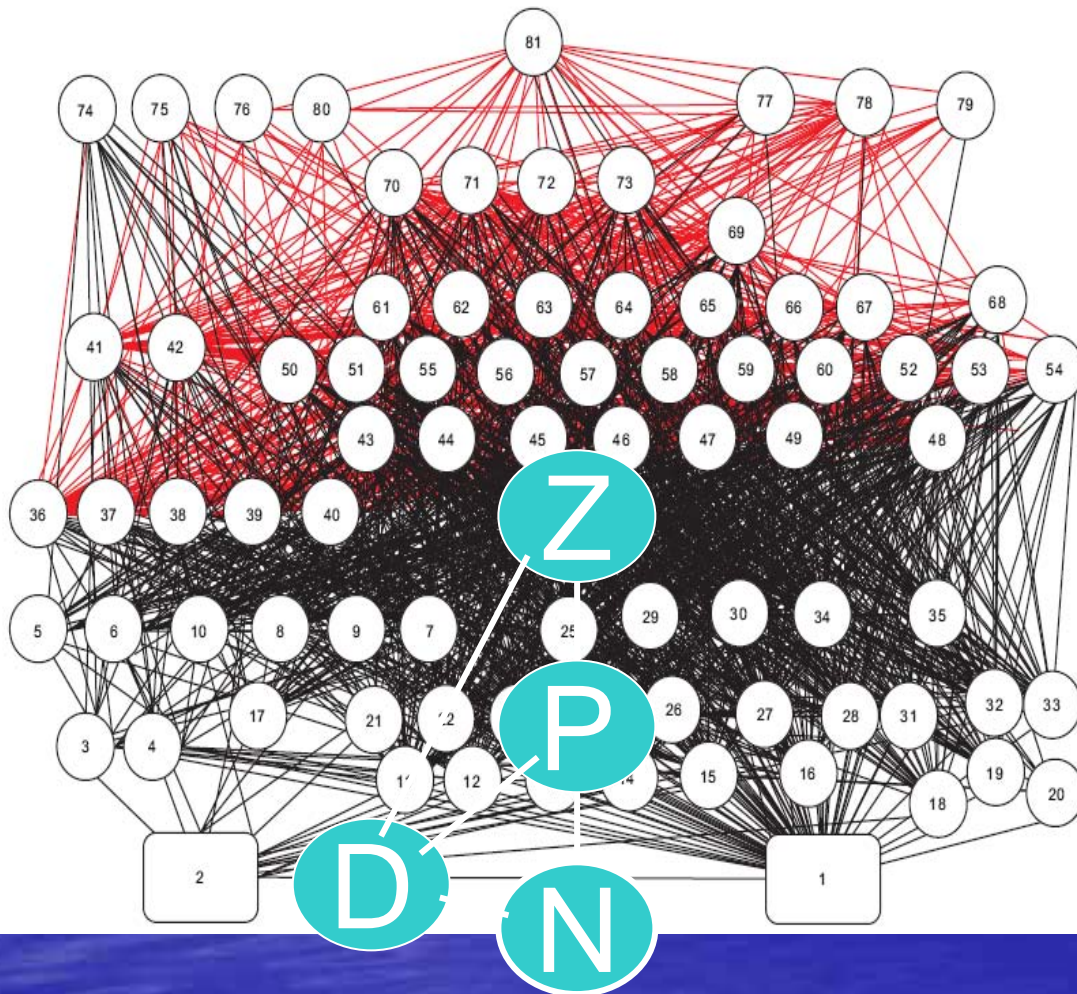
Friedrichs et al. 2007. J. Geophys. Res. 112, 10.1029/2006JC003852

# 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

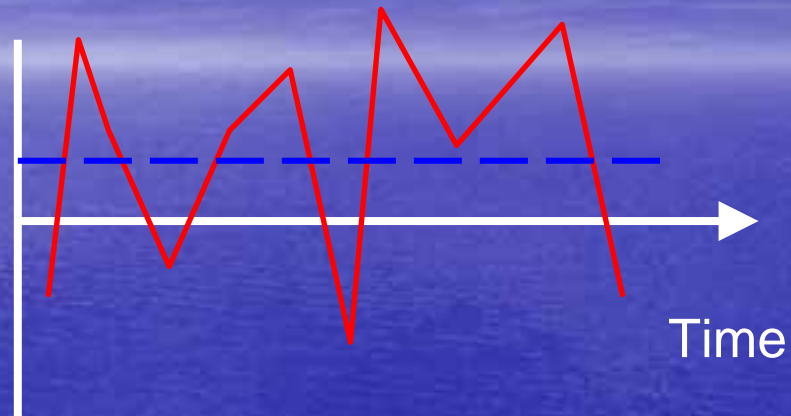
They are inherently unstable: cut-off the feedback loops

Compensate with functional response and closure terms

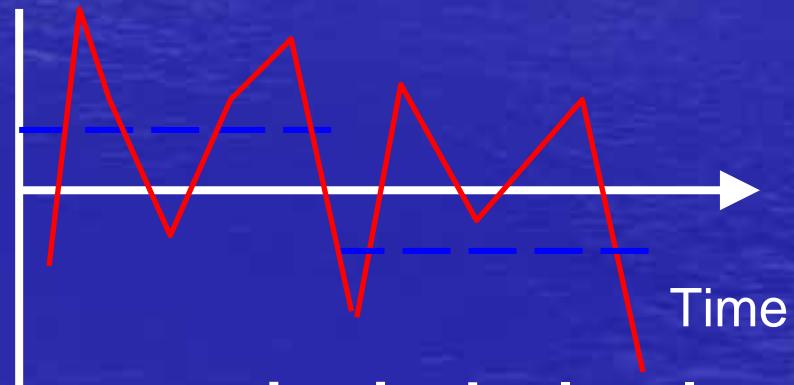
But are these fixes capture the dynamics in the whole system?

