Mesoscale Fe Enrichment in the NE Subarctic Pacific

SERIES: Subarctic Ecosystem Response to Iron Enrichment Study

(A Canadian SOLAS Network Project)

Paul J. Harrison

Hong Kong University of Science & Technology

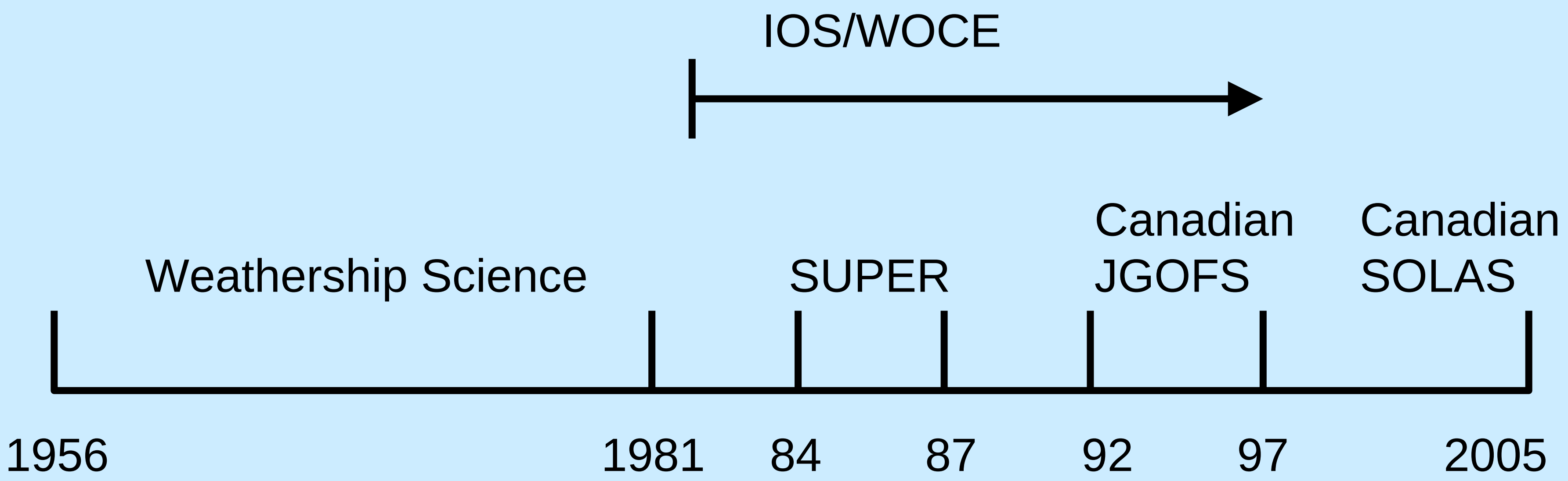
University of British Columbia

and > 40 SOLAS/SERIES colleagues

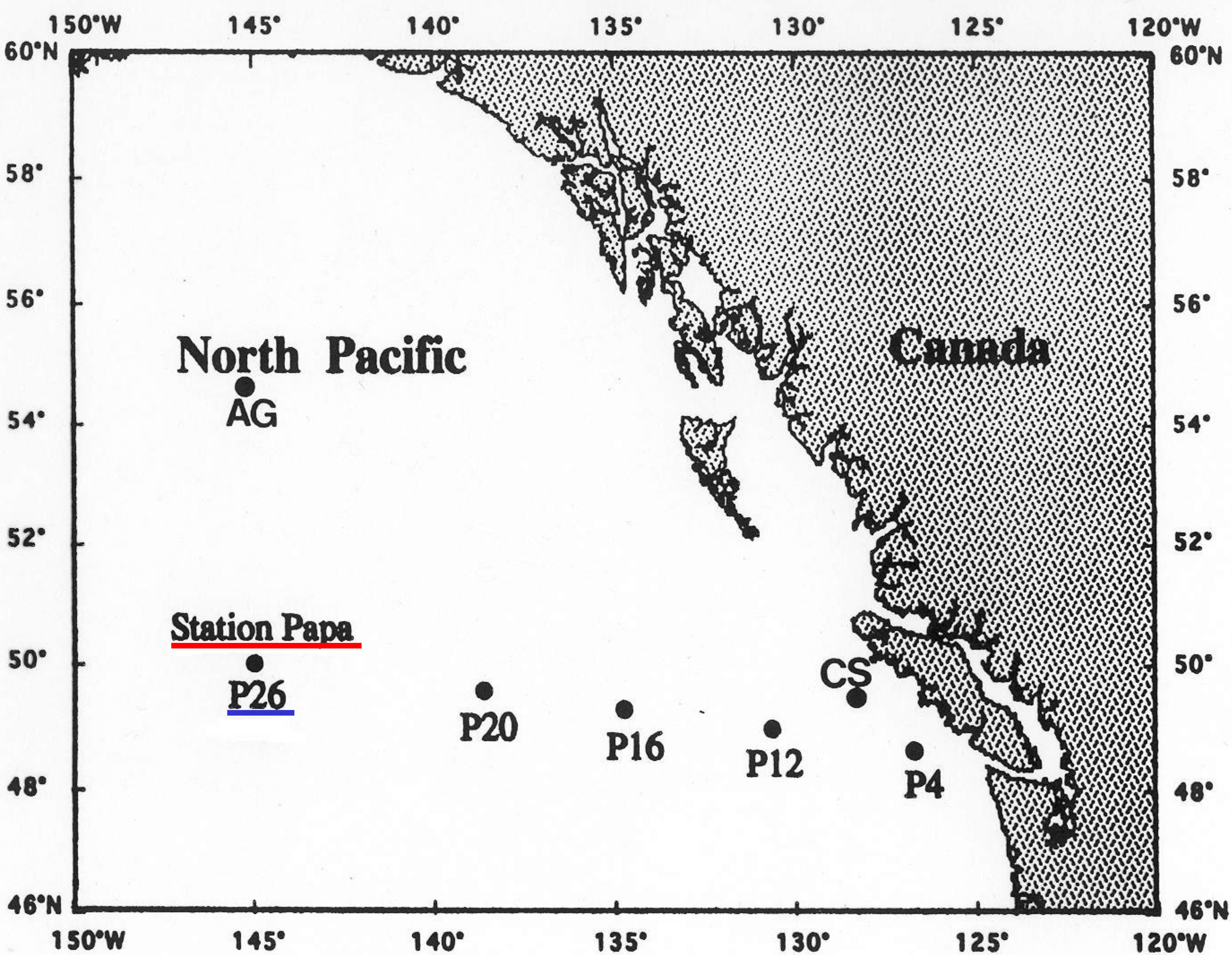
Outline

- Background for the Fe enrichment expt
- Overview of planktonic ecosystem response to the 2 Fe additions near Stn P

Stn P Time Line (50 Years)

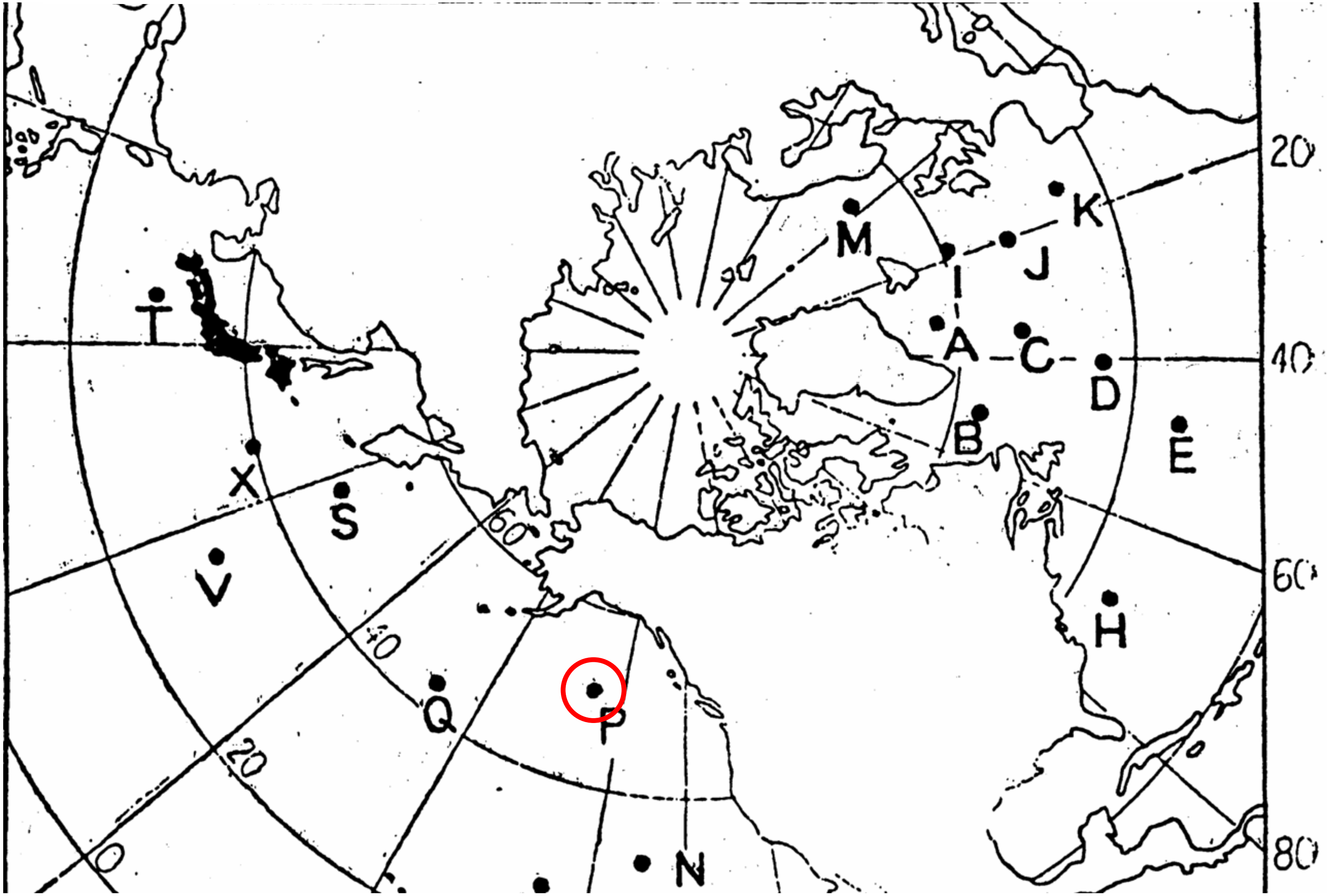


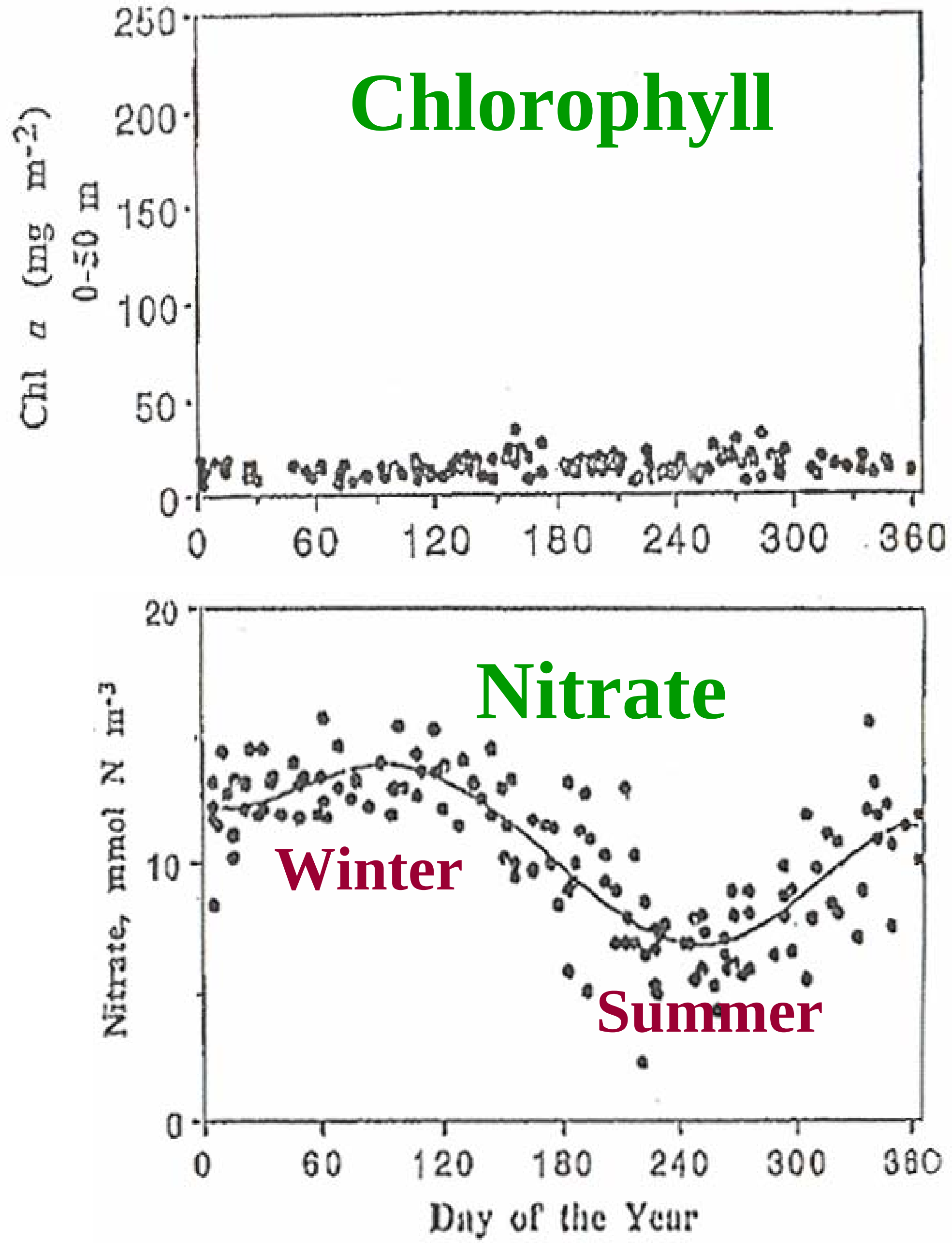
Stn P (OSP) is one of the longest open ocean time series in the world!



150°W
145°
140°
135°
130°
125°
120°W
60°N
58°
56°
54°
52°
50°
48°
46°N
North Pacific
Canada
AG
Station Papa
P26
P20
P16
P12
CS
P4

Weathership Stations





Stn P – a high nitrate, low chlorophyll region (HNLC)

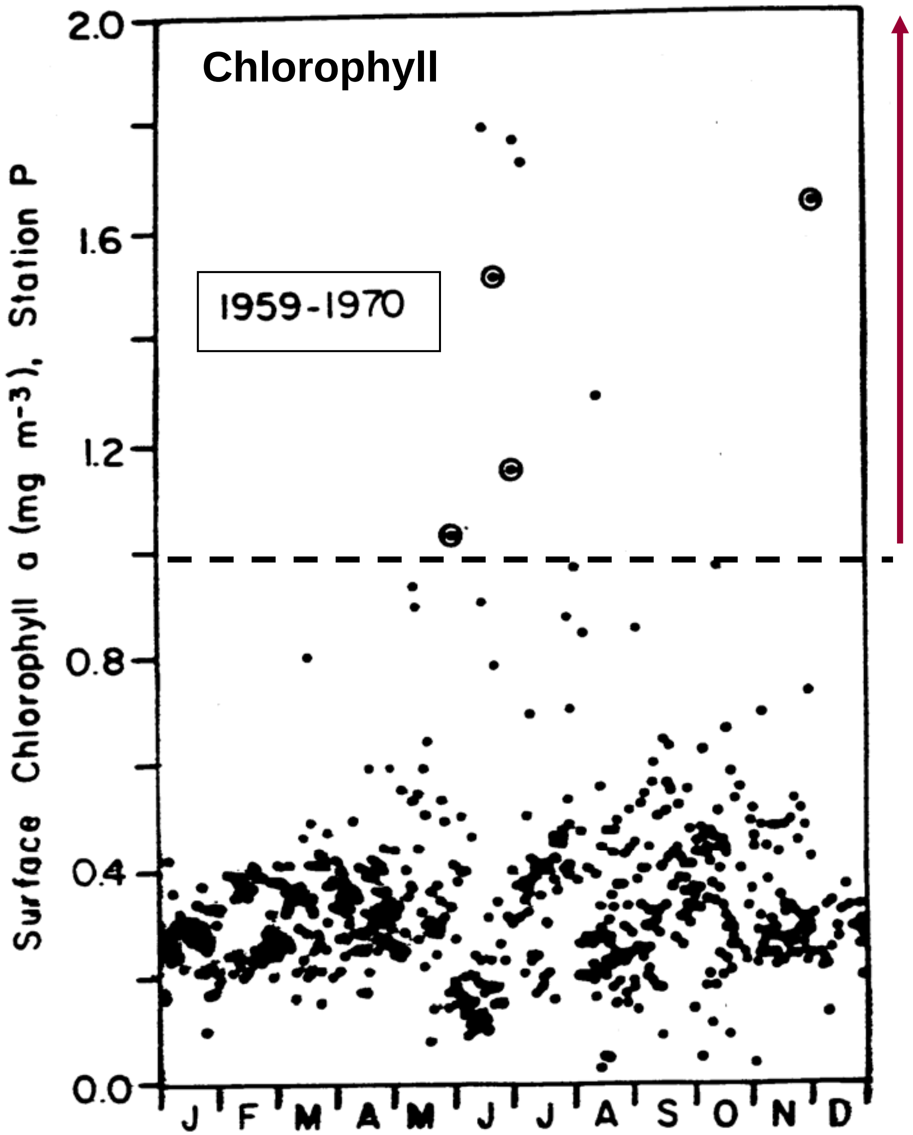
Unusual Annual Observations

1) No seasonal cycle in chlorophyll. Why?
2) No depletion of NO_3 in summer. Why?

