Tropical rivers enhance carbon and nitrogen fixation

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Tropical Rivers Help Store Carbon

Ajit Subramaniam

Institute of Earth System Science Seers and Sages

Will inspire discussion, theory and experiments (wave my hands) but have numbers, am prone to passion

Acknowledgments

- NASA SIMBIOS and Ocean Biology Program
- NSF Biocomplexity Program
- Doherty Endowment
- Bernard Bourles, Fredric Marin, IRD, France

Definition of "new production"
Dugdale and Goering 1967

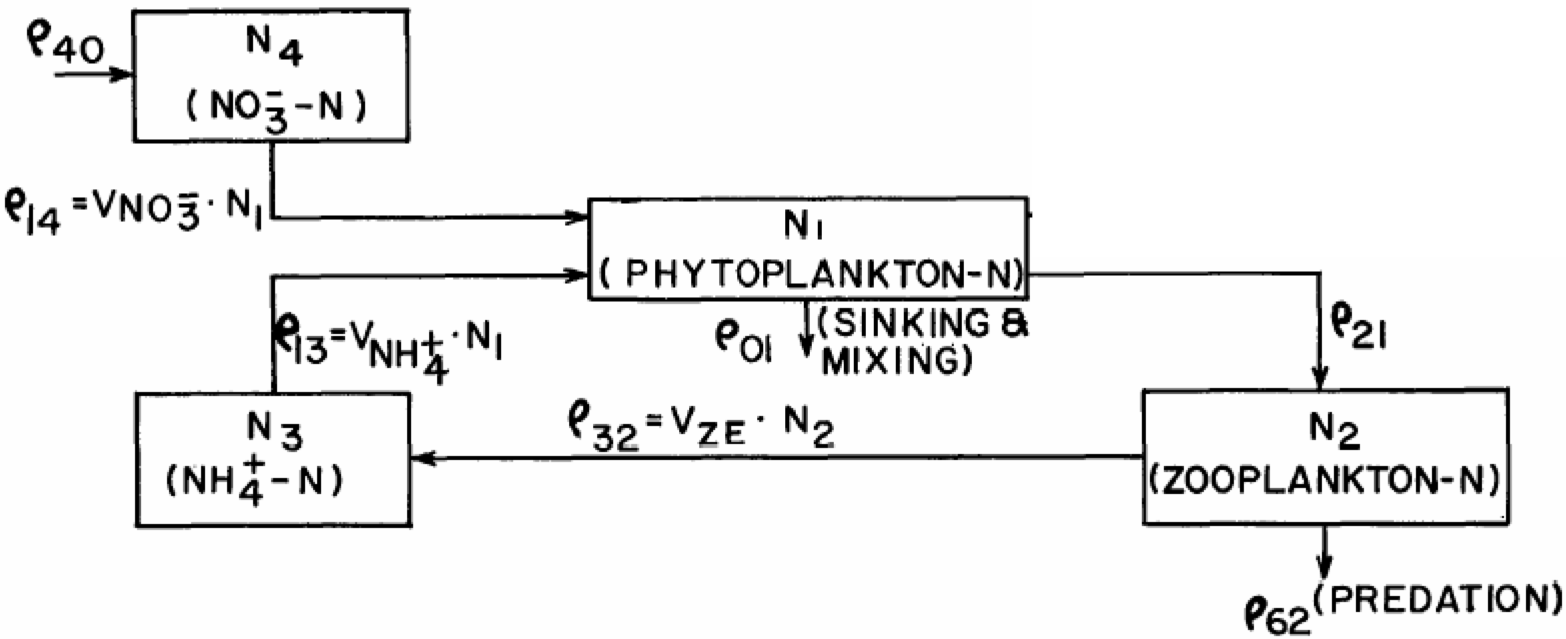


FIG. 1. Circulation of inorganic nitrogen through the euphotic zone ecosystem.

Definition of “new production”
Dugdale and Goering 1967

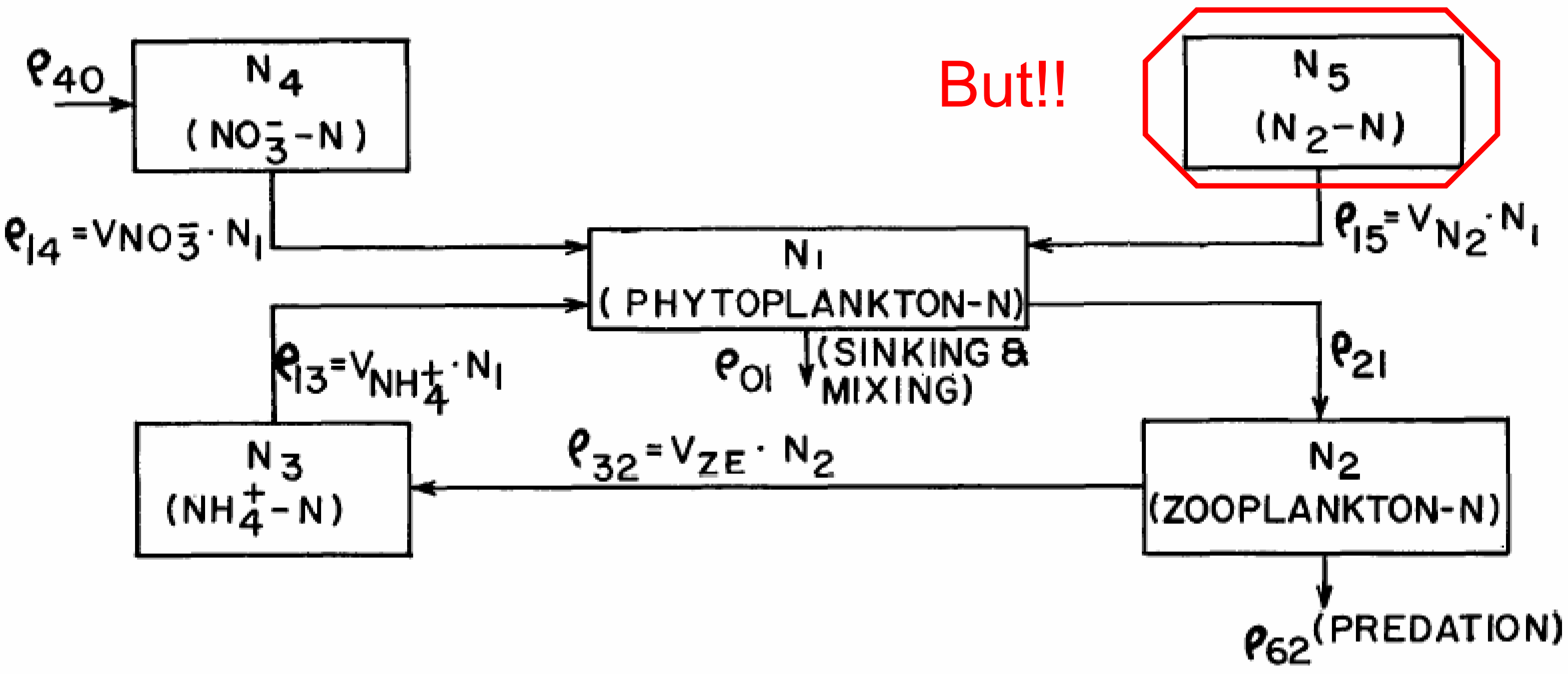
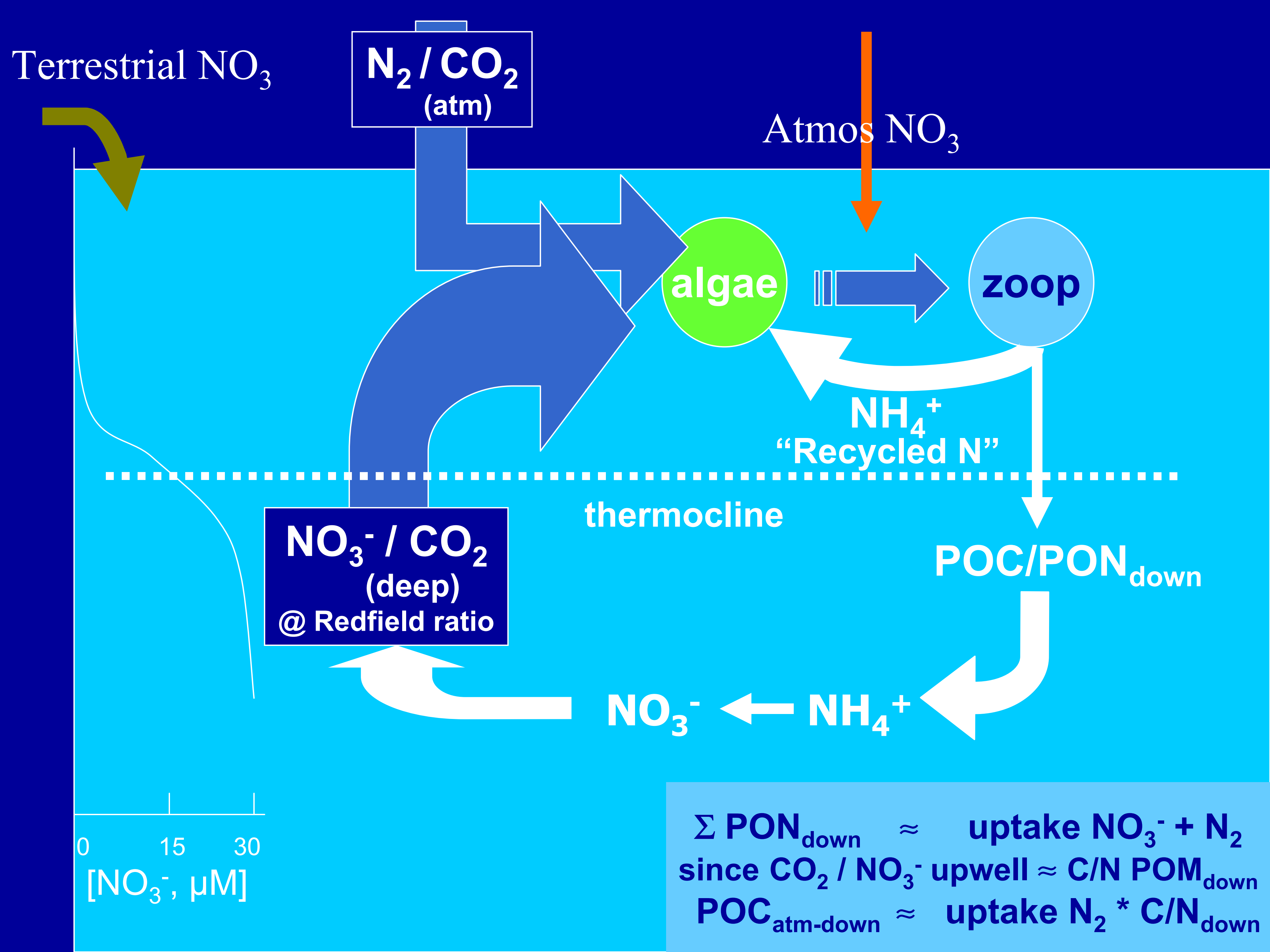