# 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.**

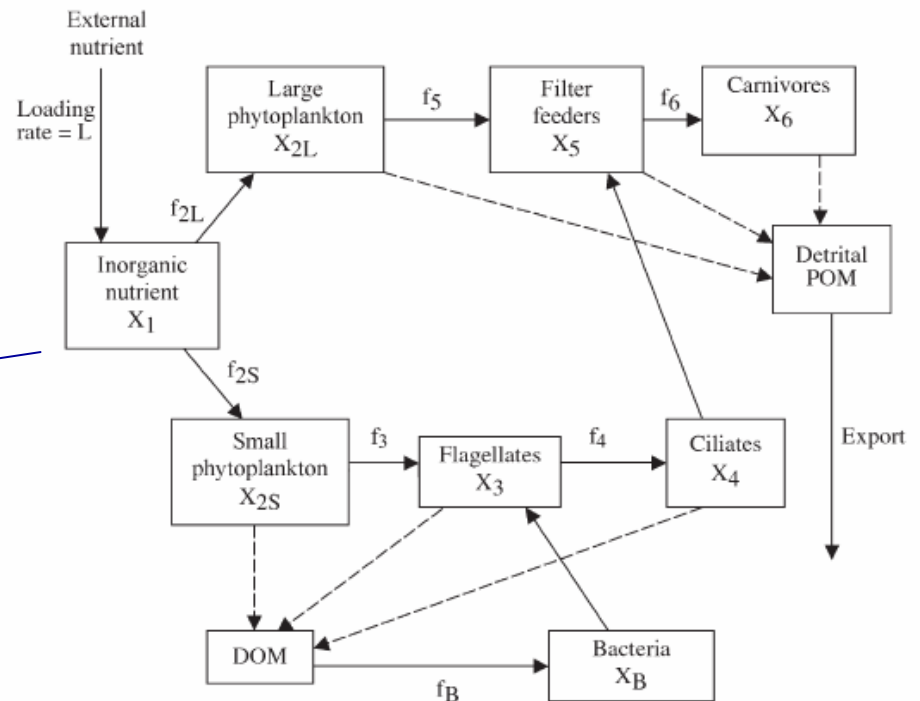
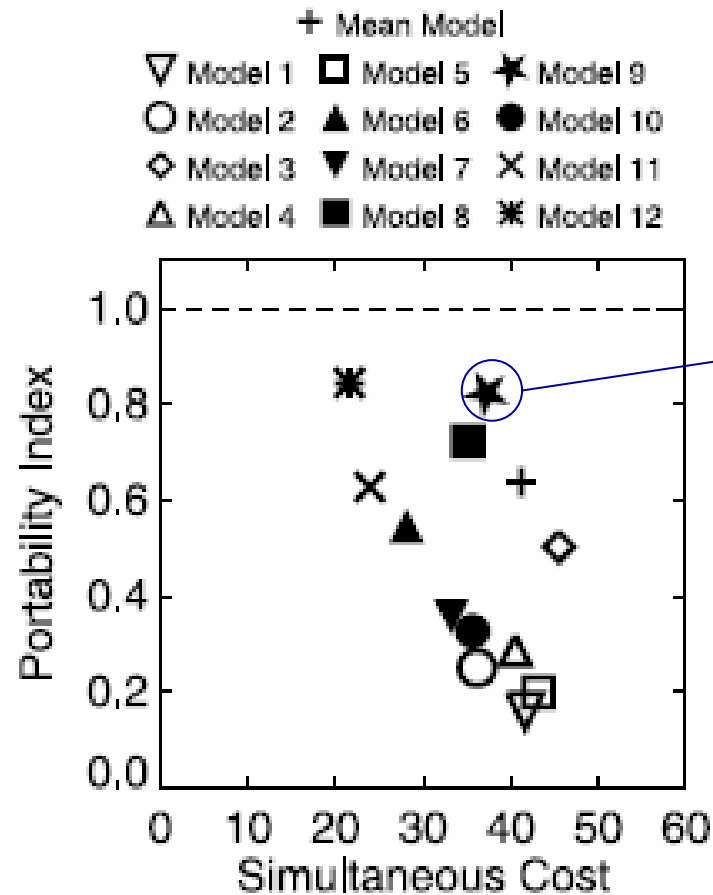
# Assembly rules for ecosystems

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

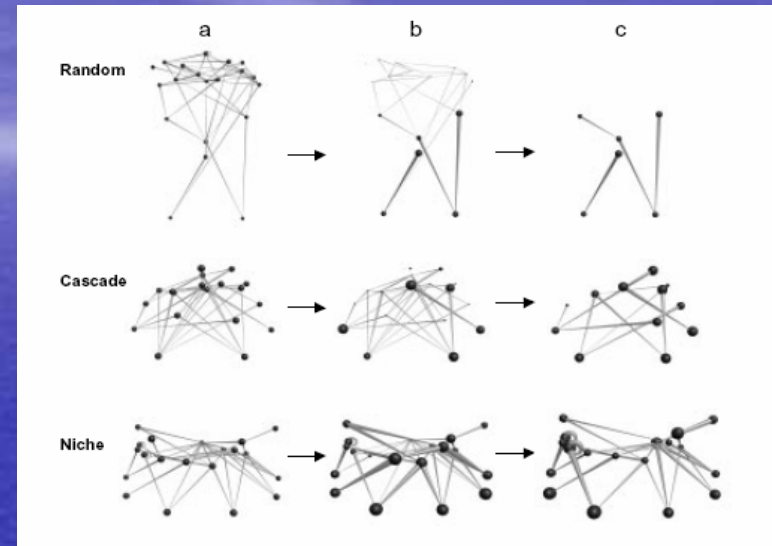
<http://www.foodwebs.org>



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

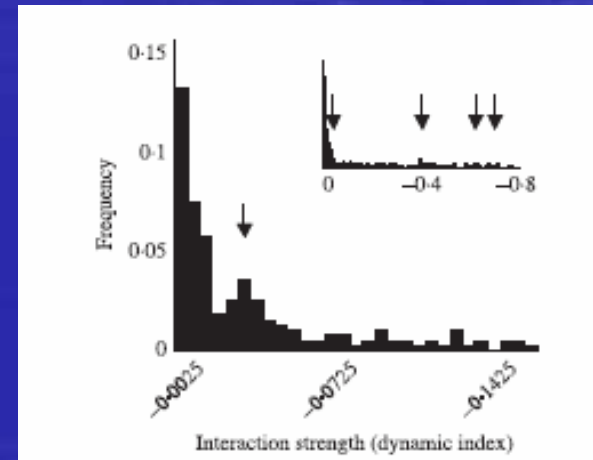
# Assembly rules for ecosystems

Certain types of topology promote ecosystem stability more than others

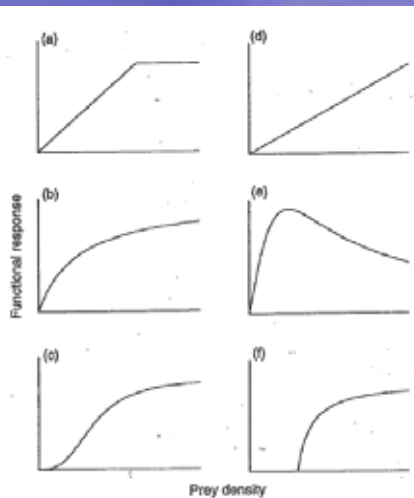


Martinez et al. 2006.

