Does Biological Community Structure Influence Biogeochemical Fluxes?

JGOFS Says Yes!

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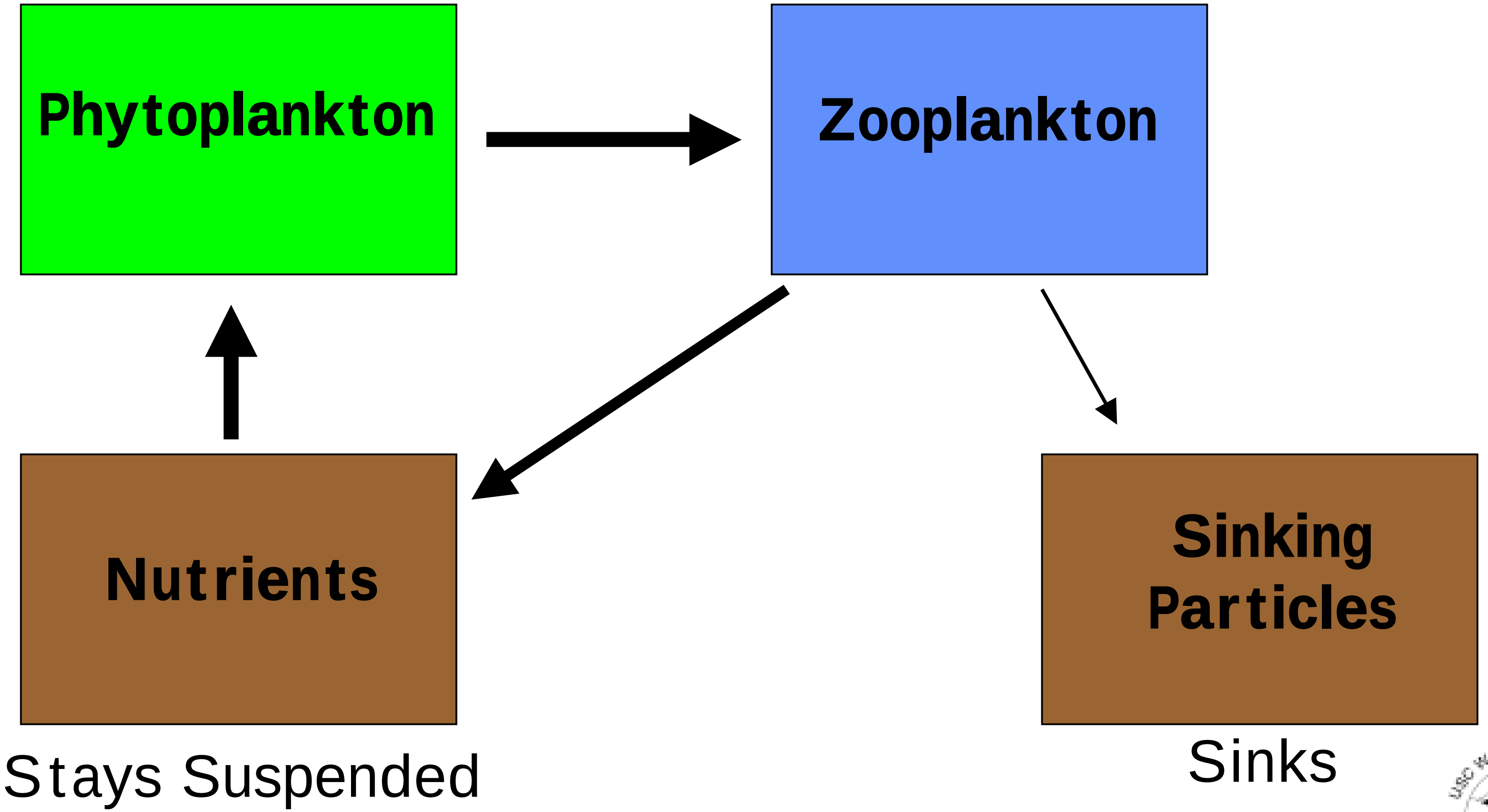
Roadmap

- What do we mean by community structure?
- Selected survey of community impacts on global carbon cycle
  - HNLC
  - Particulate Inorganic Carbon
  - Nitrogen Fixation
  - Remineralization length-scales

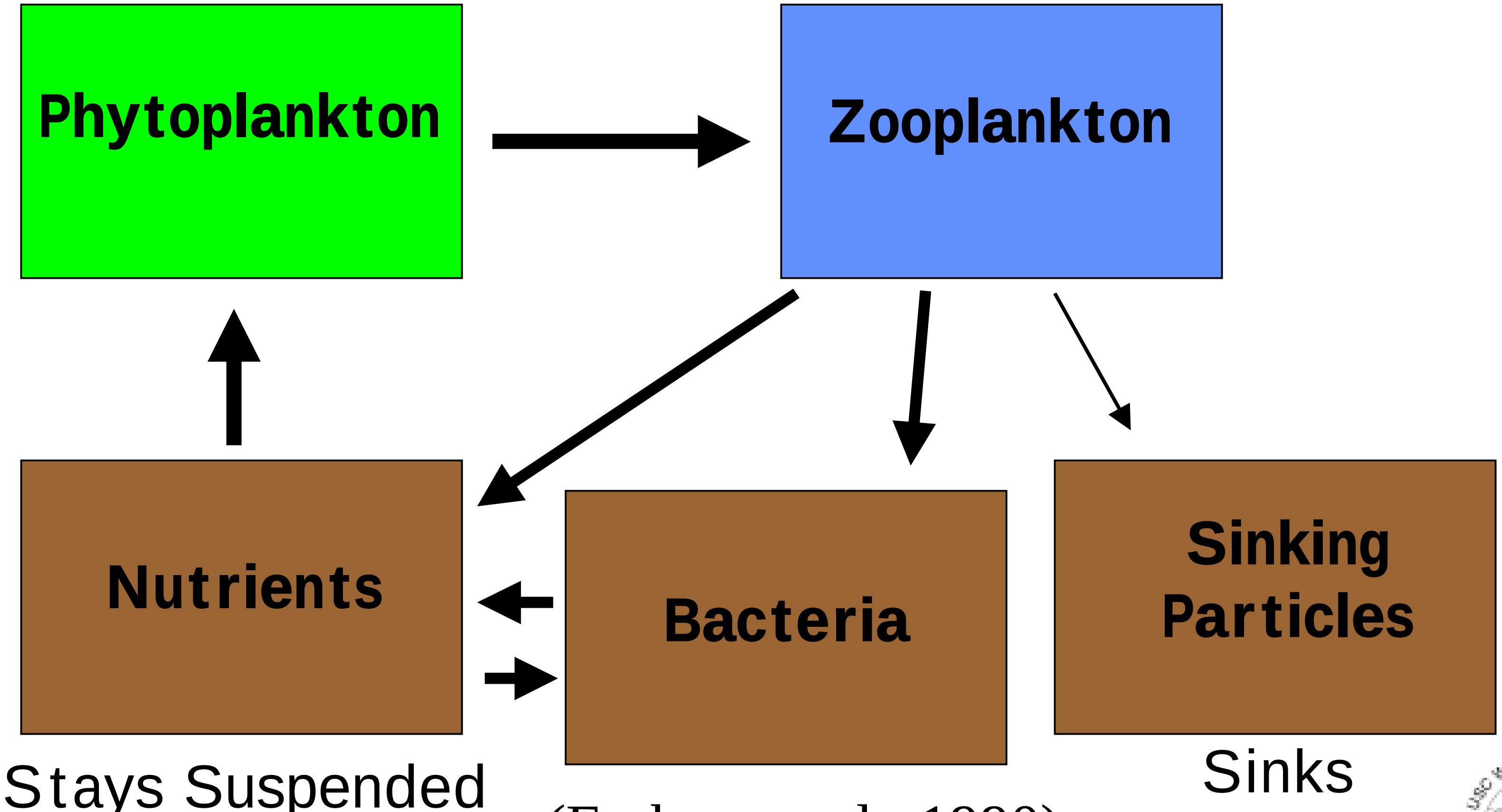
Tension and Balance

- Biologist's love of the details of life
- Biogeochemist's need to simplify in order to model global dynamics

What do we need to get a food web?

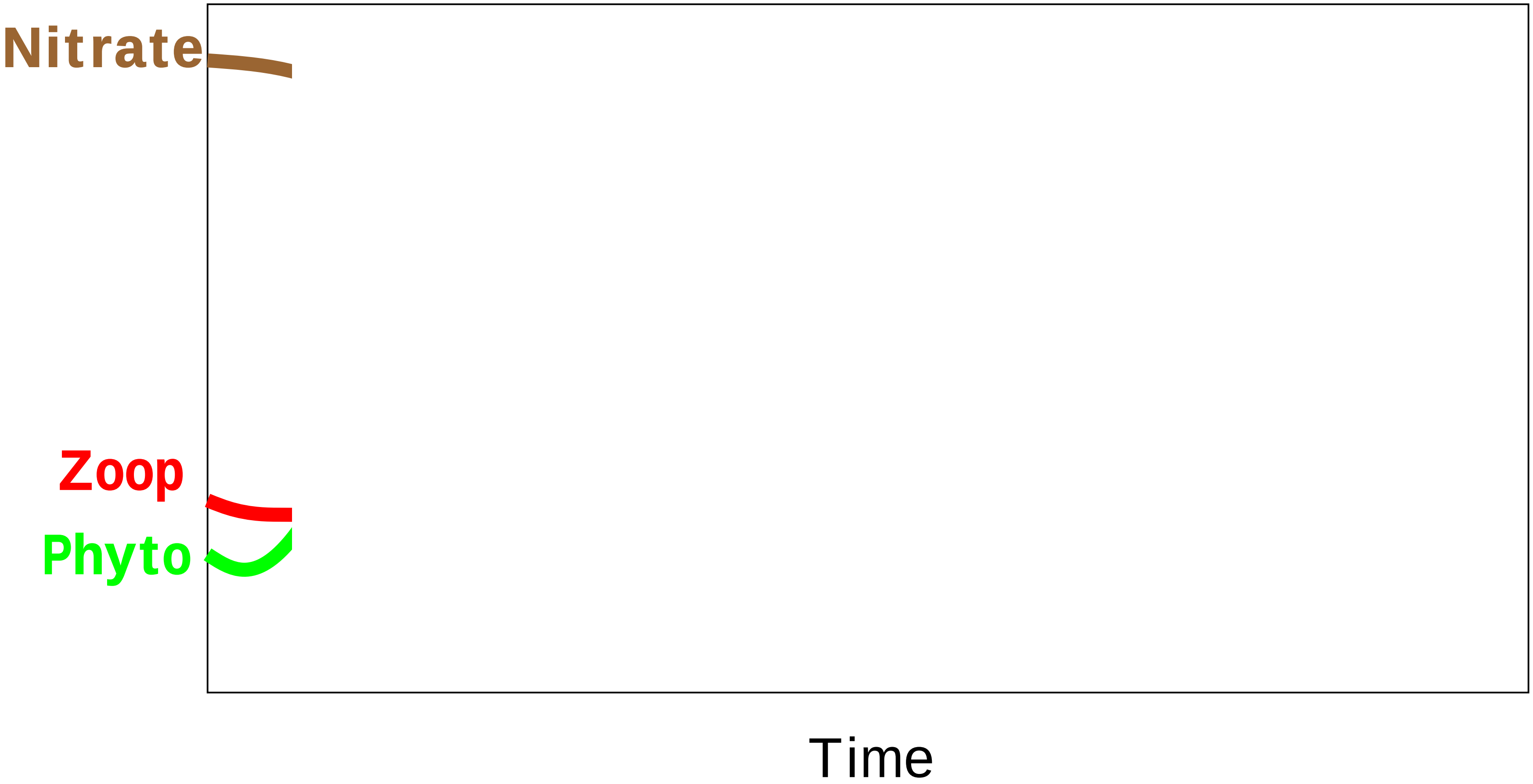


What do we need to get a food web?

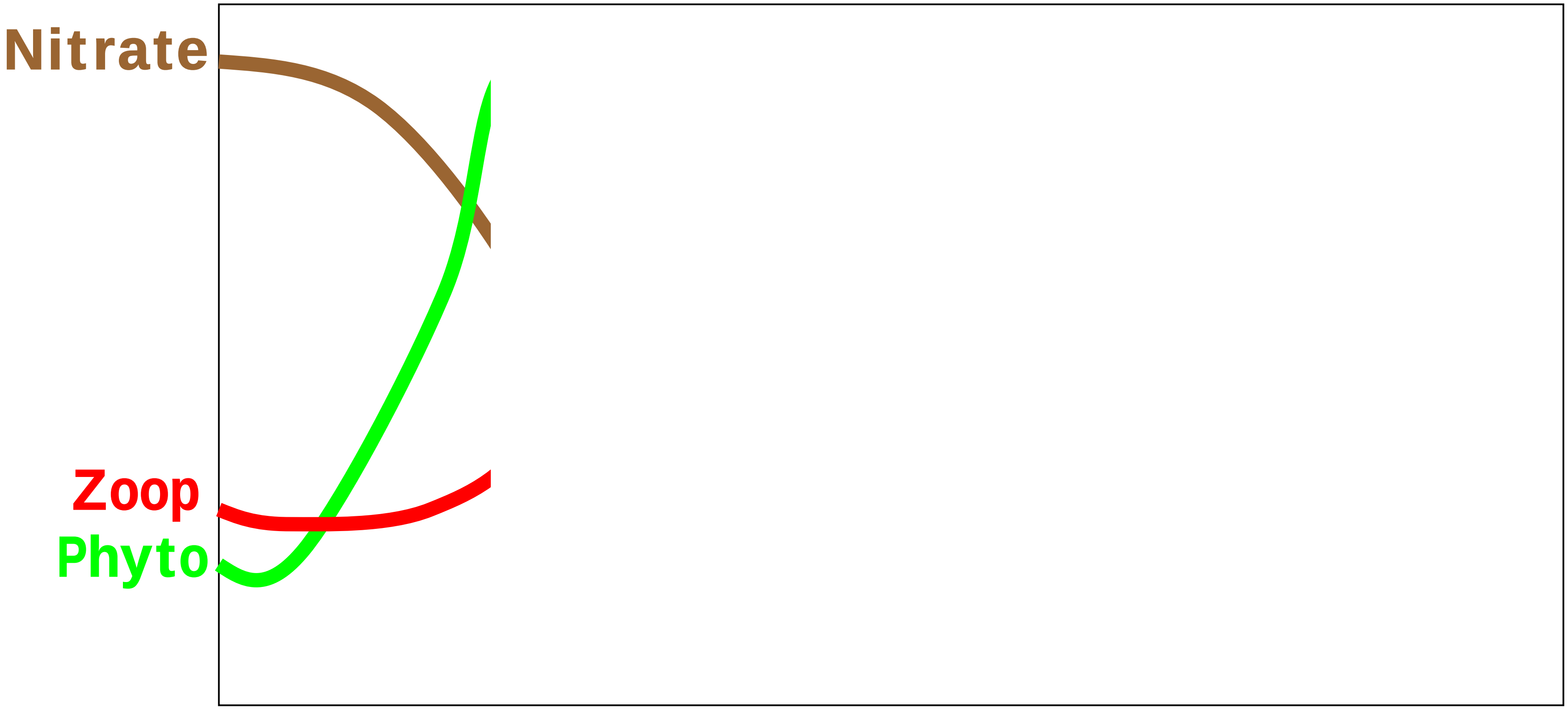


(Fasham et al., 1990)

P-Z-N Dynamics: Populations Change through Time



P-Z-N Dynamics: Populations Change through Time



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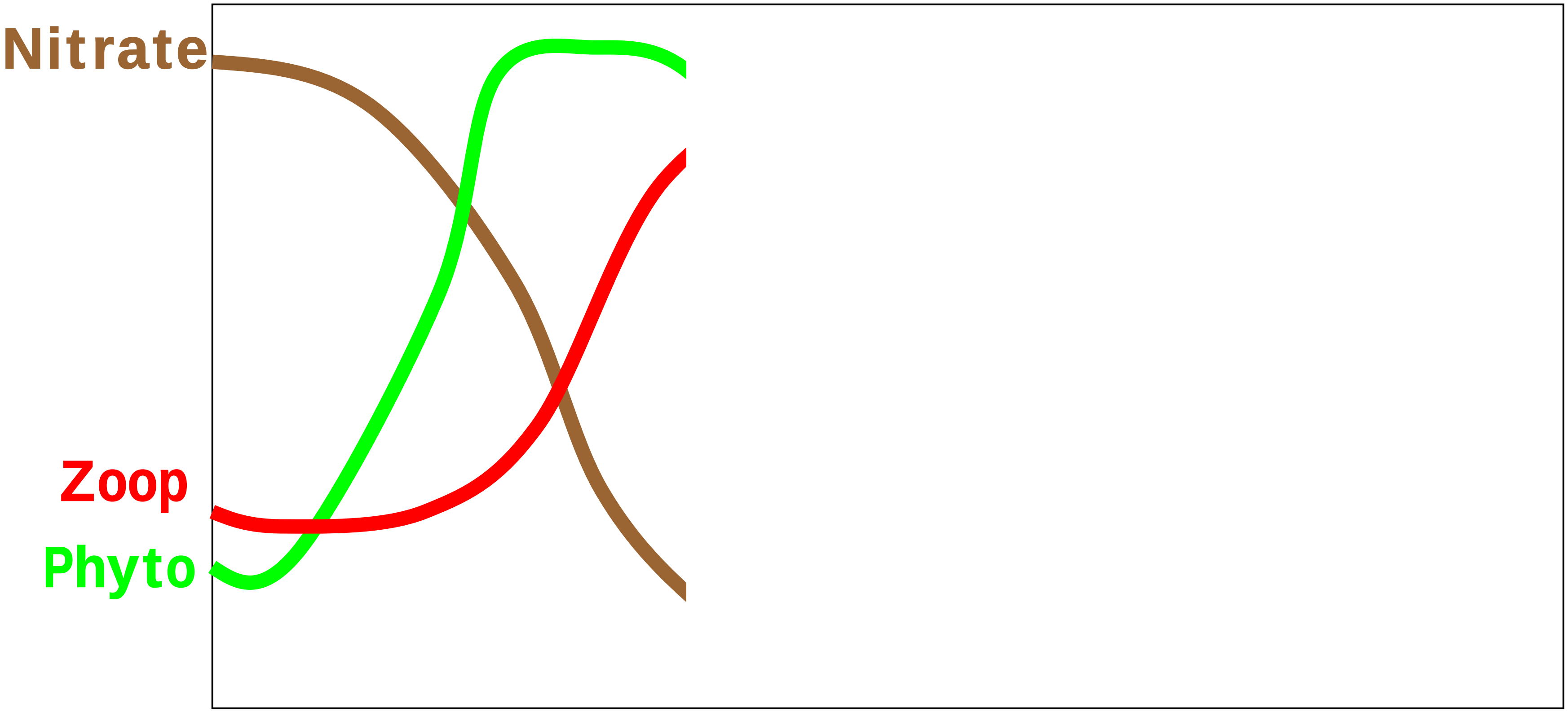

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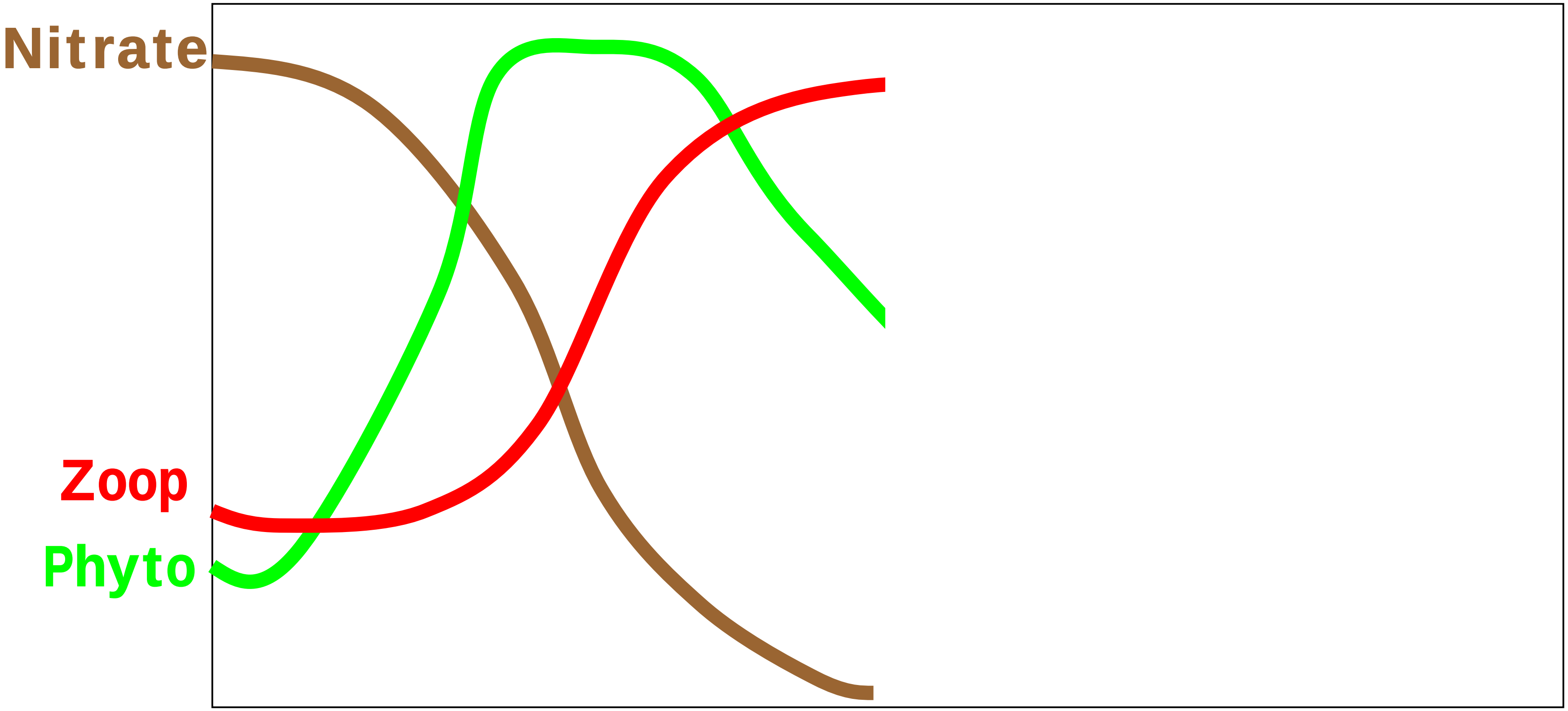