Answer

- Low light/ very cloudy.
- Grazing by large copepods – top down control.

Stn P – HNLC region

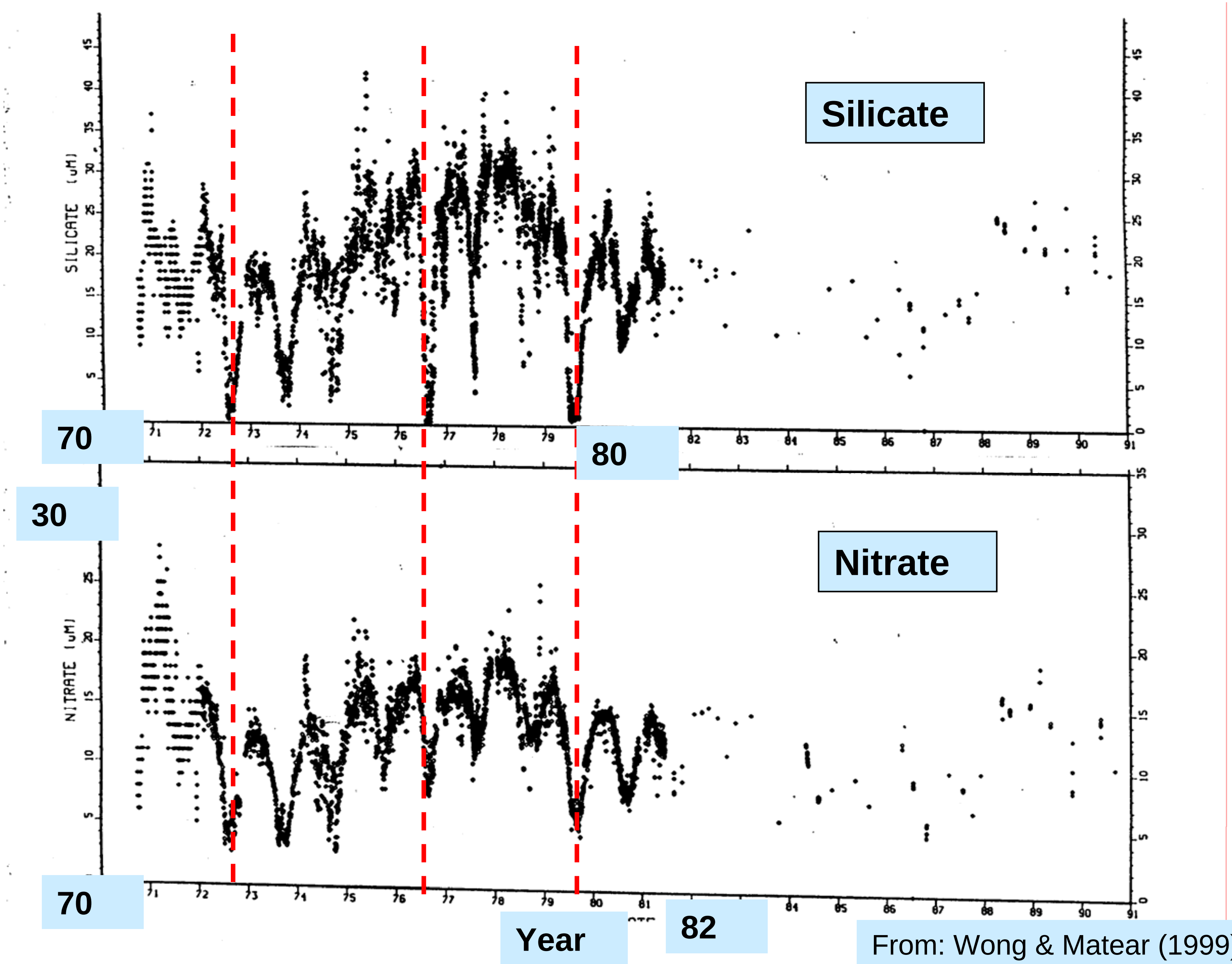


From: Wong et al. (1995)

Weathership observations

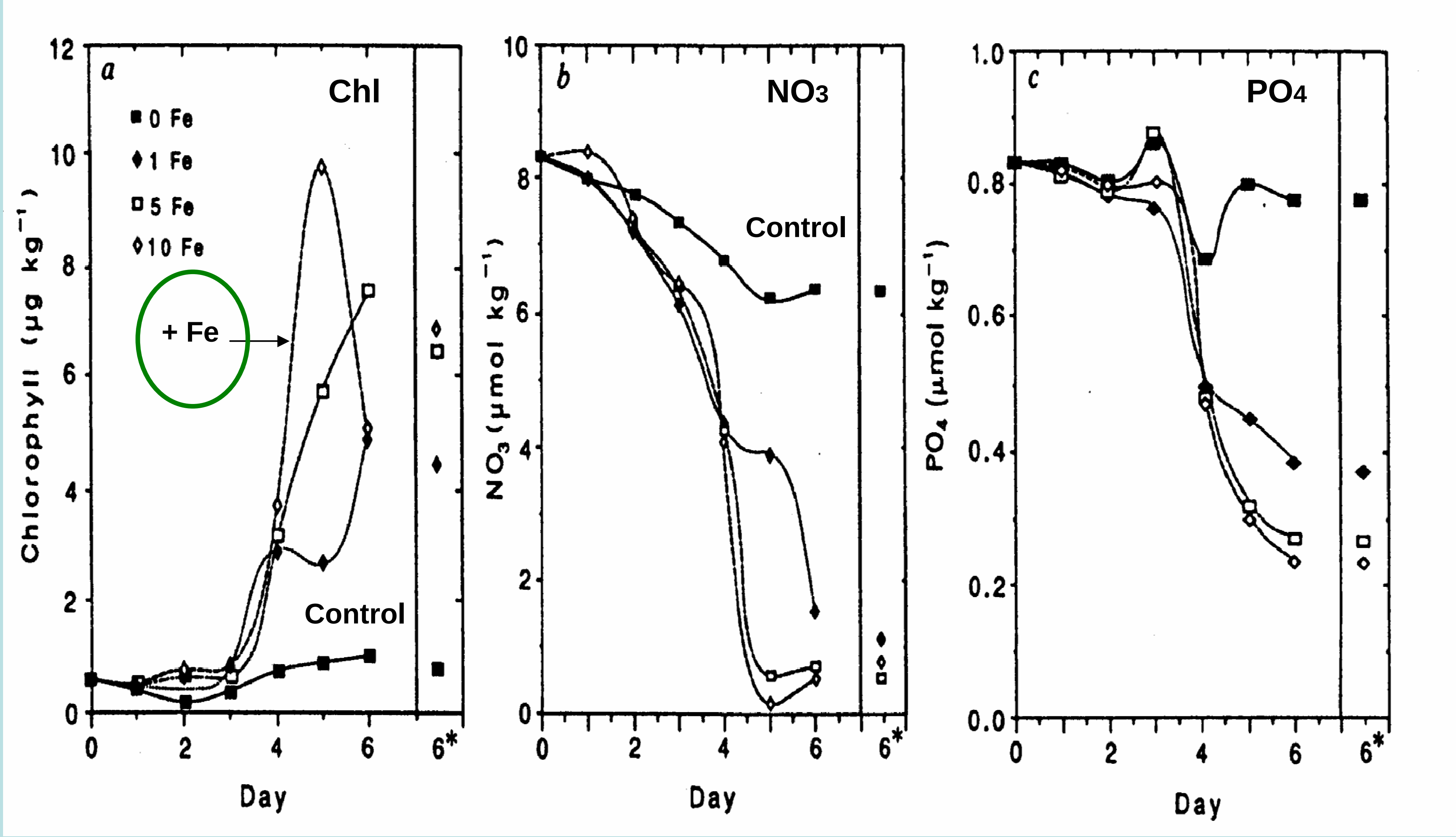
Unusually high Chl in the 1970s

Longest Open Ocean Time Series (1956 – present)

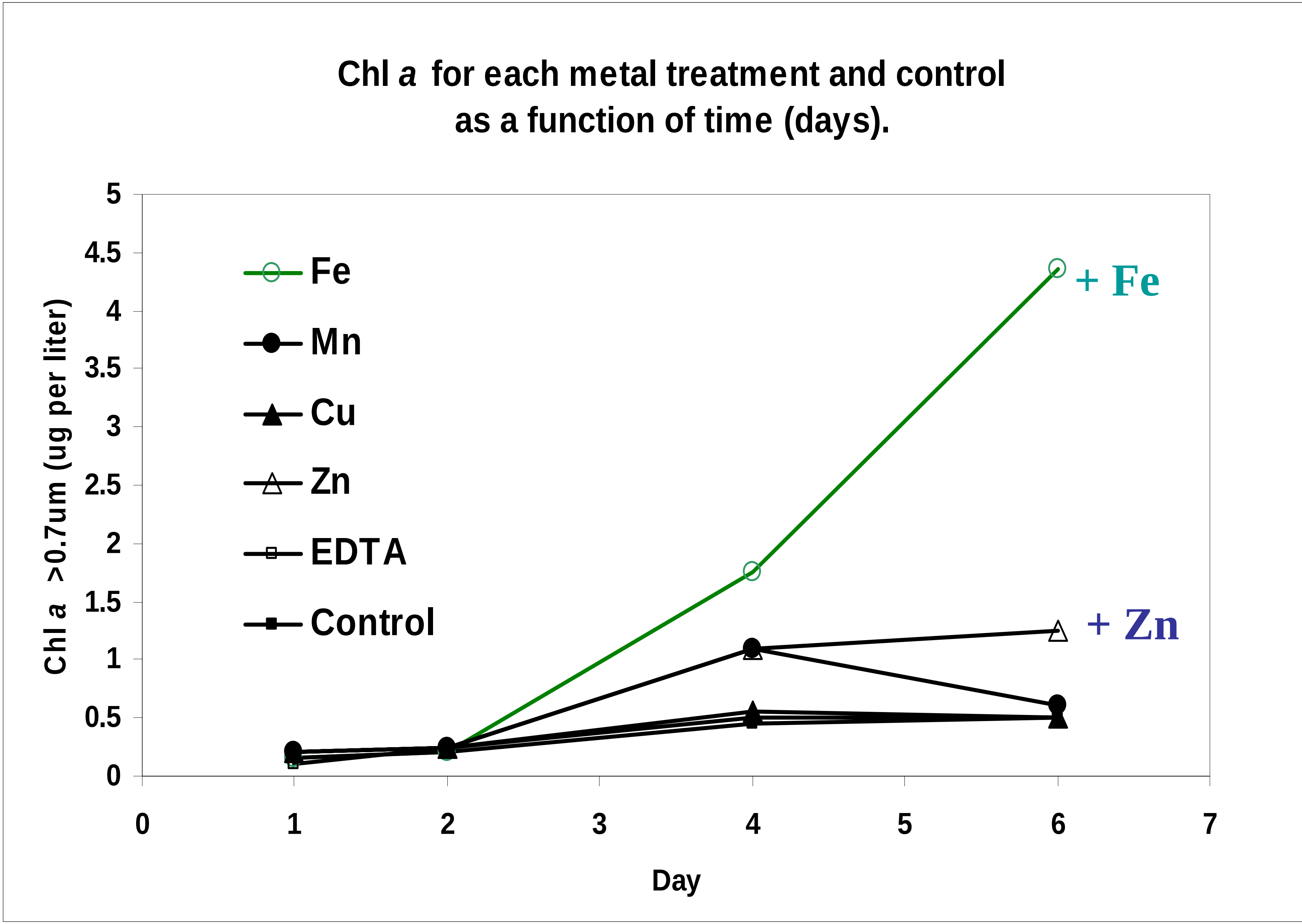


From: Wong & Matear (1999) Deep-Sea Res 46: 2530-2556

Iron Deficiency Limits Phytoplankton Growth in the NE Subarctic Pacific



From: Martin & Fitzwater (1988)
Nature 331: 341-343



Iron increases phytoplankton growth

Coale 1991

Major Diatom Species at OSP

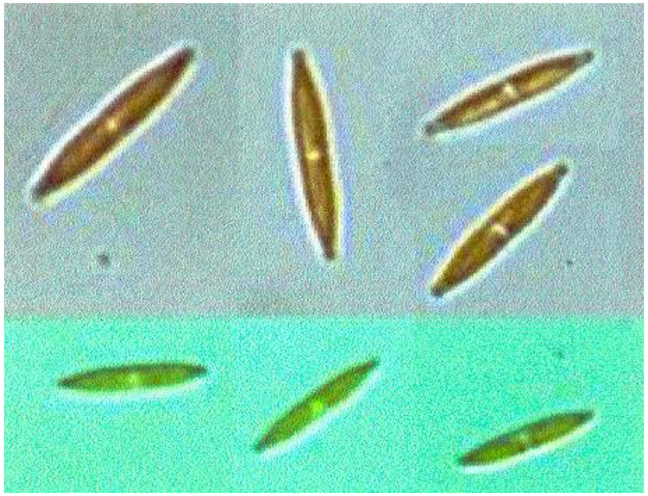
Pennates:

-*Nitzschia* and *Psedonitzschia* species. Chain and individuals.

-Most dominant diatom group at OSP year round.

-Lengths can range from 5 µm to > 200 µm.

-Difficult to identify.



Pseudonitzschia sp.

Factors Controlling Primary Productivity

Zooplankton

Top Down Control
By Grazing

Phytoplankton

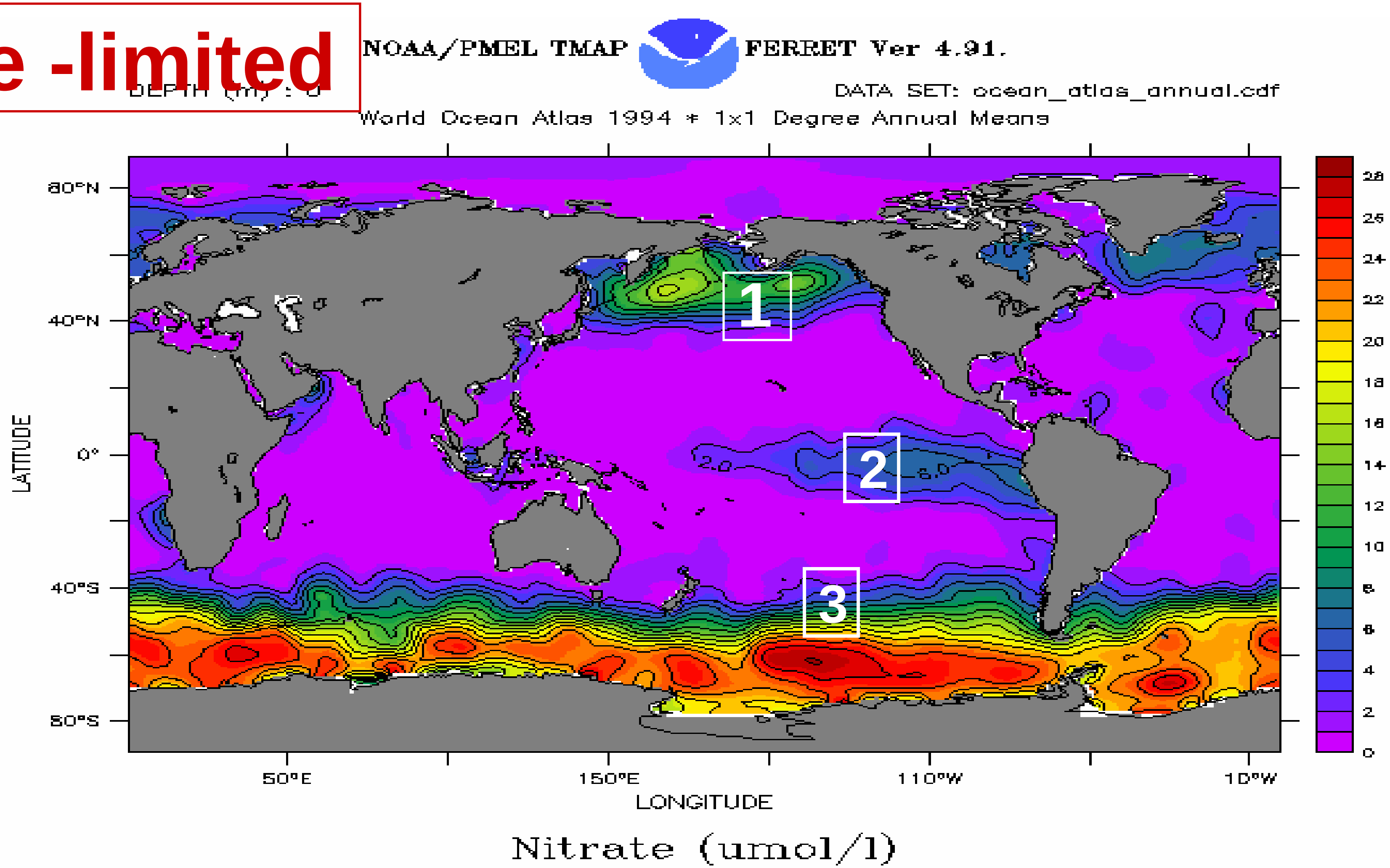
Bottom Up Control

Nutrients (N, P, Si including Fe)