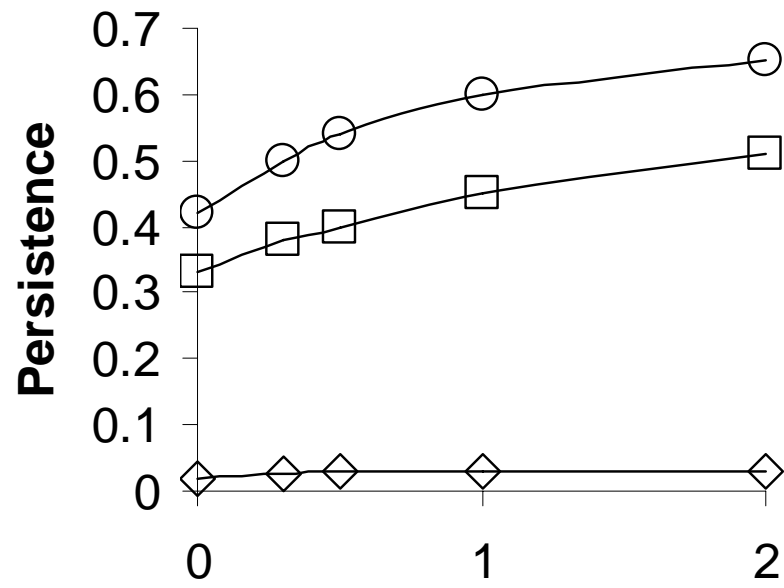
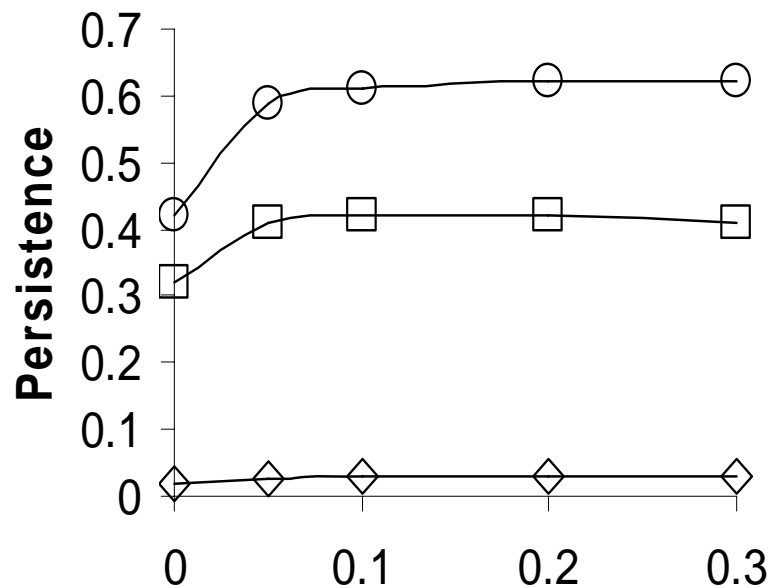
Most interactions in ecosystems are weak, but are crucial to maintaining stable networks



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)