FIG. 1. Circulation of inorganic nitrogen through the euphotic zone ecosystem.

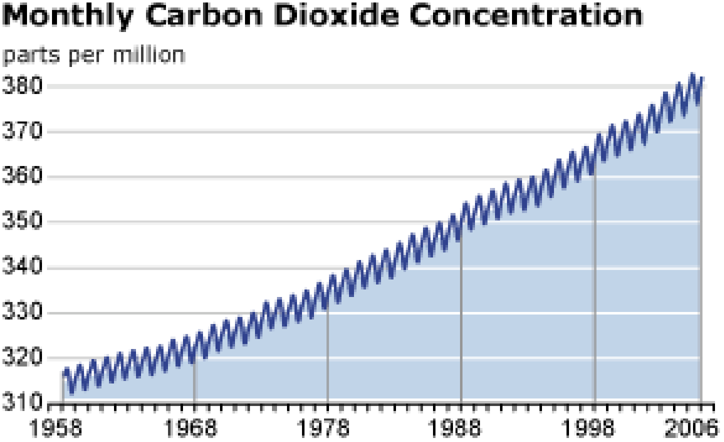
And……

To what extent does the sinking flux of particulate organic carbon constitutes a ‘sink’ for atmospheric CO_2 from fossil fuel burning? Since dissolved inorganic carbon moves upward along with the vertically transported nitrate, in approximately the Redfield ratio[21] of 106 C atoms : 16 N atoms, only the sinking flux due to new production associated with nitrogen fixation and nutrient inputs from terrestrial and atmospheric sources can be identified as a biologically-mediated transport of atmospheric carbon dioxide to the deep ocean.

Eppley and Peterson, Nature 1979.