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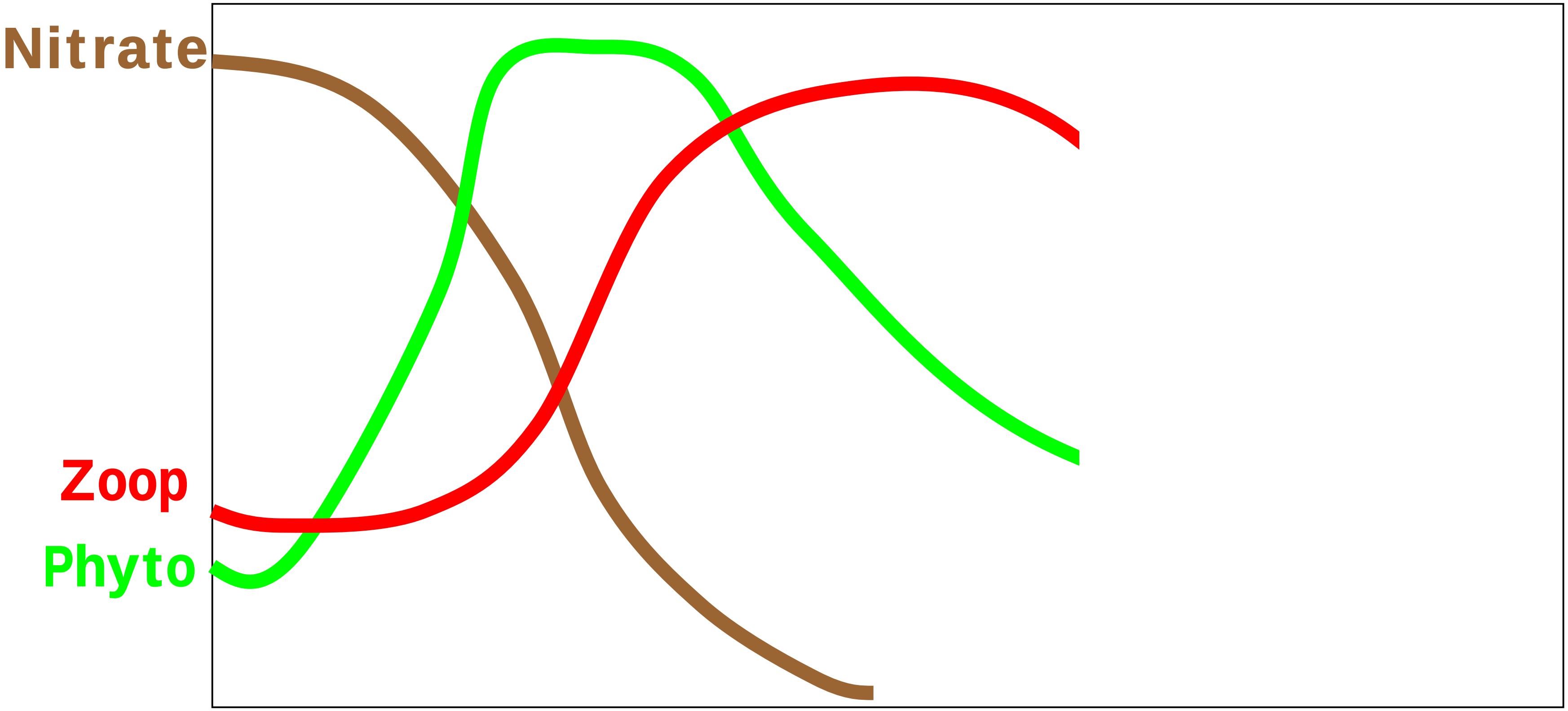

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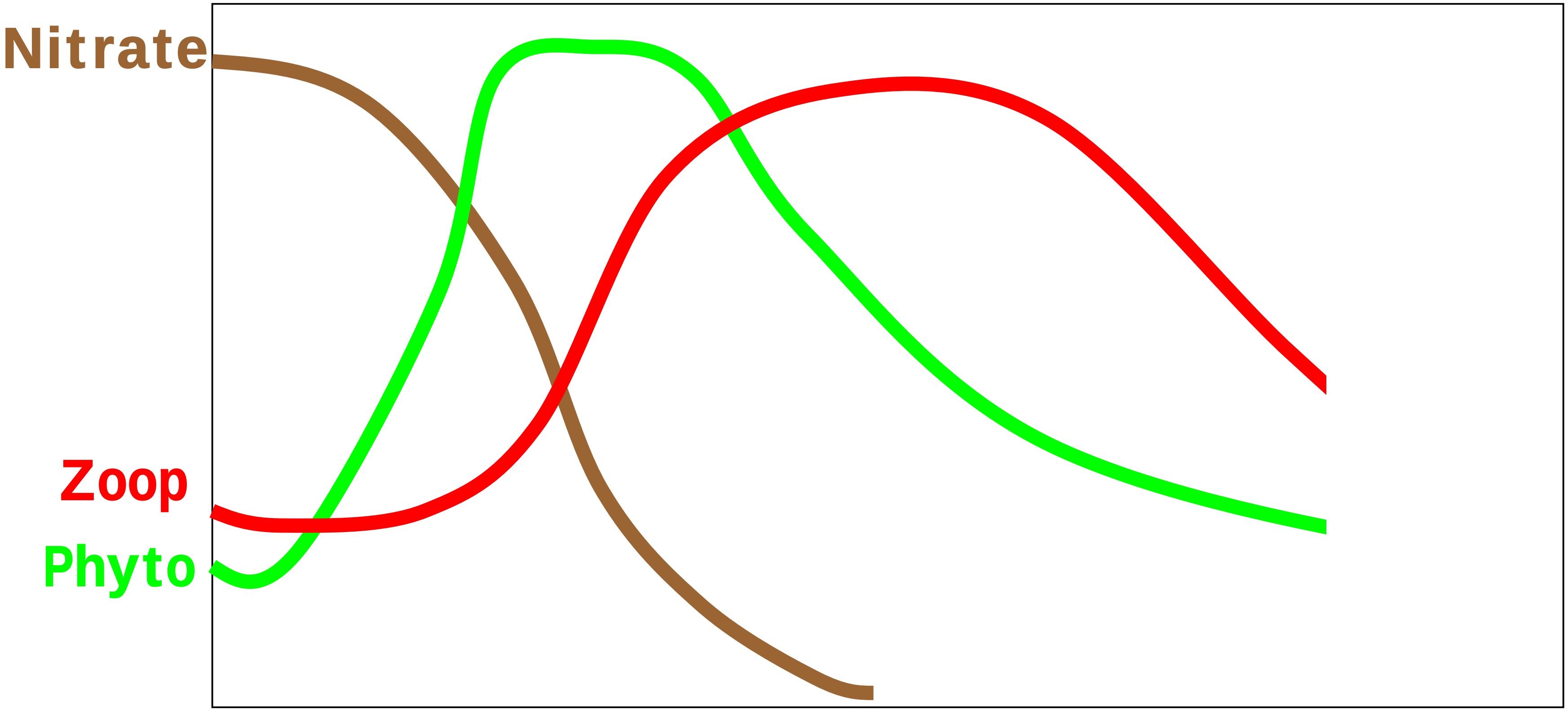

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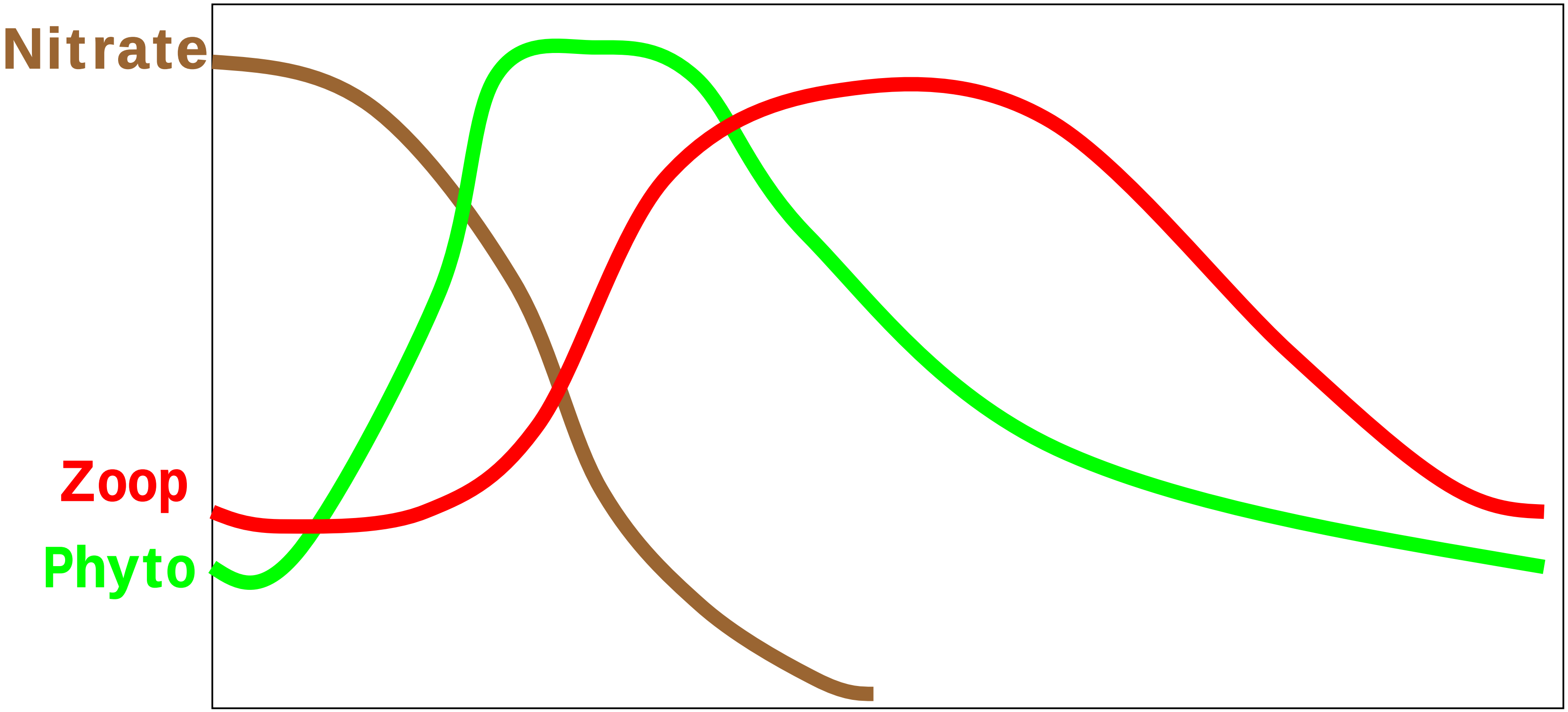
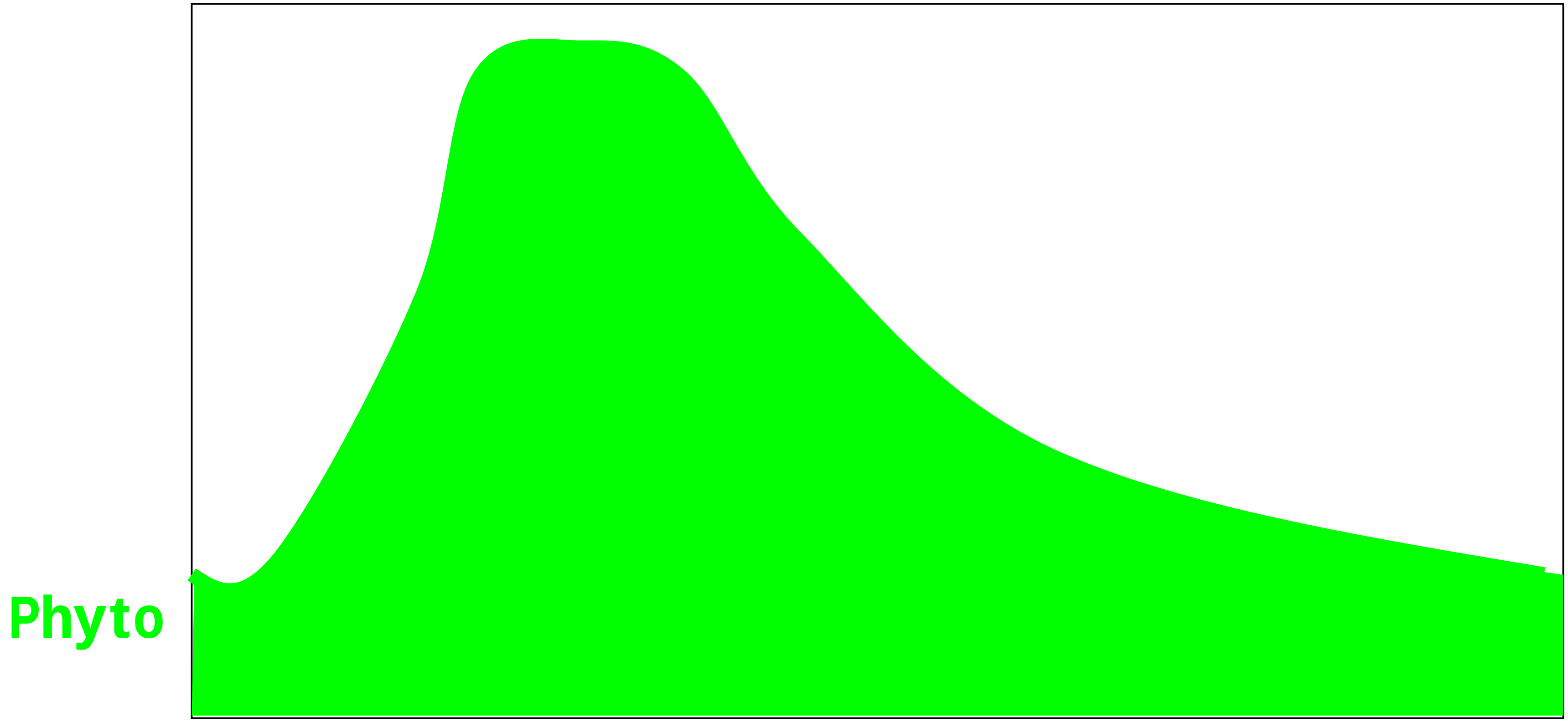


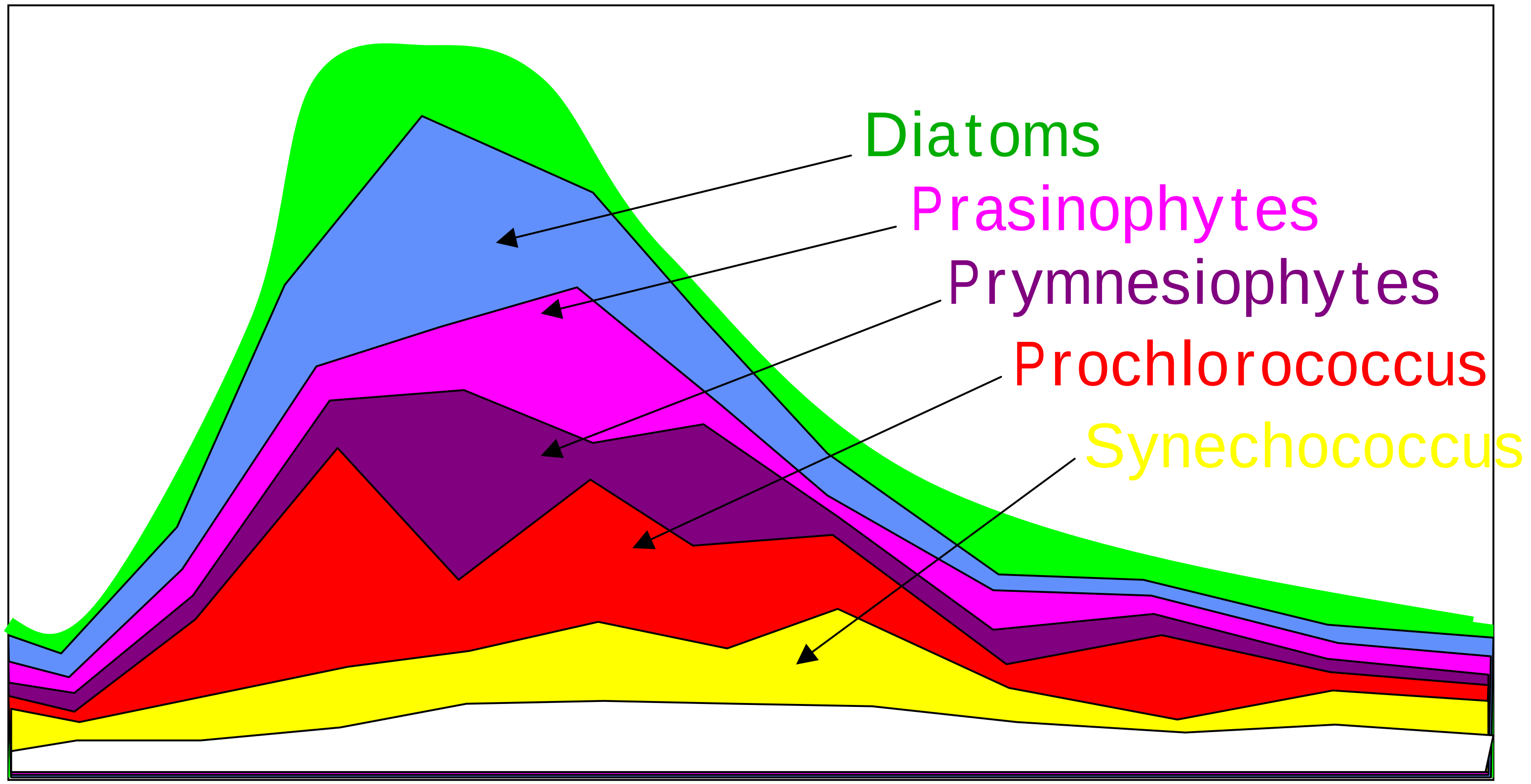
So, what are we *really* asking?

Does it matter what biology is hidden within each box?



Is this level of details necessary to understand the carbon cycle?

Phyto



Rephrase the Question

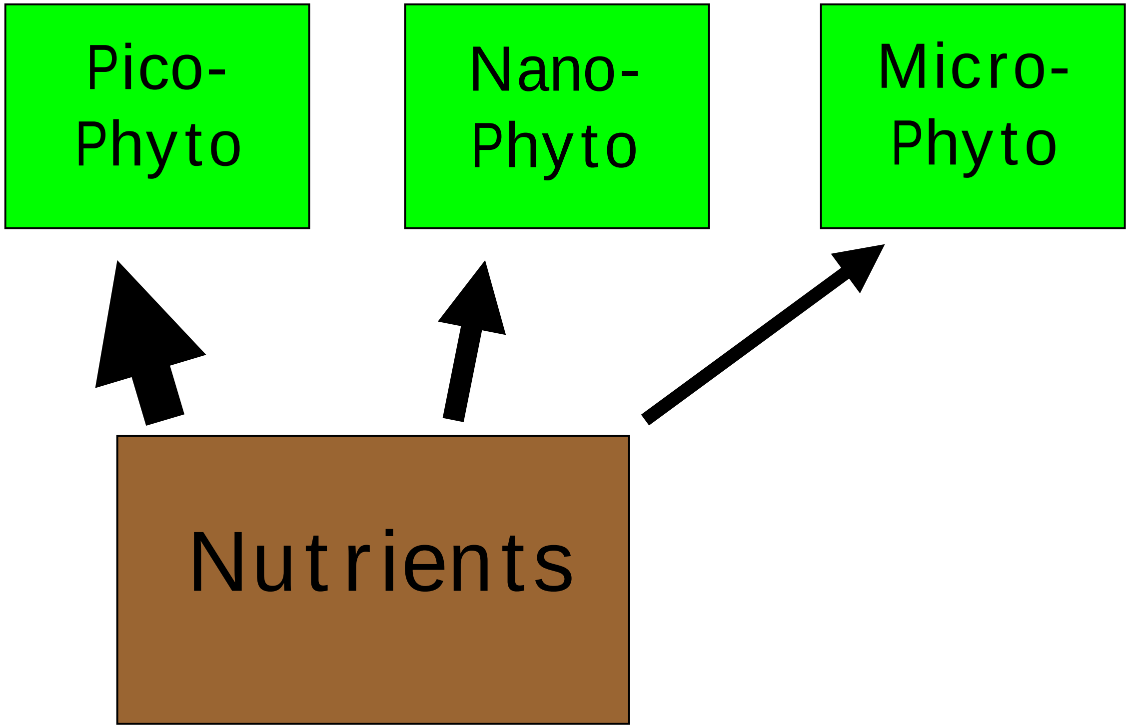
Do we need more structure than P-Z-N-B to capture the important carbon dynamics for *global* scales?

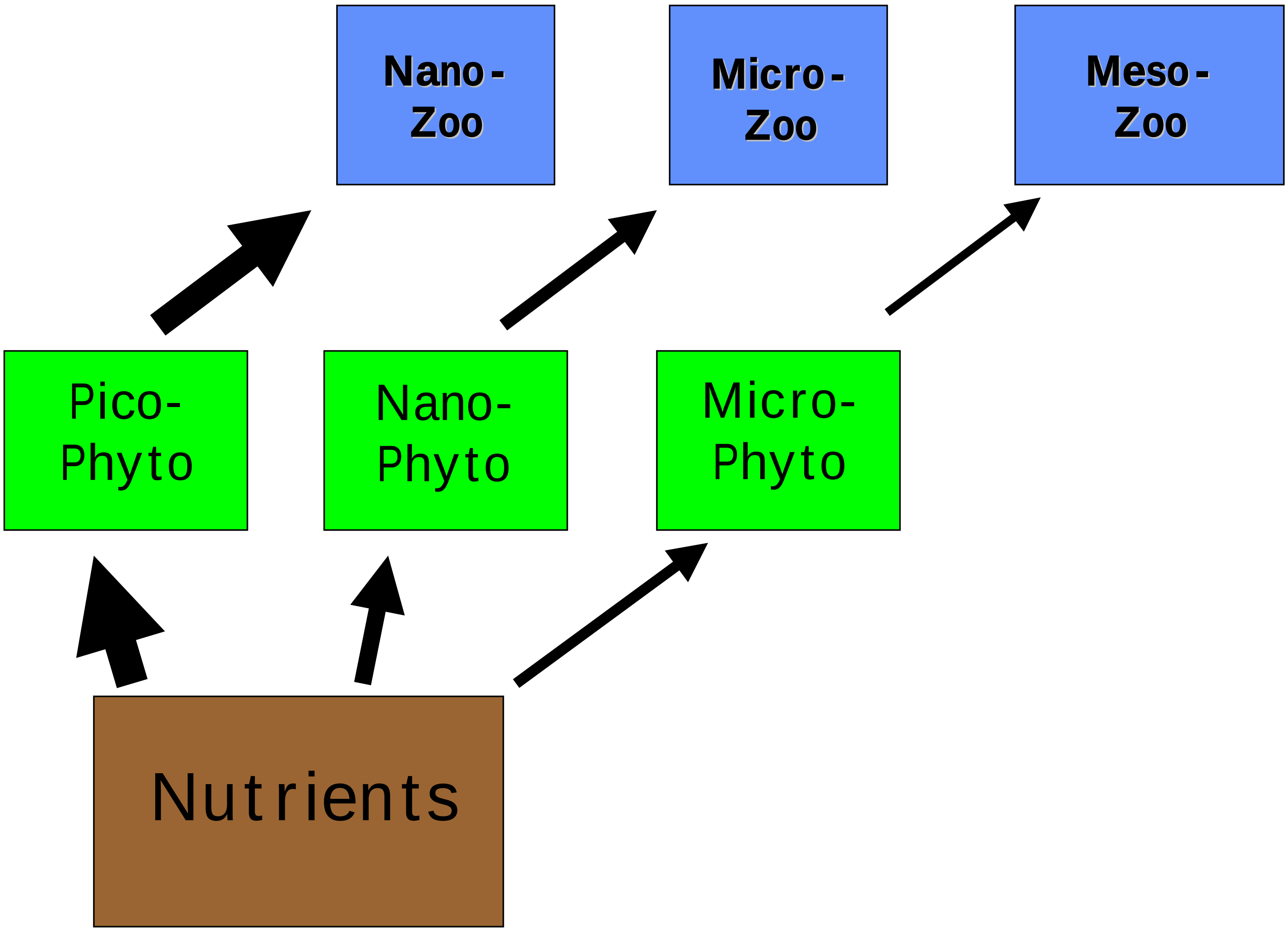
(*e.g.,* more phytoplankton, more zooplankton, viruses, marine snow, etc.)