Also light and temperature

3 High Nitrate Low Chlorophyll (HNLC) Regions

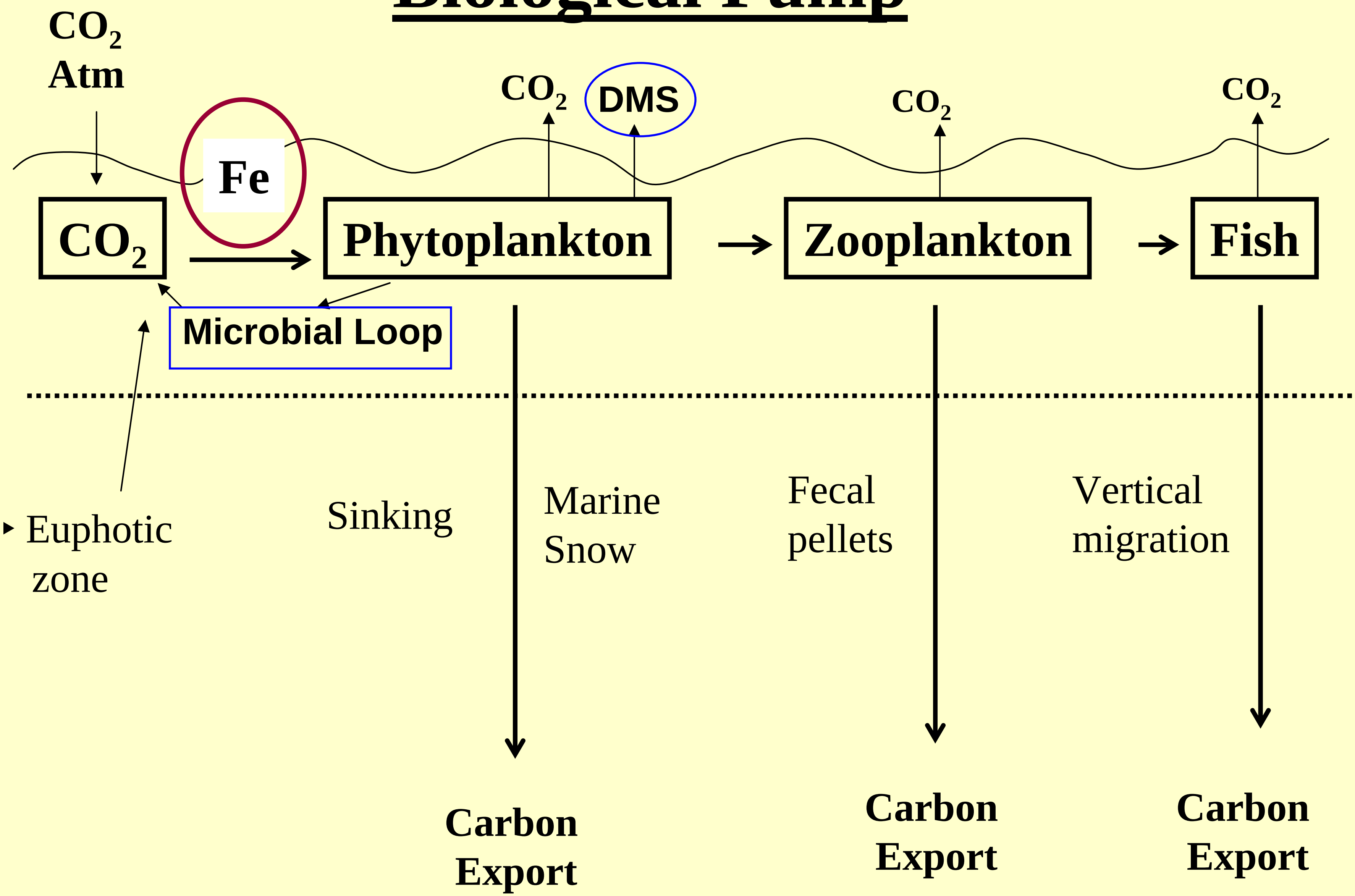
Fe -limited



John Martin's iron hypothesis:

"Phytoplankton growth and biomass are limited by low concentrations of available iron in large regions of the world's oceans where other plant nutrients are abundant"

Biological Pump

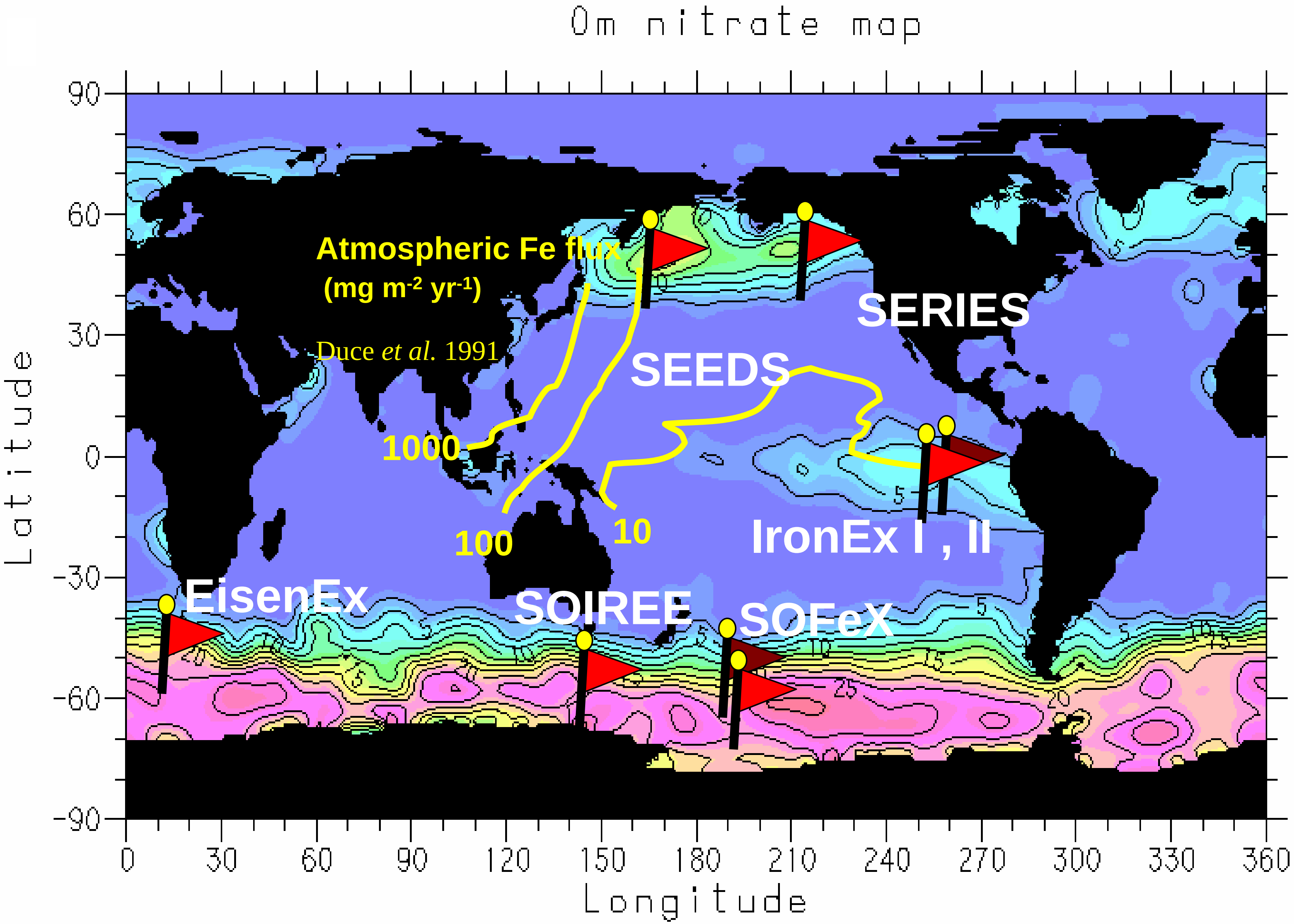


Moving from Bottles to the Ocean

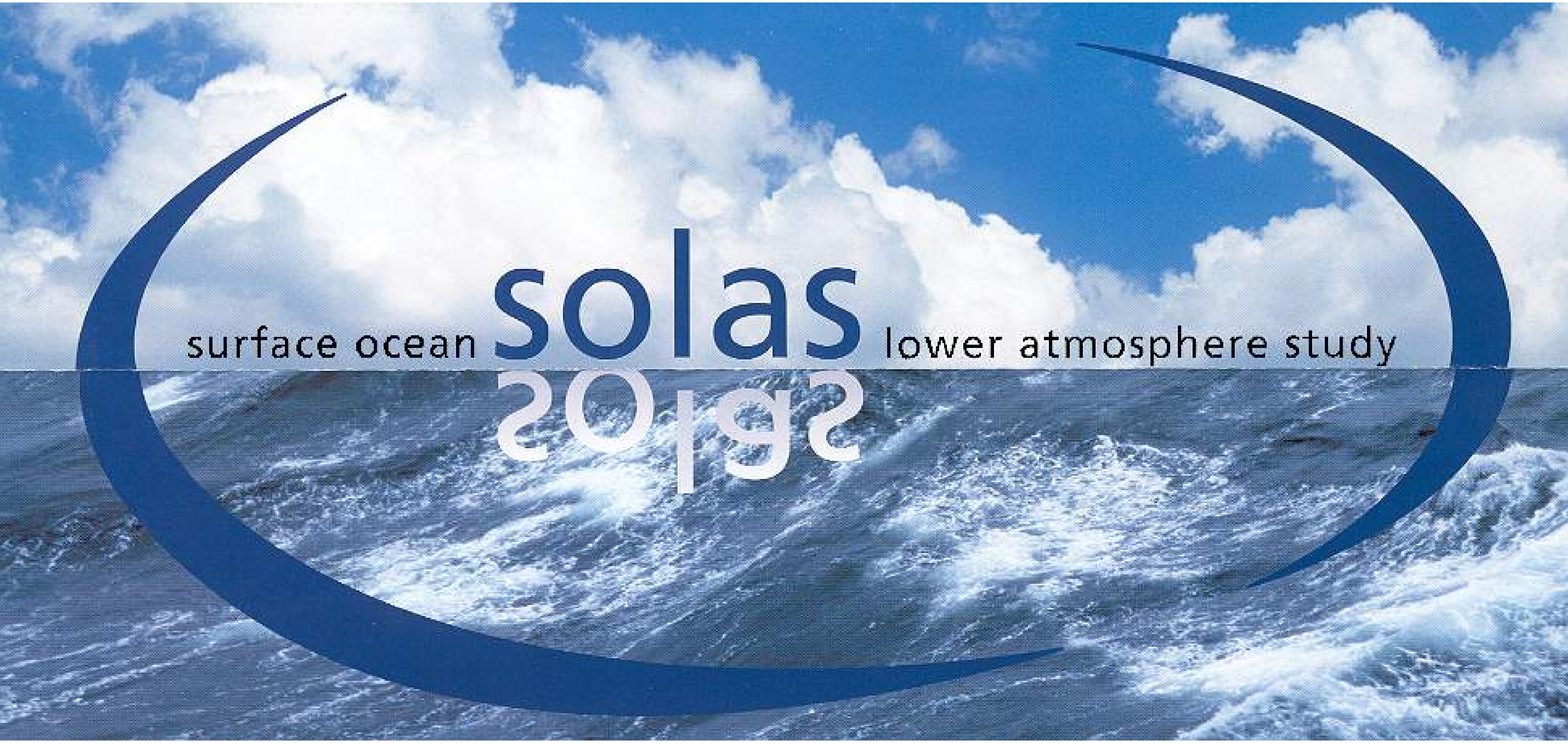
- Is a bottle = real ocean??

- Add Fe with a tracer in a 100 km^2 patch in equatorial waters.

-Simulation of episodic Fe input (dust, etc.)



Mesoscale Fe addition Experiments



International Oceanographic Program to study how the surface ocean absorbs and produces climate change gases such as CO_2, DMS and organic halides.

SERIES 2002

(Subarctic Ecosystem Response to Iron Enrichment Study)

Scientific Questions/Objectives

- **Community response to Fe addition**
- **Natural longitudinal dust/Fe gradient**
- **Fe chemistry and complexing agents**
- **Carbon export to deep ocean**
- **Trace gas production e.g. DMS & organic halides**

Goals of SERIES

- Mesoscale Fe addition to the subarctic NE Pacific (one of 3 HNLC world regions) – simulated natural addition (e.g. dust)

- Follow the ecosystem response (chemical parameters, plankton, microbial loop, etc.)

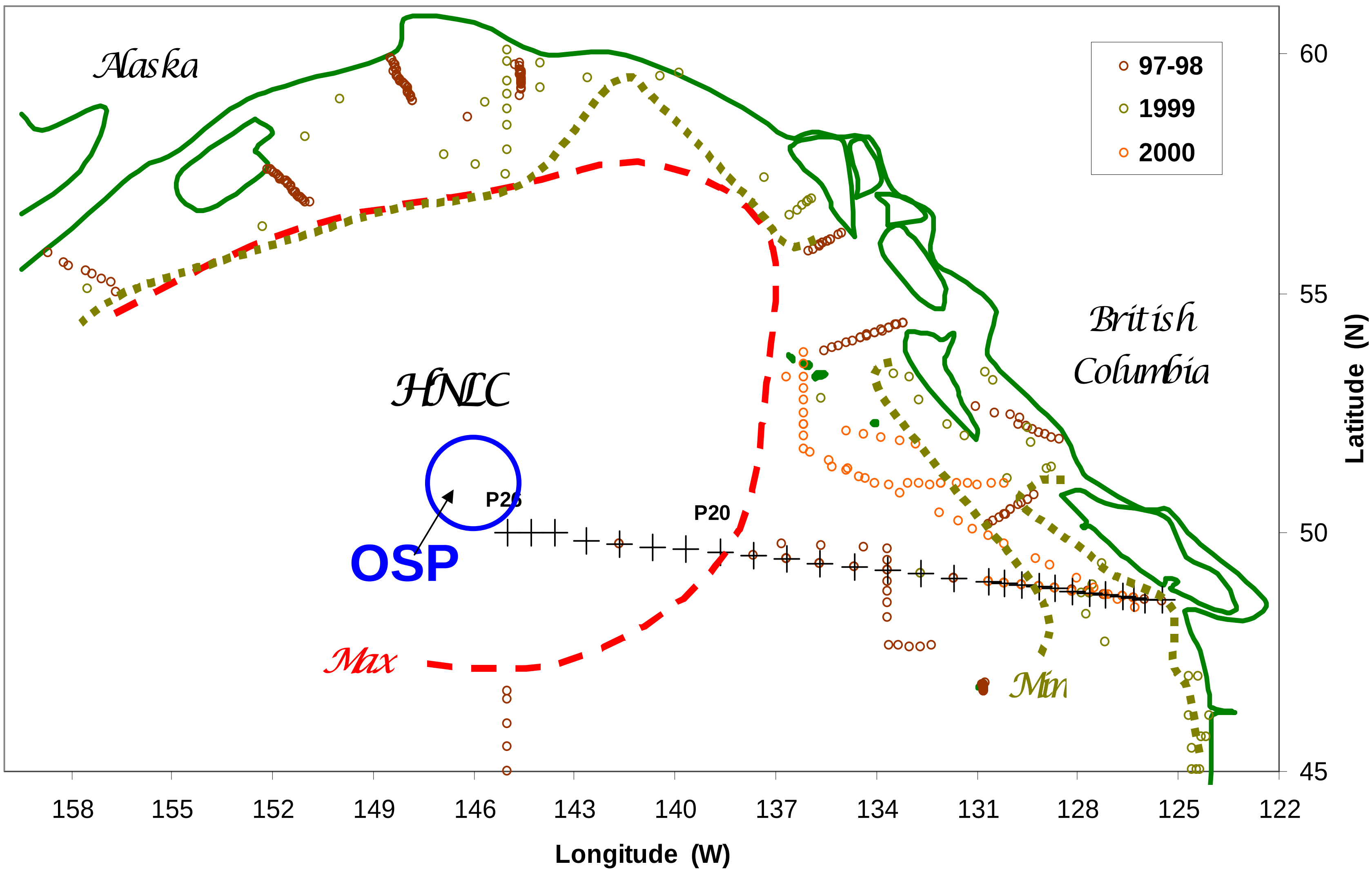
- Dynamics of climate active gases (CO_2, DMS, etc.)