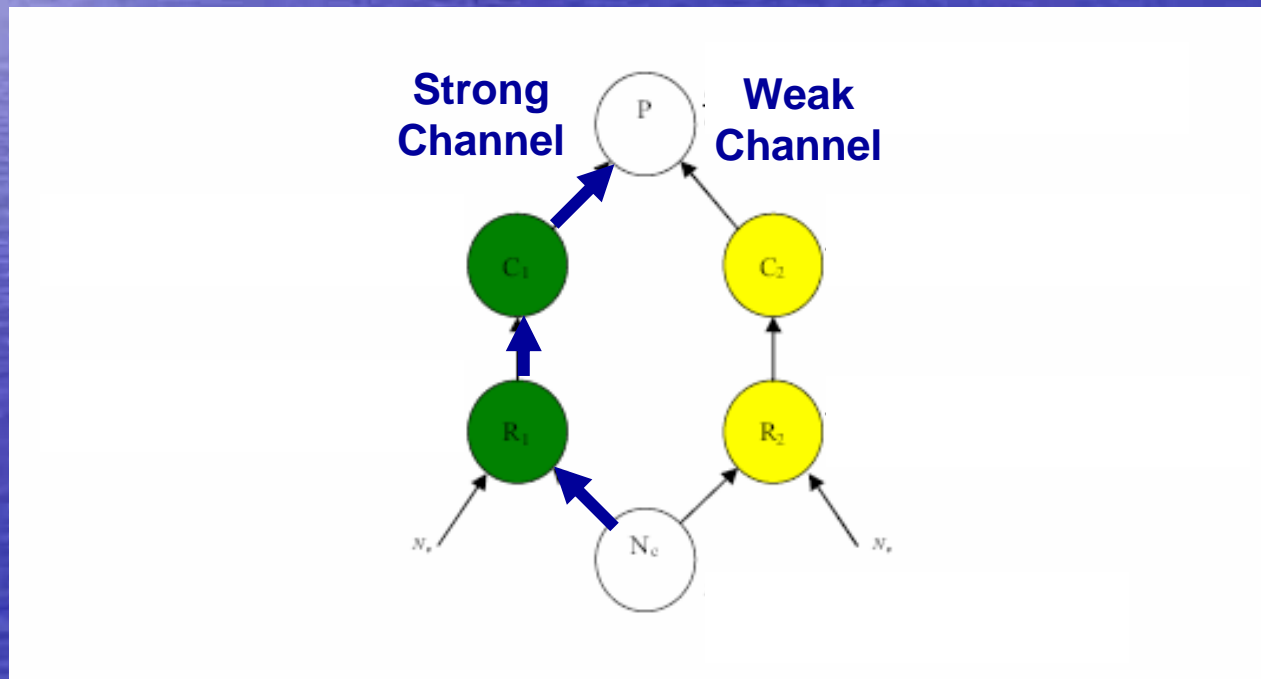


Type II  $\xrightarrow{q}$  Type III  
 $q=0$   $q=1$

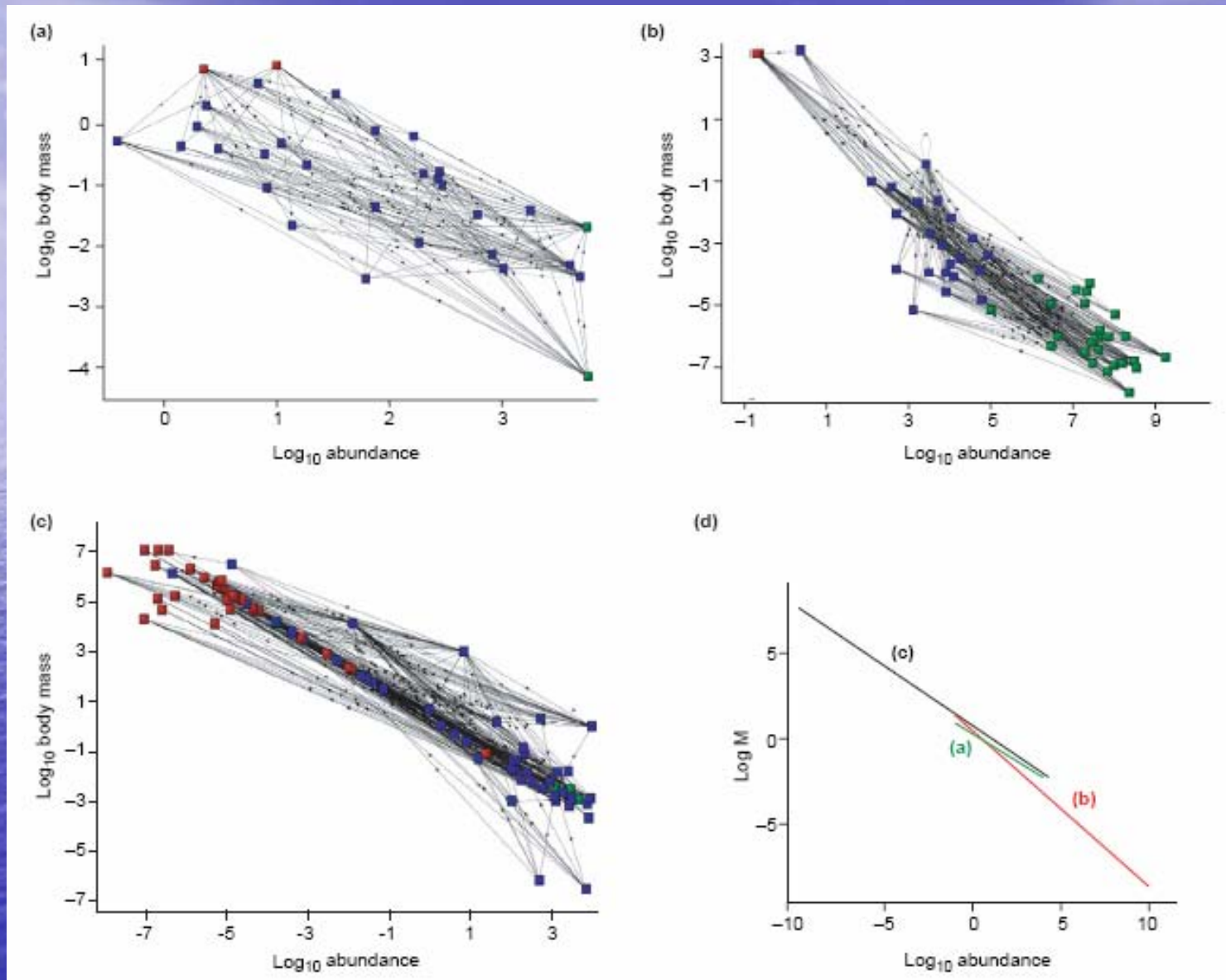
Type II  $\xrightarrow{c}$  P.I.  
 $c=0$

# Compartmentalized food webs

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



# Body size is a powerful constraint



# 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

## 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.



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

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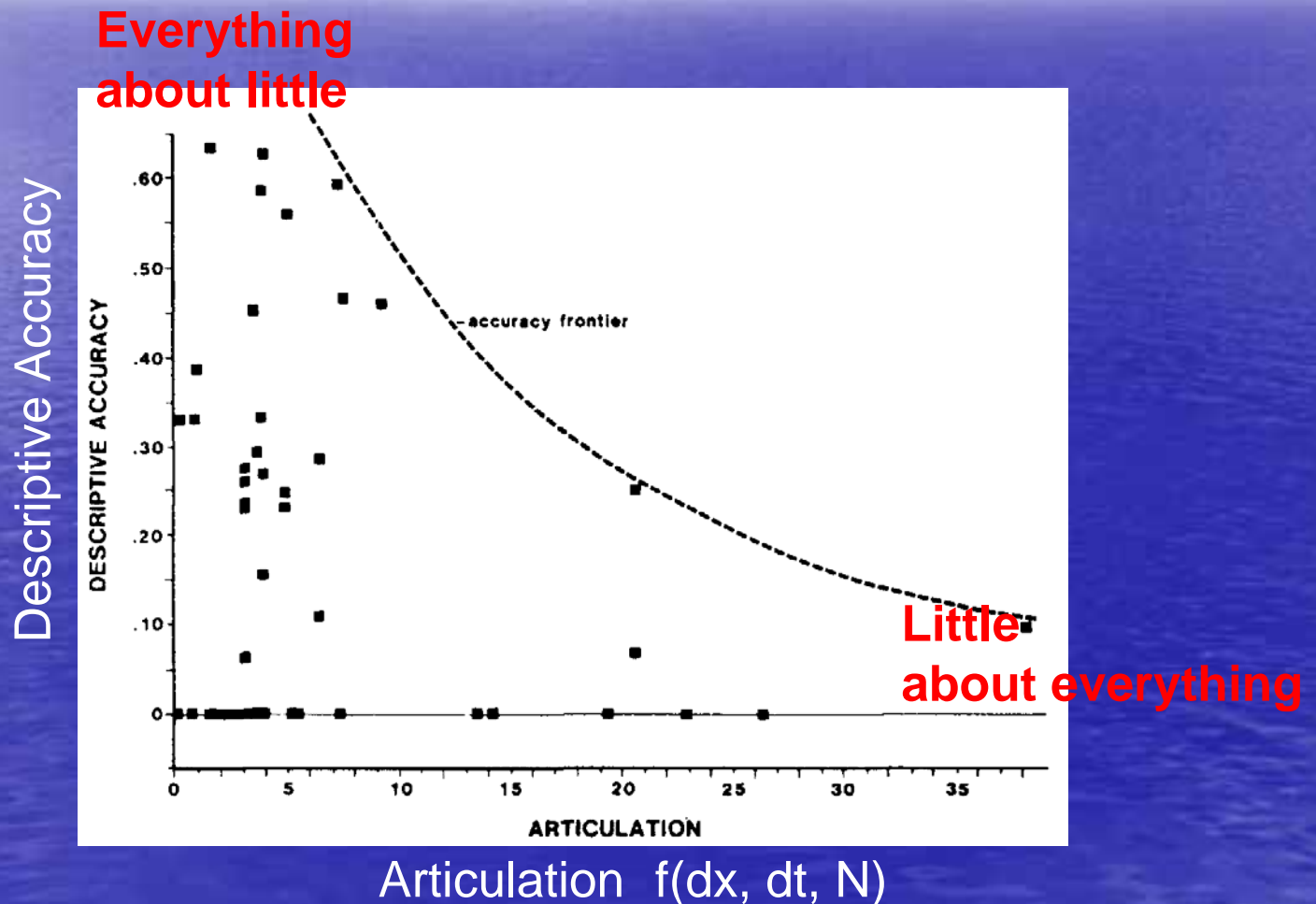
<sup>a</sup> CSIRO Division of Marine Research, GPO Box 1538, Hobart, Tasmania 7001, Australia