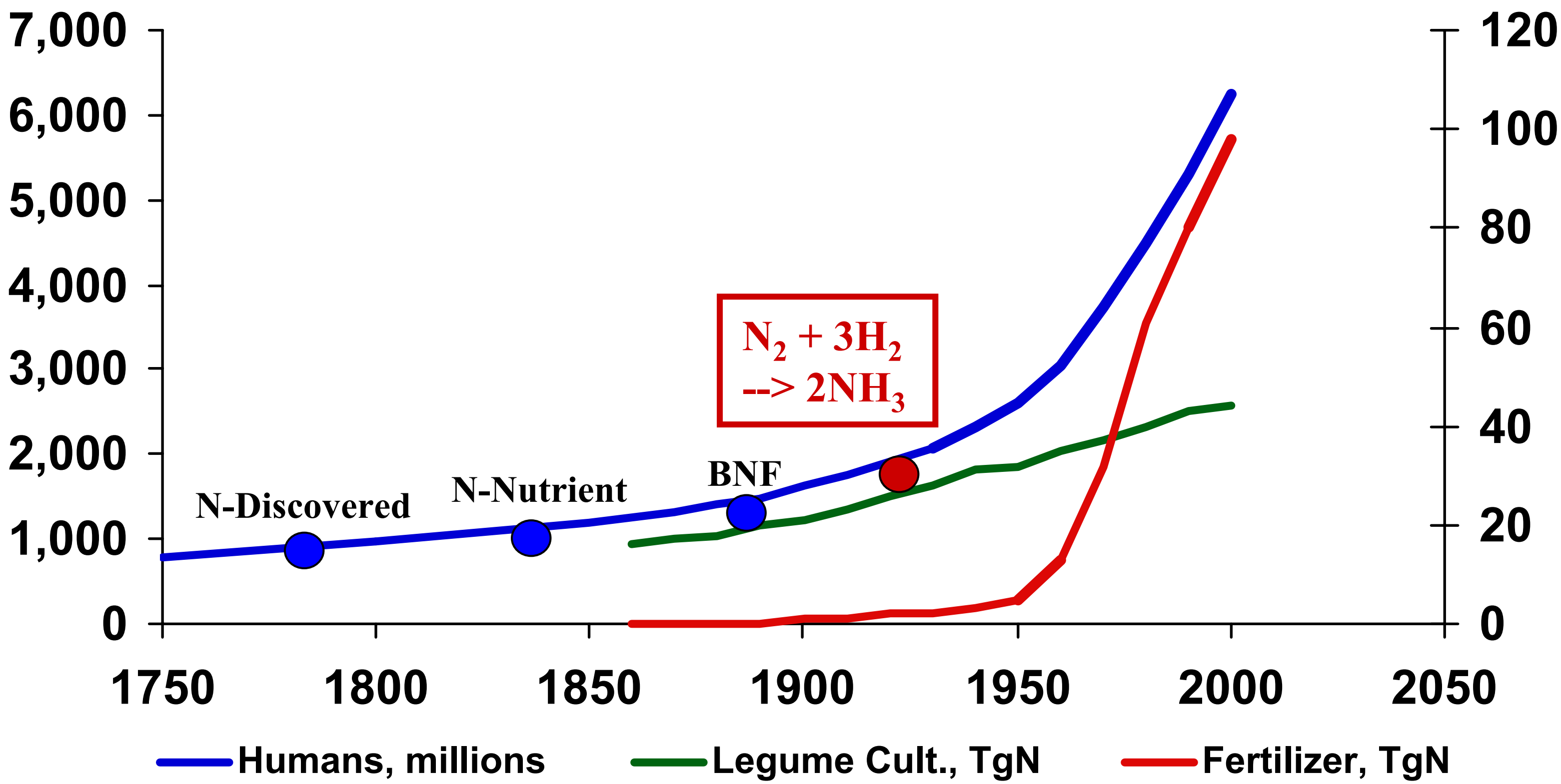


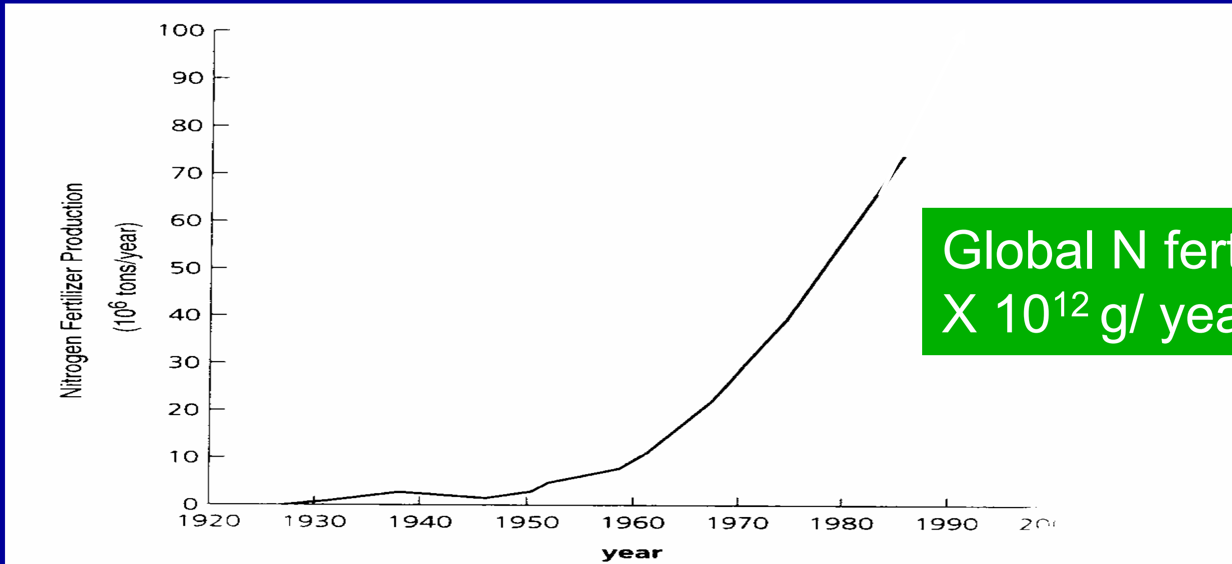
Terrestrial NO_3
N_2 / CO_2 (atm)
Atmos NO_3
algae
zoop
NH_4^+ "Recycled N"
thermocline
NO_3^- / CO_2 (deep) @ Redfield ratio
POC/PON_{down}
NO_3^- ← NH_4^+
0 15 30
[NO_3^-, μM]
$\Sigma\ PON_{down} \approx$ uptake $NO_3^- + N_2$
since CO_2 / NO_3^- upwell ≈ C/N POM_{down}
$POC_{atm\text{-}down} \approx$ uptake N_2 * C/N_{down}