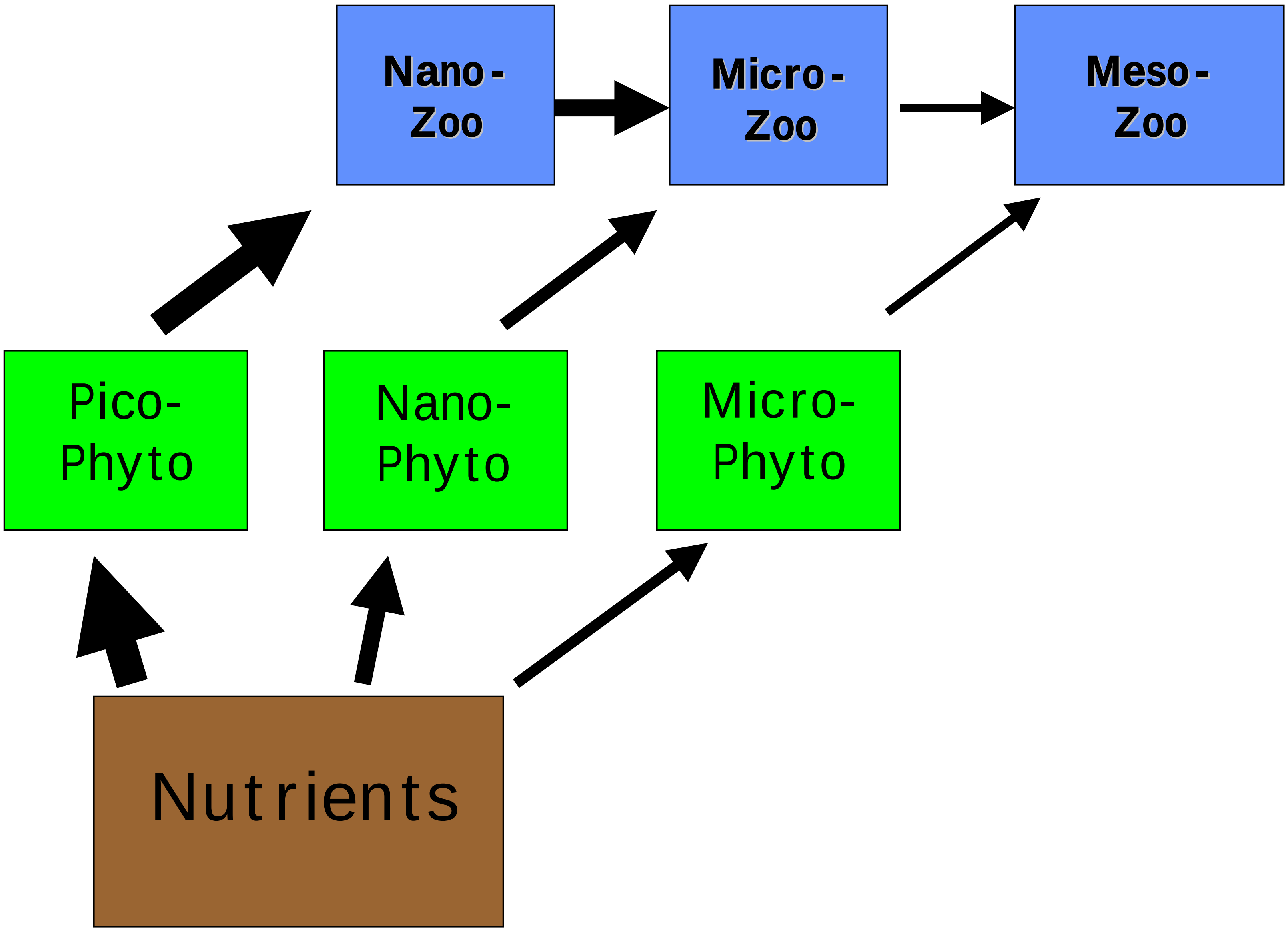
Community Structure and Flux: Circa 1988

Start with big size range of plants

Pico-Phyto	Nano-Phyto	Micro-Phyto
<2 µm	2-20 µm	20-200 µm


Pico-
Phyto
Nano-
Phyto
Micro-
Phyto
Nutrients


Nano-
Zoo
Micro-
Zoo
Meso-
Zoo
Pico-
Phyto
Nano-
Phyto
Micro-
Phyto
Nutrients


Nano-
Zoo
Micro-
Zoo
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Zoo
Pico-
Phyto
Nano-
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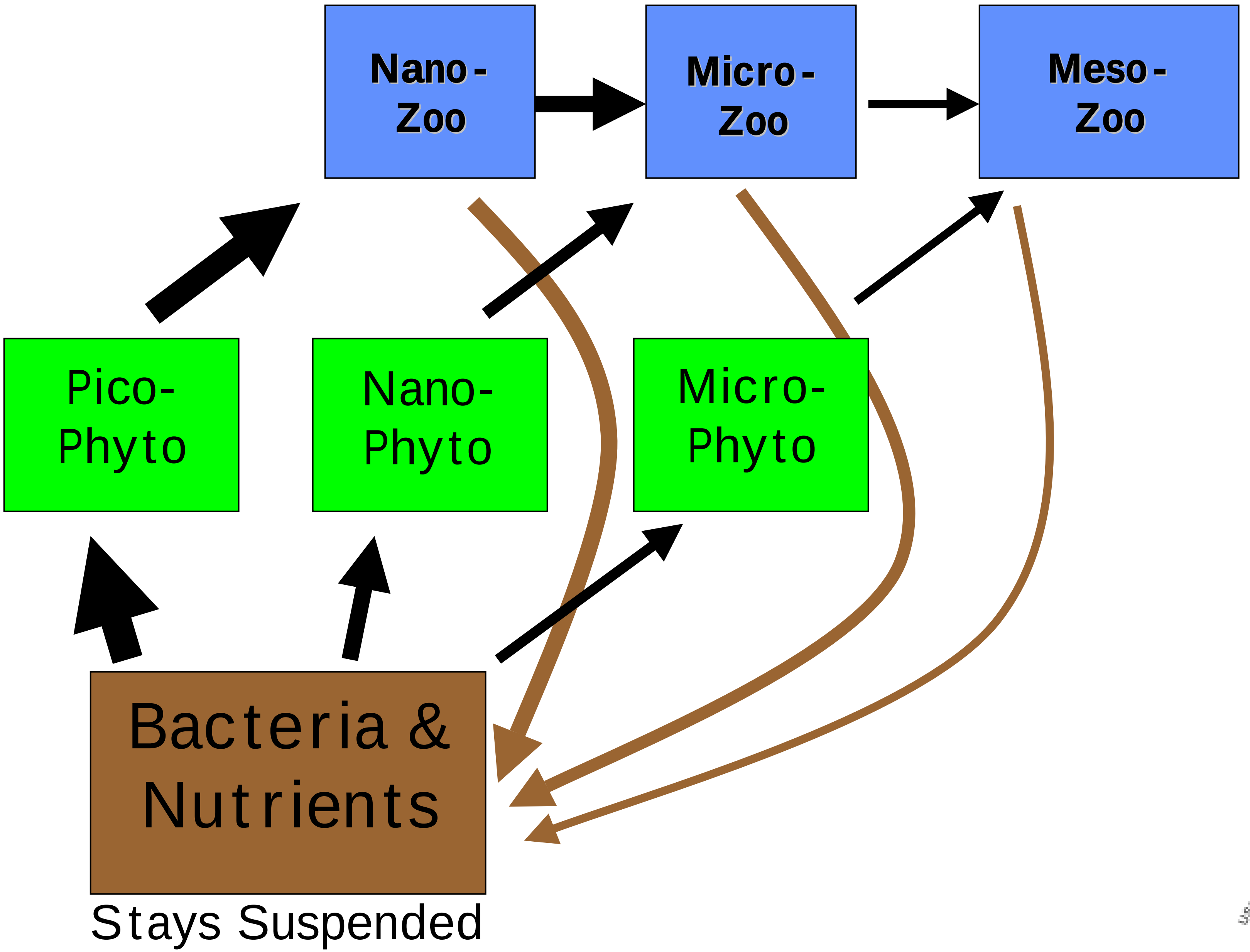
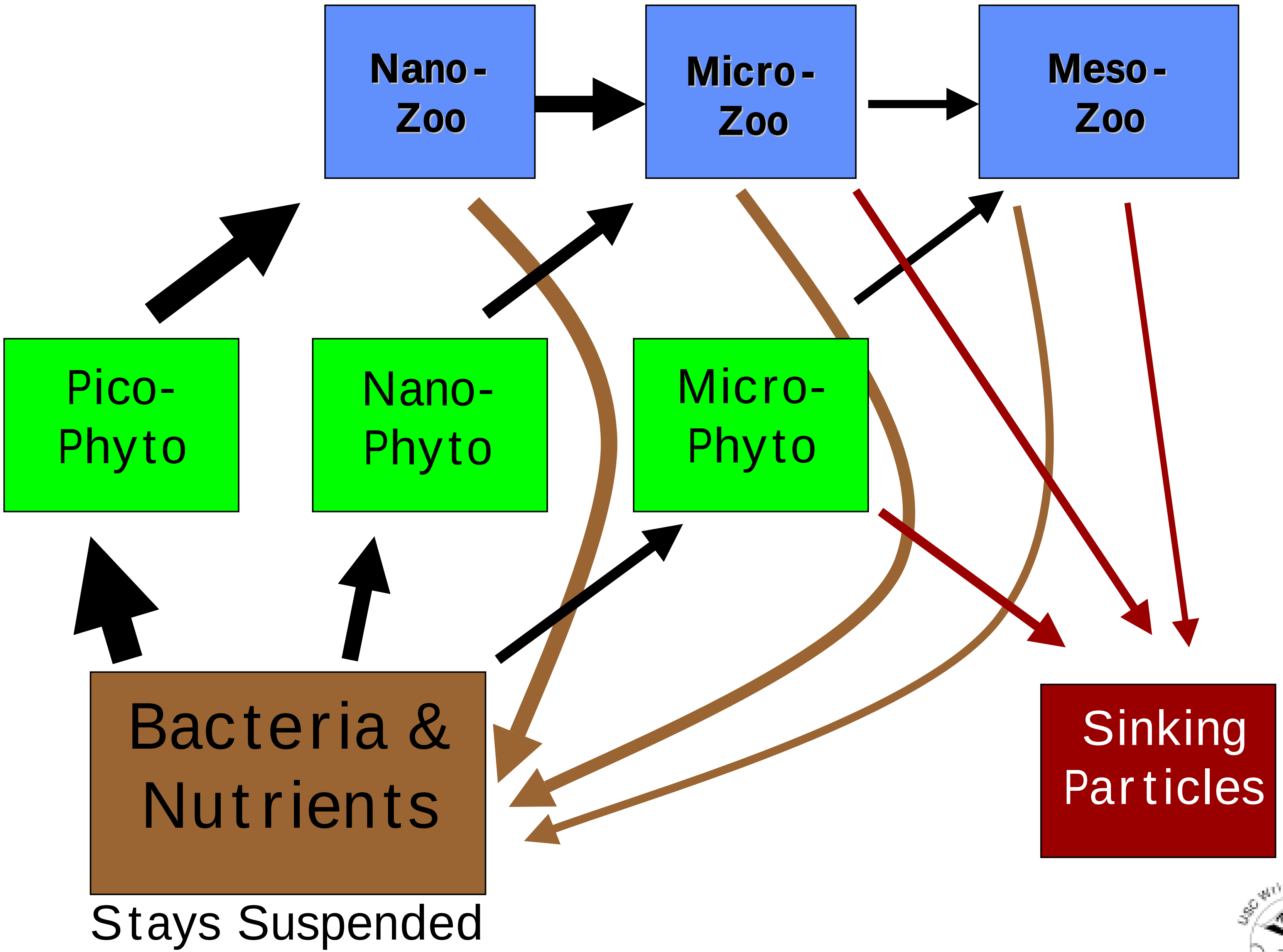
Micro-
Phyto
Nutrients

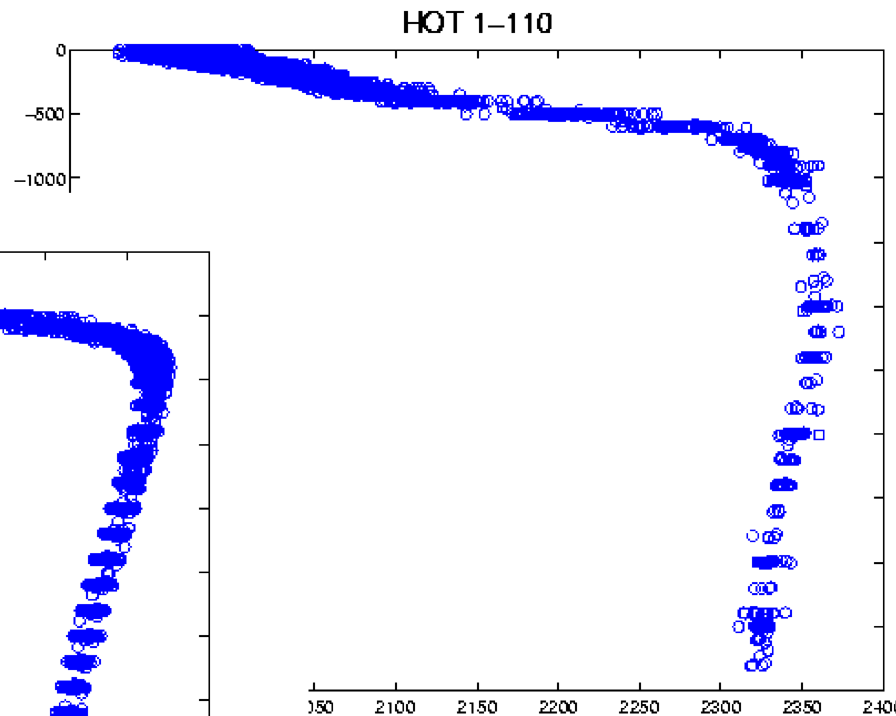

Nano-
Zoo
Micro-
Zoo
Meso-
Zoo
Pico-
Phyto
Nano-
Phyto
Micro-
Phyto
Bacteria &
Nutrients
Stays Suspended


Nano-
Zoo
Micro-
Zoo
Meso-
Zoo
Pico-
Phyto
Nano-
Phyto
Micro-
Phyto
Bacteria &
Nutrients
Stays Suspended
Sinking
Particles

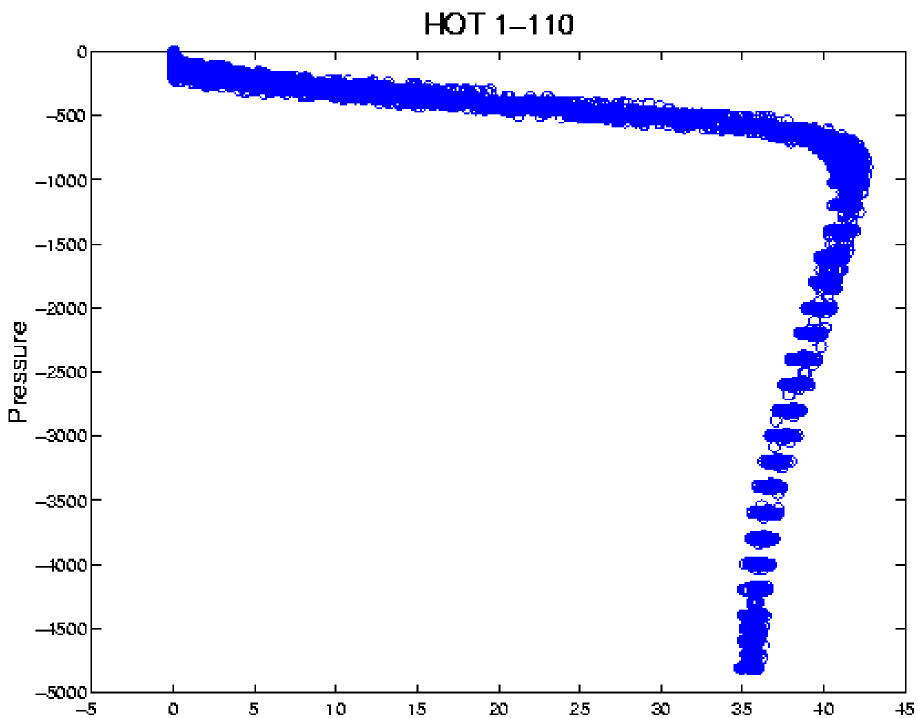
Foodwebs and Flux - 1988

- Focus on f-ratio and the amount of export from surface waters
- "Ryther-esque" outcome (# trophic steps, transfer efficiency)
- Imply that removal of carbon from surface is directly related to exchange with atmosphere

Ocean biology maintains a vertical DIC gradient: Balance of biology and physics



Dissolved Inorganic Carbon



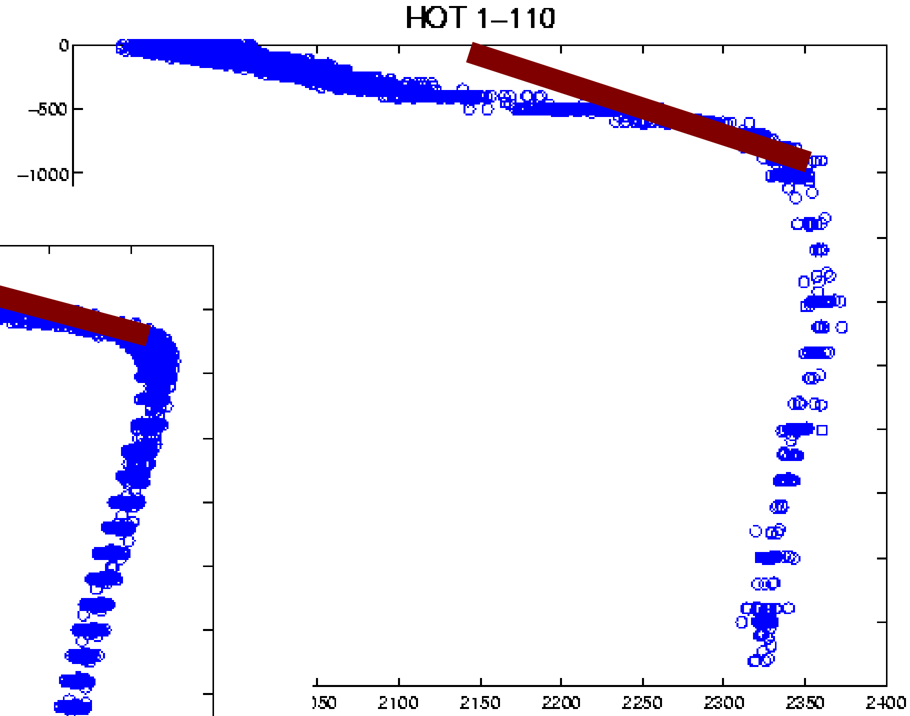
Nitrate+Nitrite

What Processes Have Significant Affects on Air-Sea Partitioning of Carbon Dioxide?

1. Incomplete Nutrient Utilization (HNLC)
2. Particulate Inorganic Carbon:Organic Carbon Ratio
3. Changes in Nitrogen fixation:Denitrification balance (LNLC)
4. Changes in Remineralization Length-scales

Do food webs matter for any of these?

1. Incomplete Nutrient Utilization in the Surface Waters (HNLC)



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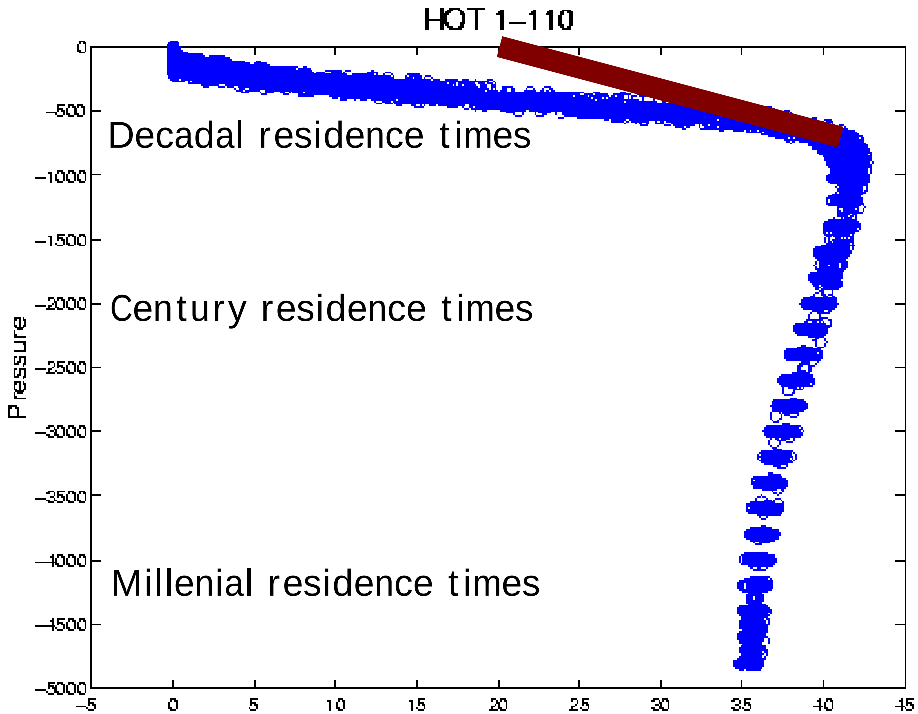
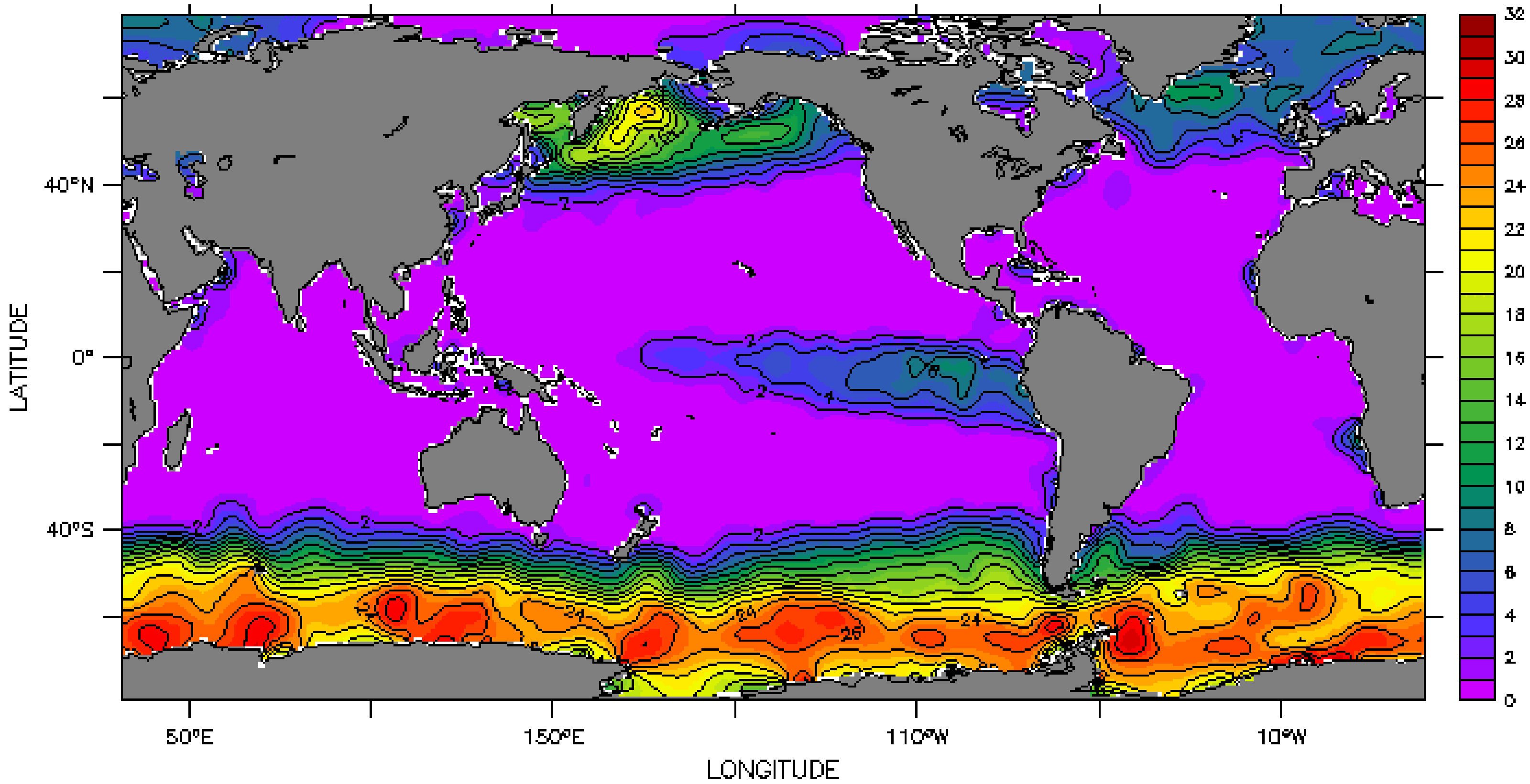