- First comprehensive measurements of decline and fate of Fe-induced bloom

- Estimate the carbon export to depth (over 30 days)

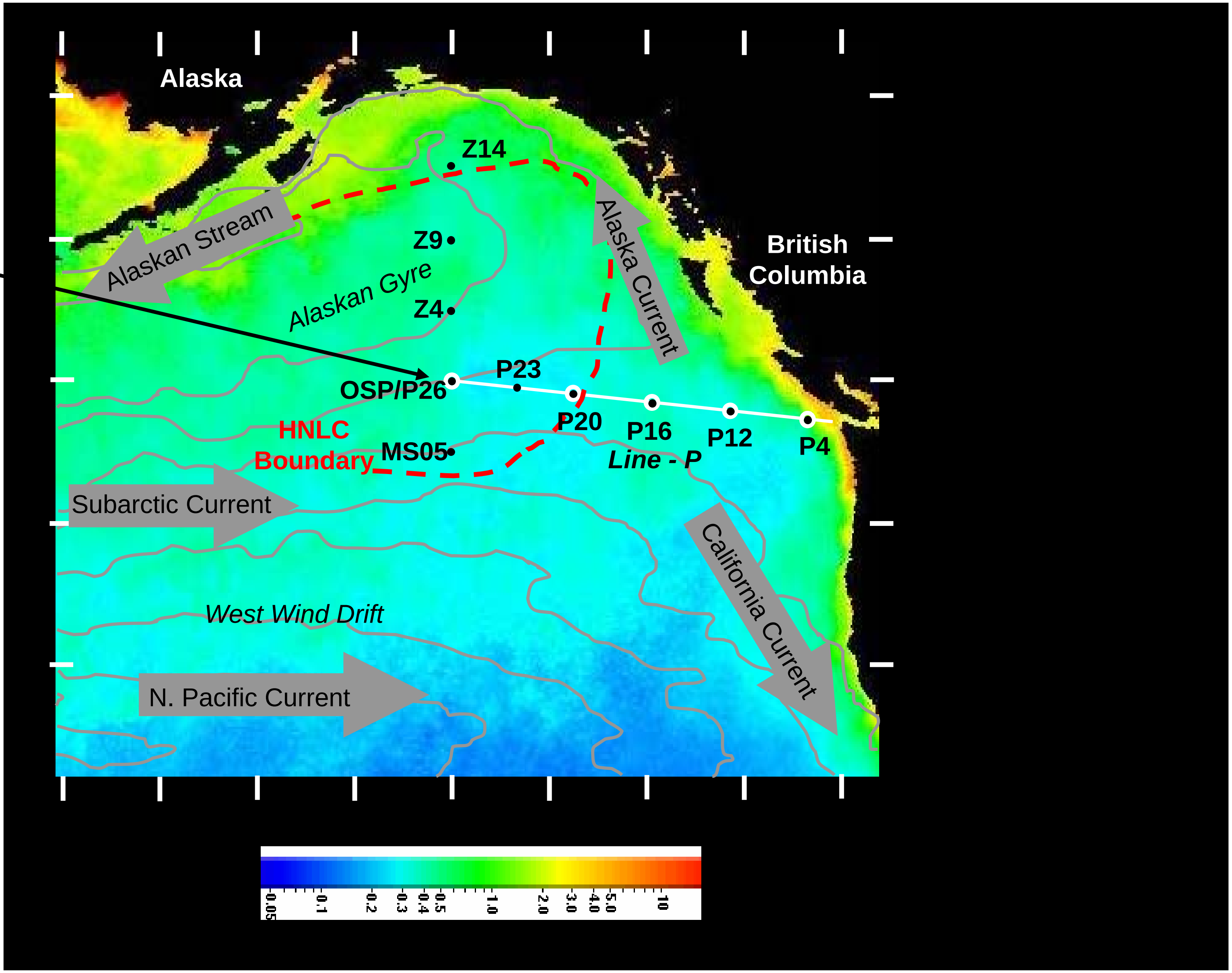
Northeast Subarctic Pacific

The iron patch will be located between P20 and P26



Fe Enrichment Near Ocean Station Papa (OSP)

SERIES (July 2002) 10 km west of OSP



SERIES ship schedule (30 days July -Aug)

		Tully	El Puma	Kaiyo-Maru
5-Jul		steam to Fe site		
6-Jul		survey Fe site, prep injection		
7-Jul				
8-Jul				
9-Jul		Fe injection #1		
10-Jul	D0			
11-Jul	D1			
12-Jul	D2			
13-Jul	D3			
14-Jul	D4			
15-Jul	D5			
16-Jul	D6			
17-Jul	D7	Fe injection #2		
18-Jul	D8			
19-Jul	D9			
20-Jul	D10			
21-Jul	D11			
22-Jul	D12			
23-Jul	D13	leave Patch		
24-Jul	D14			
25-Jul	D15			
26-Jul	D16			
27-Jul	D17			
28-Jul	D18		leave Patch	
29-Jul	D19			
30-Jul	D20			
31-Jul	D21			
1-Aug	D22			
2-Aug	D23			
3-Aug	D24			
4-Aug	D25			leave Patch

John P. Tully

El Puma

Kaiyo Maru

INJECTION TRACK

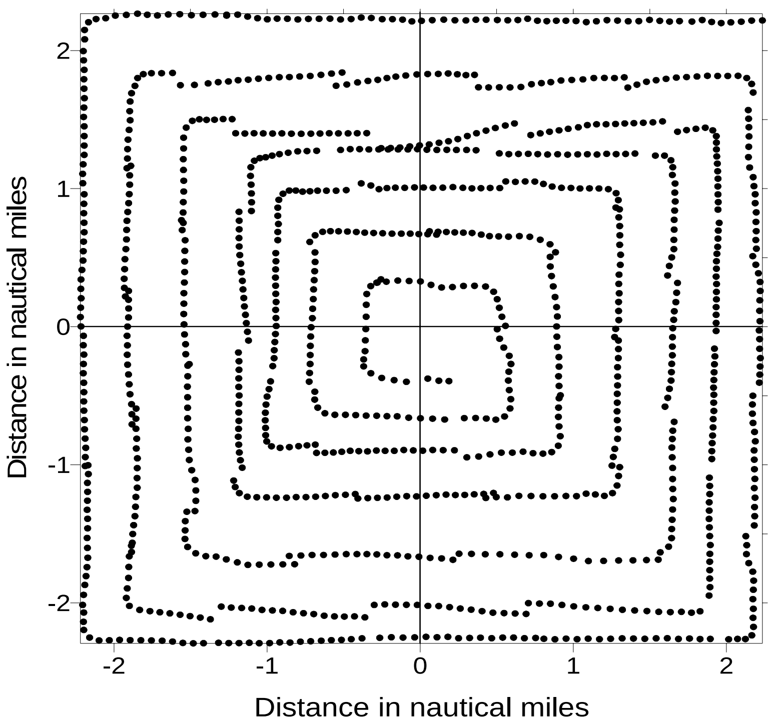
22.5 Sq Miles or 77 km^2

1st injection: 387 Kg Fe^{++} (2 metric tonnes)

2nd injection = 0.5 metric tonnes

First injection - Ship Track
with respect to drifter 29867

01h20 9 July - 18h45 9 July 2002 PDT



First injection - Ship Track

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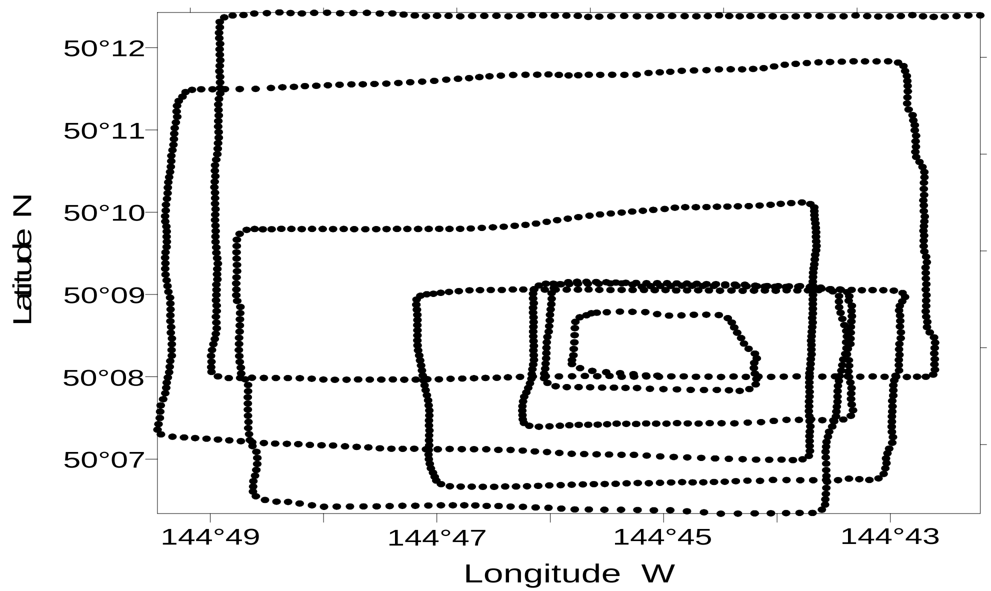