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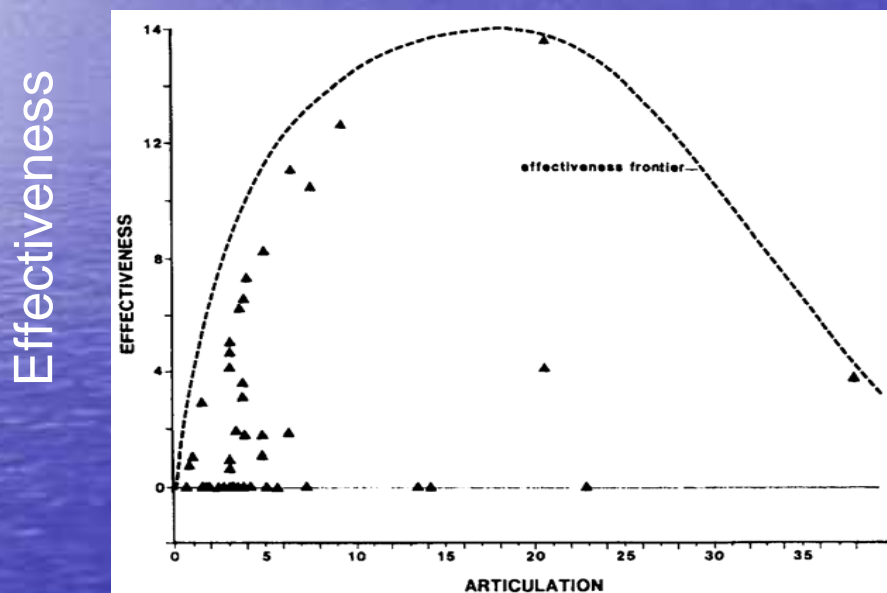
... the most dynamic and sophisticated functional responses describing grazing require more parameters and validation than the simpler Holling disk equation, but usually still lead to the same general conclusions about the system state and the effects of changes in forcing.