Nitrate+Nitrite

Most of the ocean shows near-complete nutrient utilization



Surface Nitrate (μmoles/kg)

Low Nutrient Areas

If nutrient levels stay near detection and
if C:N:P stoichiometry is constant,

then P-Z-N might be enough for the global carbon models

- Those are some big "**if**s"
- There is more of interest on this planet than just global carbon

HNLC Regions

Changes in net utilization of surface nutrients changes DIC gradient and air-sea partitioning (within limits)

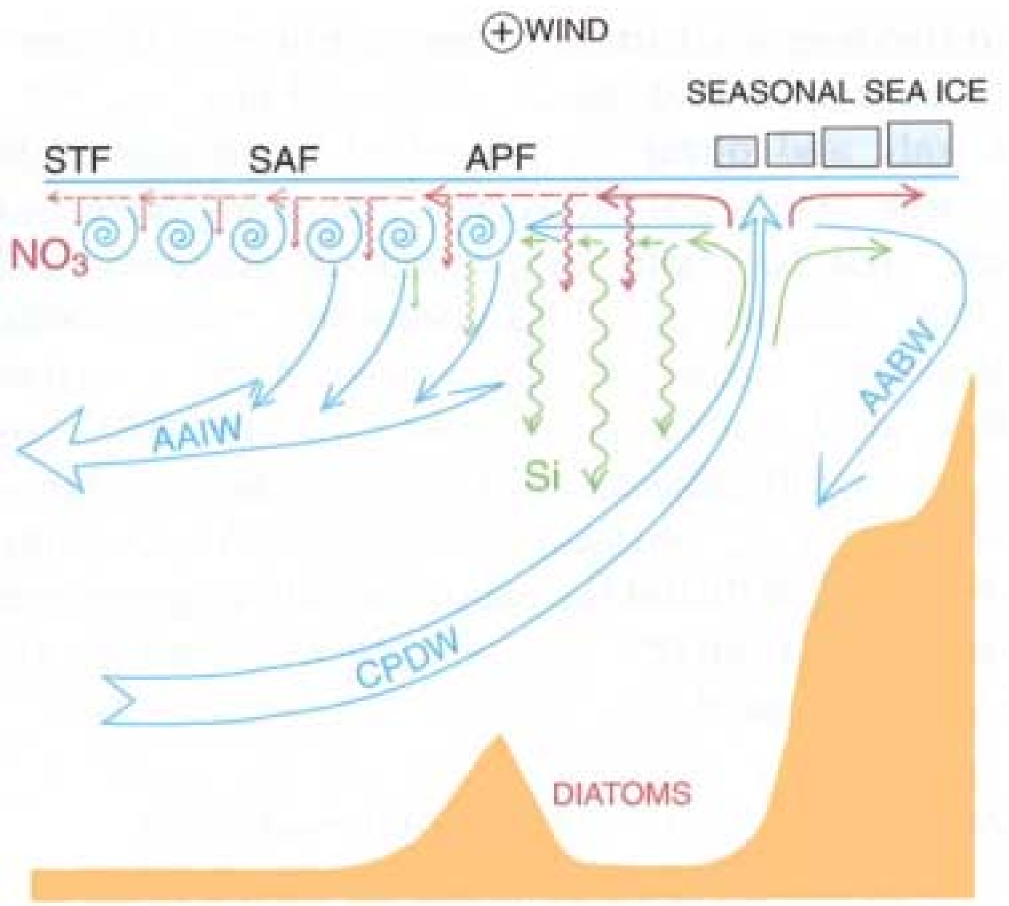
- High-nutrient, low chlorophyll areas (HNLC) in Southern Ocean, Equatorial Pacific, North Pacific and some coastal zones

- Trace nutrient limitation (Fe), Diatom blooms (Si)

- Reduce HNLC area - 15-100 ppm reduction in atm CO_2

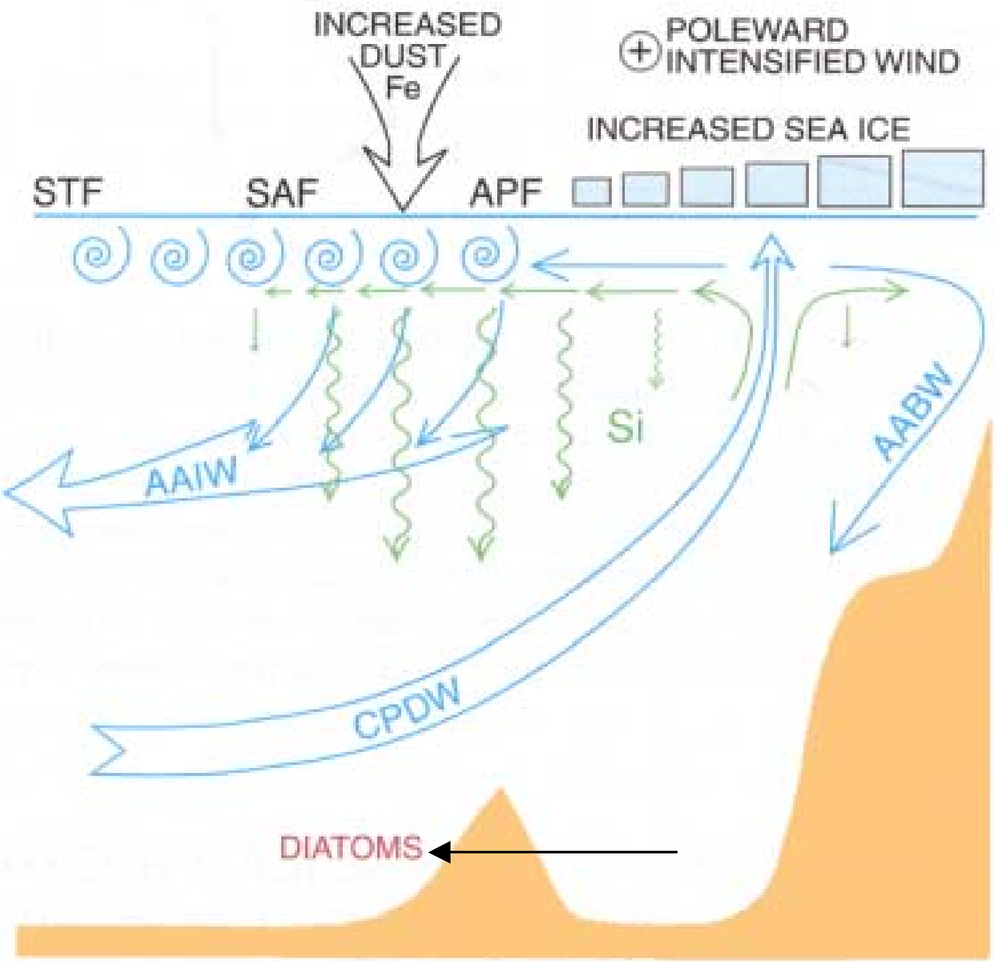
- Amenable to direct manipulation (political hot potato)

Nutrient Cycling in the Modern Southern Ocean



(Anderson et al., 2002)

Nutrient Cycling in the Glacial Southern Ocean



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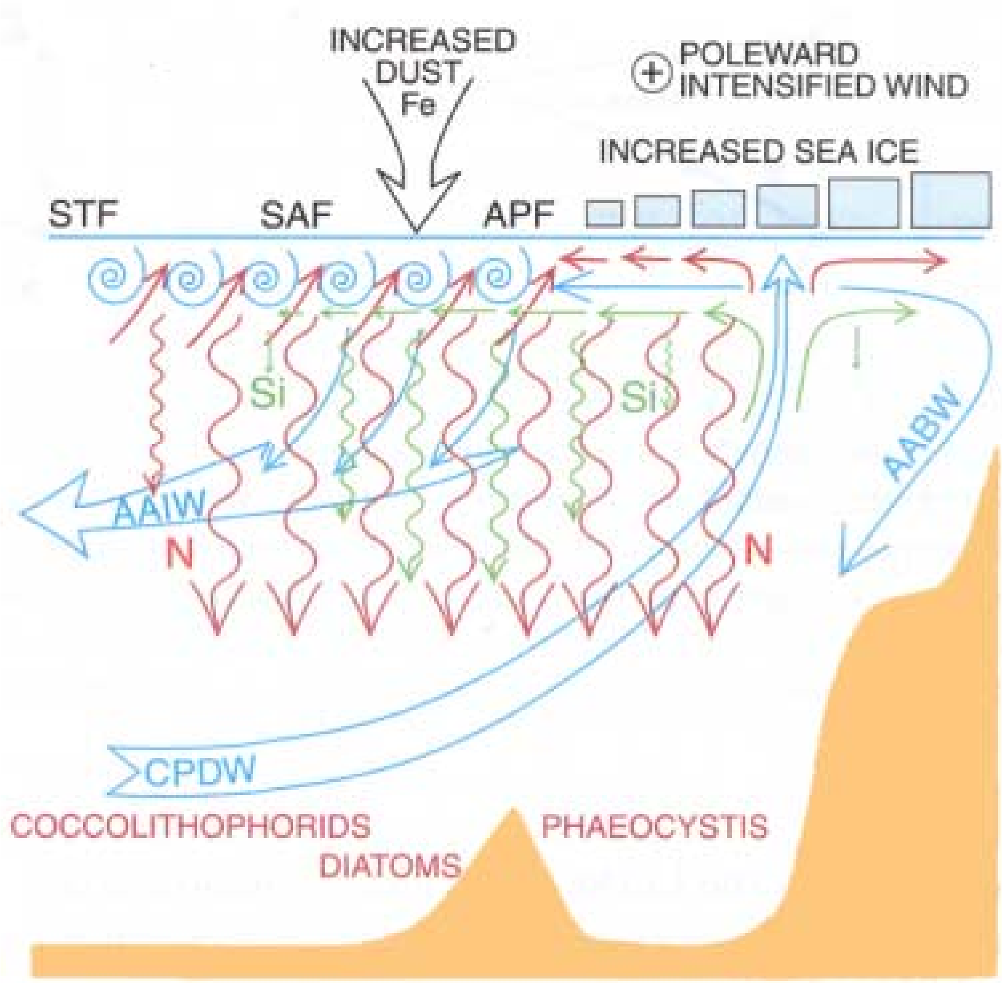

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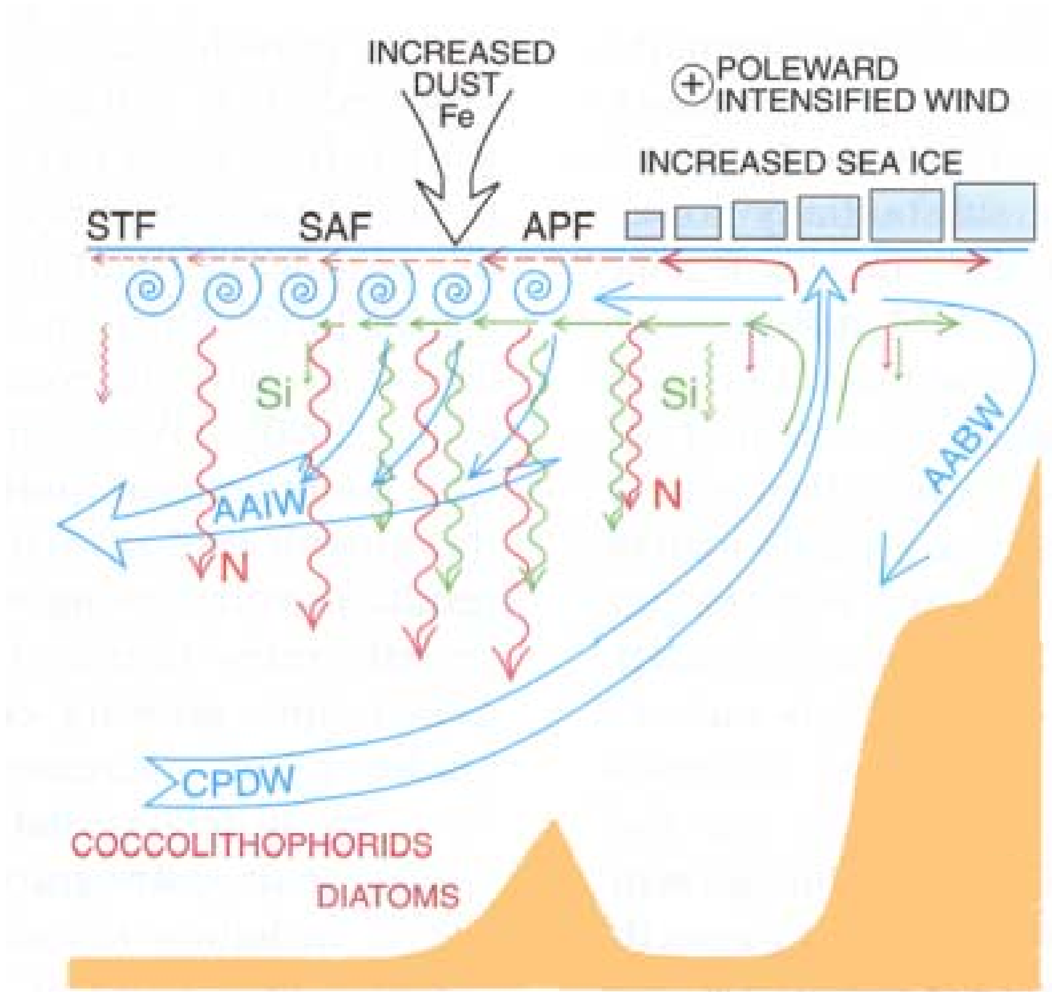


(Anderson et al., 2002)

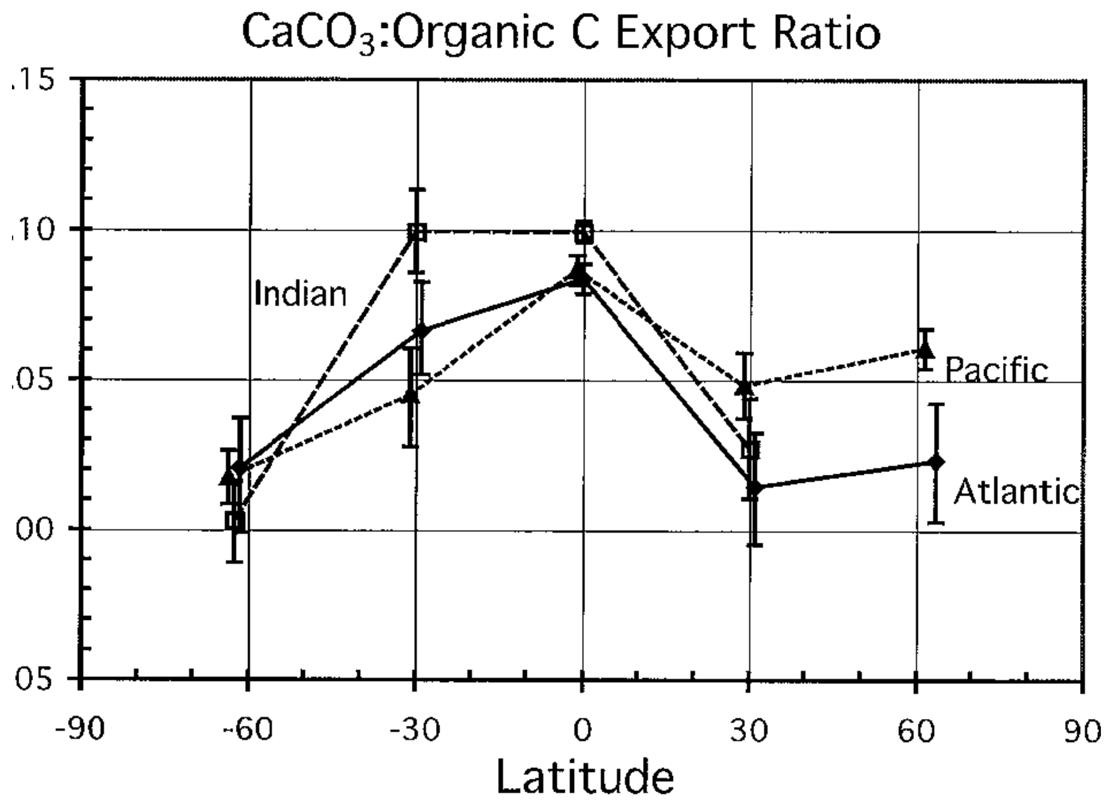
1. Incomplete Nutrient Utilization in the Surface Waters (HNLC)

Influence of Community Structure?

- Taxa-specific responses to Fe
- Si+N requirements in diatoms, N requirements in other phytoplankton
- Taxa-specific grazing responses
- Ballasting issues

2. Changes in Particulate Inorganic Carbon Flux

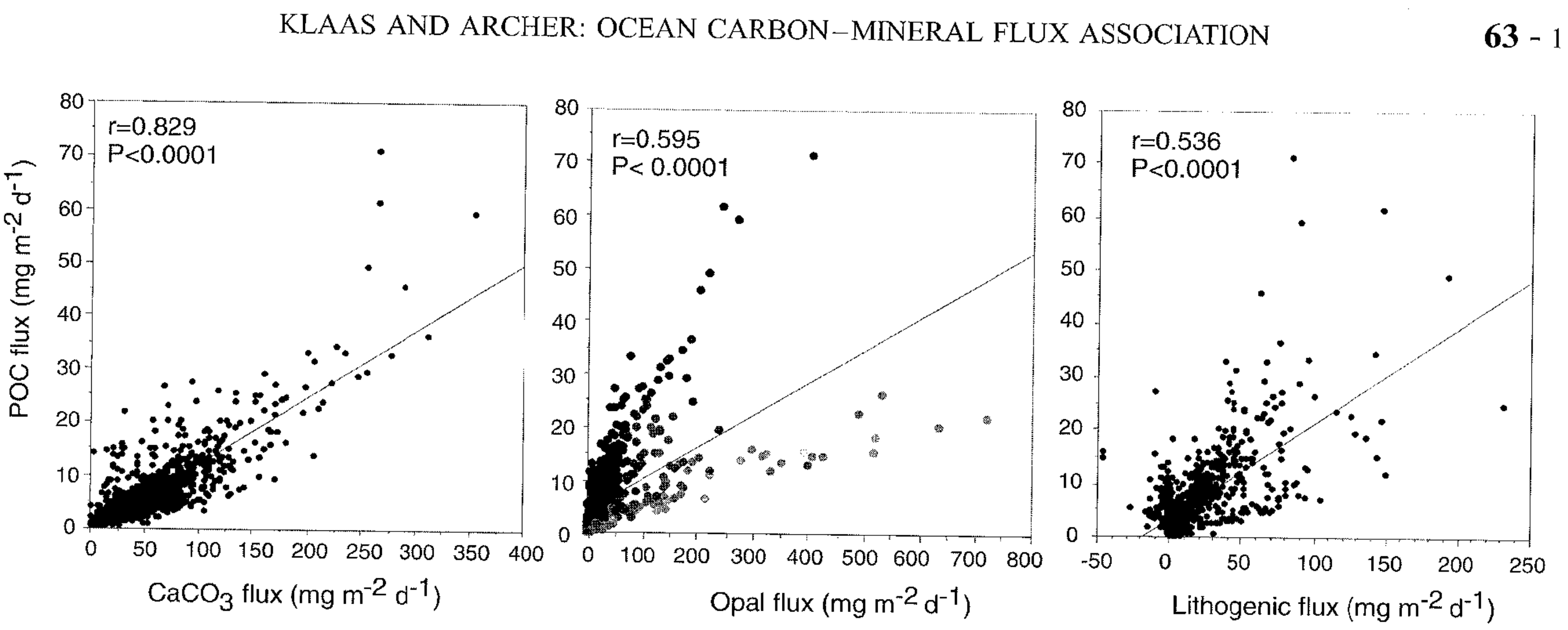
- Archer and Maier-Reimer, 1994
- Skeletons of coccolithophorids, foraminifera and pteropods
- Alkalinity change! Increase in PIC flux -> increase in pCO_2
- Net effect on atmosphere depends on PIC:POC ratio
- Community structure effects analogous to remineralization length scale



(Sarmiento et al., 2002)

Carbonate Flux Linked to Organic Carbon Flux via Ballasting

(a la Armstrong et al, 2002)



(Klaas and Archer, 2002)

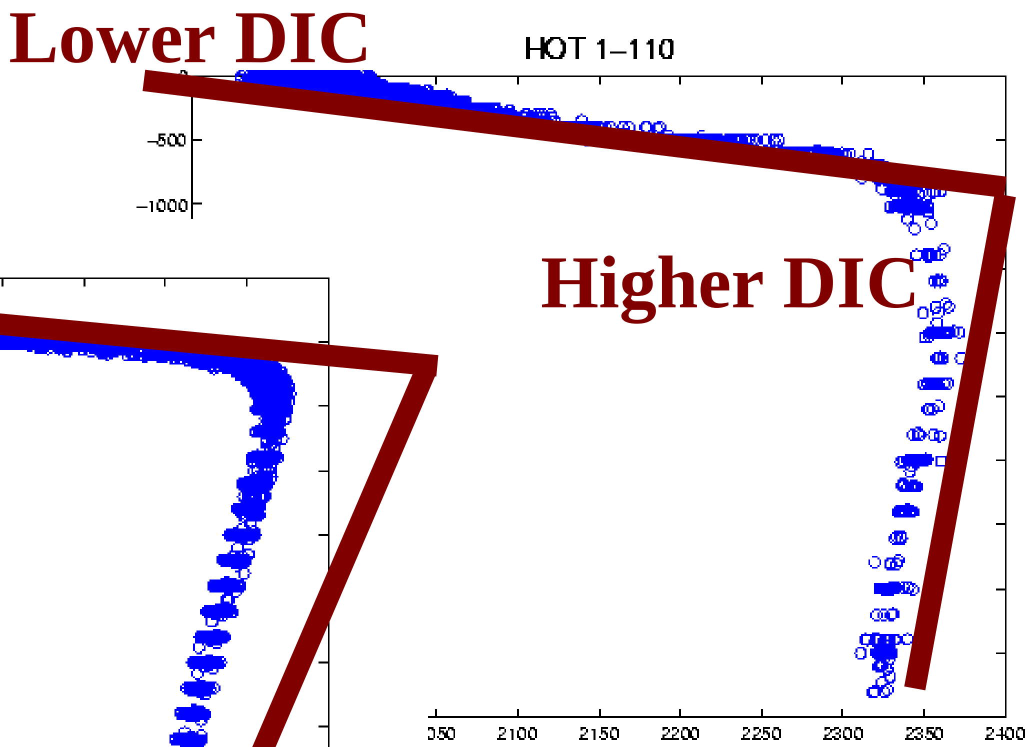
2. Changes in Particulate Inorganic Carbon Flux

Influence of Community Structure?