The History of Nitrogen

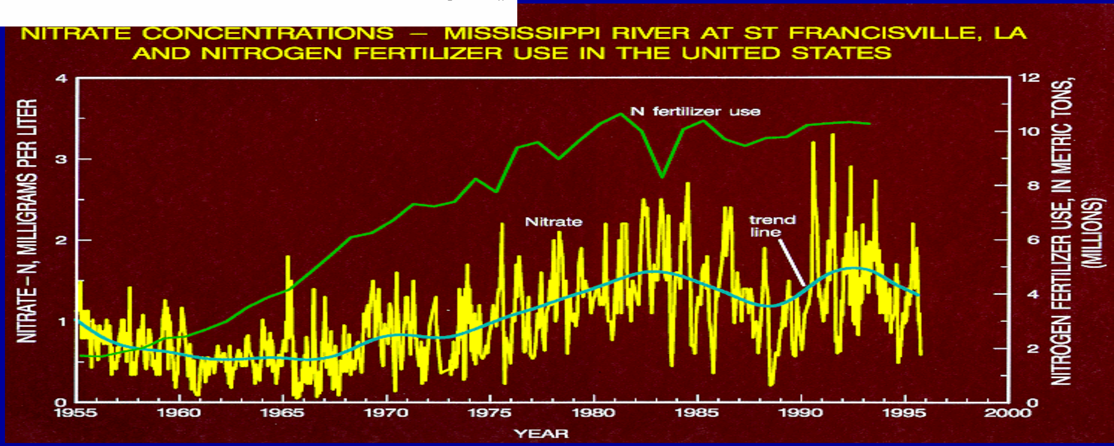
--Haber & Bosch!--

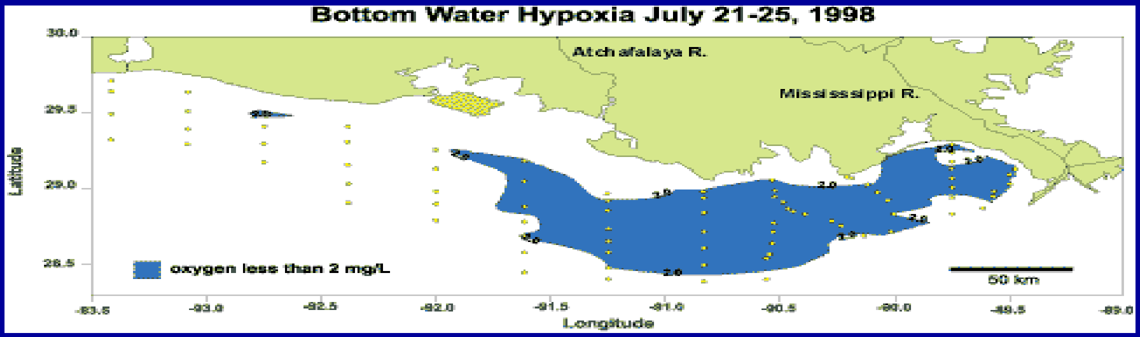




12.4 The global production of nitrogen fertilizer from 1920 to 198… From Smil

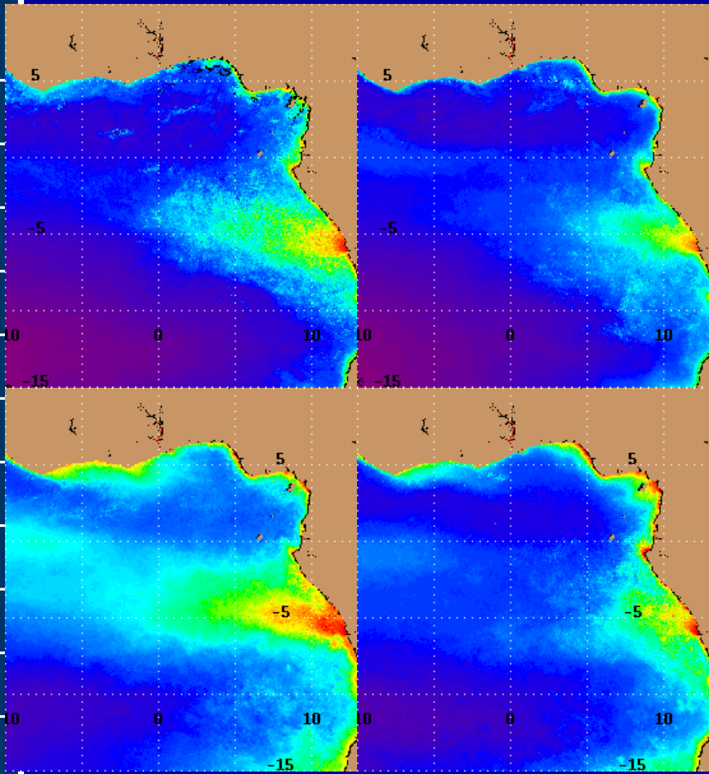
Global N fertilizer use
X 10^{12} g/ year

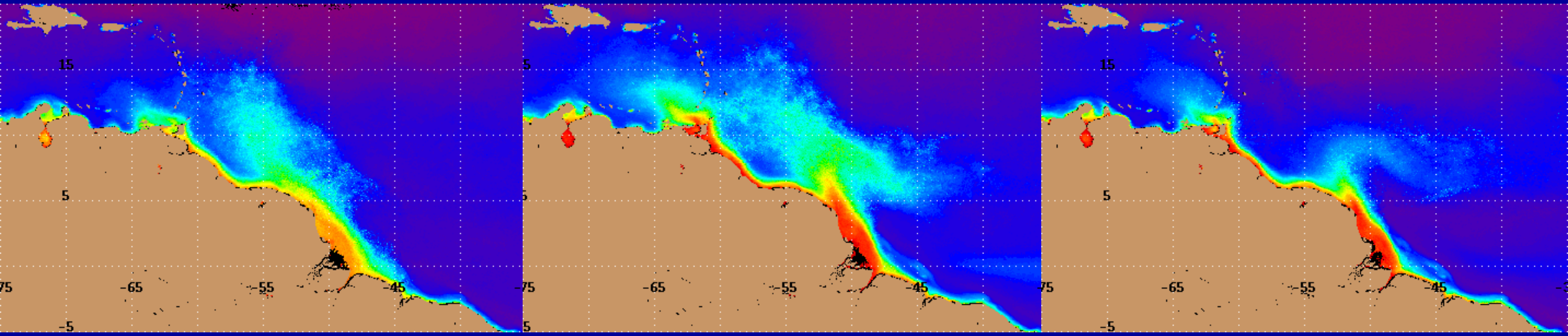


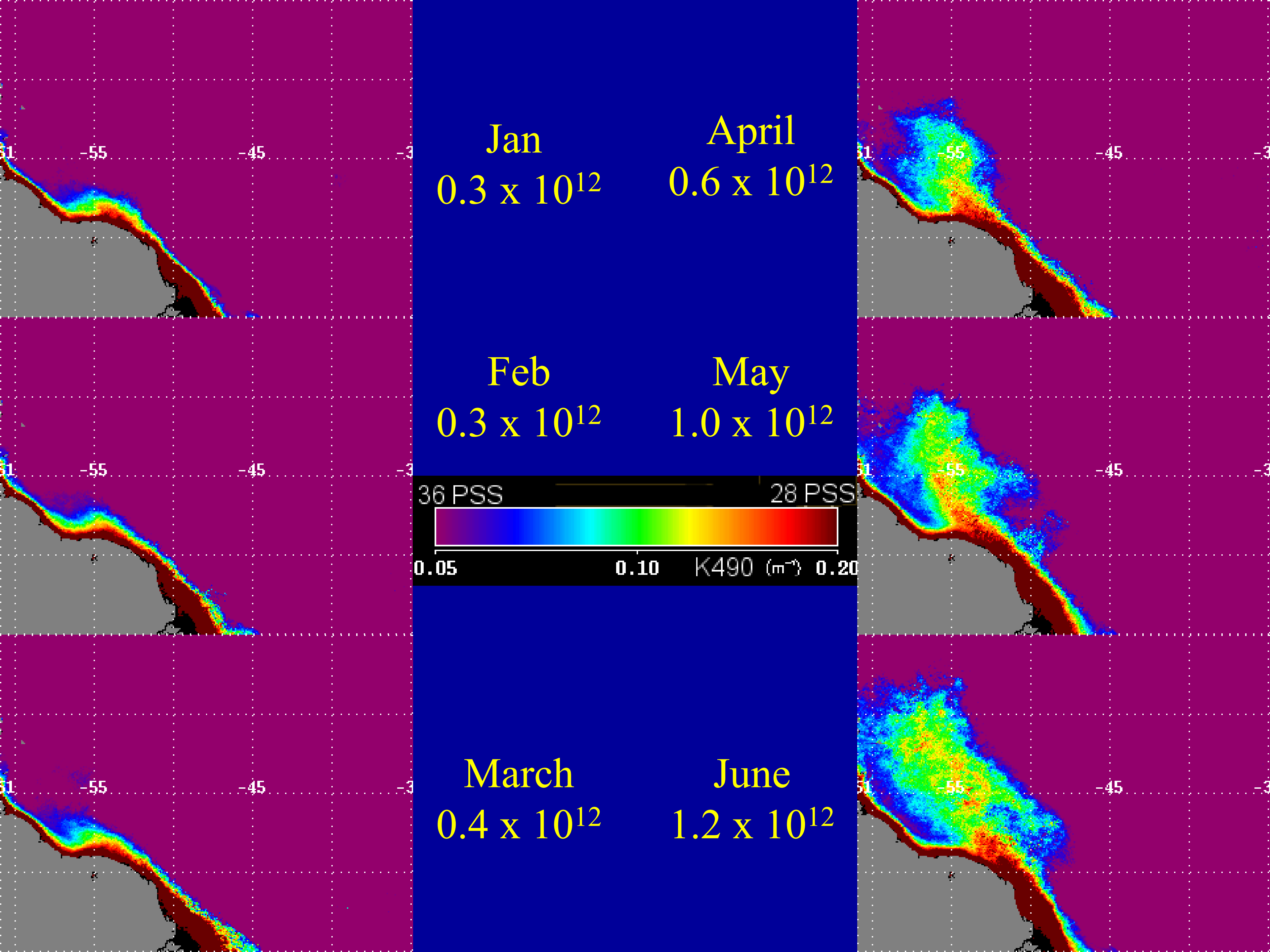


The Mississippi plume “dead zone”