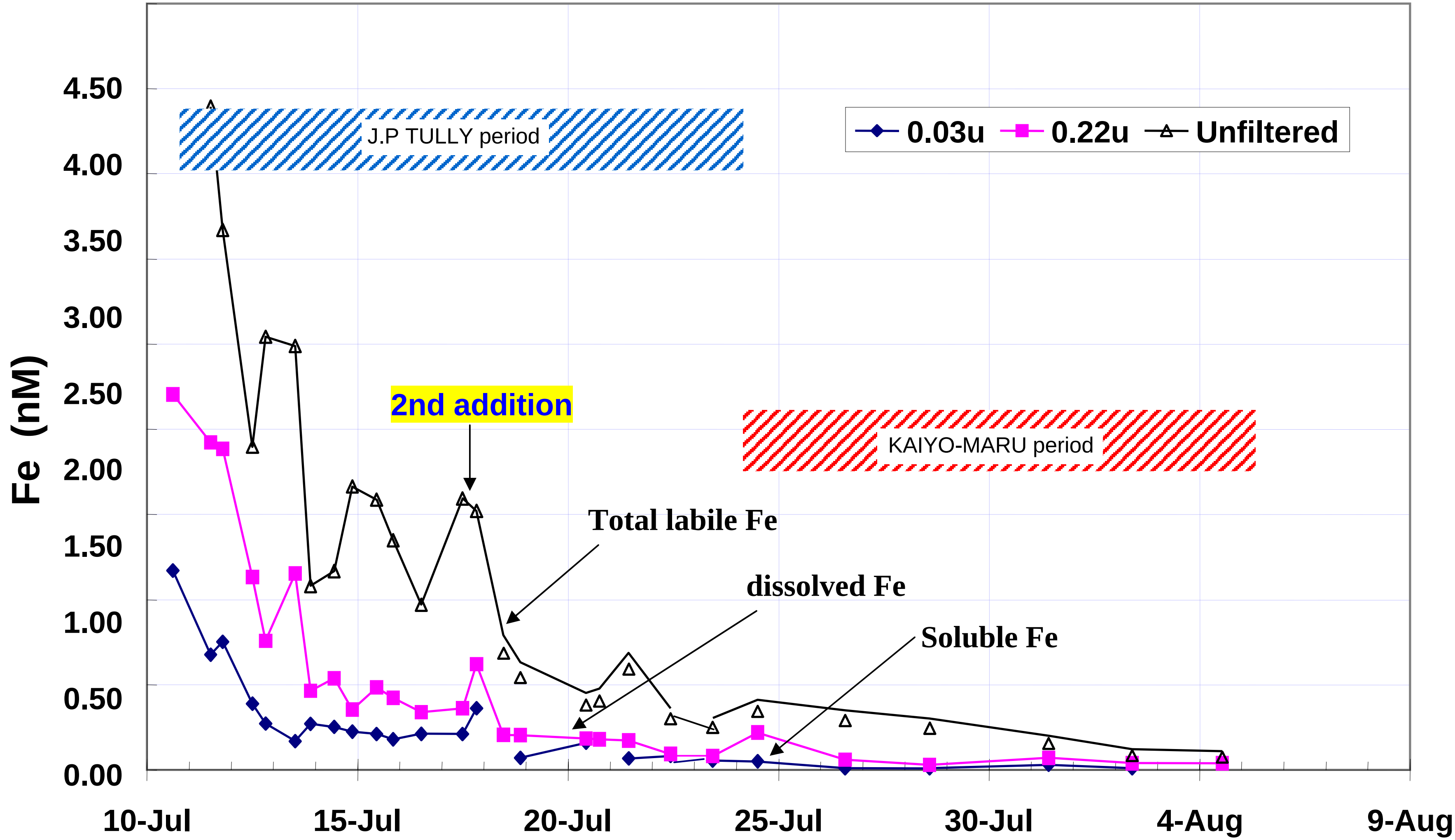
5.1 x 7.0 nm
9.5 x 13.0 km

Prepared by Marie Robert

Prepared by Marie Robert

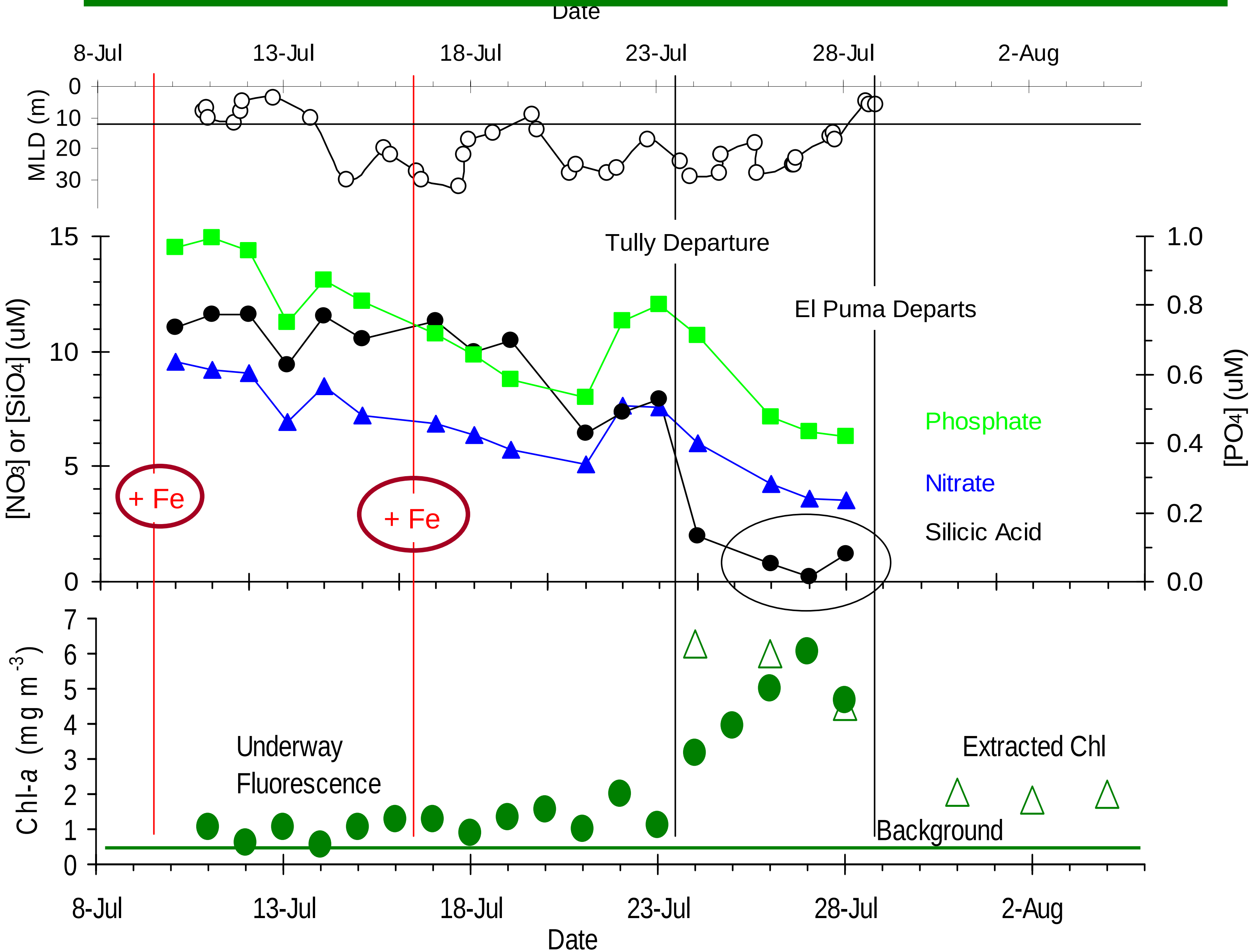
Tanks for Fe and SF_6

IRON Fractions at 10 m - Time Series

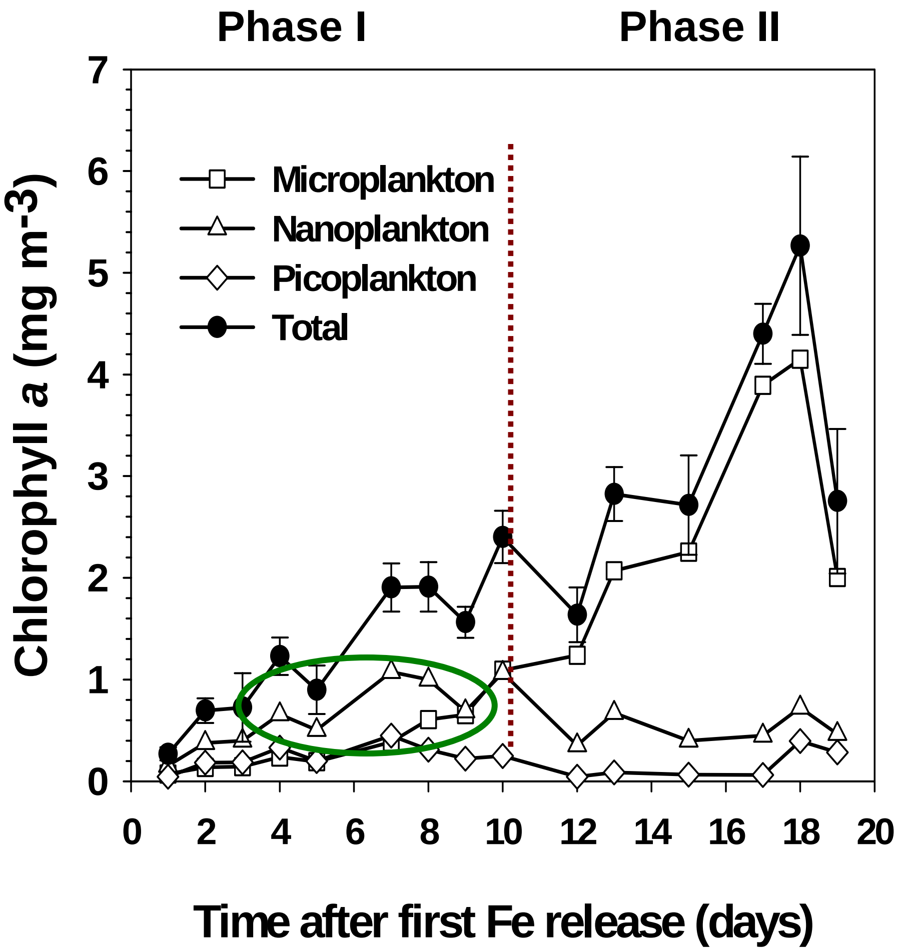


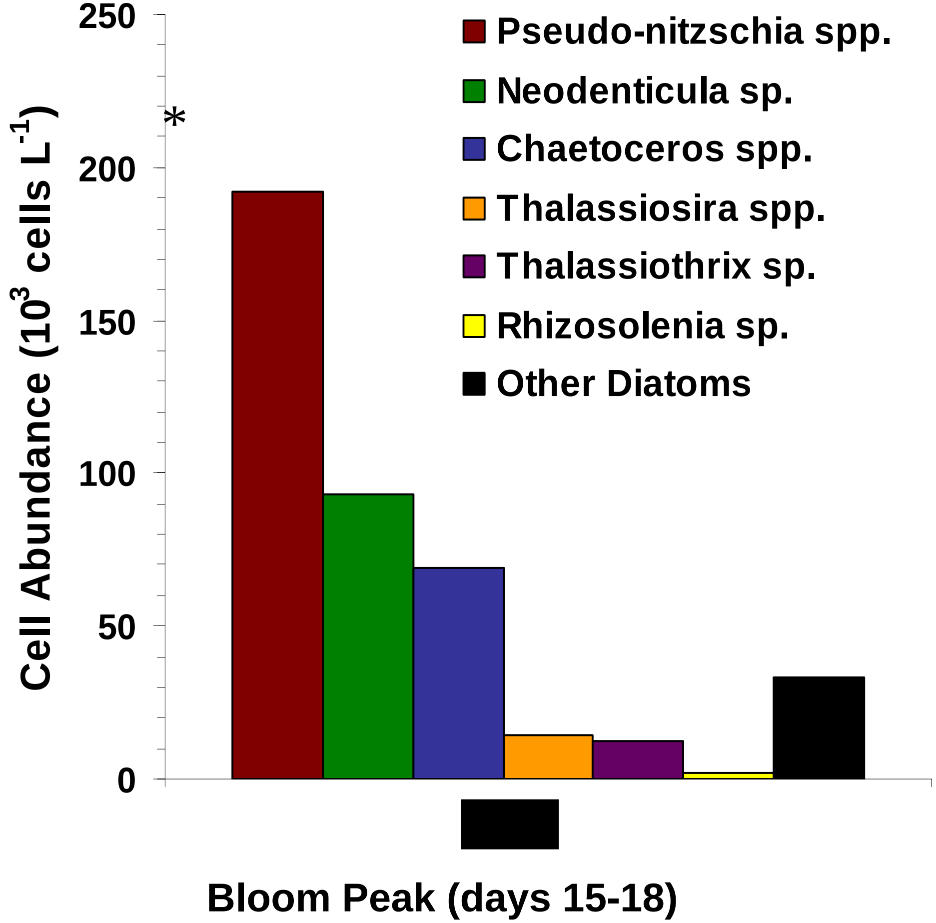
(Nishioka et al.)

Mixed Layer Depth, Nutrients and Chl



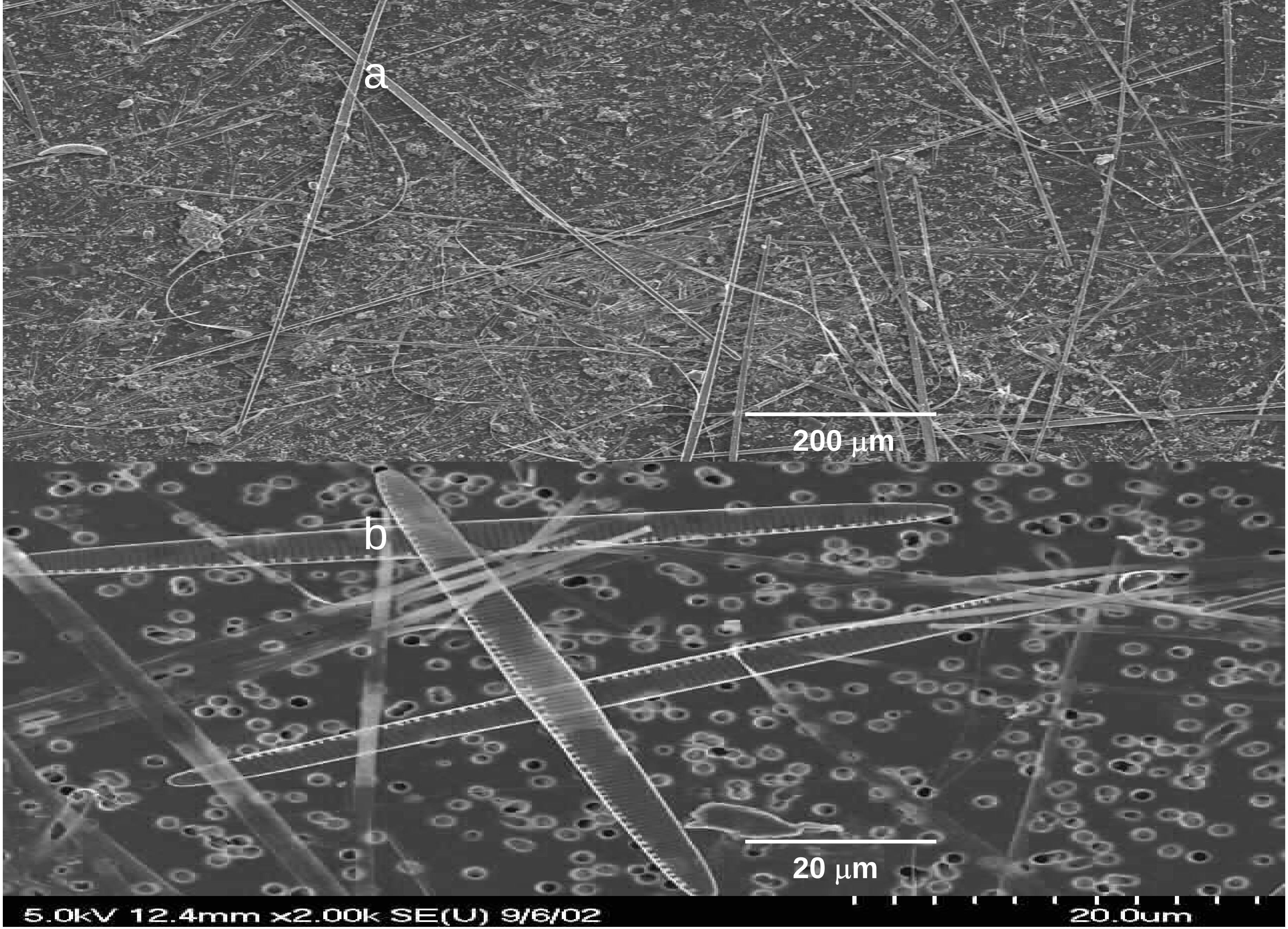
Phytoplankton Biomass and Species





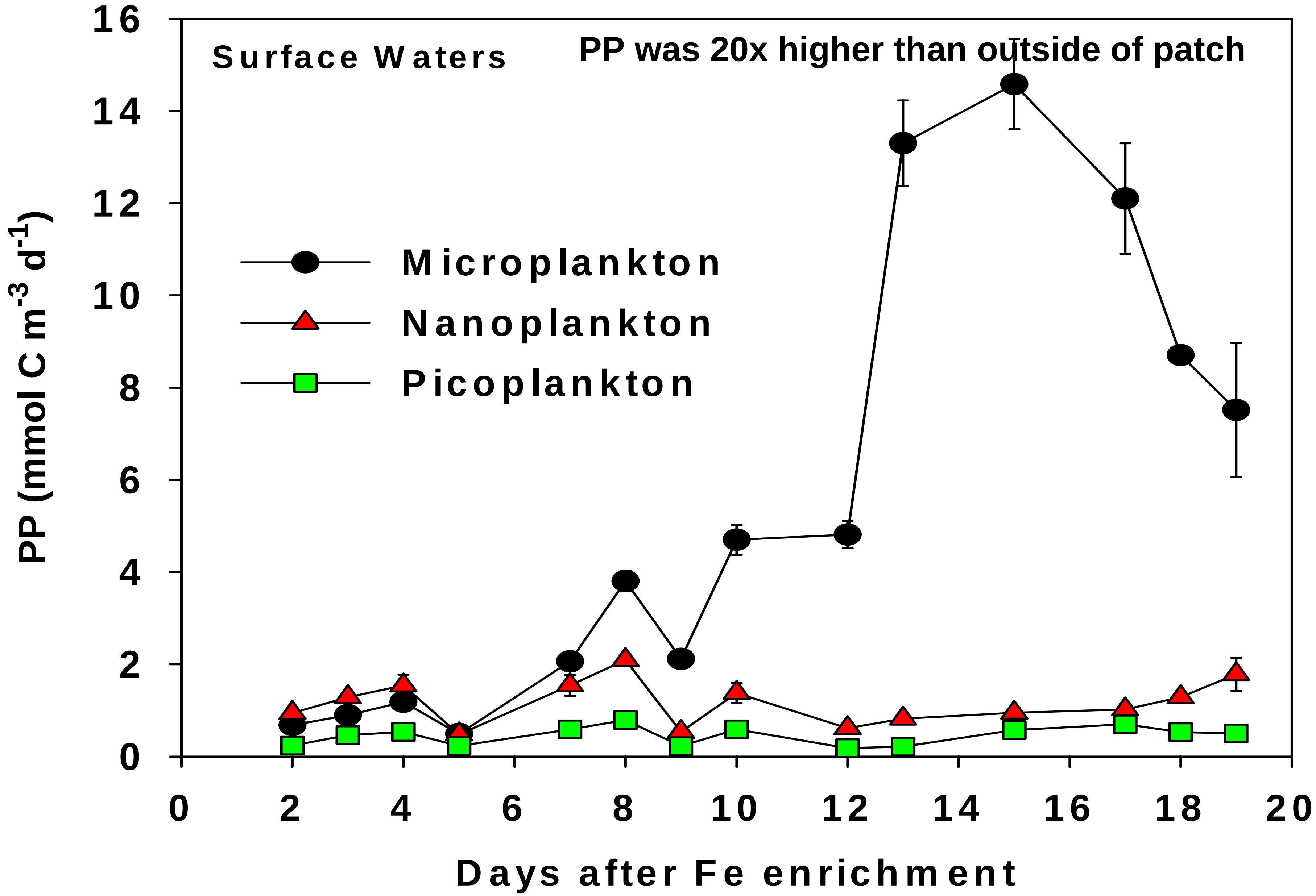
Integrated Chl increased 8 times to 114 mg m^{-2}

- Phase II, diatoms were dominant (>80% of chl *a* by day 15)
- *Pseudo-nitzschia* spp. most abundant at peak of bloom, but centrics had most carbon



Pennate Diatom *Pseudo-nitzschia* sp.

3 Size-fractions of Phytoplankton Primary Productivity



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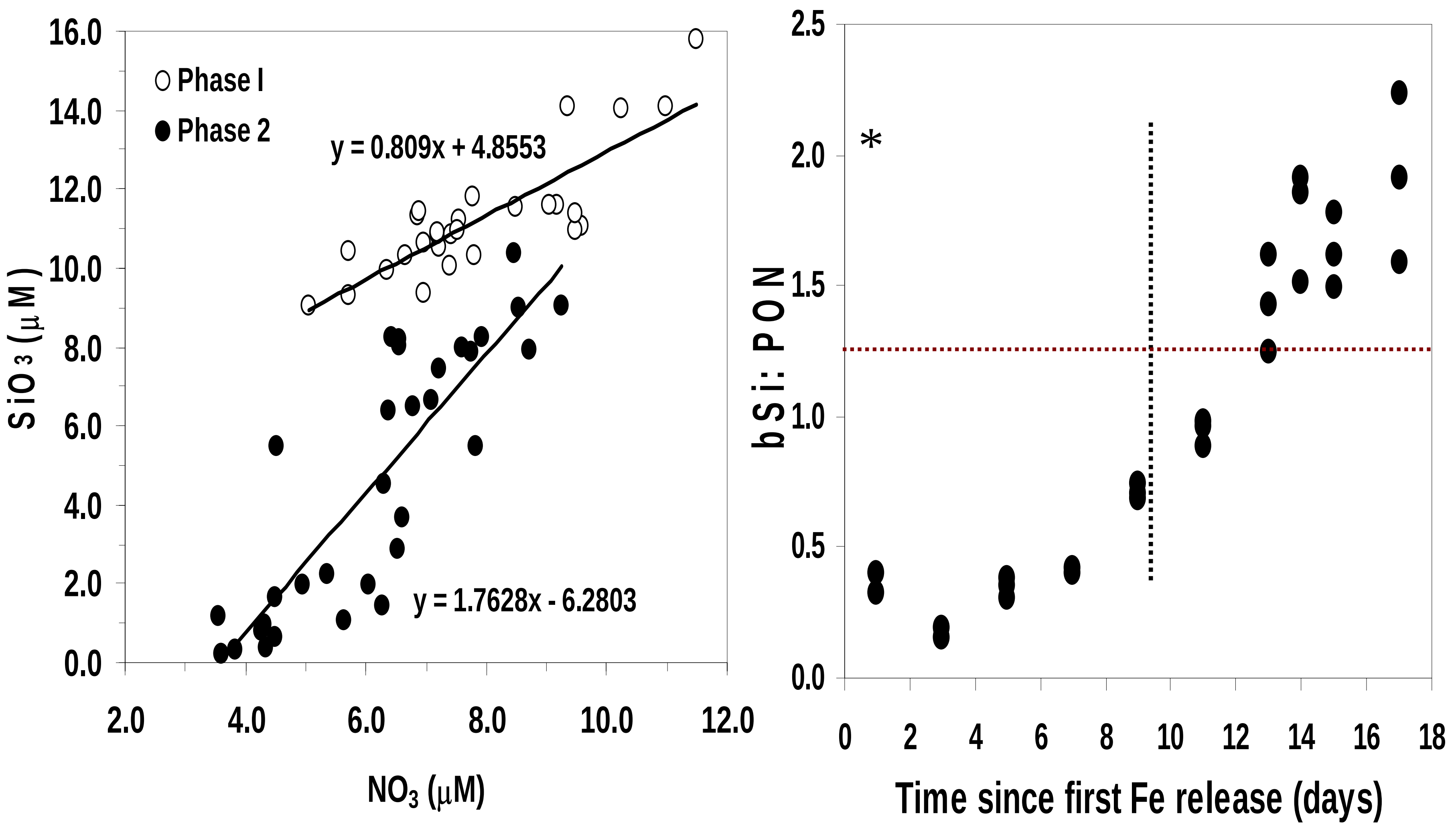
2-Aug	D23			
3-Aug	D24			
4-Aug	D25			leave Patch

John P. Tully

El Puma

Kaiyo Maru

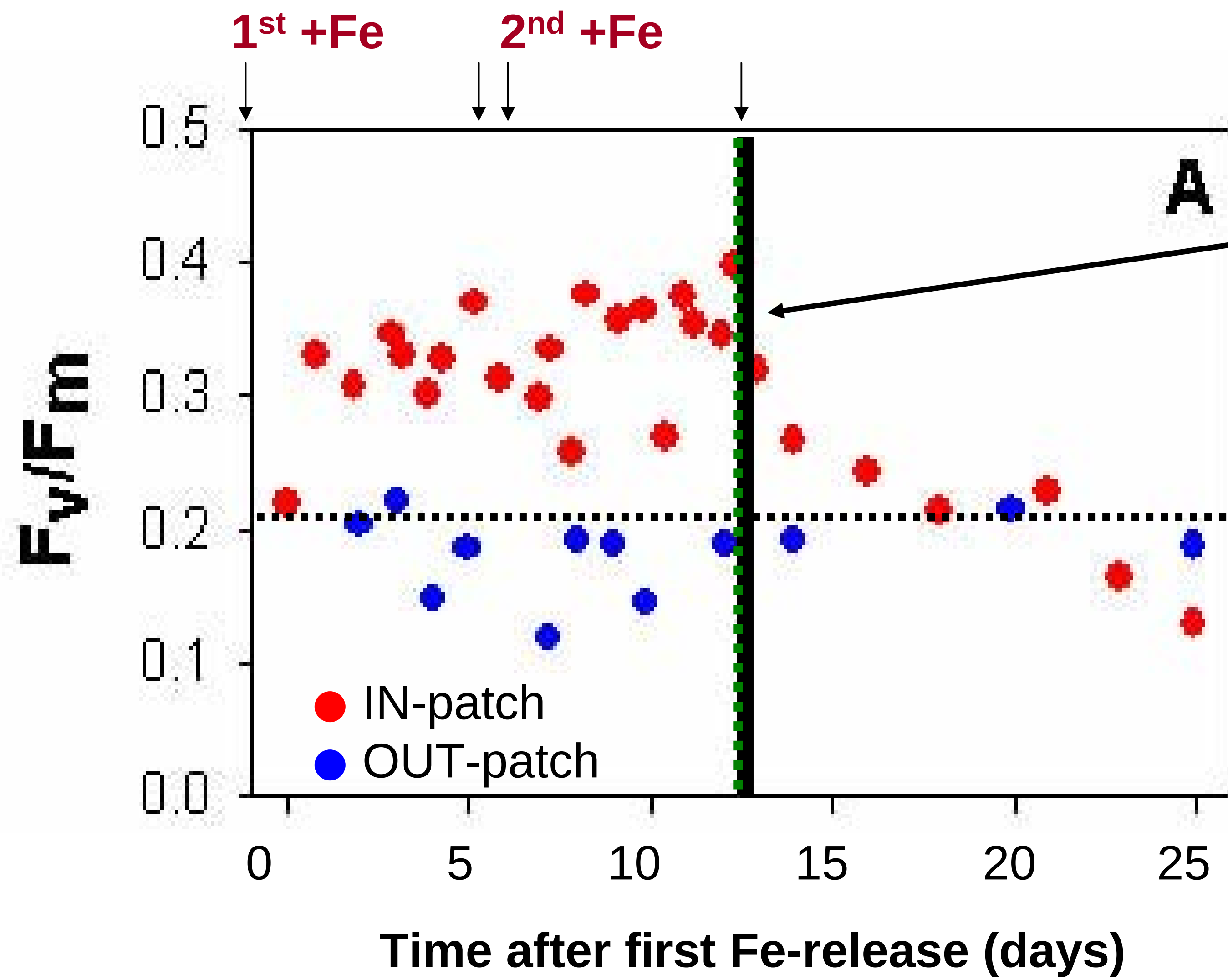
Nutrient Dynamics: Drawdown and BSi:PON ratios



- Phase II - $Si(OH)_4$ drawn down = 2x NO_3 drawdown.
- Si:N ratios increased 2x in the particulate matter.