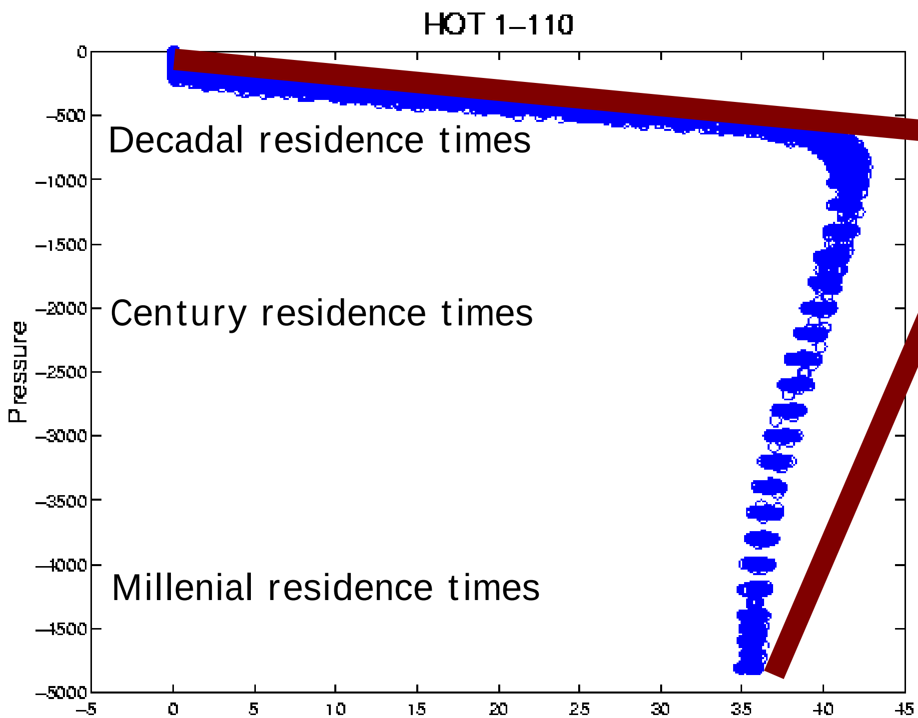
- Carbonate skeletons found in a subset of taxa: coccolithophorids, foraminifera and pteropods
- Ecosystem dynamics will determine relative contributions of these taxa
- Mix of autotrophs and heterotrophs - must be mix of top-down and bottom-up controls
- Some of these taxa susceptible to creating blooms
- Ballasting link to organic carbon fluxes, stronger for carbonate fluxes than opal (correlation - causation?)

3. Changes in Nitrogen Fixation - Denitrification Balance

Extra Nitrogen Fixation



Dissolved Inorganic Carbon



Nitrate+Nitrite

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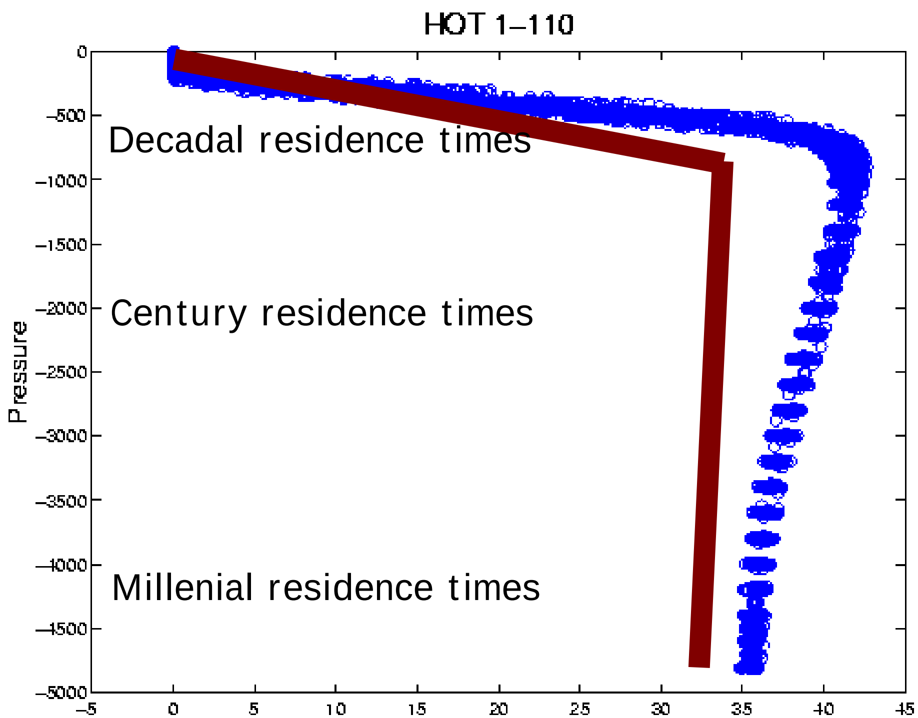
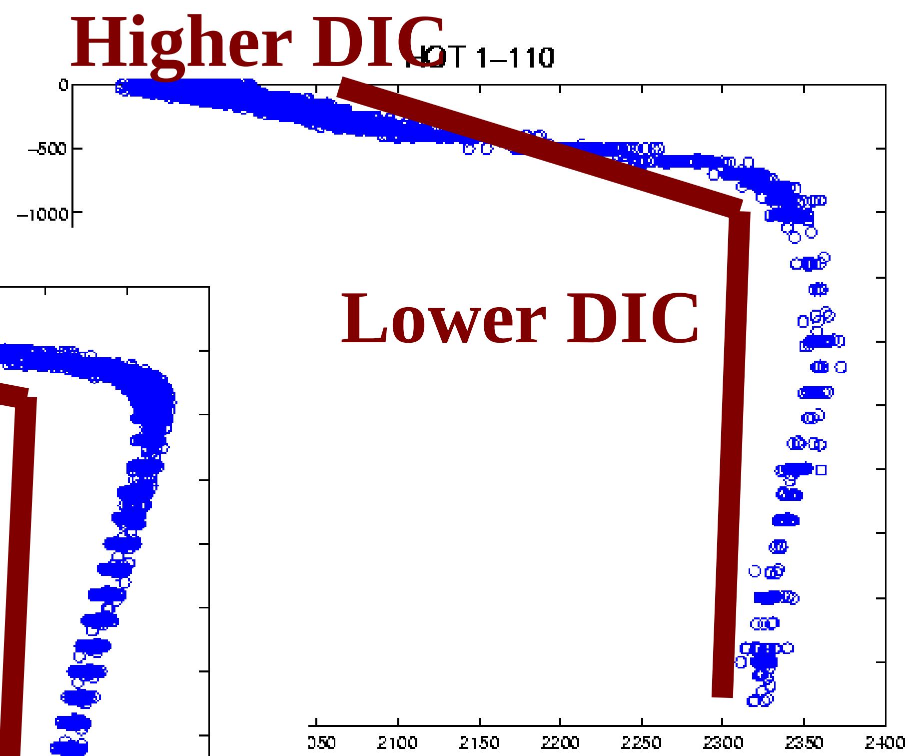
Extra Denitrification

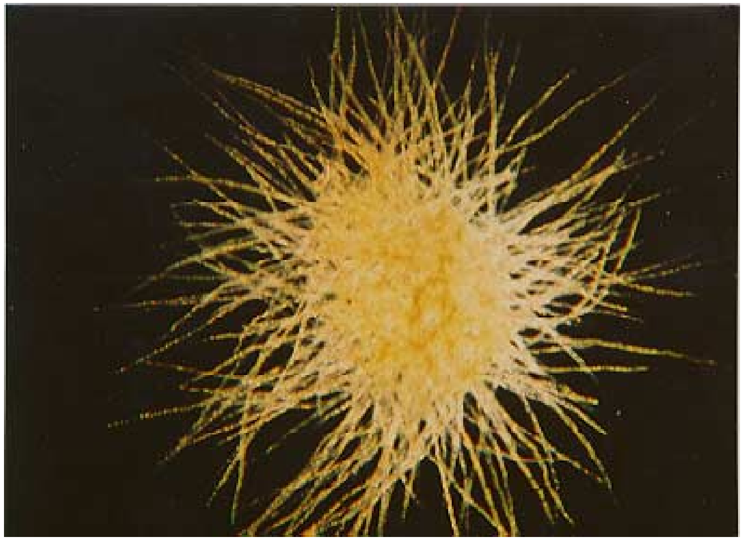


Nitrate+Nitrite



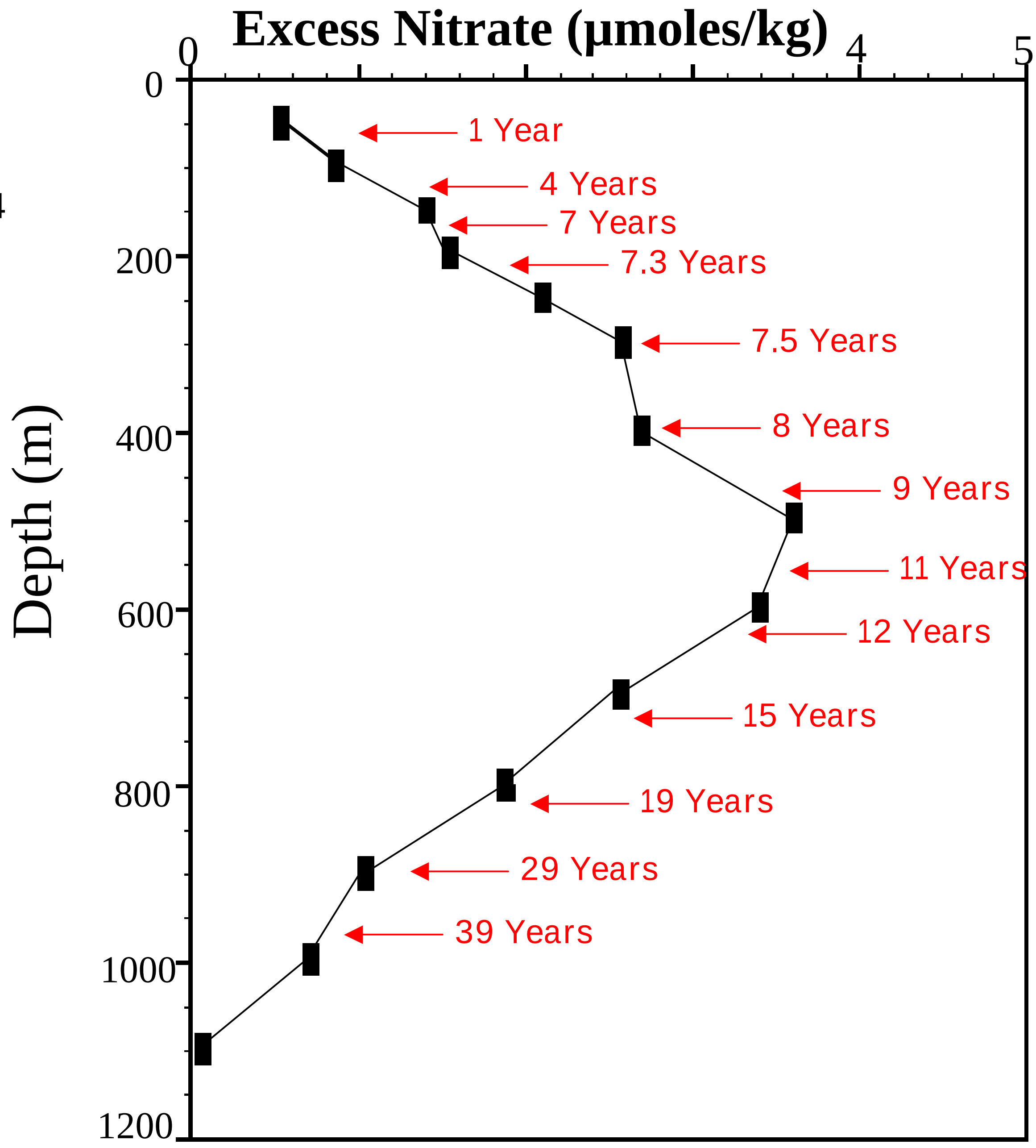
Dissolved Inorganic Carbon

Trichodesmium spp.
Best Known Planktonic Diazotroph

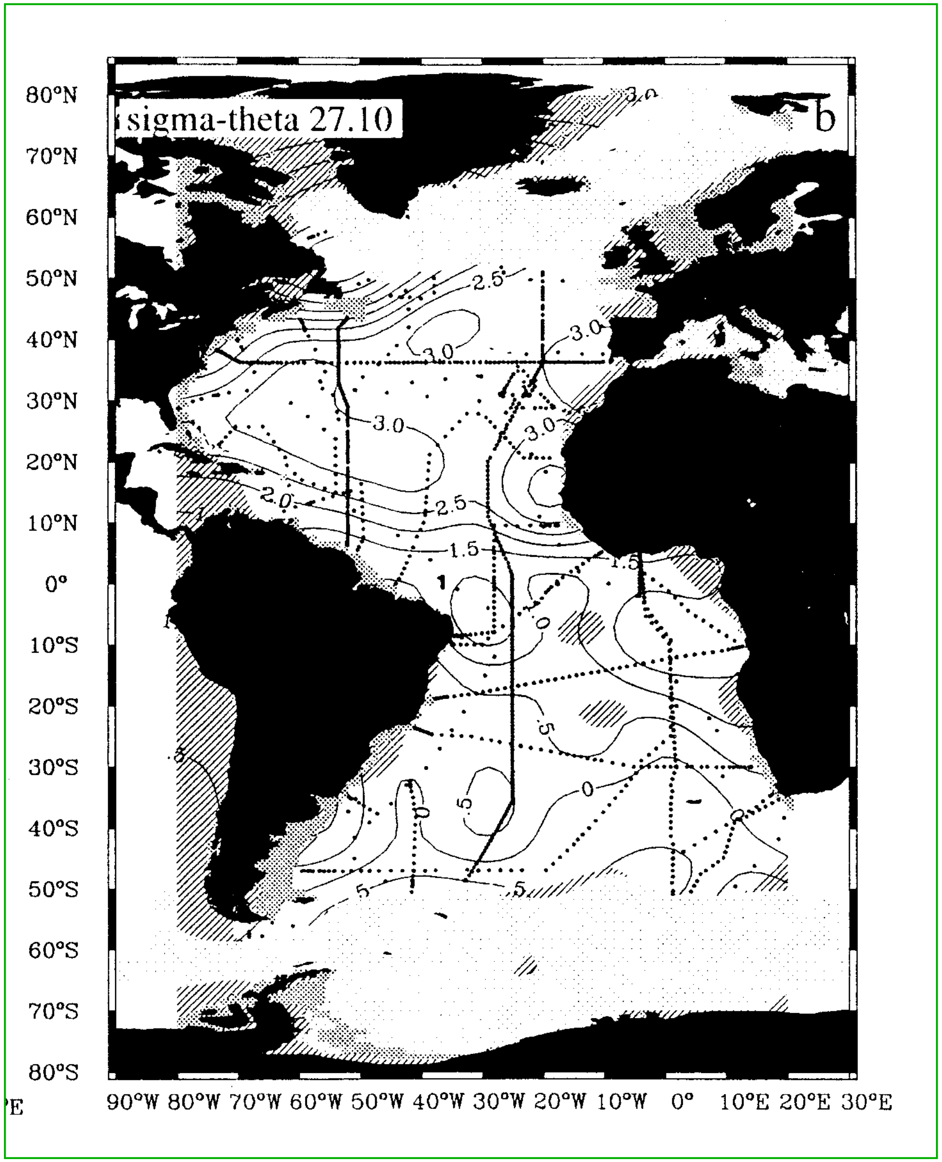


Excess Nitrate
= $NO_3 - 16*PO_4$

Data from BATS

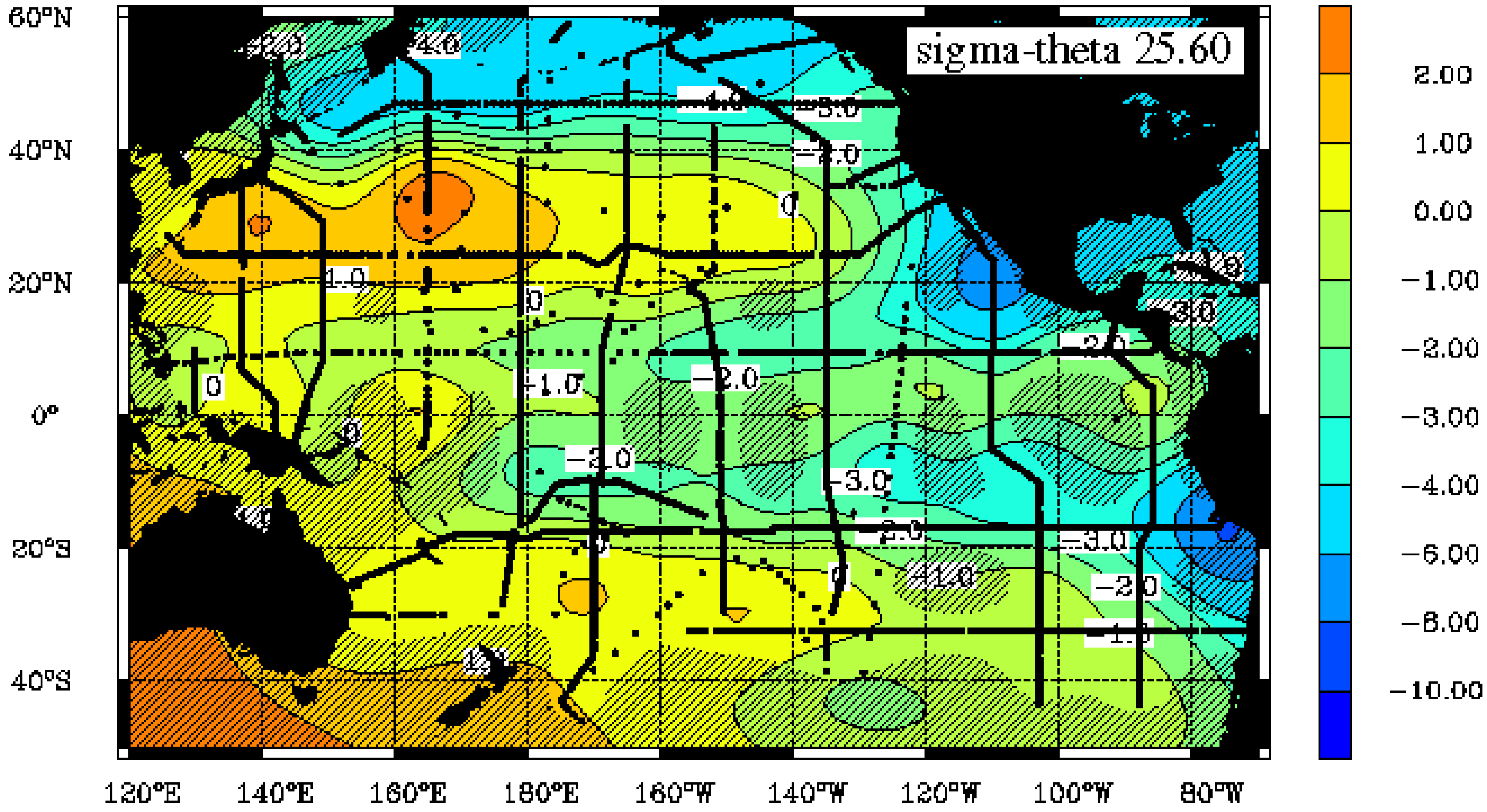


N* in the Atlantic Ocean

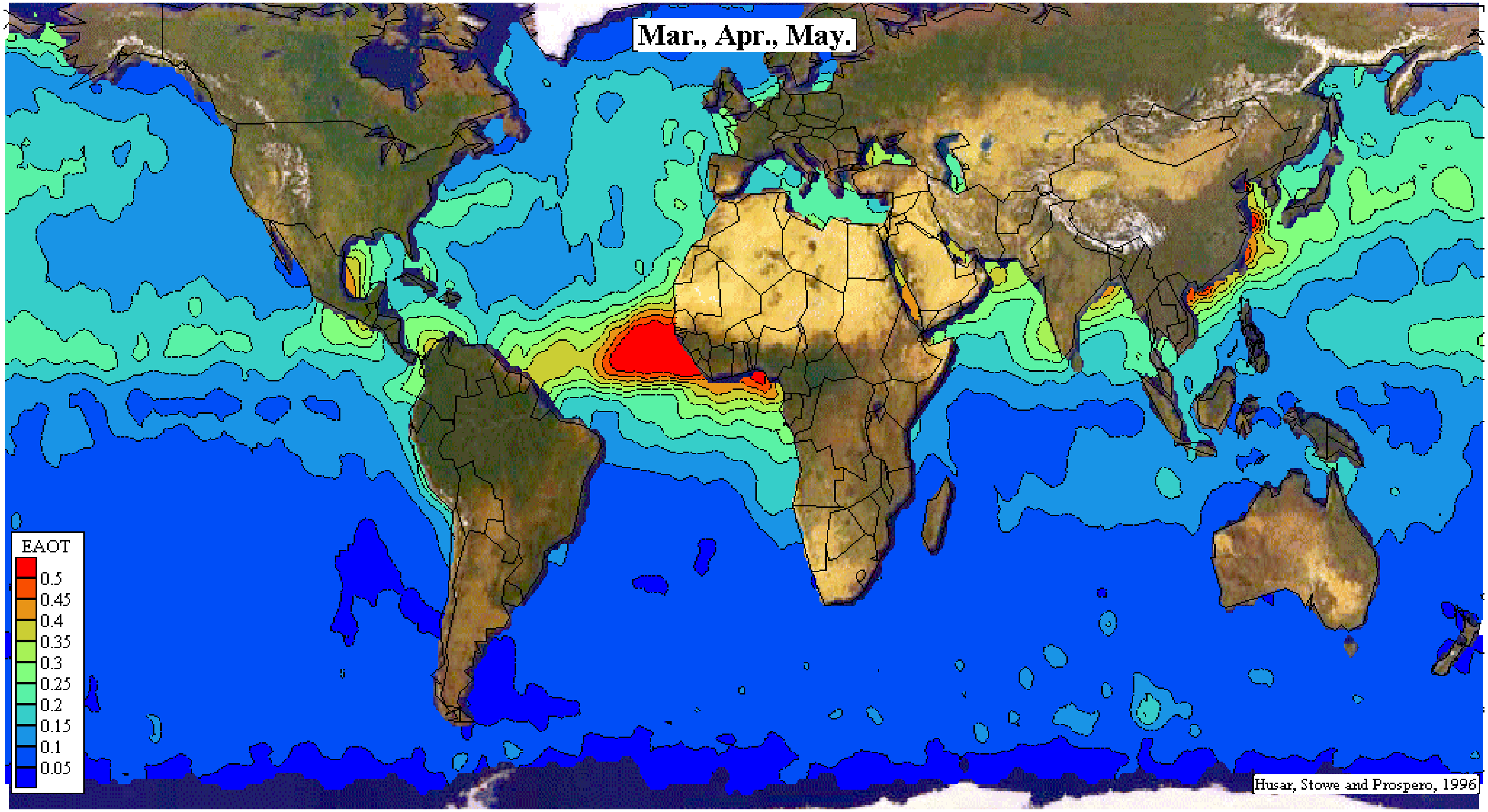


(Gruber and Sarmiento, 1997)

N* in the Pacific Ocean



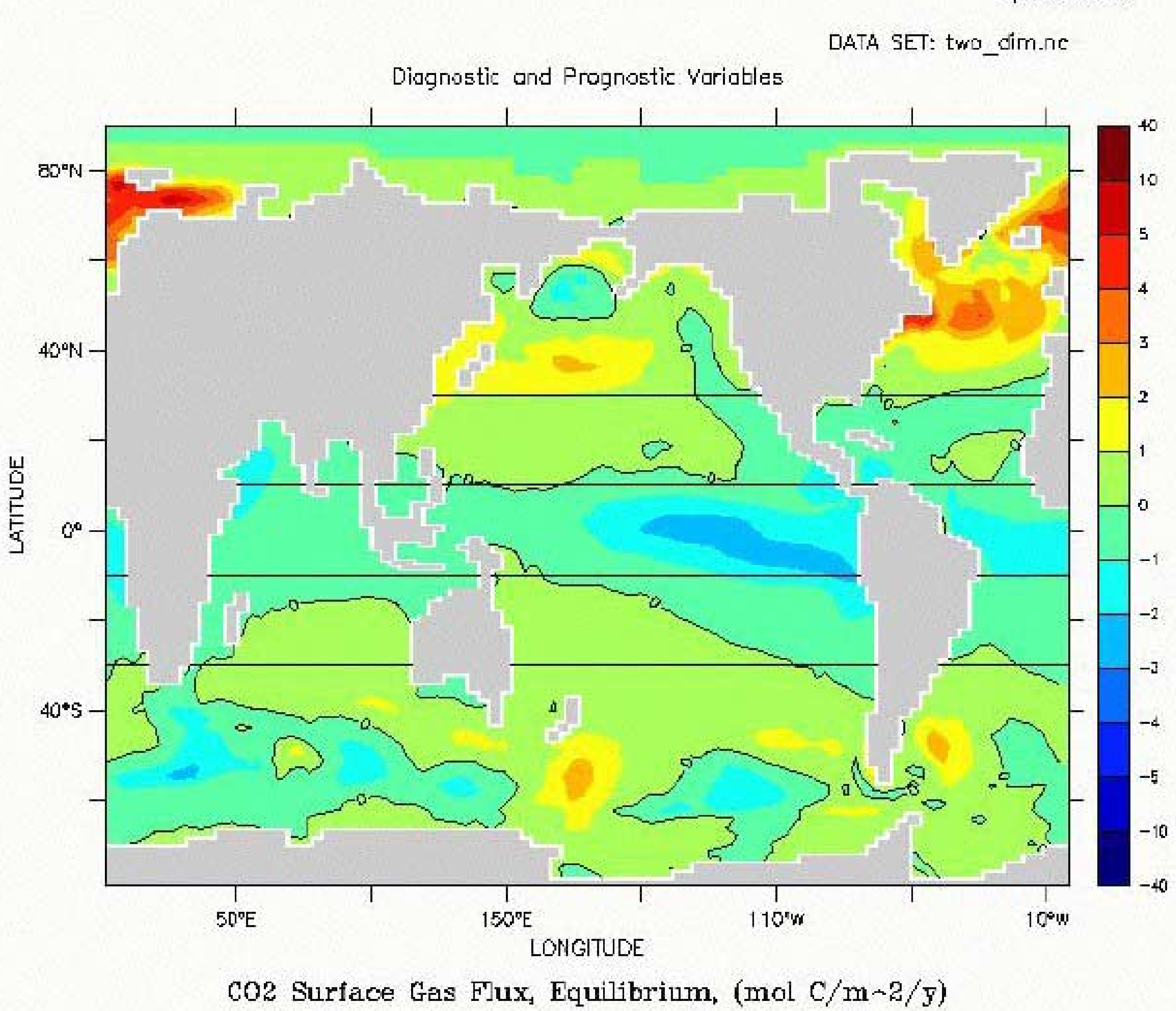
(Deutsch et al., 2001)