# Costanza and Sklar 1985



# Intermediate complexity

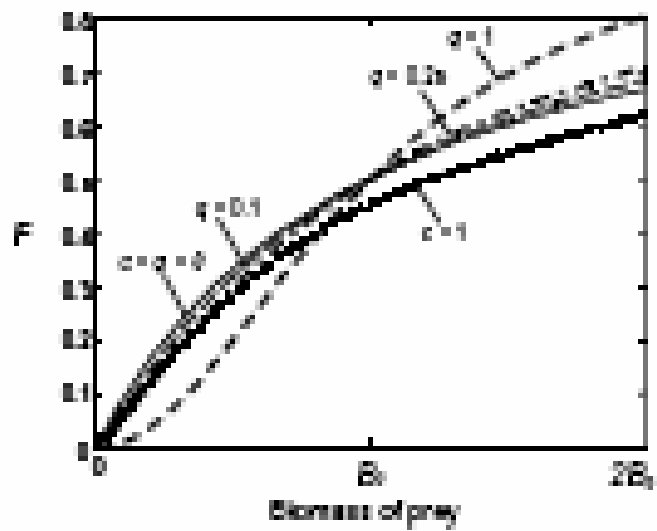
Effectiveness frontier

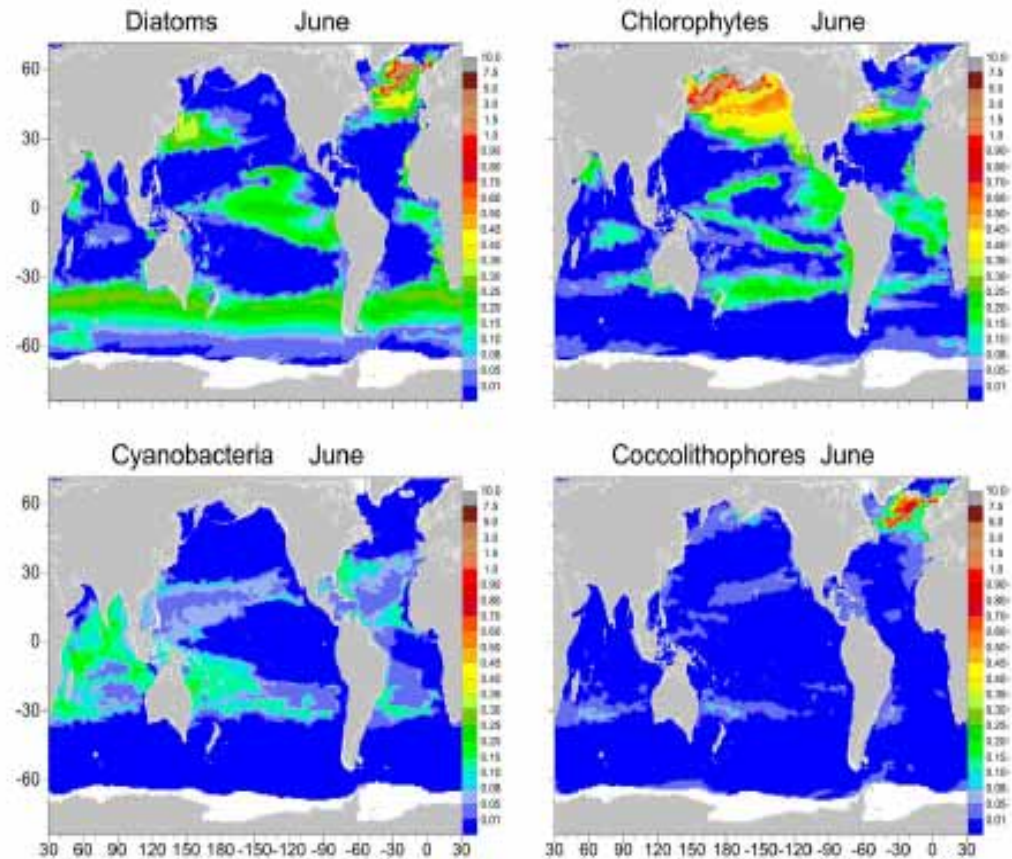
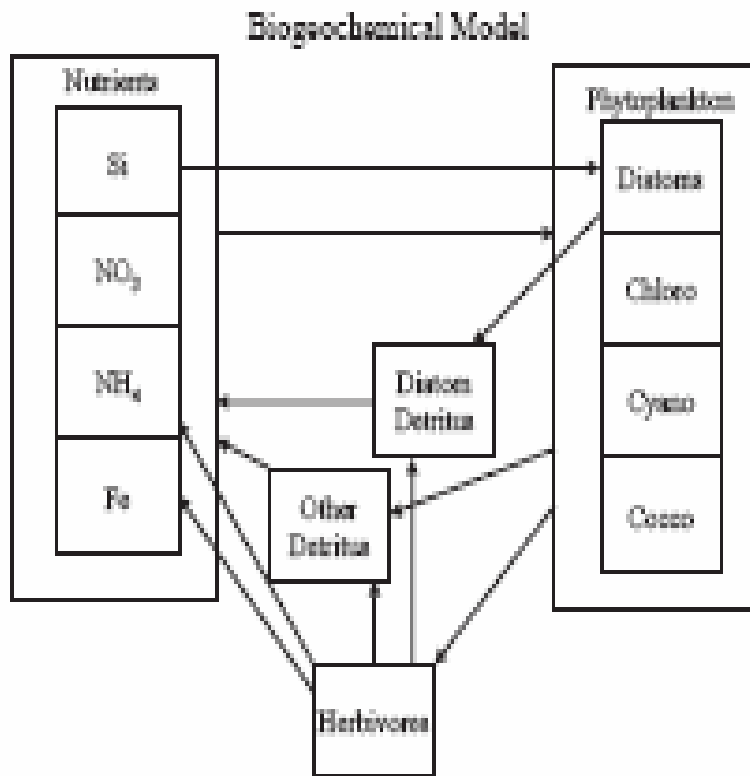