*Courtesy of C.S. Wong and Y. Nojiri

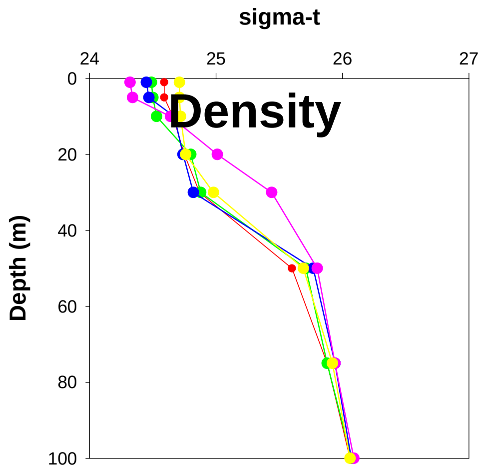
Photosynthetic Efficiency (F_v/F_m) indicates Fe stress

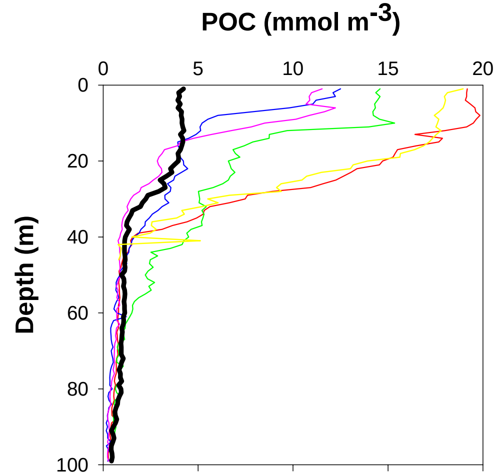


Low F_v/F_m indicates phytoplankton were Fe-stressed

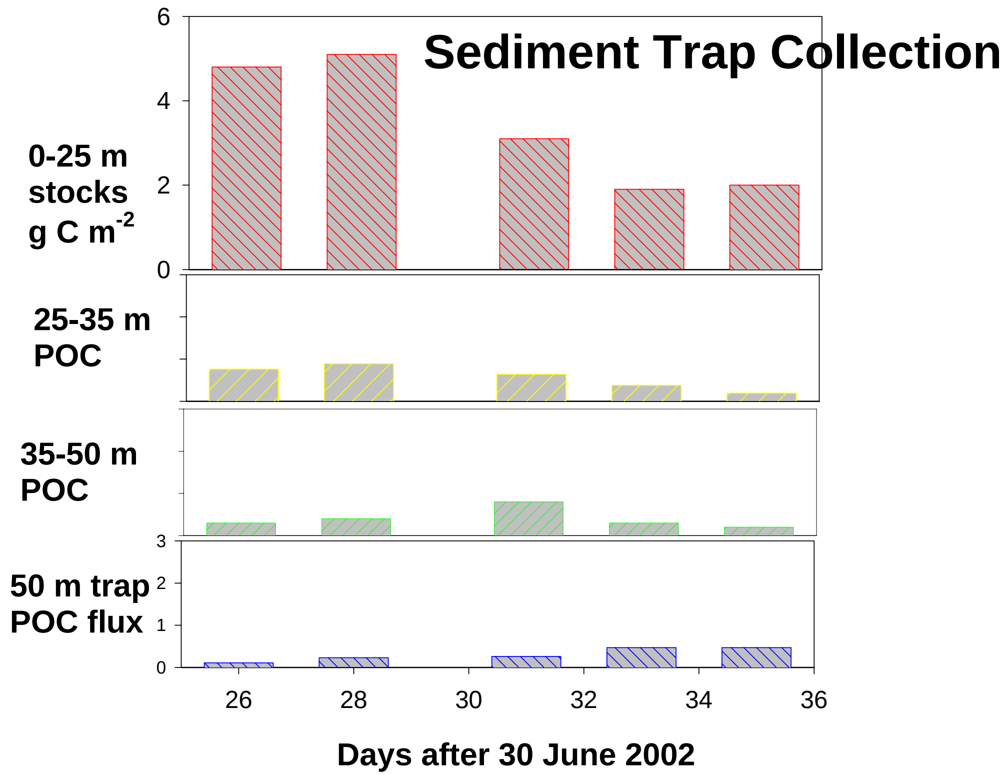
Courtesy of P. Boyd

POC Vertical Distribution and Sediment Trap Collections

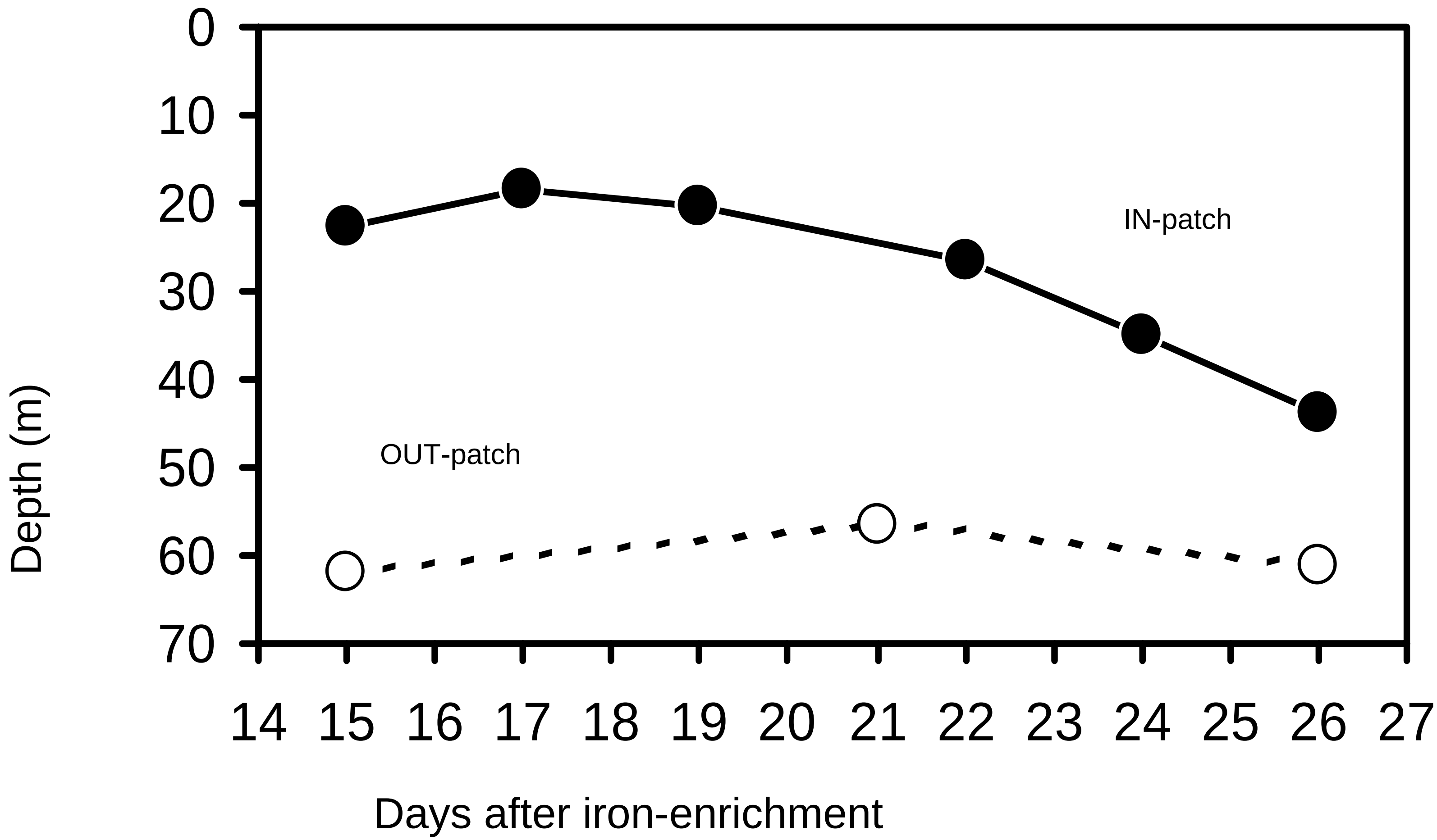




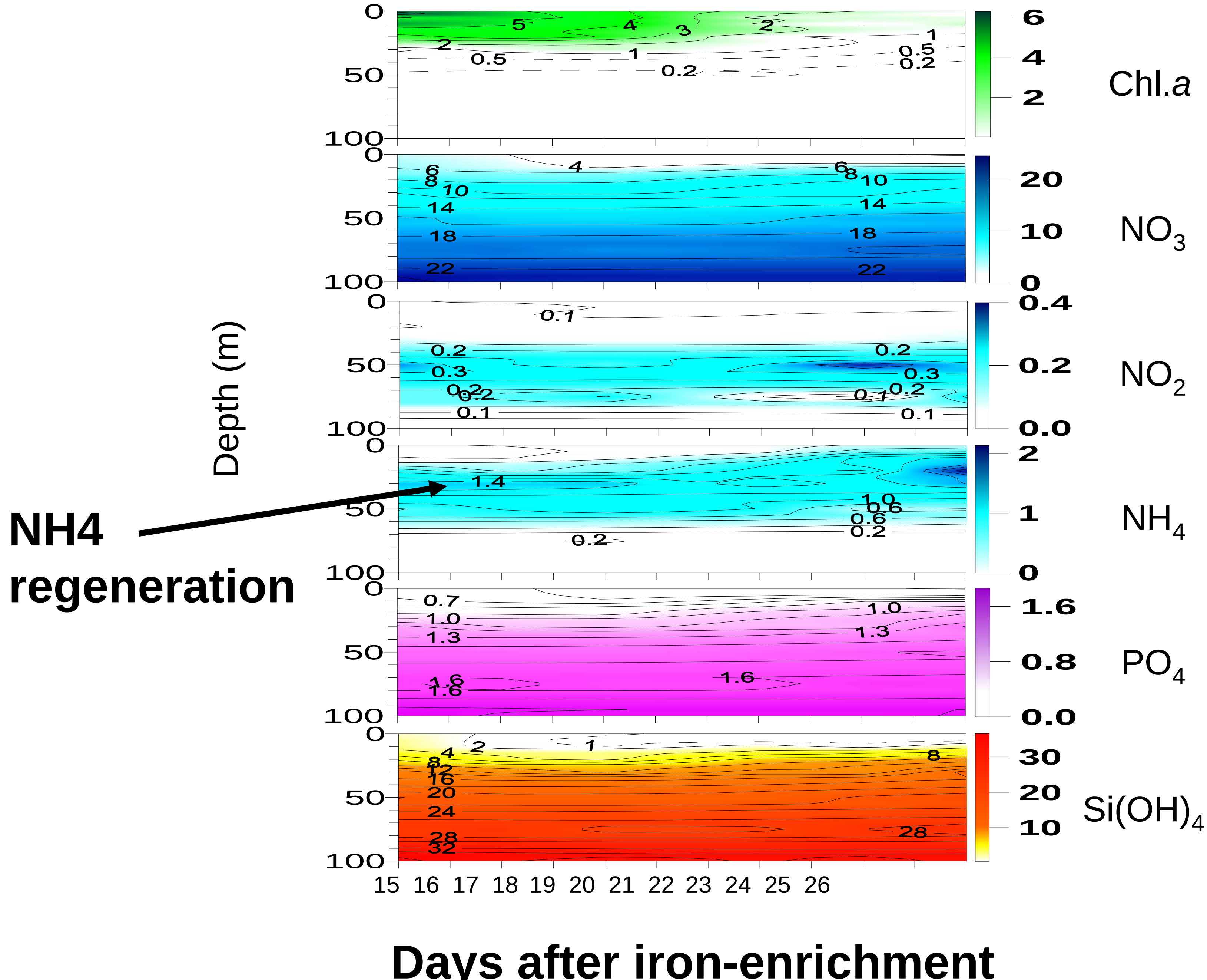
Partic Org Carbon



18% of POC exported to 50 m & 8% below the permanent thermocline at 120 m

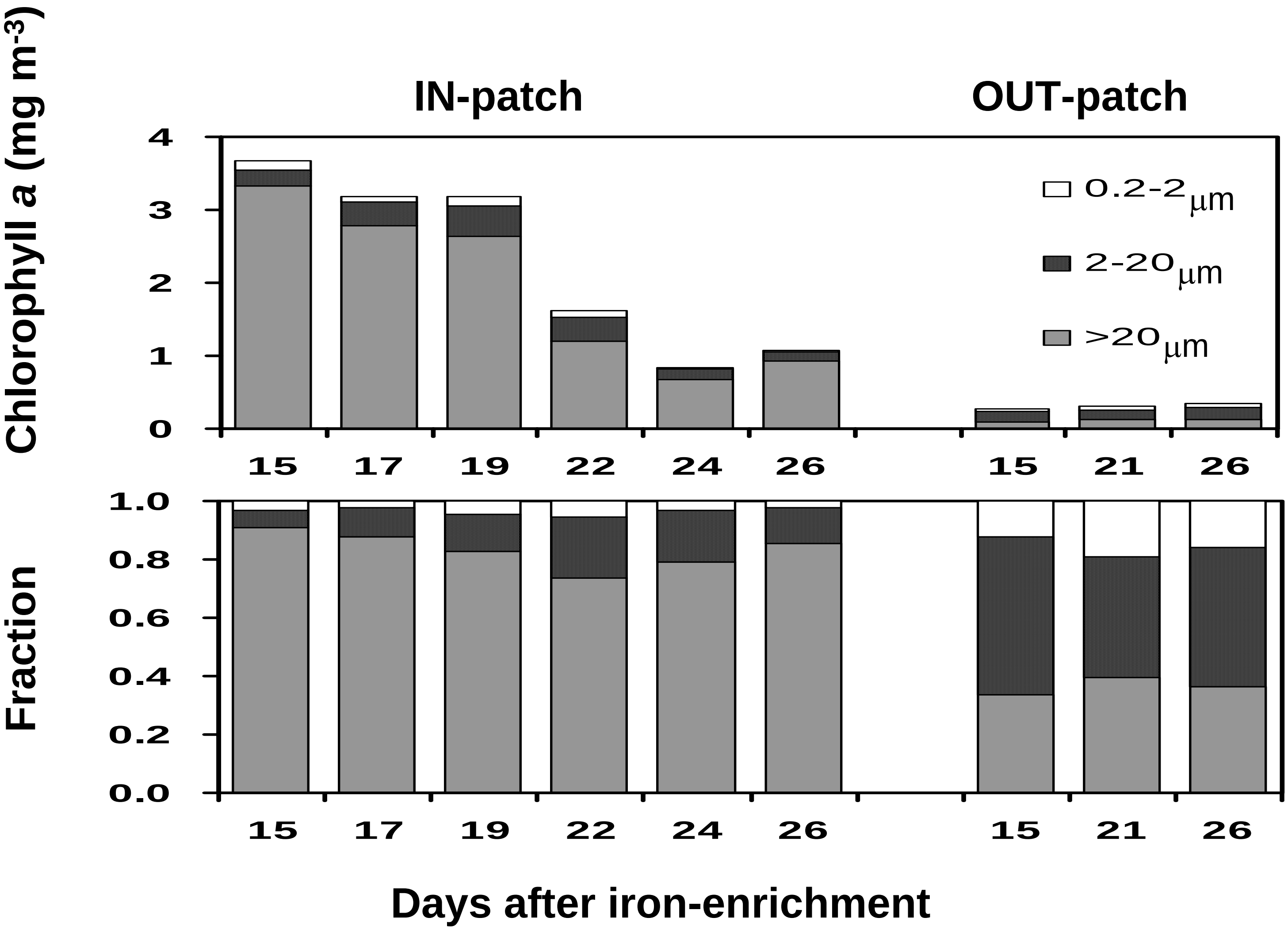


Photic Zone Depth


Chl.a
NO3
NO2
NH4
PO4
Si(OH)4
Depth (m)
NH4 regeneration
Days after iron-enrichment
15 16 17 18 19 20 21 22 23 24 25 26