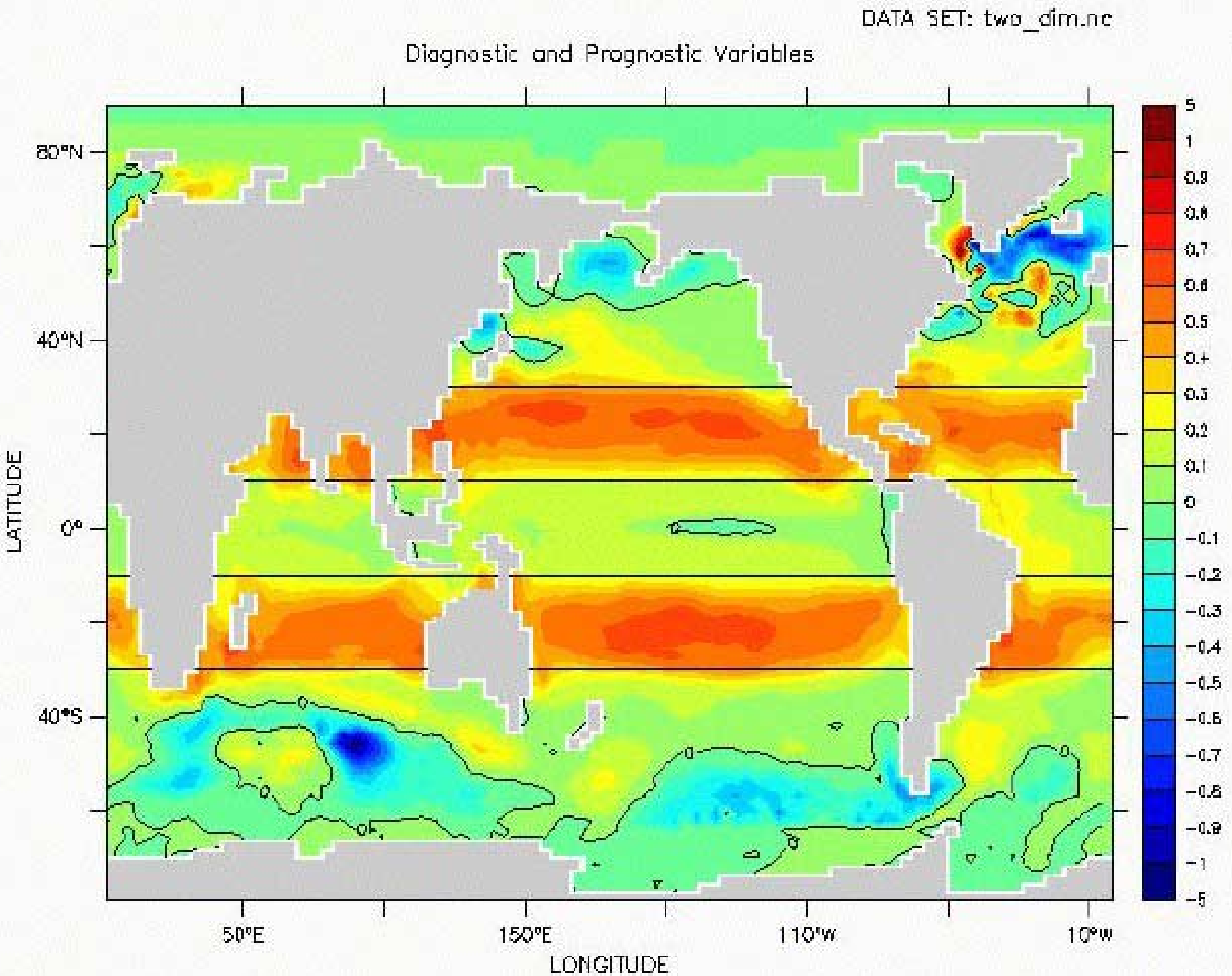
(Husar et al., 1997)

Key Assumptions and Dynamics:

- Iron from dust limits nitrogen fixation
- Reasonable flexibility in N:P ratios and nutrient controls on N-fixation
- Carbon Modeling
  - NCAR Ocean GCM (Doney)
  - Multi-compartment box model (Sigman)
  - Add adequate N fixation for 1 Gt/y C fixation
  - Restrict N fixation to 10-40° (N and S)
  - C:N=6.6, Assume flexible N:P within N* range
  - 100-300 year runs

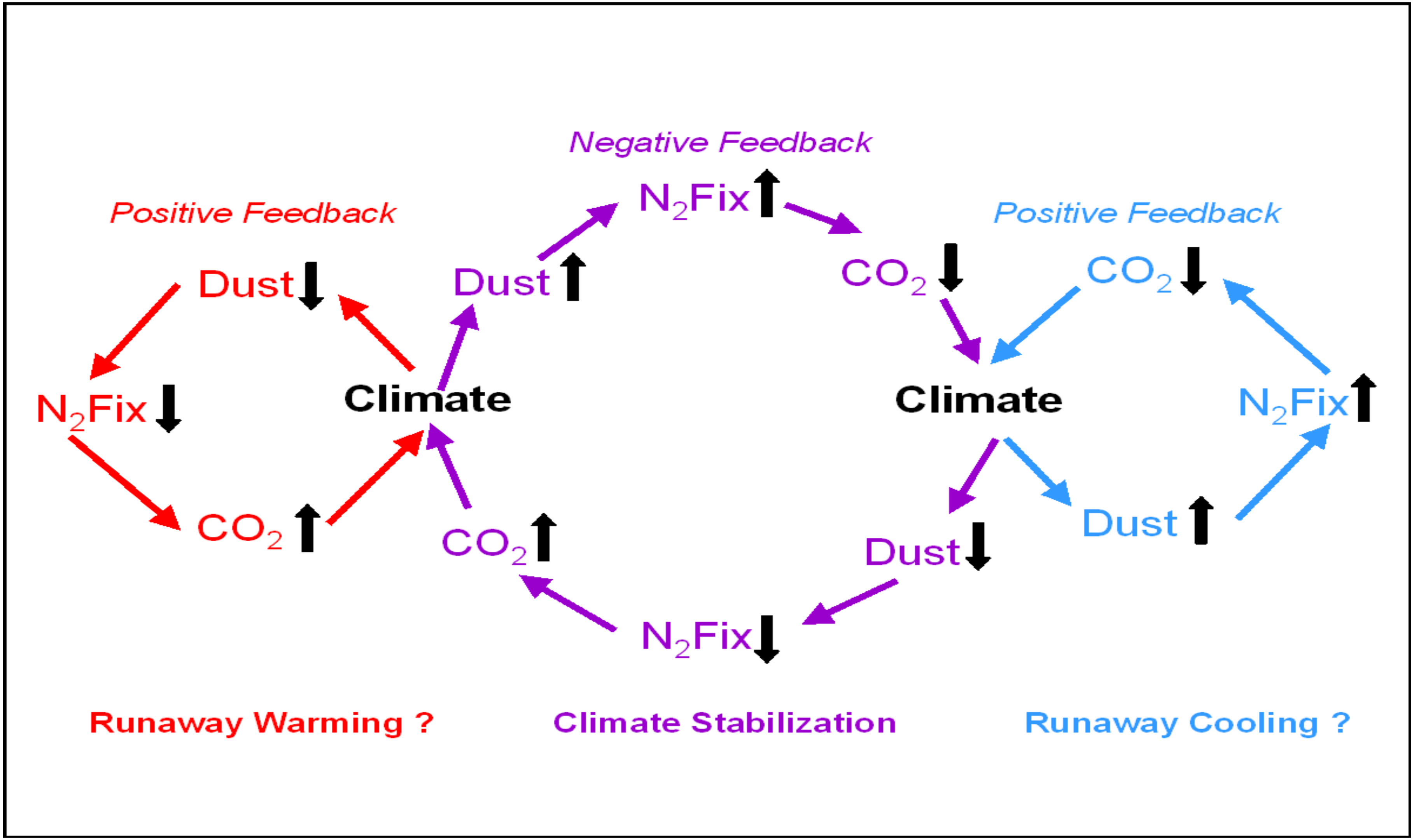


(Doney, Moore in prep)



CO2 Surface Gas Flux, Perturbation, Year 100, (mol C/m~2/y)

(Doney, Moore in prep)



Nitrogen Fixation Feedback Cycle Hypothesis
(as an example)

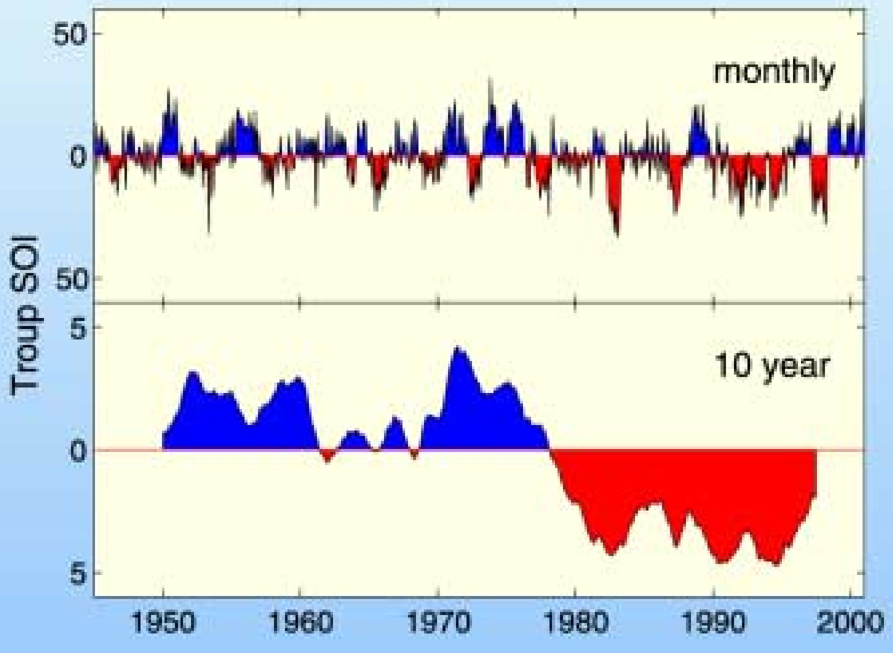
Two Additional Biological Characteristics:

- Diazotrophs form large surface blooms

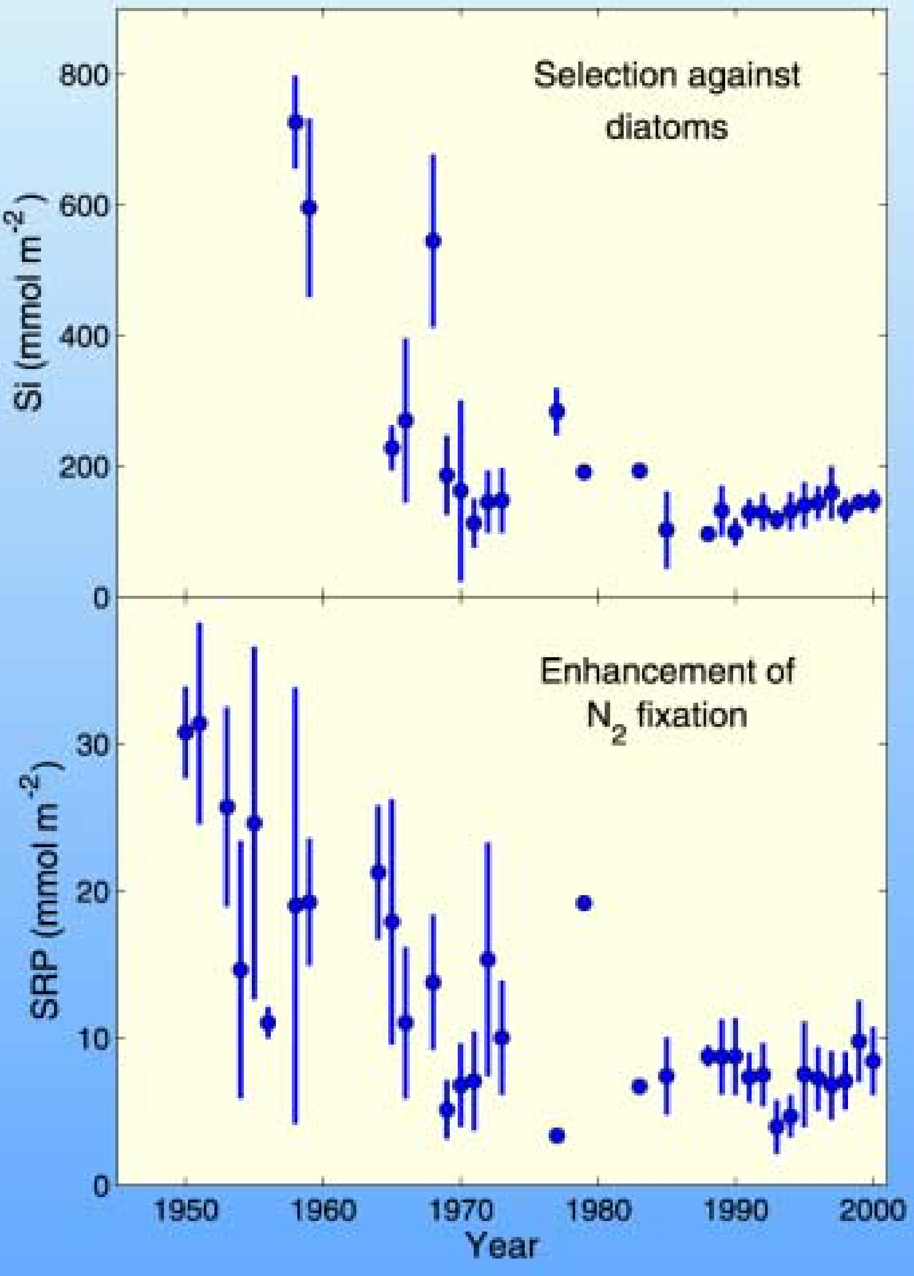
Two Additional Biological Characteristics:

- Diazotrophs form large surface blooms

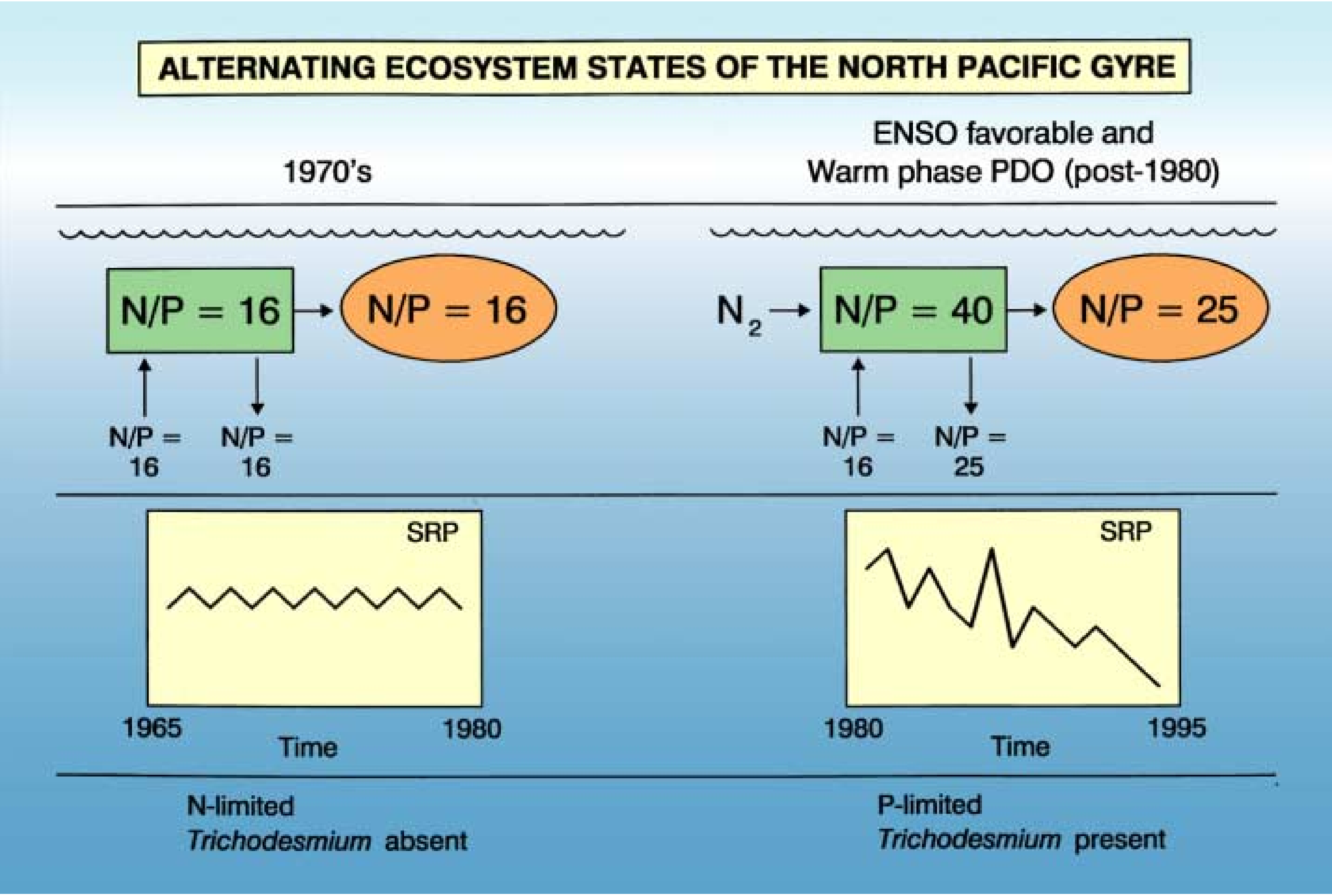
- Nitrogen fixation dynamics seem to change on decadal time-scales (at least in the Pacific Ocean)



NUTRIENT DYNAMICS IN THE NORTH PACIFIC SUBTROPICAL GYRE



Dave Karl and co-workers



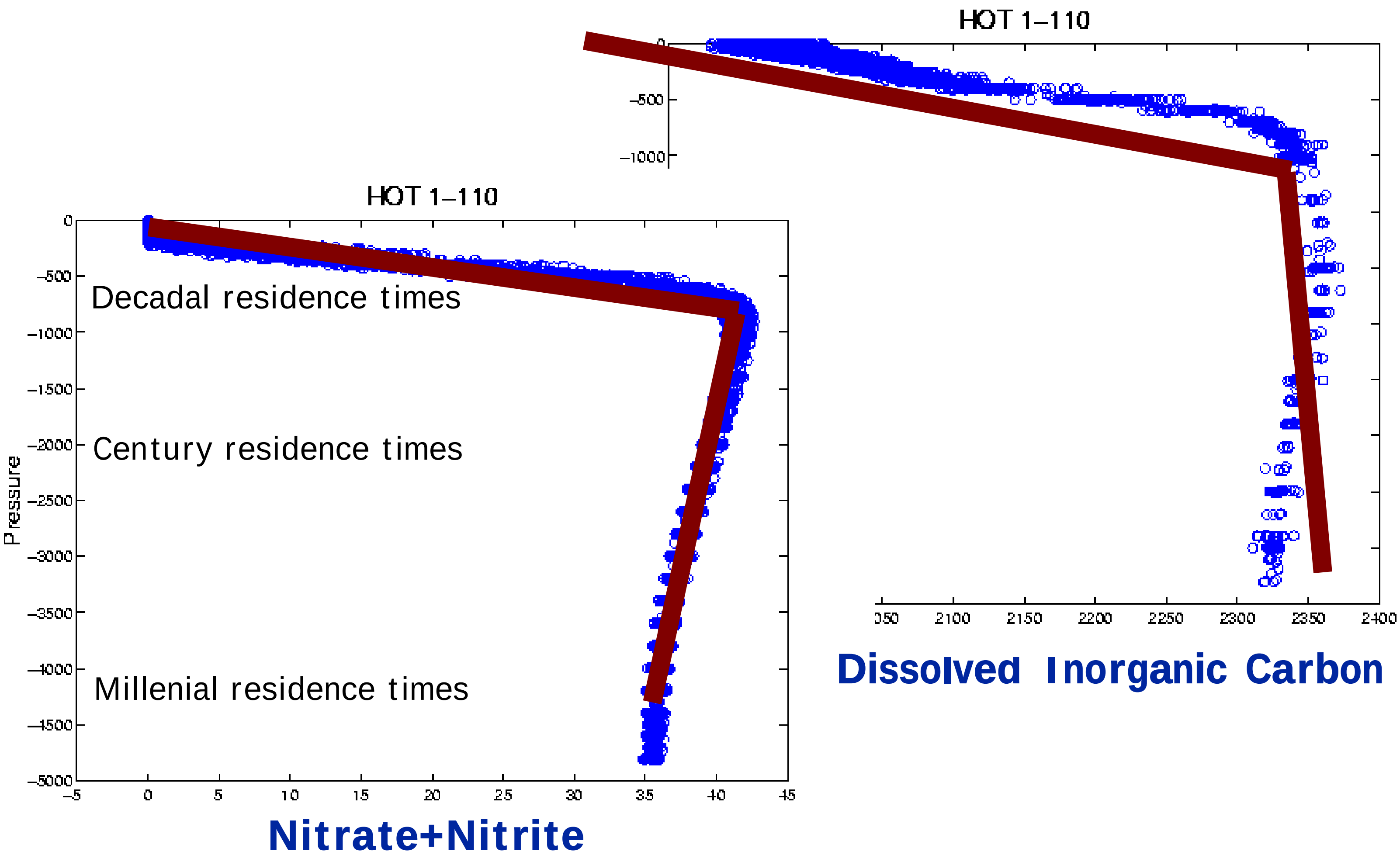
Dave Karl and co-workers

3.Changes in Nitrogen Fixation - Denitrification Balance

Influence of Community Structure?