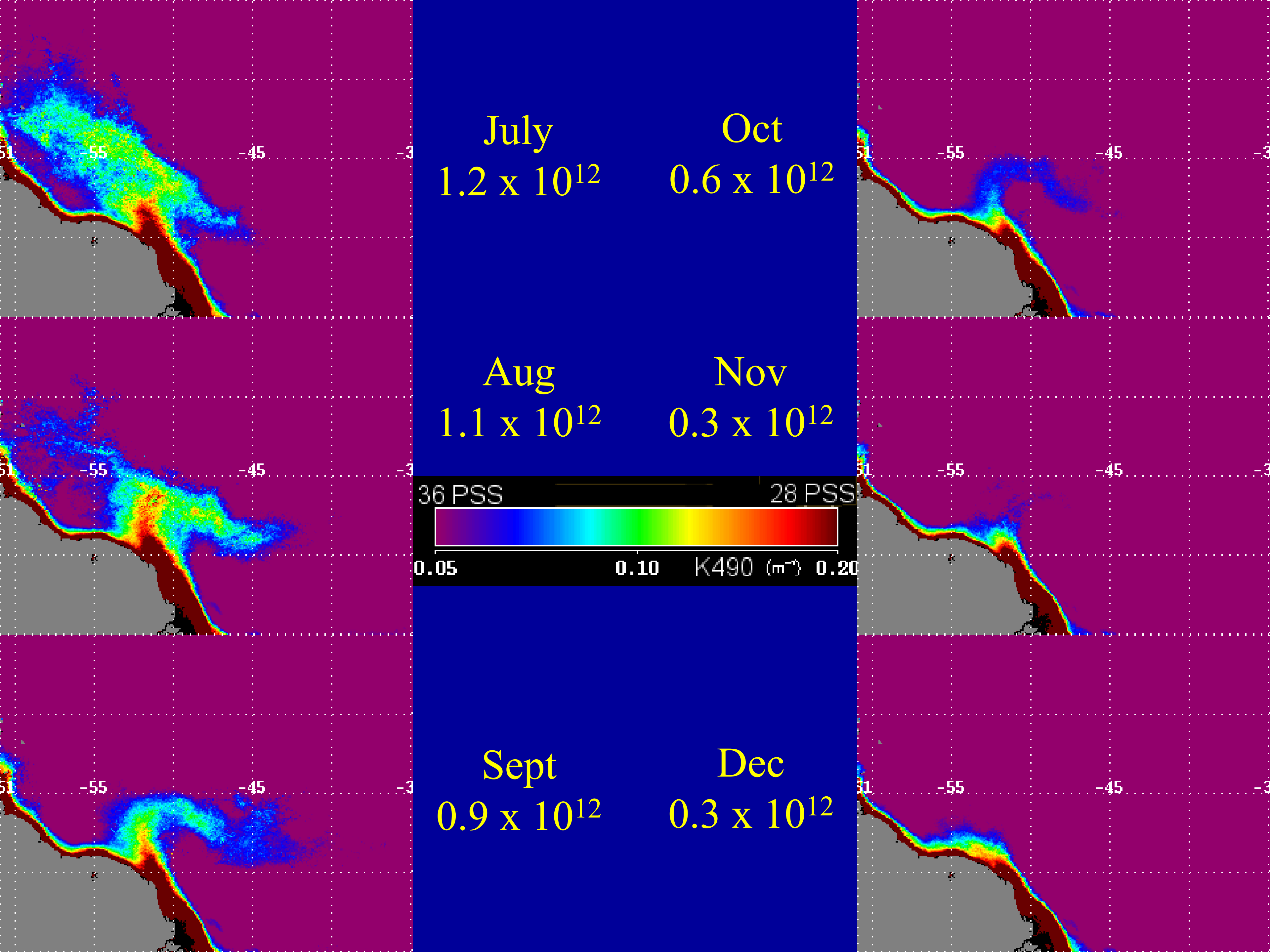
River	Discharge	Cumulative %	Drainage area
Amazon	6300	18	6.15
Zaire	1250	22	3.82
Orinoco	1200	25	0.99
Ganges-Brahmaputra	970	28	1.48
Chiang Jiang	900	31	1.94
Yenisey	630	33	2.58
Mississippi	530	34	3.27
Lena	510	36	2.49
Mekong	470	37	0.79
Parana	470	38	2.83
All others	21168	100	





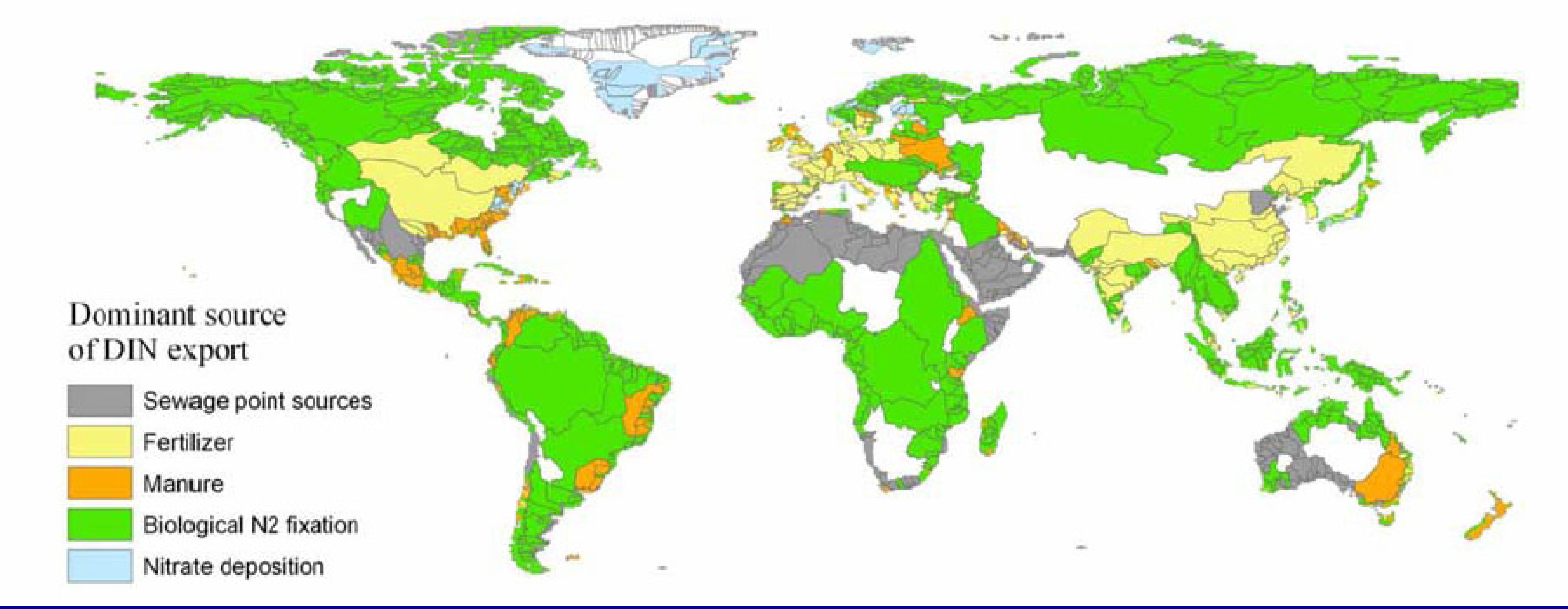


Jan
0.3 x 10^12
April
0.6 x 10^12
Feb
0.3 x 10^12
May
1.0 x 10^12
March
0.4 x 10^12
June
1.2 x 10^12
36 PSS
28 PSS
0.05
0.10
K490 (m⁻¹)
0.20
-55
-45