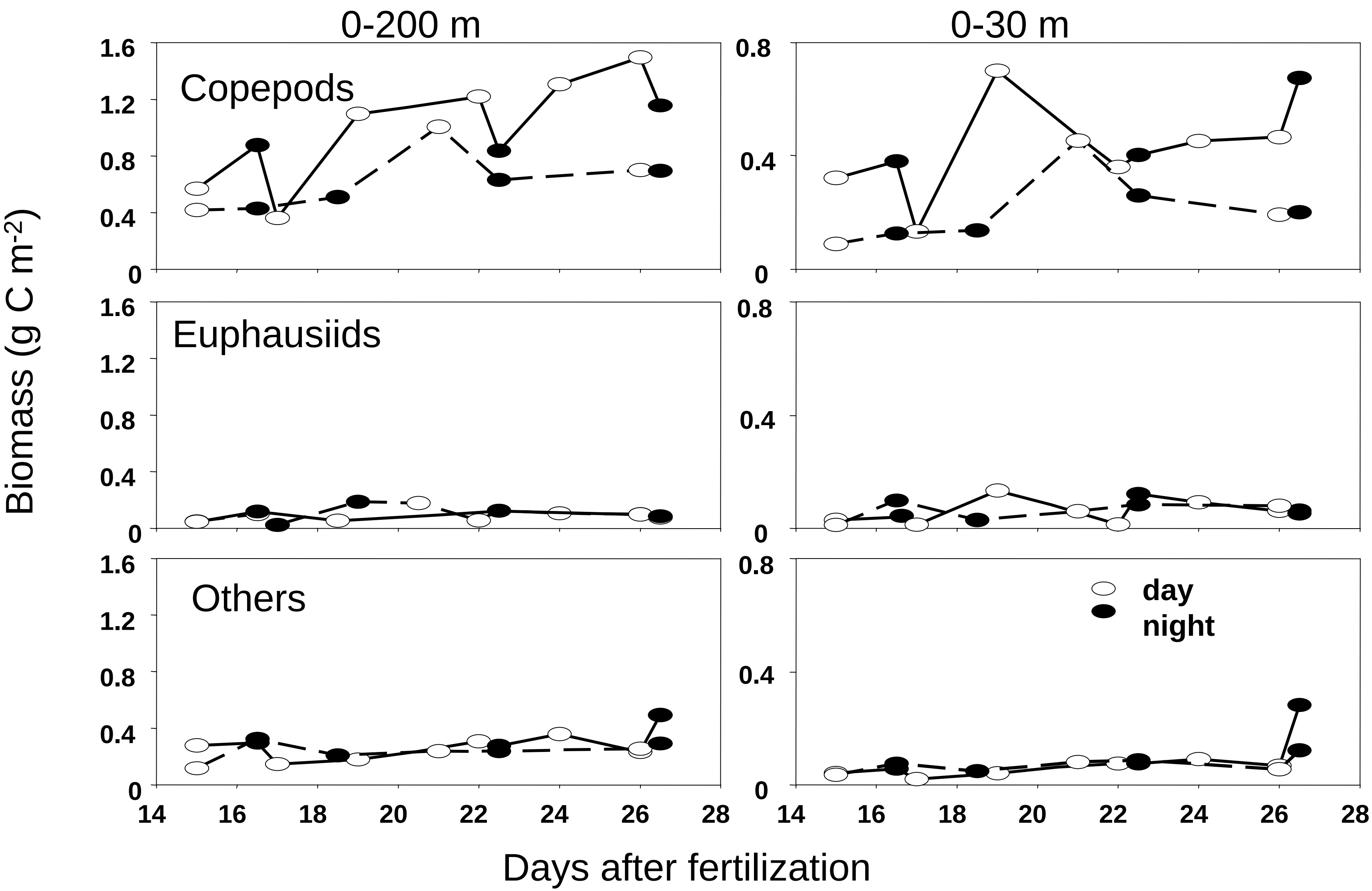
Saito et al. Fig. 7

Change in Size-fractionated Chlorophyll



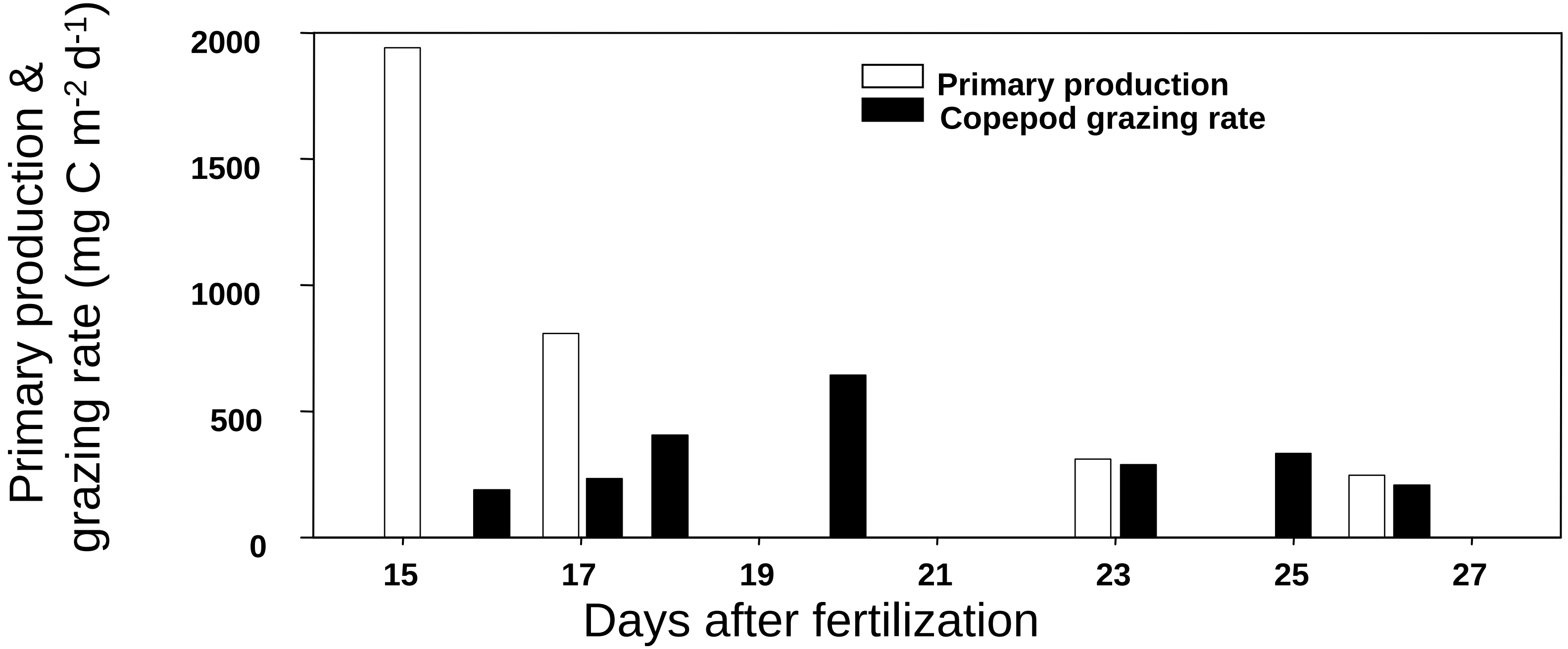
Smaller size fraction increases

Mesozooplankton Groups

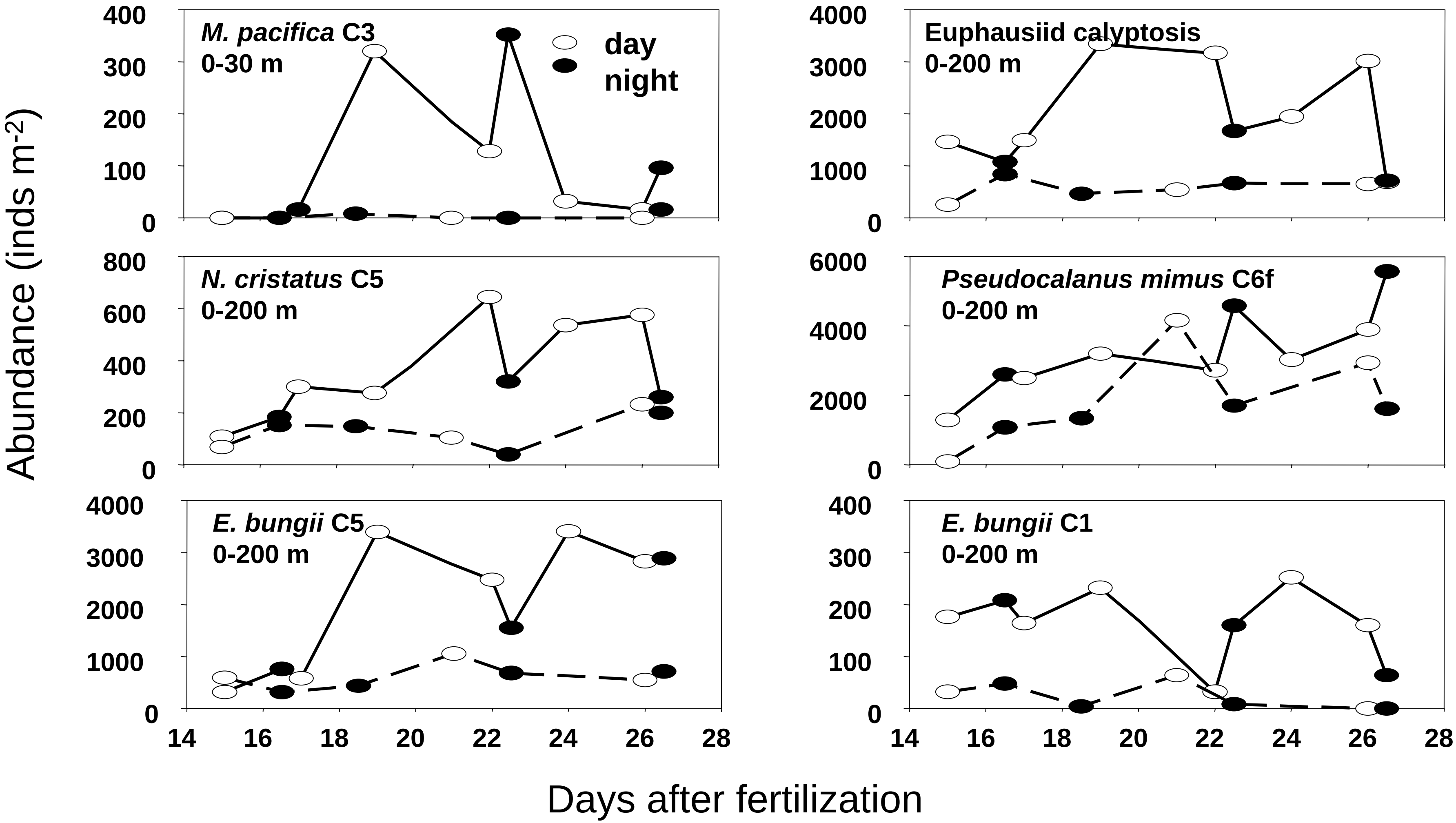


Tsuda et al. Fig. 2

Primary Production & Grazing Rate



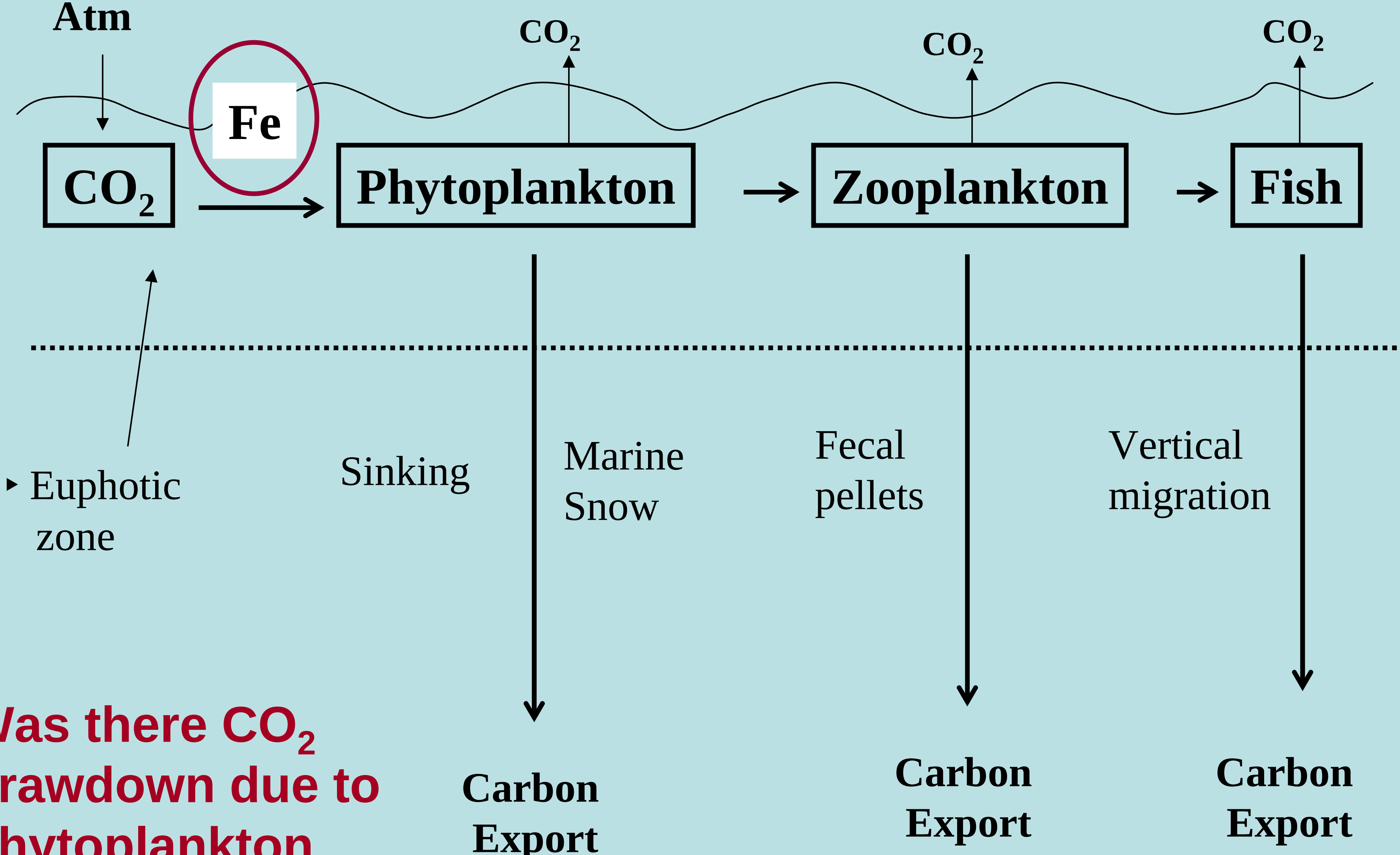
Tsuda et al. Fig. 10



Eucalanus, *Pseudocalanus* and Euphausiids > in patch

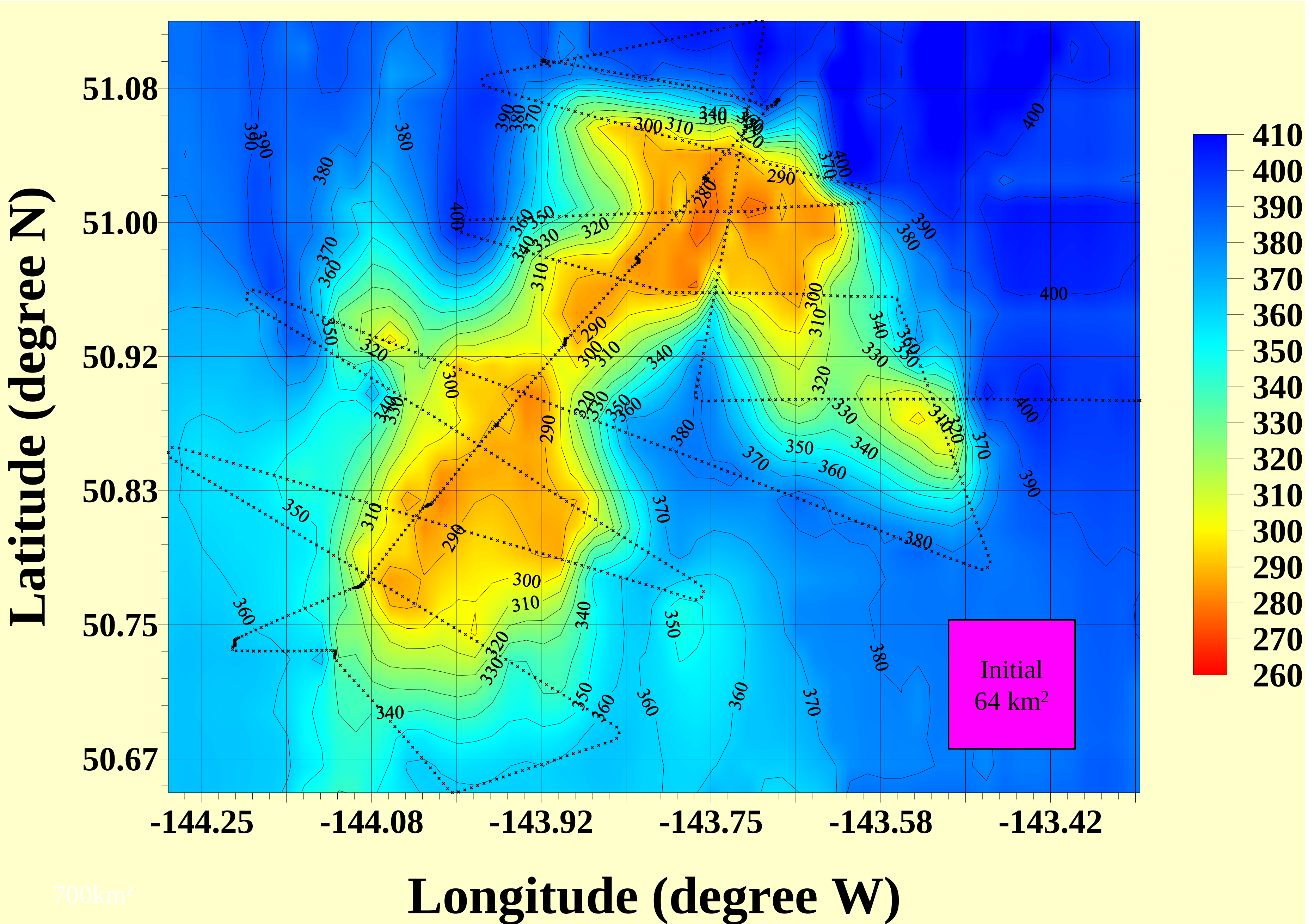
Tsuda et al. Fig. 4

Biological Pump

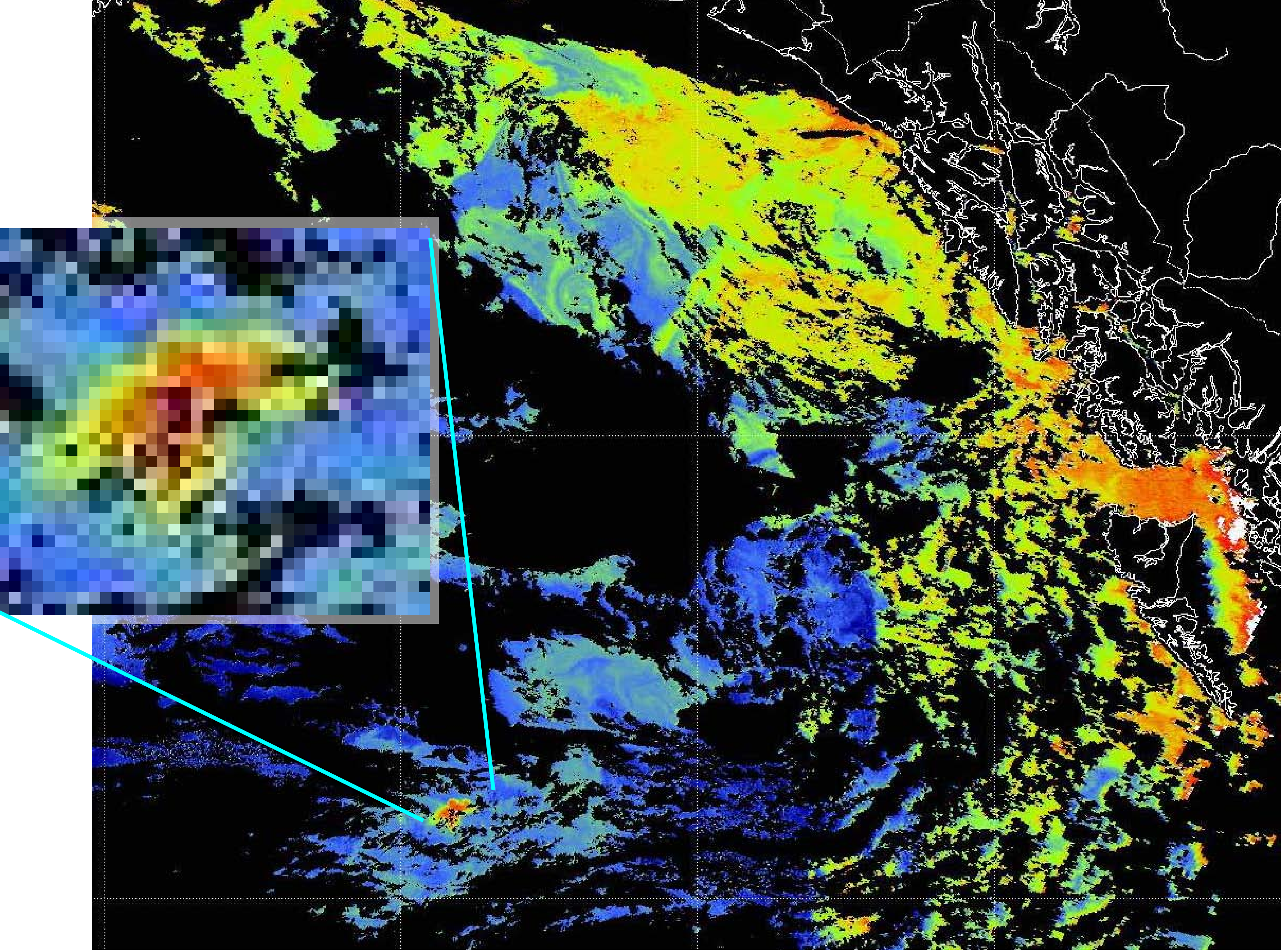


Was there CO_2 drawdown due to phytoplankton growth?

fCO_2 (Day 25) decreased from 340 to 260 uatm

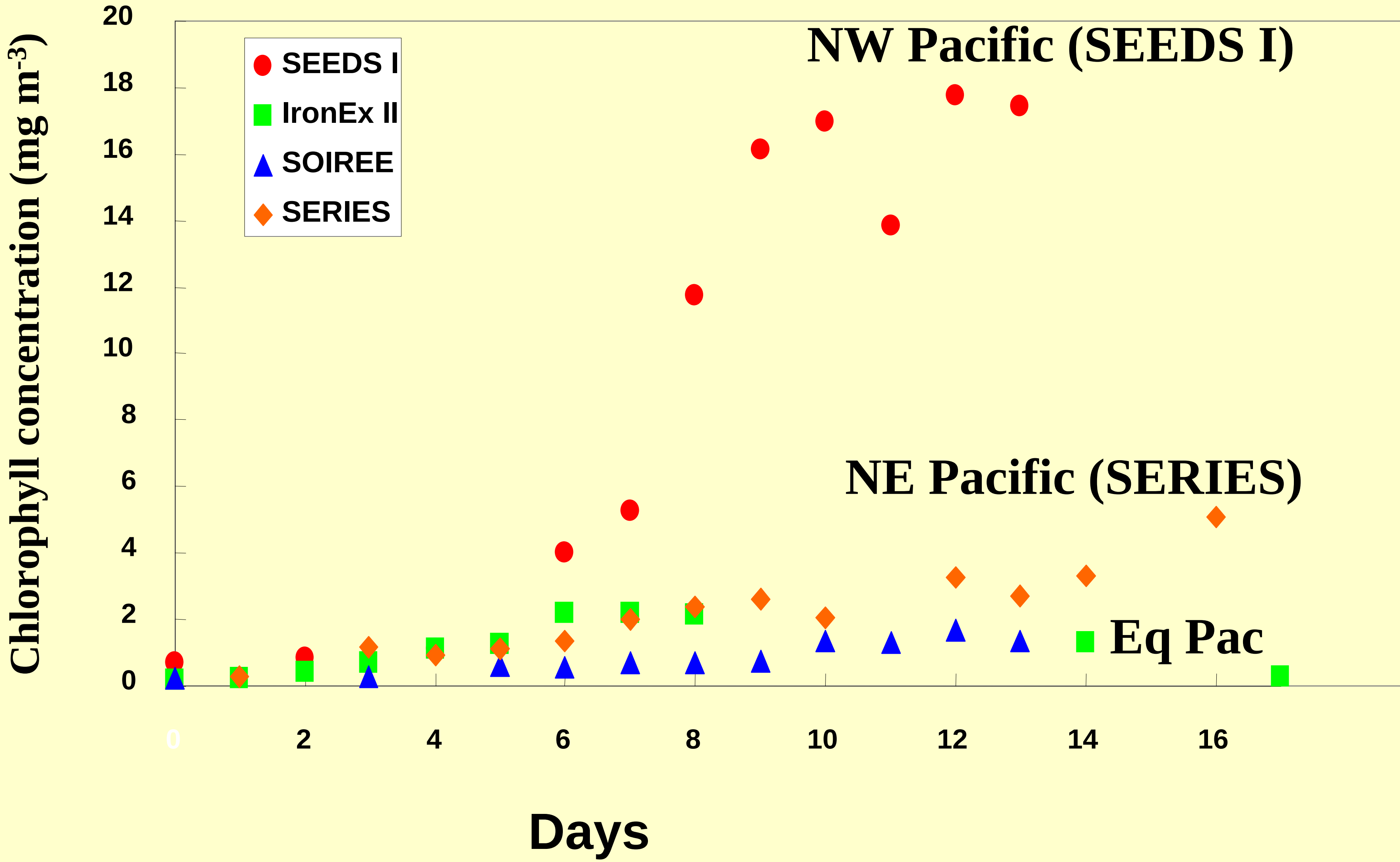


Outside station (No Fe added) **Fe patch → algal bloom**

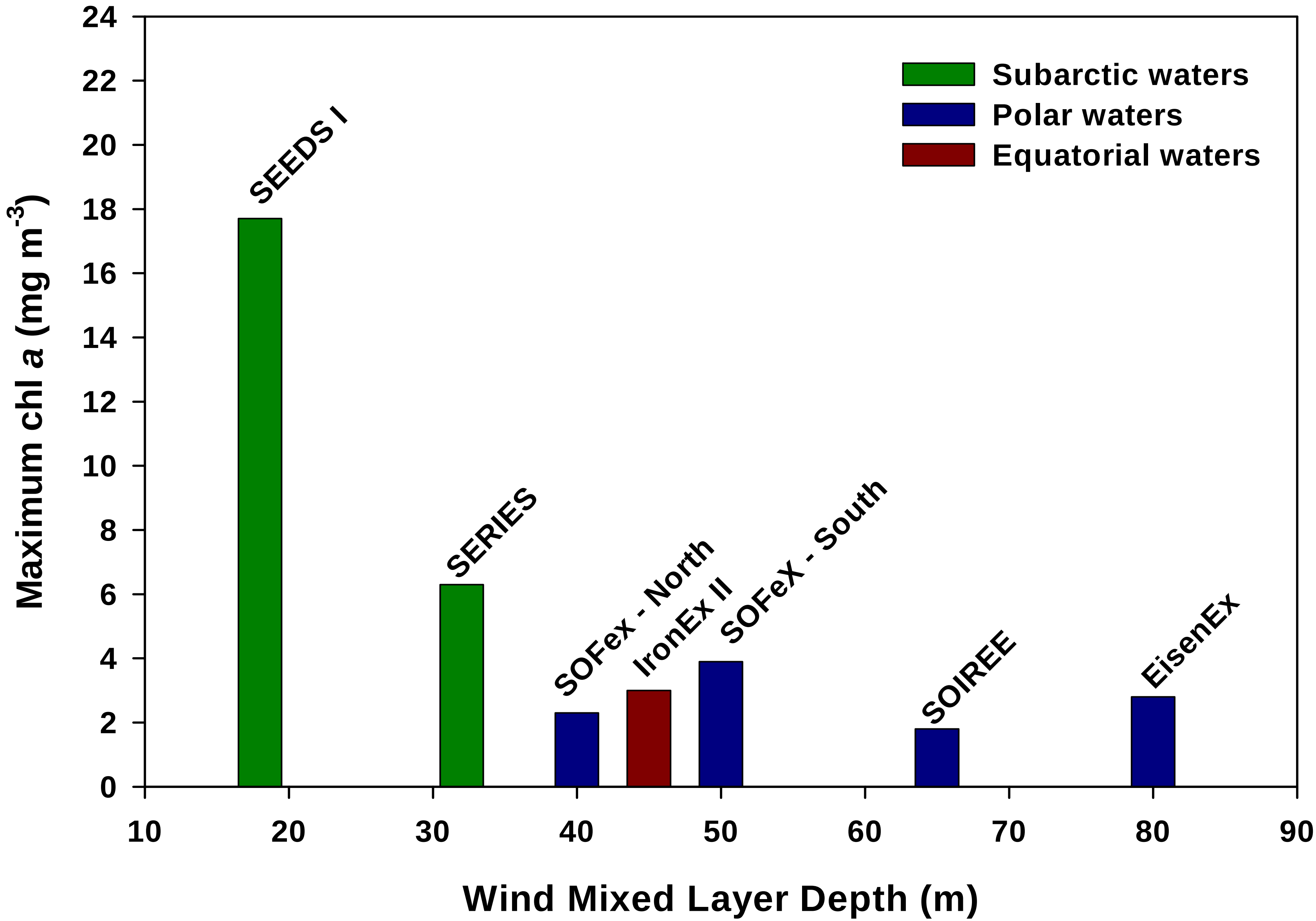


700 km^2 chlorophyll patch as seen by SeaWifs Satellite, July 29, 2002

Comparison of chl *a* biomass in 4 iron fertilization expts



Comparison of 7 Fe Expts (Chl biomass vs Mixed Layer Depth)



Current View of Food Chain at Stn P

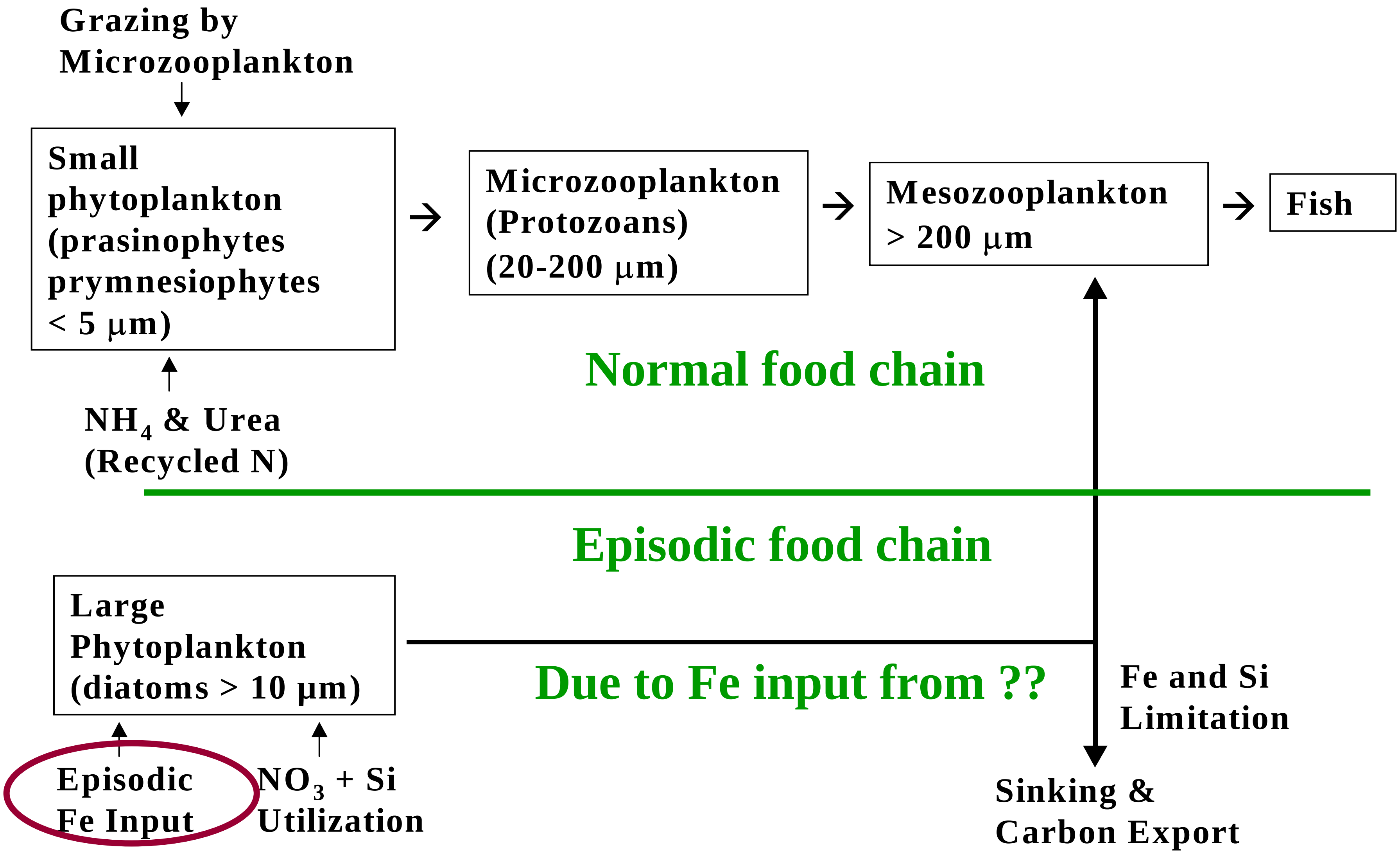


Fig. 12

Summary

- Bloom terminated by Si and Fe (NO_3 and PO_4 remained at saturating levels)

- Sediment trap data indicated about ~5 - 8% C flux

- Microbial loop- recycled ~25% of C

- Added Fe:C exported below the permanent thermocline ~1000x more than previous assumptions