- Diazotrophy found in a distinct subset of all prokaryotic taxa
- Chemical defenses against grazing in some
- Some taxa symbiotic in eukaryotes (esp. diatoms, creates silica requirement)
- Denitrification - special environmental conditions, specific prokaryotes

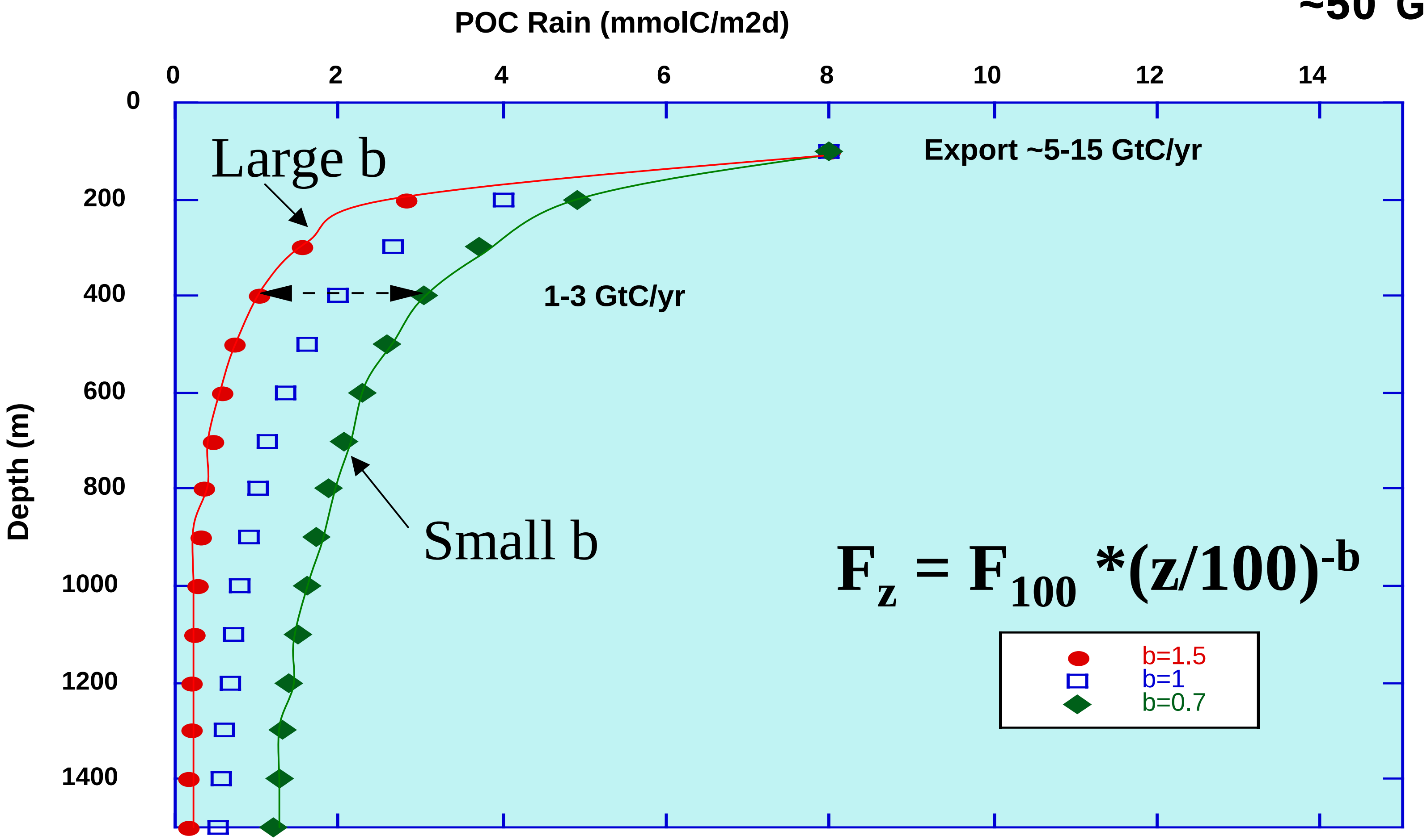
4. Changes in remineralization length-scales and C-N-P stoichiometry



Changes in remineralization length-scales

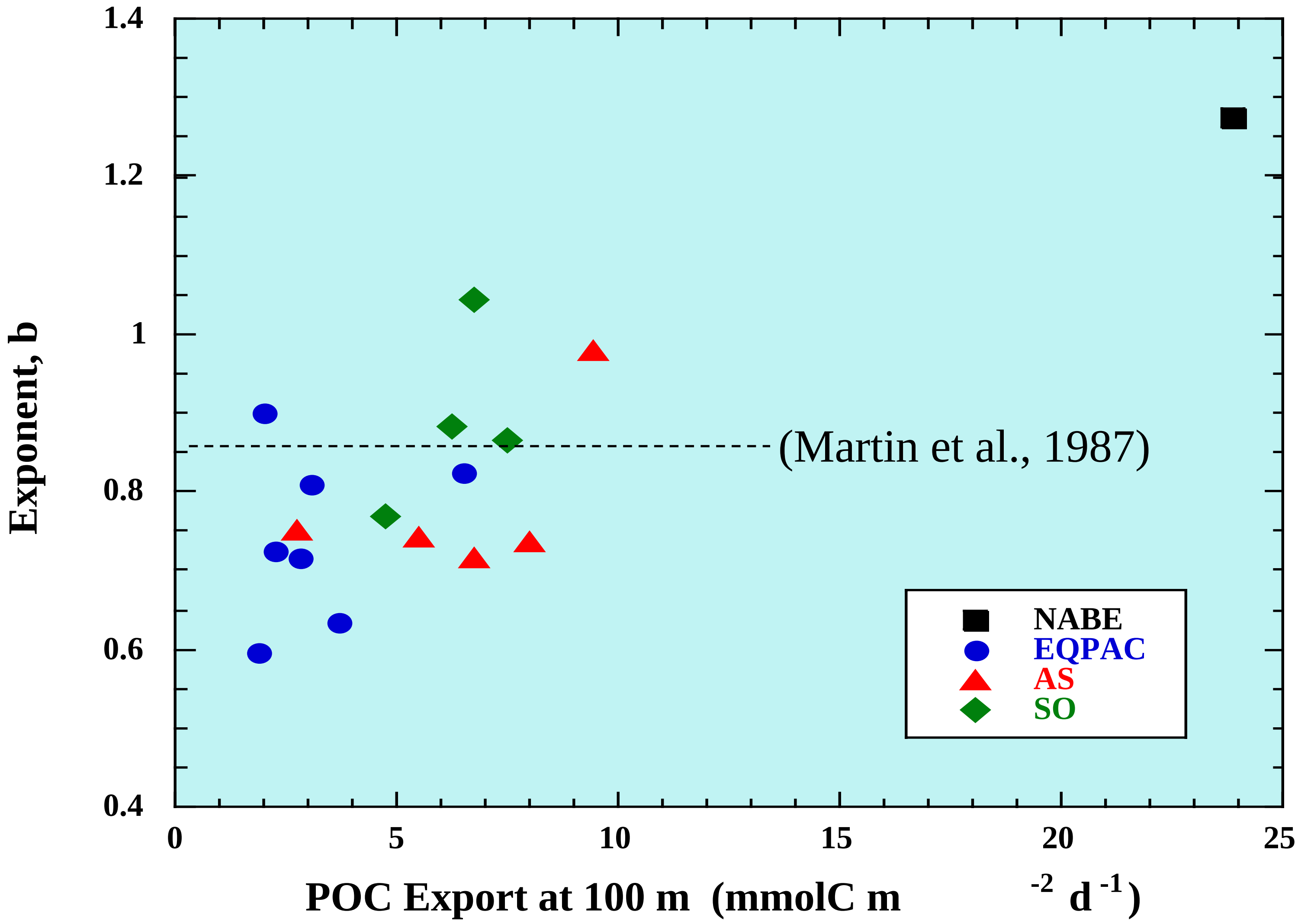
- Depends on the depth horizon and ventilation time-scale:
  - Annual: 10-20 Gt C/y
  - Multi-annual (>200 m): 5-10 Gt C/y
  - Multi-Decadal: 2-4 Gt C/y
  - > Centennial: ~1-2 Gt C/y

Global PP
~50 GtC/yr

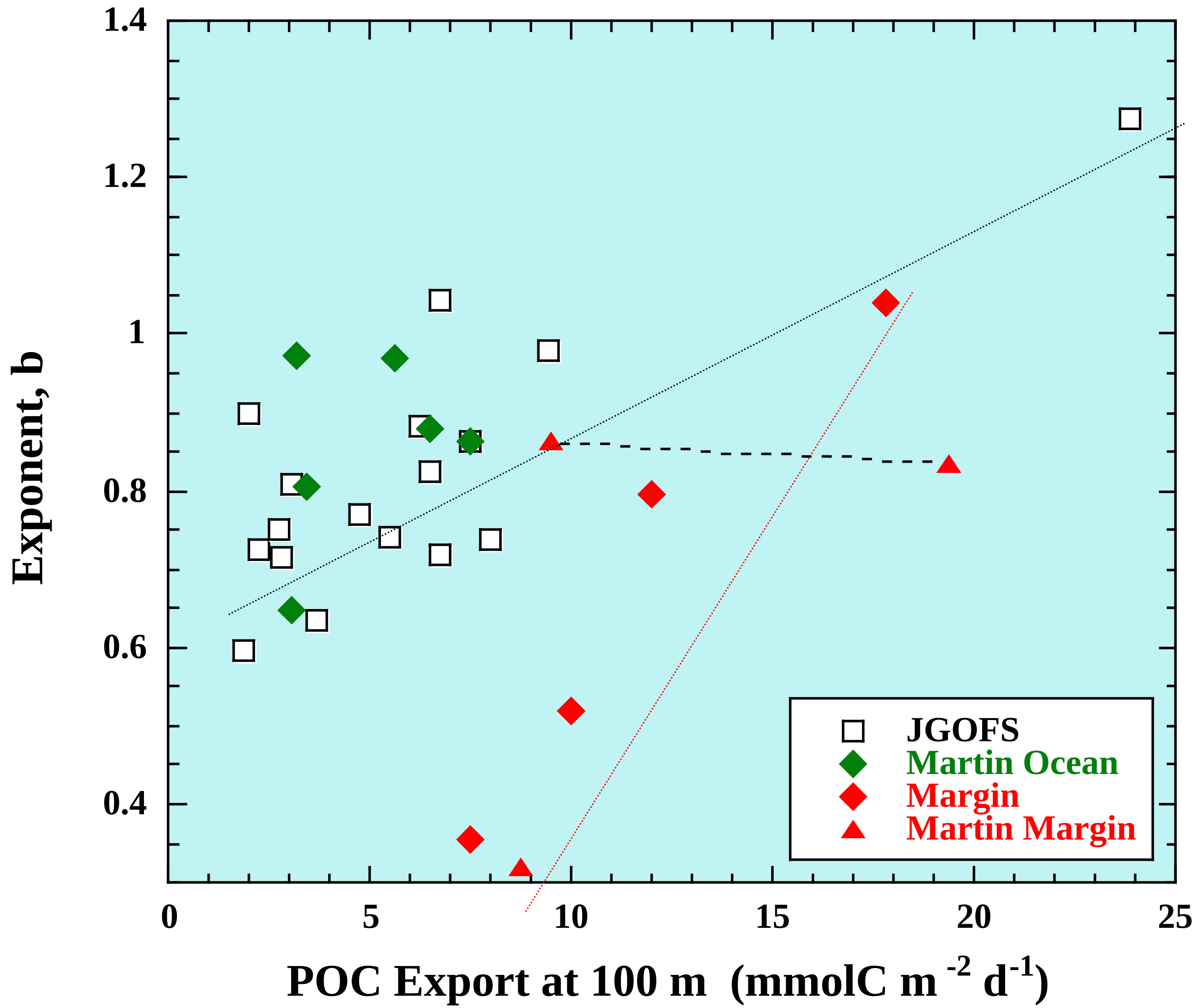


Larger b value, more POC is recycled in upper ocean
Smaller b value, more POC gets to deep ocean

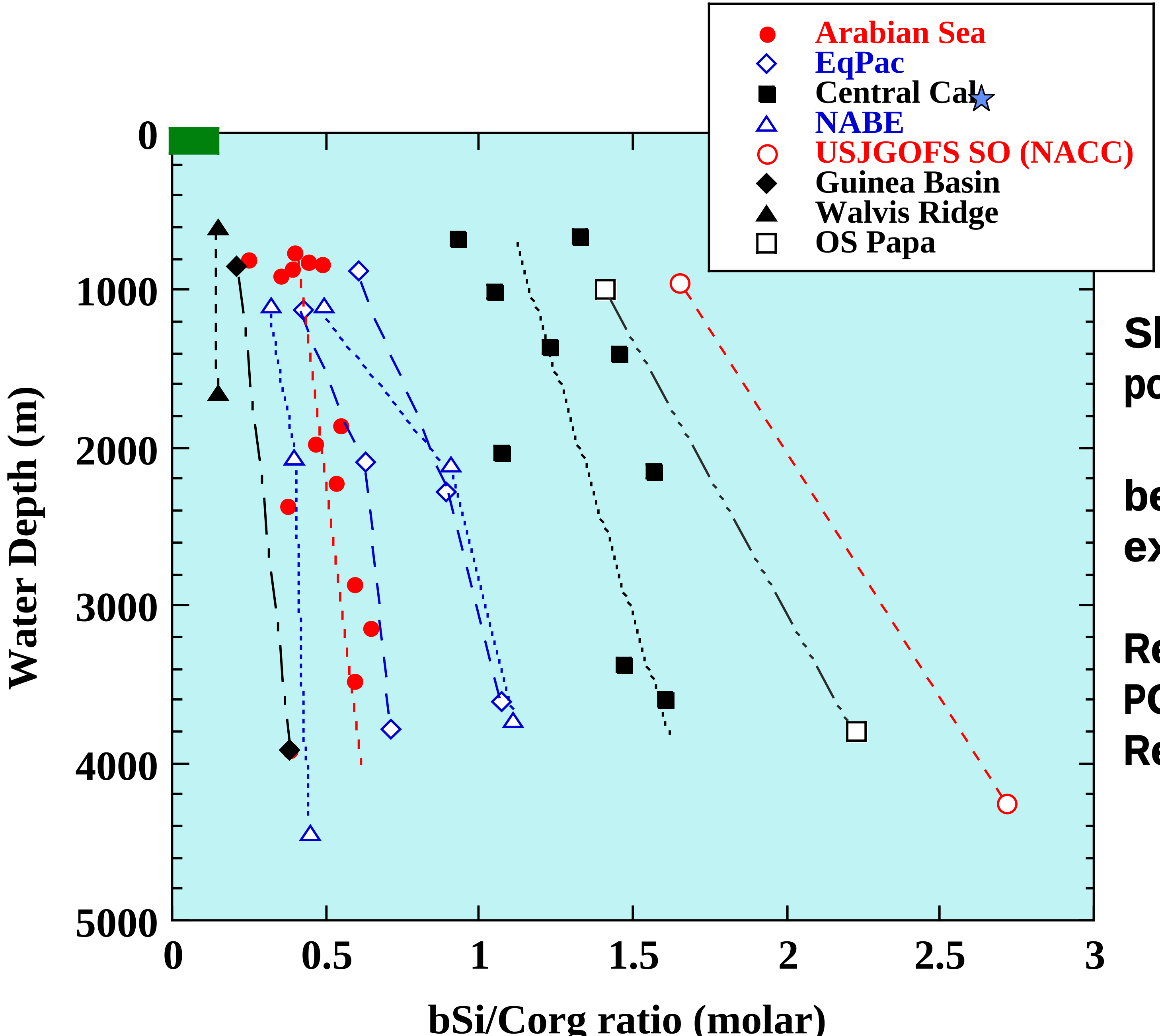
US-JGOFS Open-Ocean Sites



(Berelson, 2001)



Berelson (in prep)



Slope's always positive---

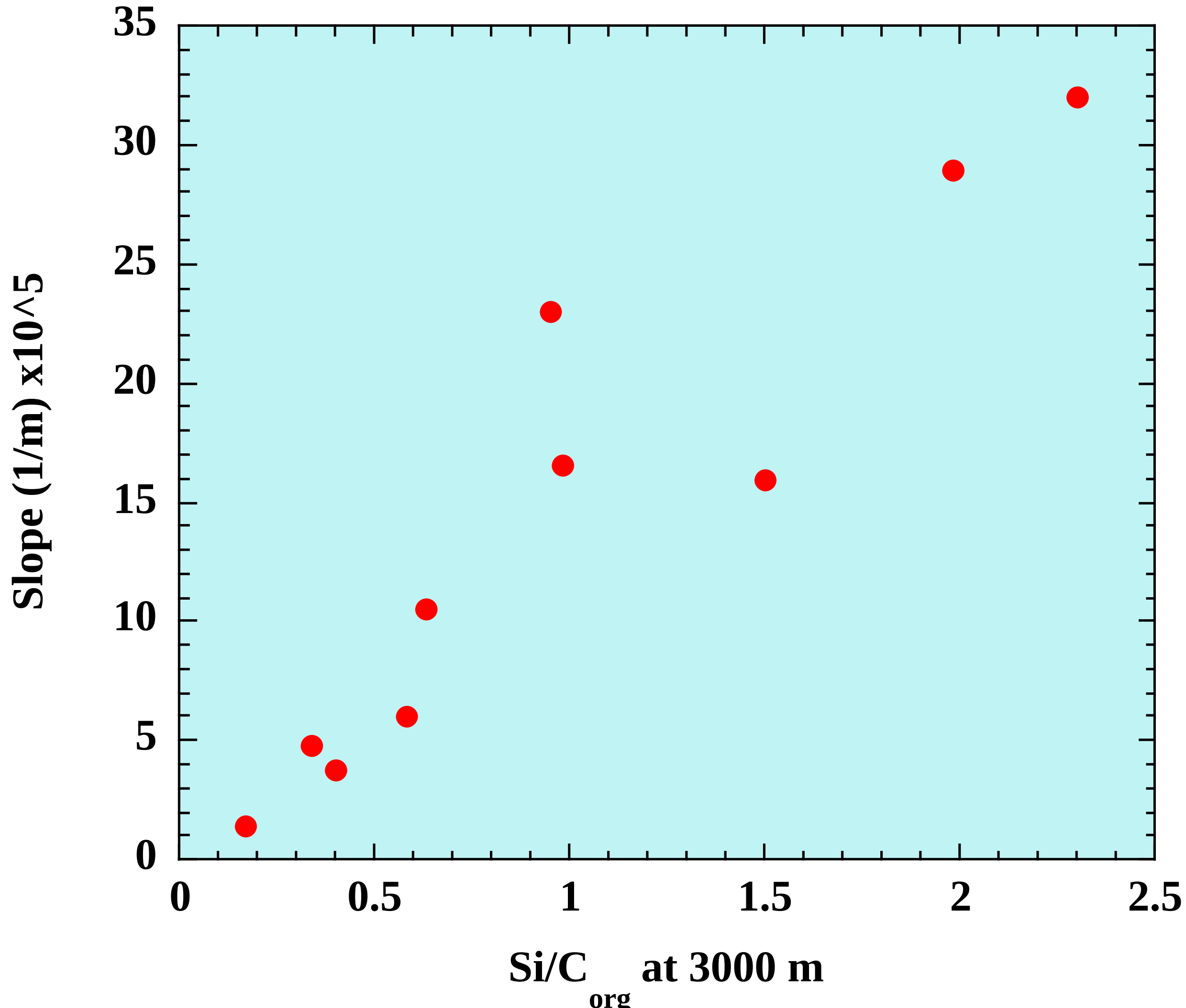
best explanation-

Reactivity POC > Reactivity bSi

Berelson (in prep)

Sediment Trap Data

Steeper Slope

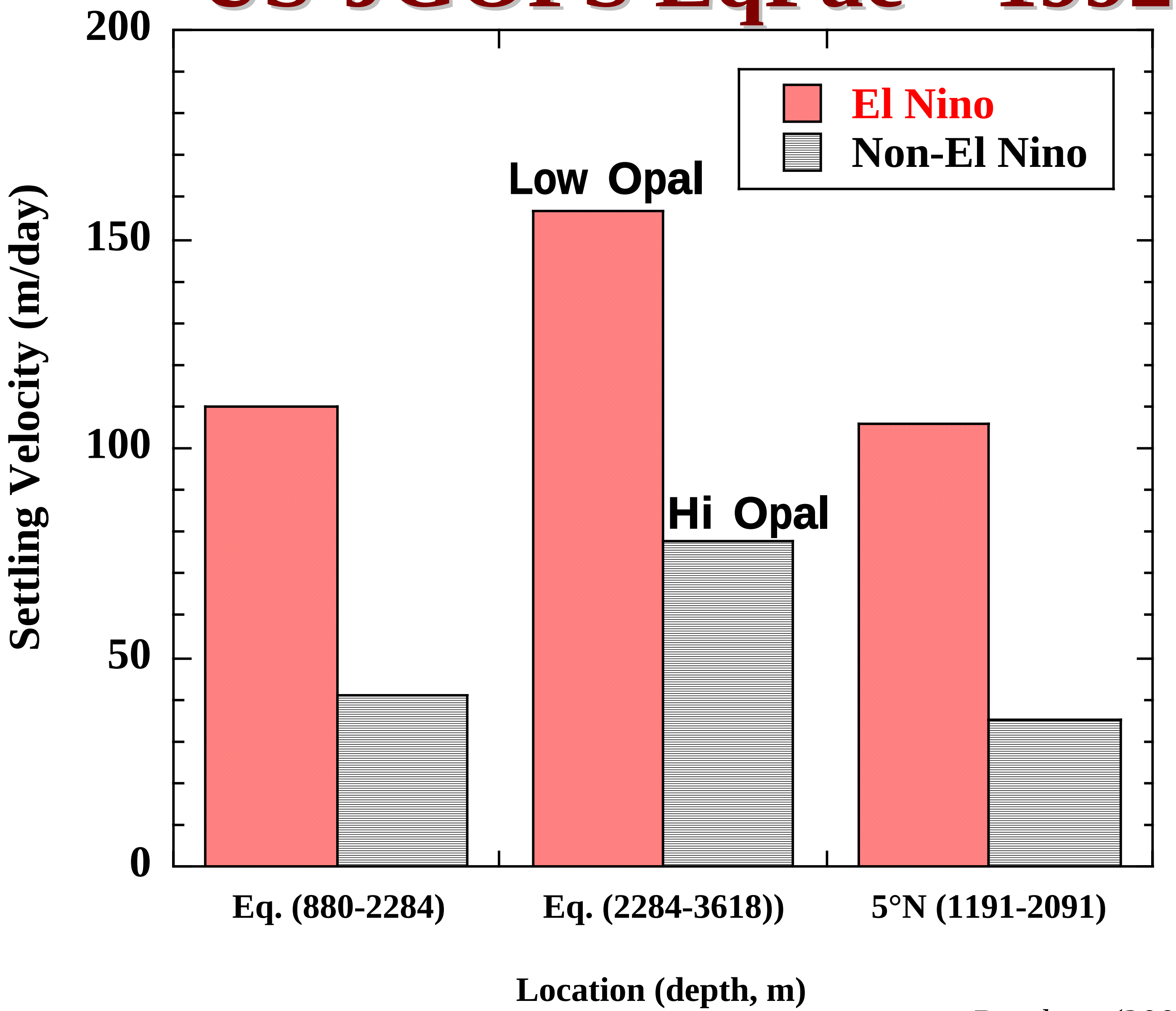


Higher bSi Content

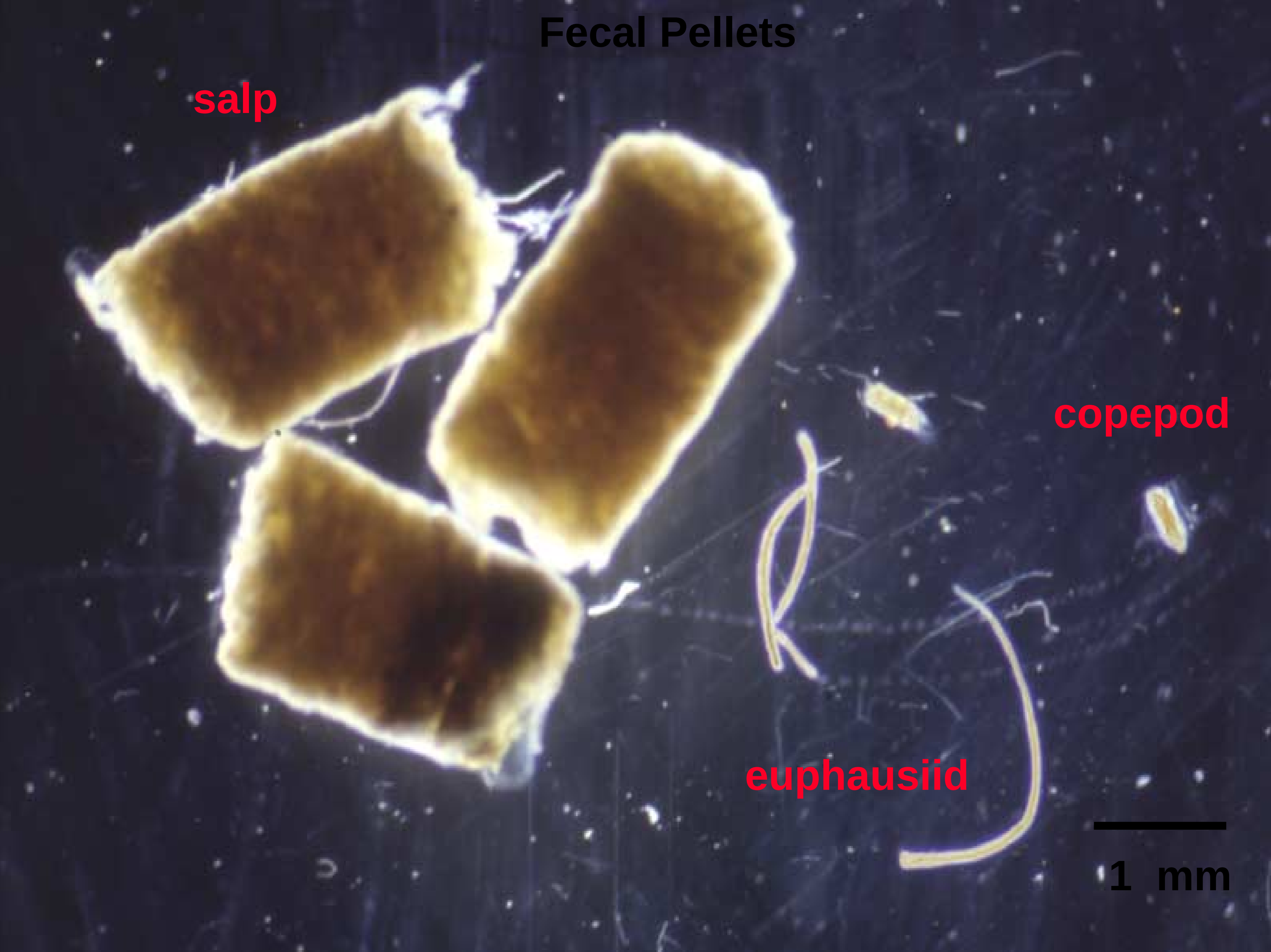
Can bSi content slow net particle settling rates?
(Hypothesis: Yes)