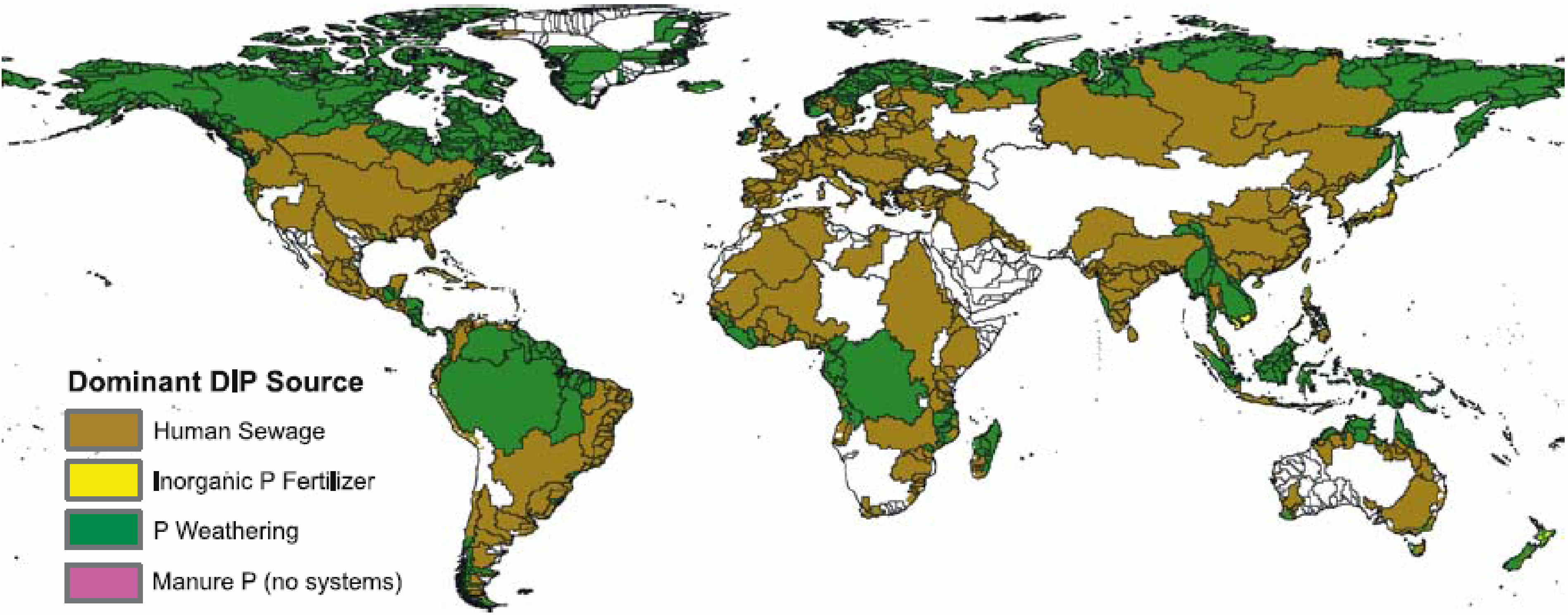
July
1.2 x 10^12
Aug
1.1 x 10^12
Sept
0.9 x 10^12
Oct
0.6 x 10^12
Nov
0.3 x 10^12
Dec
0.3 x 10^12
36 PSS
28 PSS
0.05
0.10
K490 (m-1)
0.20
-55
-45

NEWS-DIN-predicted dominant sources of DIN export



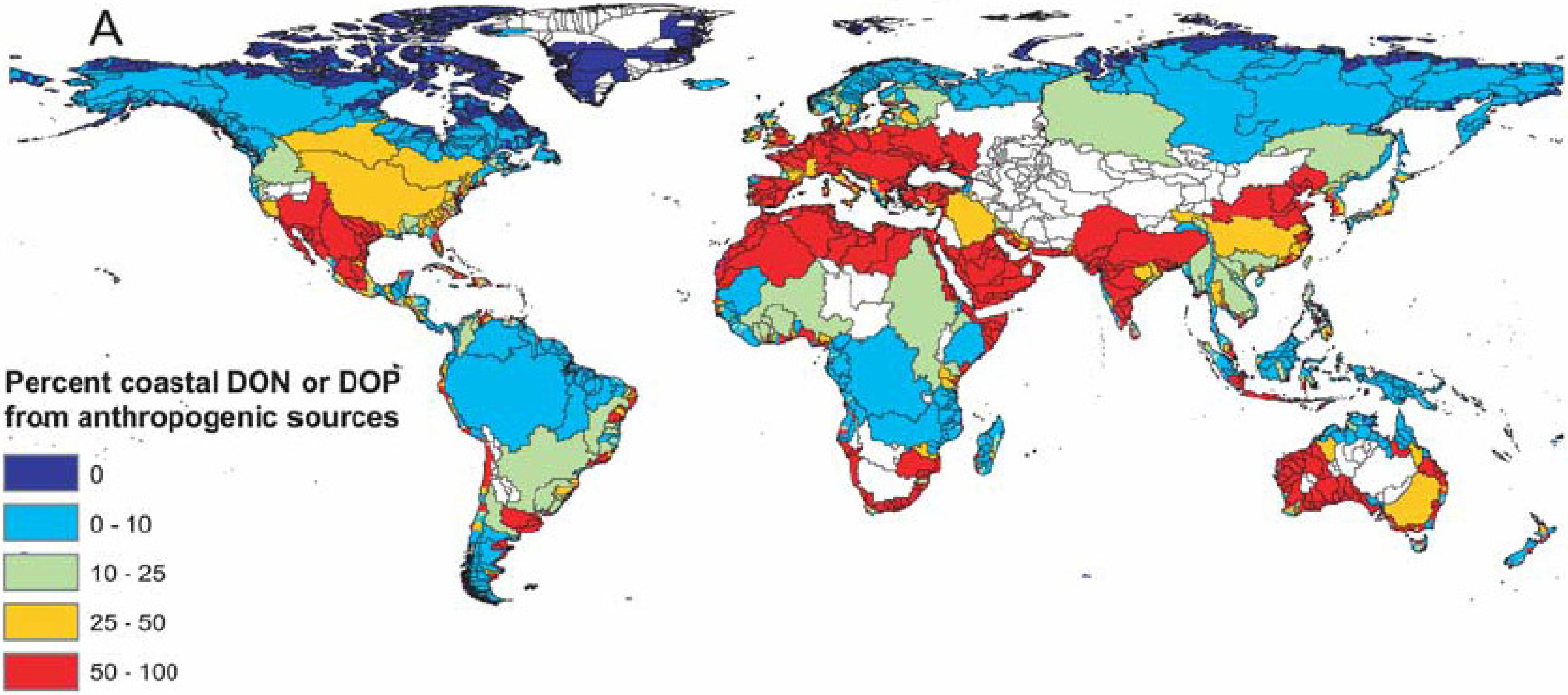
Dumont et al 2005 GBC

Dominant sources of DIP



Harrison et al 2005 GBC

DON/DOP – Percent from Anthropogenic Sources



Harrison et al 2005 GBC

TABLE 1

Nutrients concentrations in some major unpolluted rivers ($\mu g\ l^{-1}$)

	$P\text{-}PO_4$	TDP	$N\text{-}NO_2$	$N\text{-}NH_4$	N_K	DON	$N\text{-}NO_3$	TDN	DOC	TOC
Tropical rivers										
Sumatra-Borneo	7						175			
Niger	13		1.4	14			100			
Zaire	24	60	3	7			90			8800
Orinoco	6.2						90			
Zambezi	10									
Purari	1.5			40			40			
Mekong							240			
Solimoes	15	25	1	(40)		150	50	(240)	2000	
Negro	6	8	1	(25)		300	25	(350)	6300	8360
Amazon	12	(20)	1	(35)		200	40	275	(5000)	(10000)
Desert rivers										
Orange	9.1							41		

From Meybeck 1982

River	P	N	N:P
Amazon	20	275	13.75
Orinoco	6.2	90	14.5
Congo	24	90	3.75

Devol (1991) found that Amazon alone is responsible for 30% of the global transport of SRP