**Effectiveness:**  
A function of descriptive accuracy and articulation (complexity)

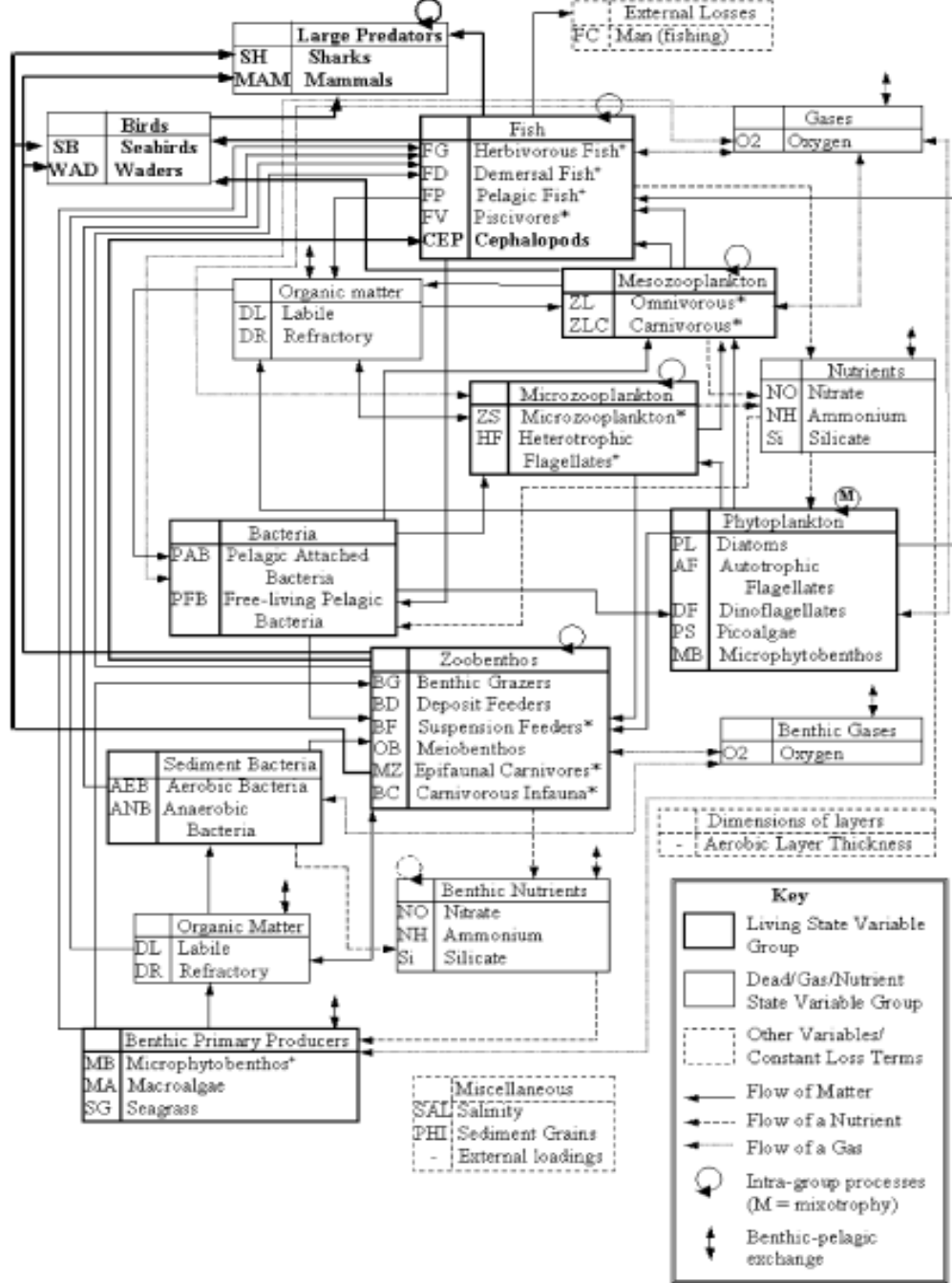
Articulation  $f(dx, dt, N)$

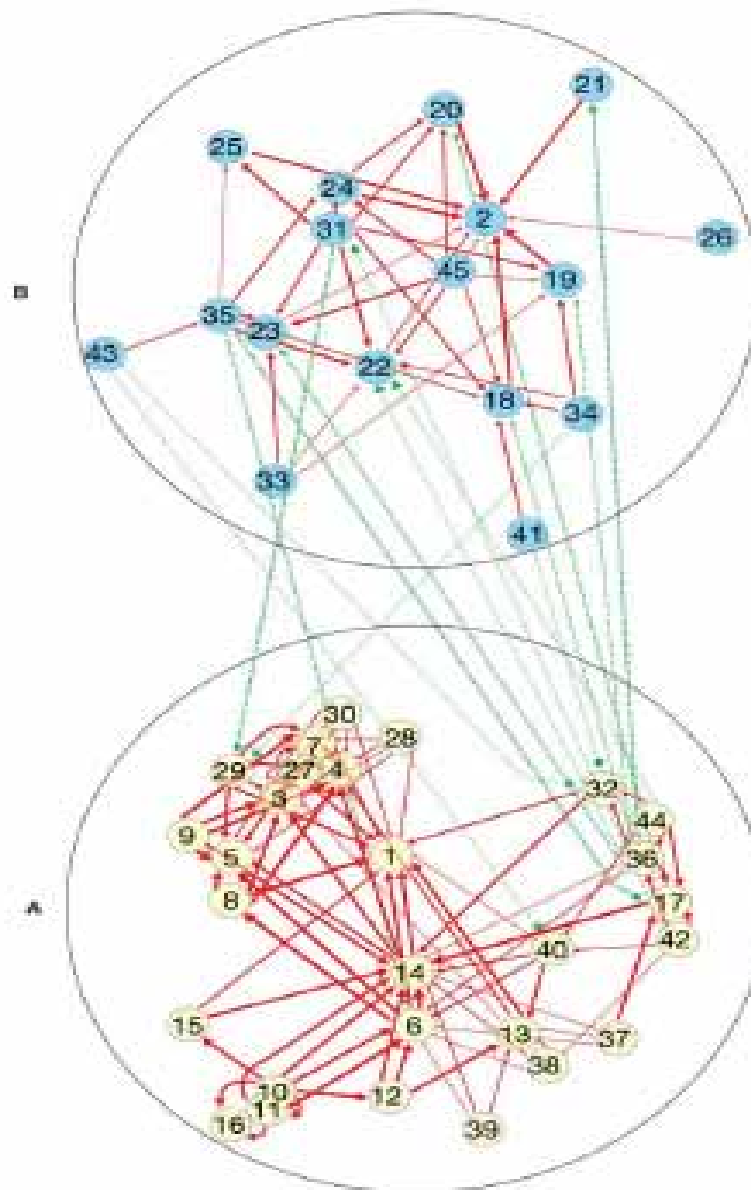
Measure of complexity



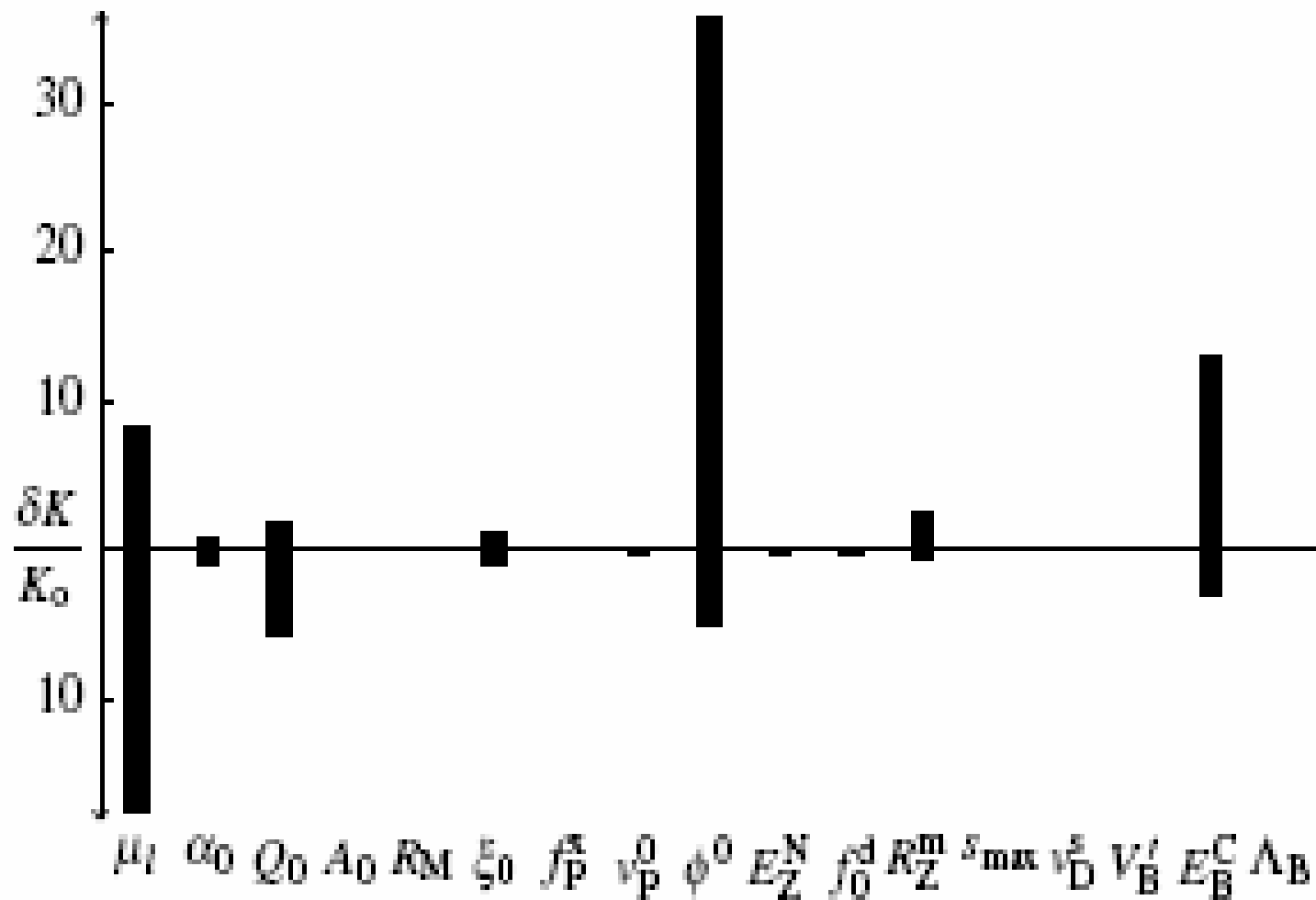


Gregg et al. 2003. Deep-Sea Res. 50, 3143





... and less sensitivity to model parameters



# Scheffer and Carpenter 2003

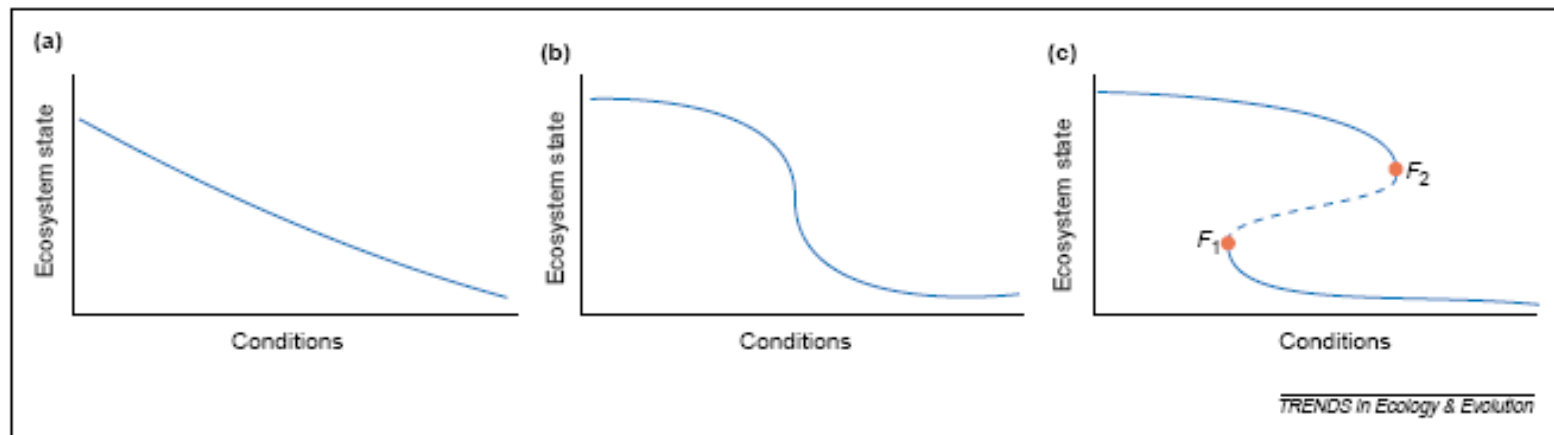
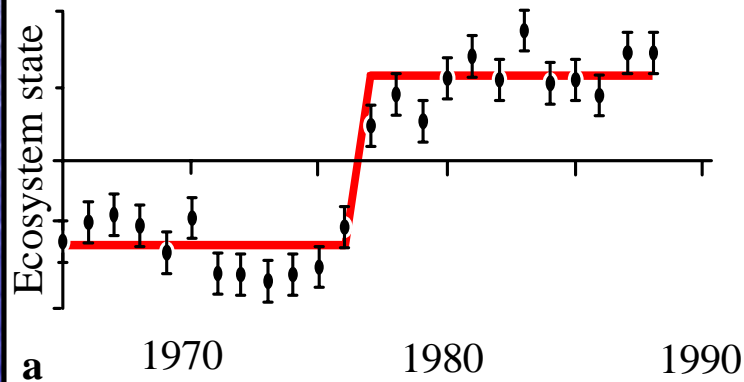