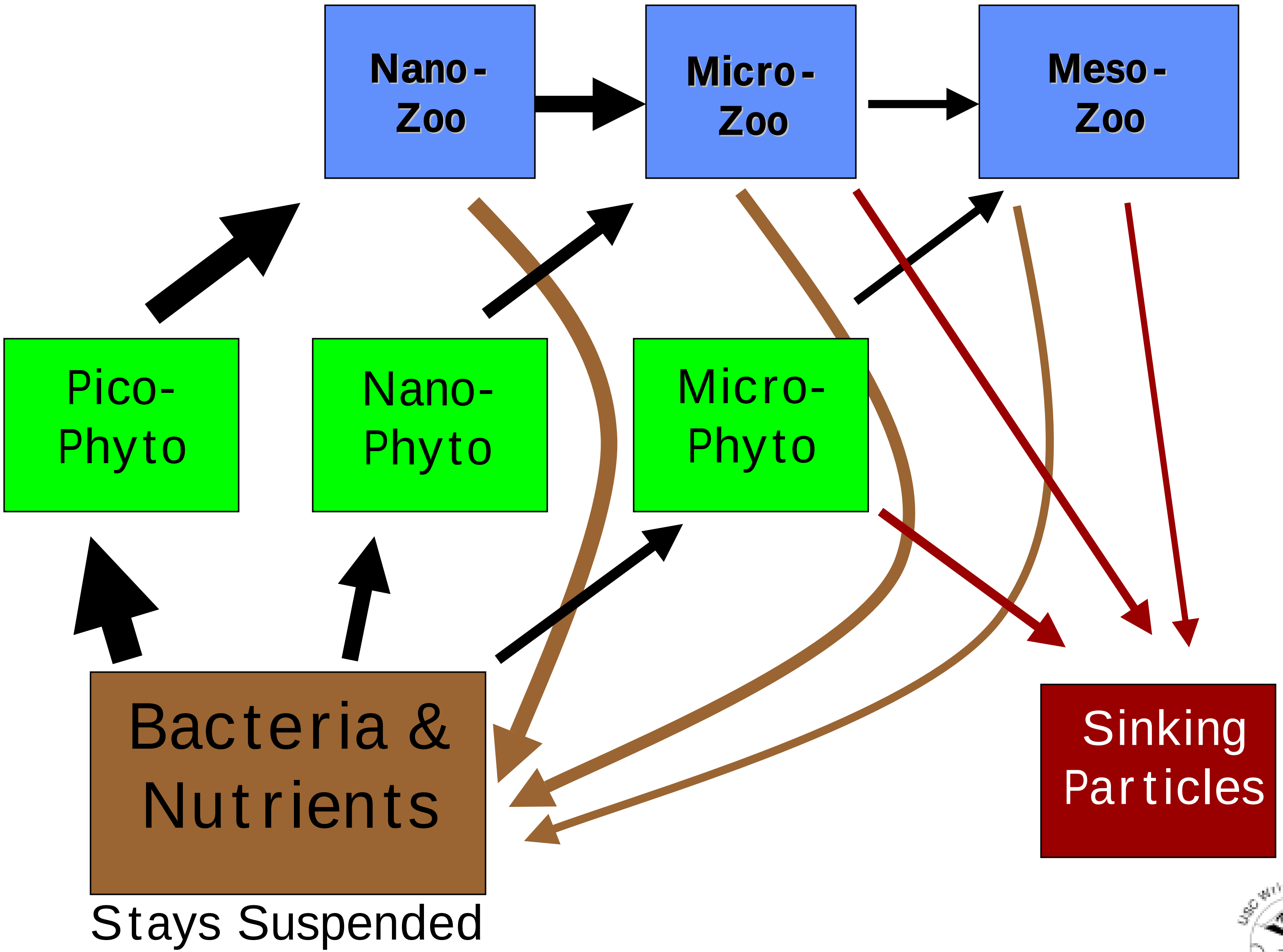
Berelson (in prep)

US-JGOFS EqPac—1992



Berelson (2001)


Fecal Pellets
salp
copepod
euphausiid
1 mm



Nano-
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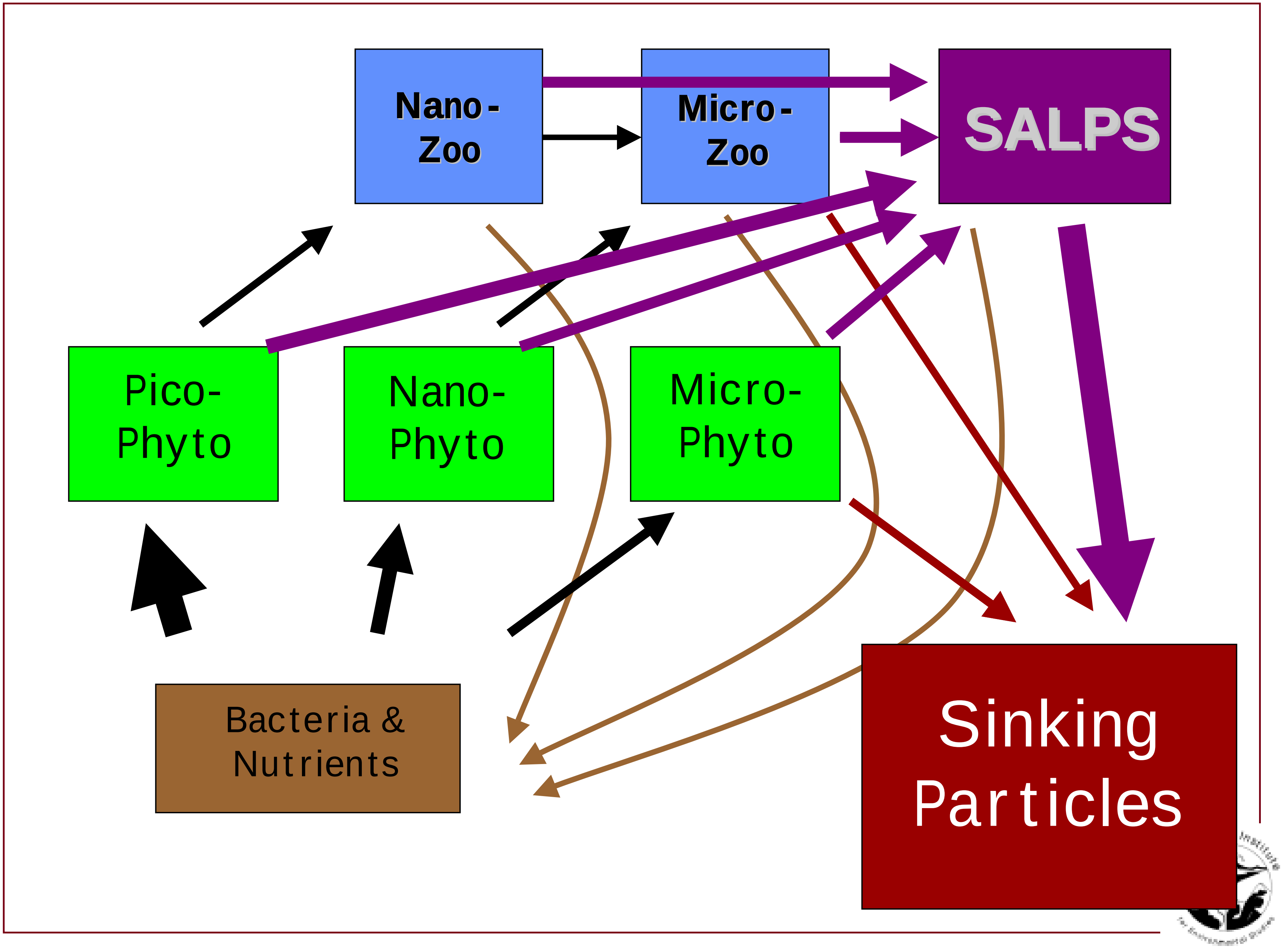
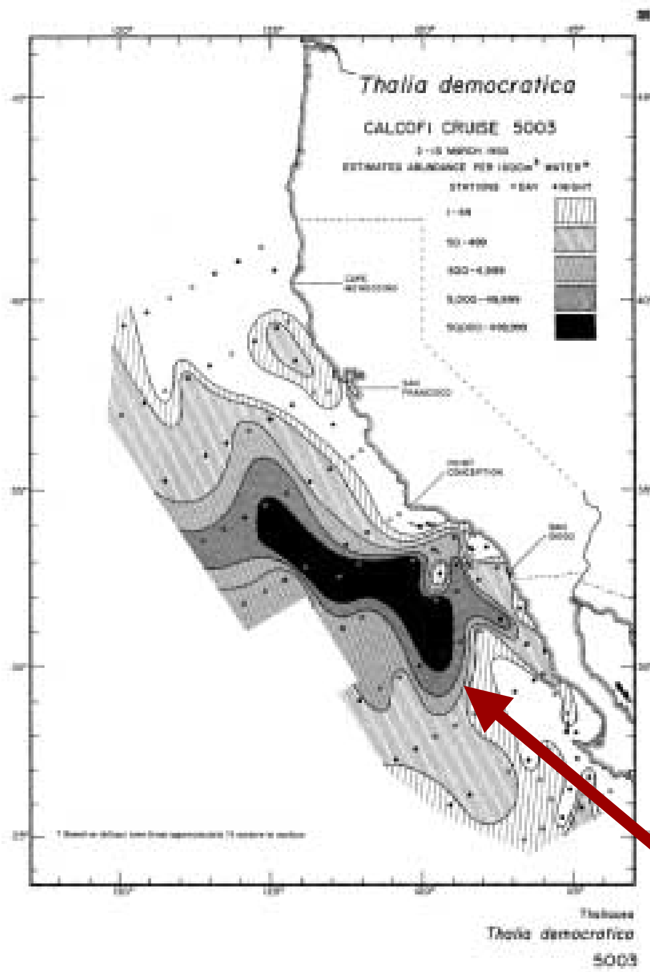
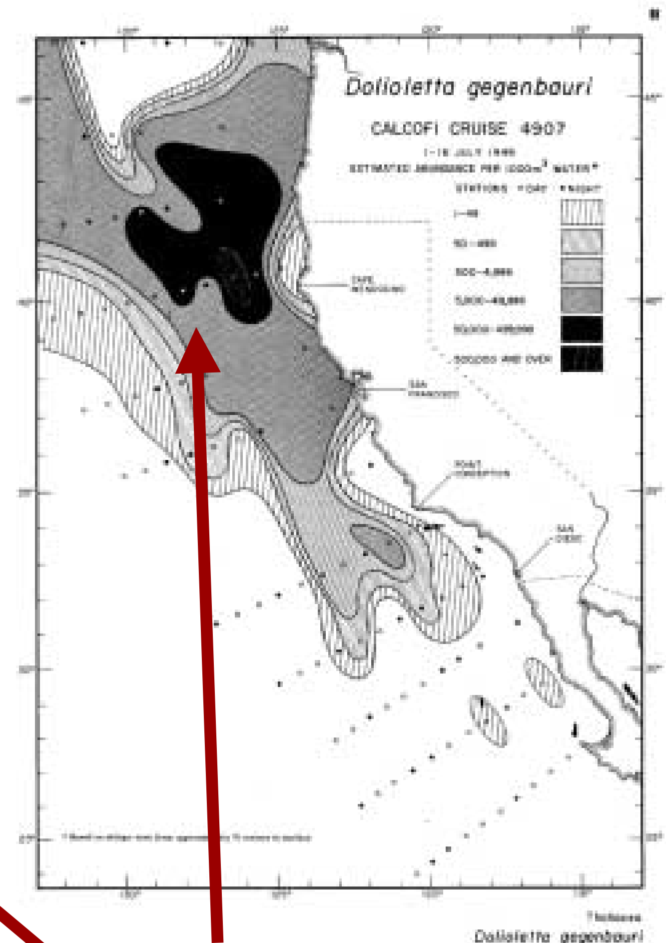


Nano-
Zoo
Micro-
Zoo
SALPS
Pico-
Phyto
Nano-
Phyto
Micro-
Phyto
Bacteria &
Nutrients
Sinking
Particles

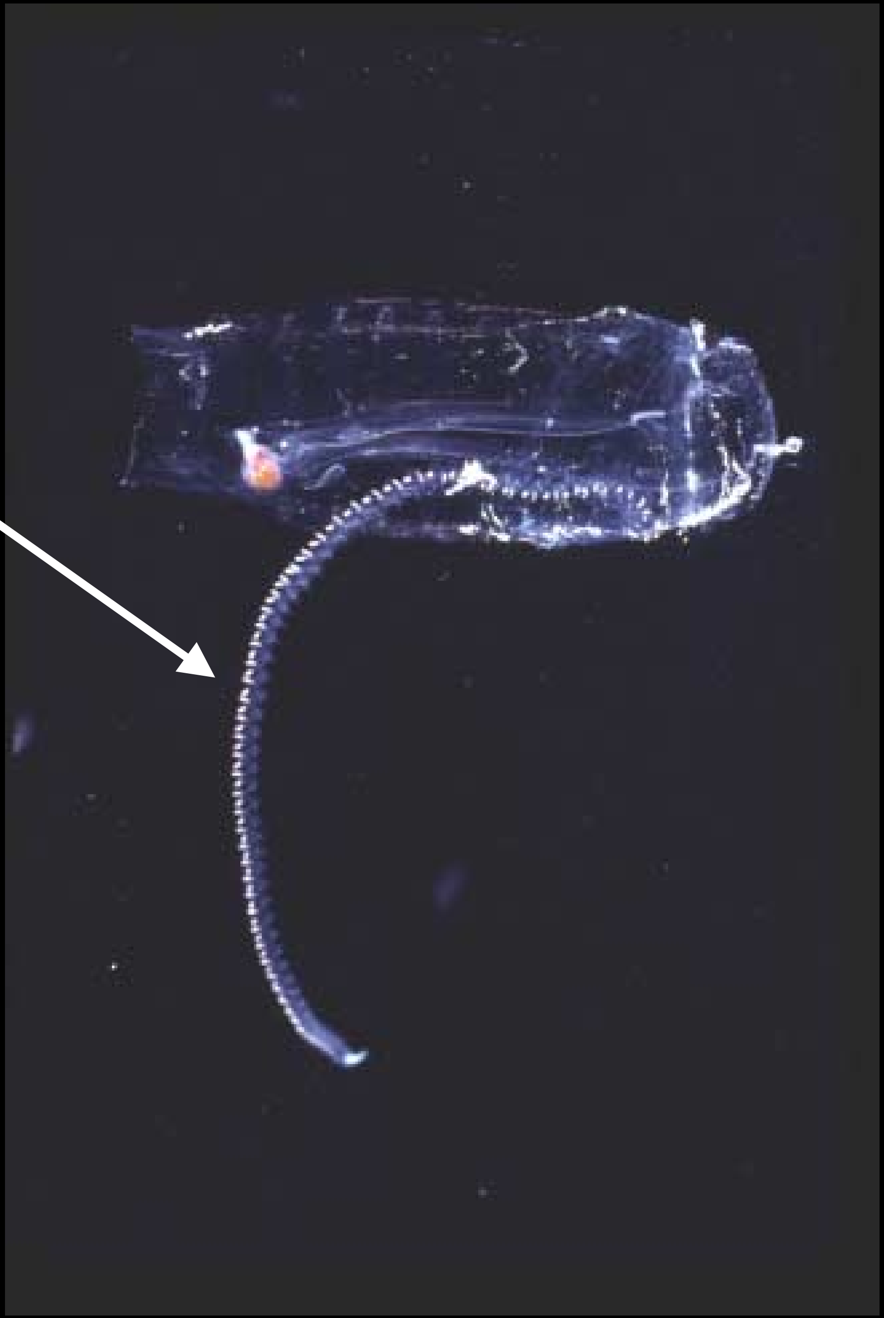
Twice in a decade!



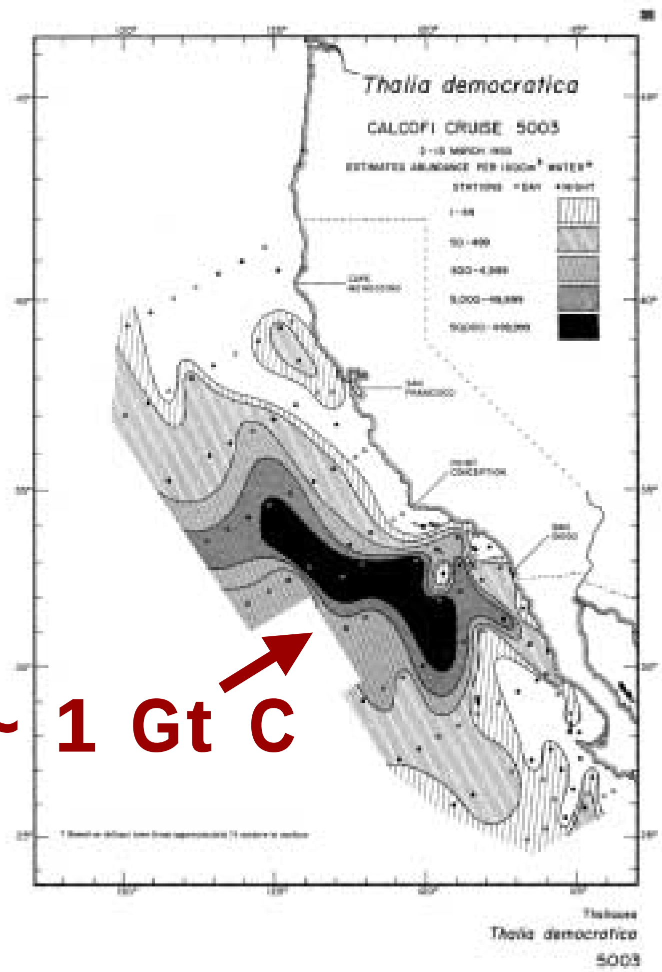


Enormous Blooms!

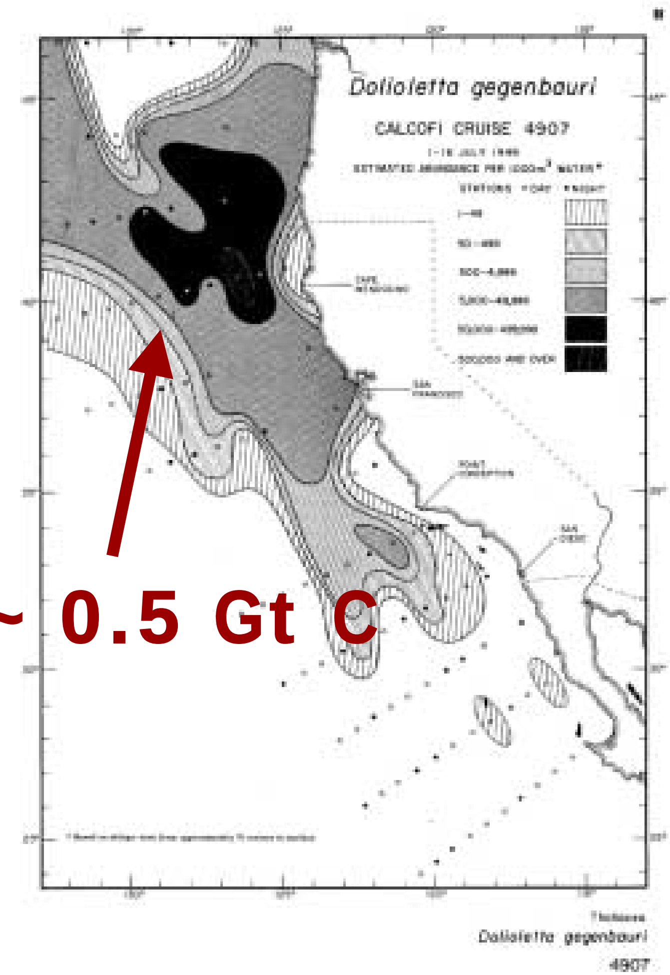
Asexual reproduction by budding



The Outer Limits



~ 1 Gt C



~ 0.5 Gt C

Ecosystems and Plankton Blooms

- Ecosystems are complex-dynamical systems
- Bloom dynamics are poorly understood and hard to study
- Top-down vs bottom-up, a debate that is sorely lacking in ocean science
- Blooms created and controlled by internal dynamics of ecosystem, rarely bounded by external controls like nutrients

4. Changes in remineralization length-scales and C-N-P stoichiometry

Influence of Community Structure?

- Mix of biological and physical sources to different types of sinking particles
- Ballasting signals (mechanisms?)
- Diatom blooms may have non-intuitive impact on remineralization length-scale
- Bloom forming organisms create unique time-space scale issues for remineralization and for science.

Conclusions

- Community structure matters for the partitioning of carbon between ocean and atmosphere.
- JGOFS has clarified some simple issues that now allow us to ask much more sophisticated questions.
- We still lack tools to study these processes on the time, space and taxonomic levels that are required.
- When community structure is important, the outcome is often emergent from internal dynamics.

Future Directions

- Community structure where it matters (HNLC, nitrogen fixation, etc.)
- The “twilight zone” and below
- Bloom dynamics (when they occur and when they matter)
- Complex systems approaches
- Be ready for surprises (viruses, archea, who knows what else).

Thank you!