Amazon Nutrients

DeMaster and Pope 1996

Subramaniam et al in review

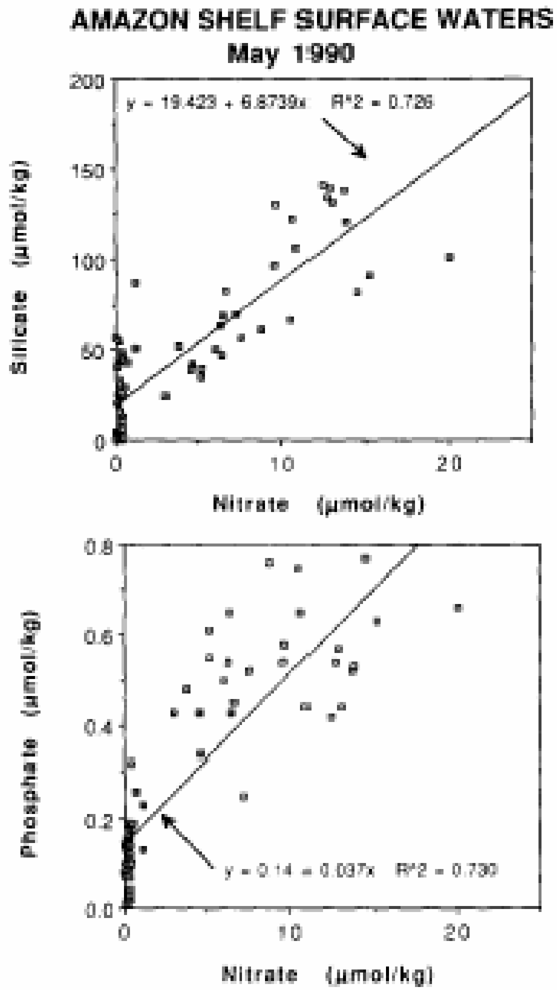
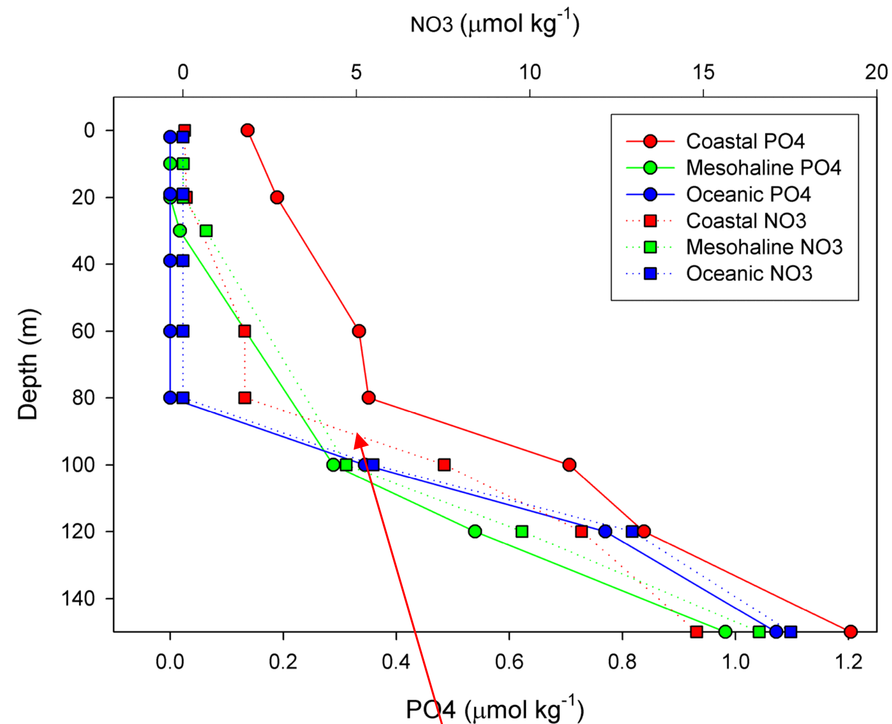


Fig. 7. Phosphate and silicate concentrations in Amazon shelf surface waters plotted as a function of nitrate concentration for AMASSEDS Cruise III (May 1990; high river discharge). In all four of the cruises the phosphate and the silicate intercepts (i.e. zero nitrate concentration) were positive and significantly different from zero indicating that the algae on the shelf are primarily limited by nitrate and not phosphate or silicate.



Buoyancy effect

Source of P/ Si

DeMaster and Aller 2001

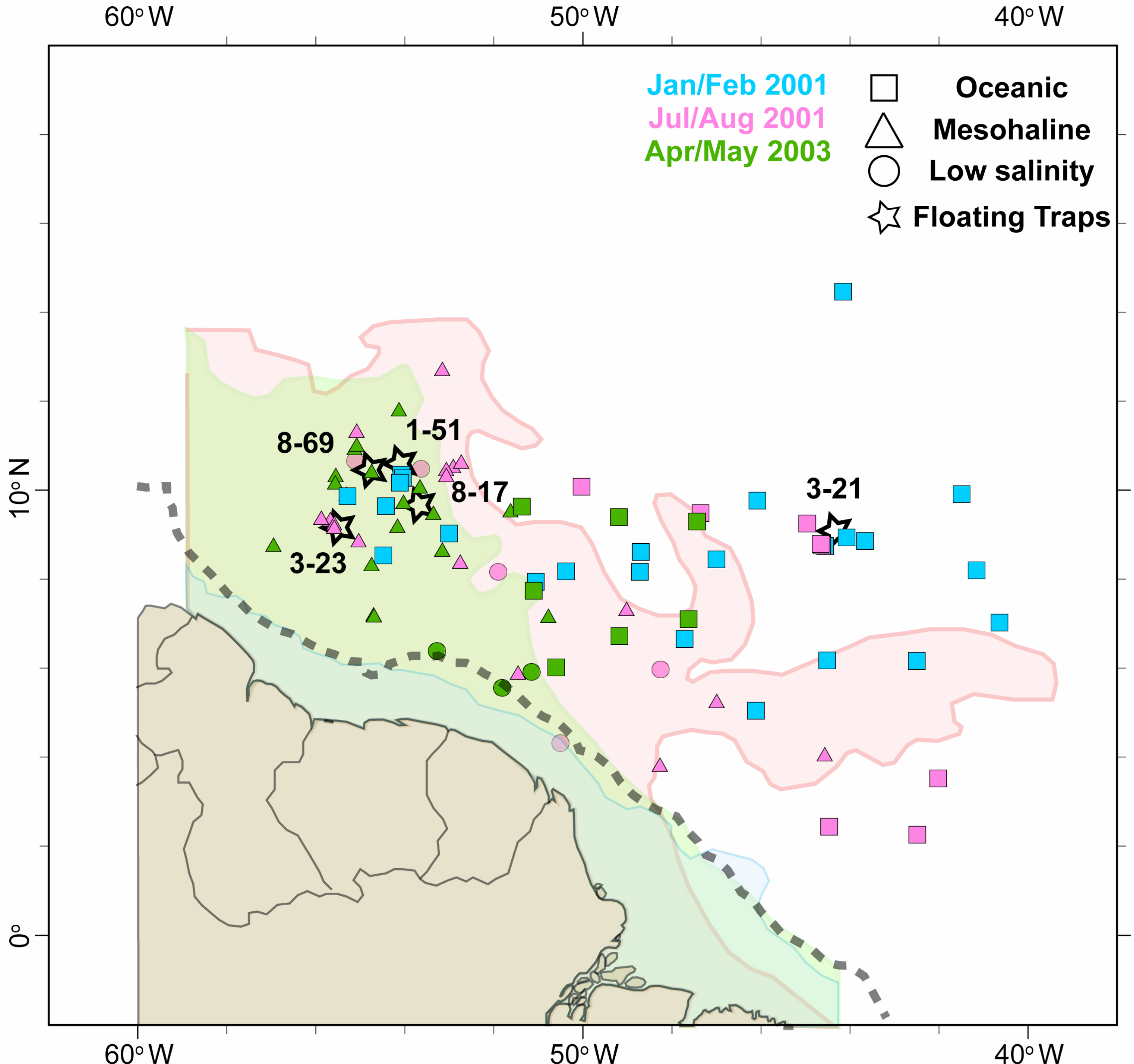
Table 17.2 Biogeochemical Cycling of Si, P, and N on the Amazon Shelf