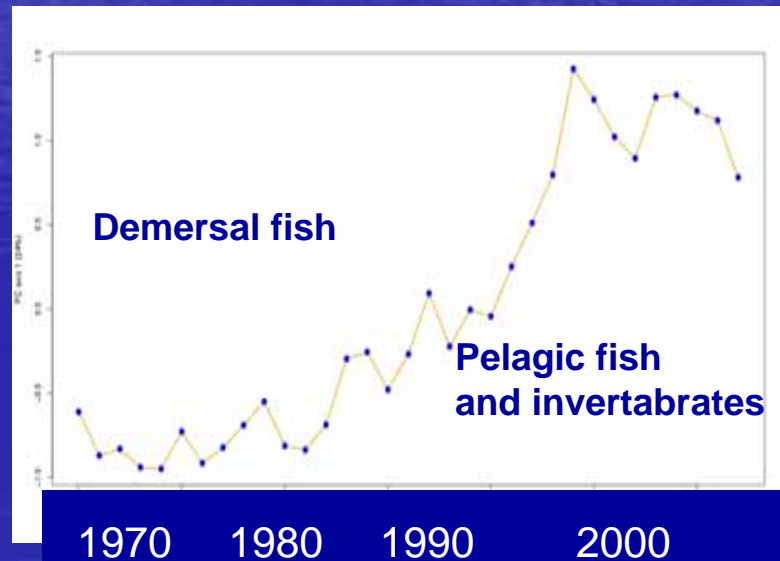
Figure 2. Different ways in which an ecosystem can respond to change in conditions. Although dynamic systems can respond smoothly to change in external conditions (a), they can sometimes change profoundly when conditions approach a critical level (b) or have more than one stable state over a range of 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>

## North Pacific 1977 Regime Shift



Hare and Mantua 1999



Frank et al. 2005