  (i.e. less C exported per unit of Fe added)

Summary (Cont'd)

- Low carbon export indicated Fe fertilization may not be an efficient method to draw down excessive CO_2 in the atmosphere.

- SERIES simulated natural additions of Fe by dust, etc.

- C-SOLAS was the first extensive collaboration between oceanographers and atmospheric scientists in Canada.

Special Volume

Deep-Sea Research Vol 53 (20-22)

- 24 papers
- Some proofs are now on the Elsevier website

Future Directions

- **Temporal variability**
  – episodic events to decadal climate change

- **Need to continue time series**
  - with ships and automated sampling

- **Microzooplankton (e.g. heterotrophic dinoflagellates) are not well studied.**

Future Directions

- **Sources of iron (atmospheric, horizontal, vertical)**

•Natural dust experiment

- does dust really induce an increase in chl?

•Need biogeochemistry approach + physics

+ atmospheric chemists and meteorologists.

The End of a Successful Mission

Summary

- Algal growth at Stn P is limited by Fe, and Si
- About 30% of the oceans are limited by Fe
- A natural source of Fe is atmospheric dust.
- Episodic Fe inputs simulated by mesoscale Fe additions
- Since algae require 100,000 C:1 Fe for growth, there is interest in fertilizing the ocean with Fe.
- There is concern that adding Fe could change ecosystem biodiversity.