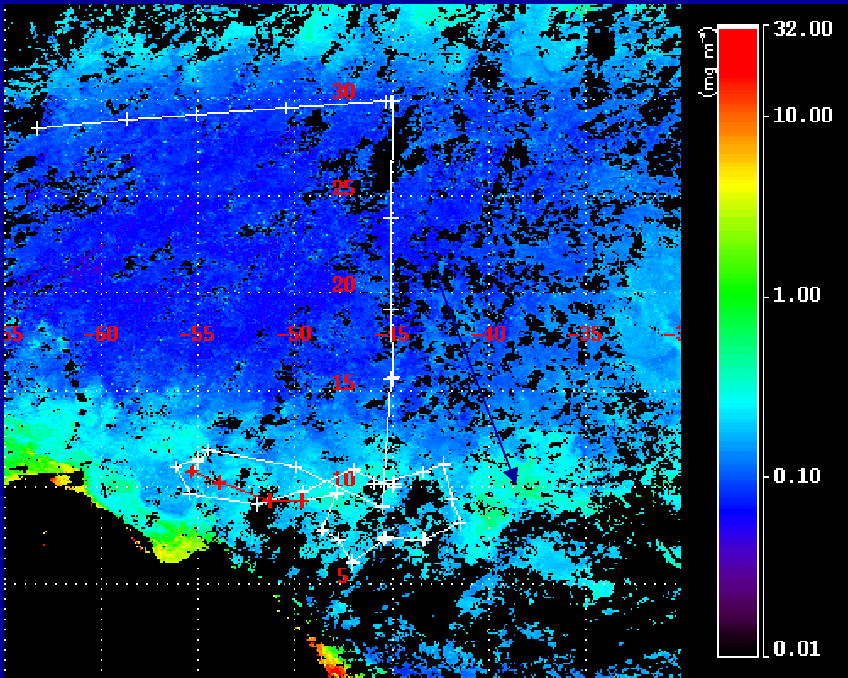
	External Nutrient Supply* ($x10^8$ mol d^{-1})	% of Ext. Nutrient Supply to Shelf from Rivers	Gross Production ($x10^8$ mol d^{-1})	%of Gross Production from Recycling	%of Ext. Nutrient Supply that is Exported Offshore**
Si	32	66%	27	0%	91.97%
P	0.7-0.8	28%	1.7	56%	100%
N	10-12	20-50%	27	60%	50%

* External nutrient supply is defined as the supply of dissolved nutrient that is biologically available for shelf plankton. The sources of these nutrients are from the river and upwelled offshore waters, nitrogen fixation regenerated terrestrial organic matter, and absorbed material. The flux of P from desorption is considered part of this external supply, whereas the recycling of estuarine biogenic material (via microbial degradation or dissolution) is not.

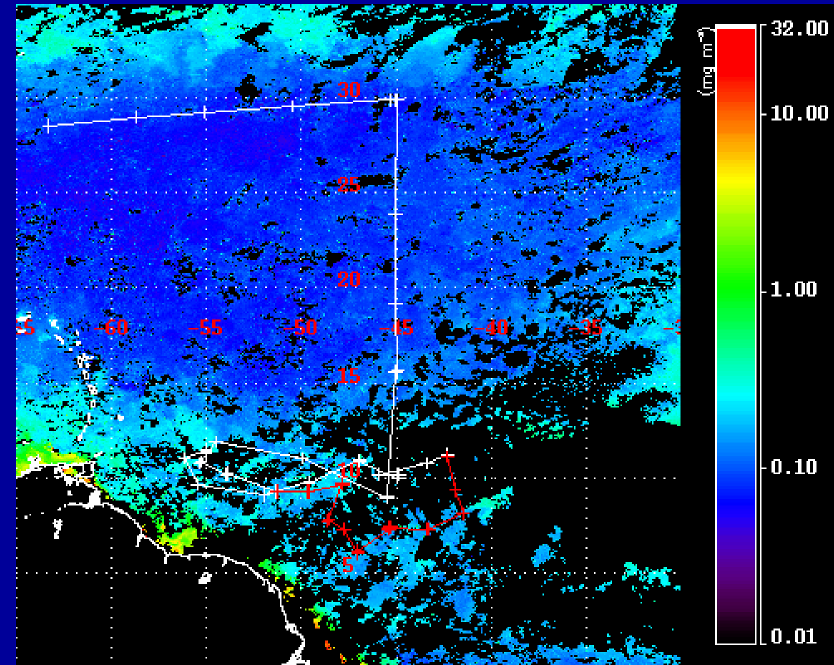
** This export includes only the dissolved species and biogenic material that re or can be (following degradation/dissolution) available to marine biota. Less than 4% of the dissolved bioavailable N supplied to the shelf is buried as marine organic matter. However, nearly all of marine PON reaching the seabed is converted to molecular nitrogen, which cannot be utilized by most oceanic plankton. Consequently, only 50% of bioavailible, dissolved, externally supplied N to the shelf is exported in a form that is useable by marine biota.

Tricho can use DOP but P limitation still occurs

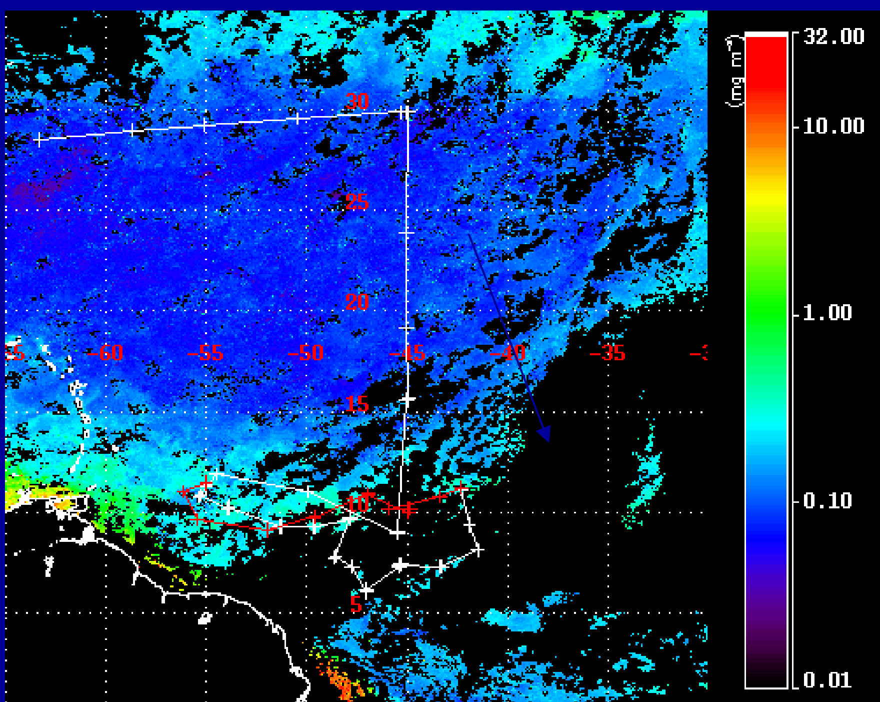

60° W
50° W
40° W
10° N
0°
Jan/Feb 2001
Jul/Aug 2001
Apr/May 2003
Oceanic
Mesohaline
Low salinity
Floating Traps
8-69
1-51
8-17
3-23
3-21



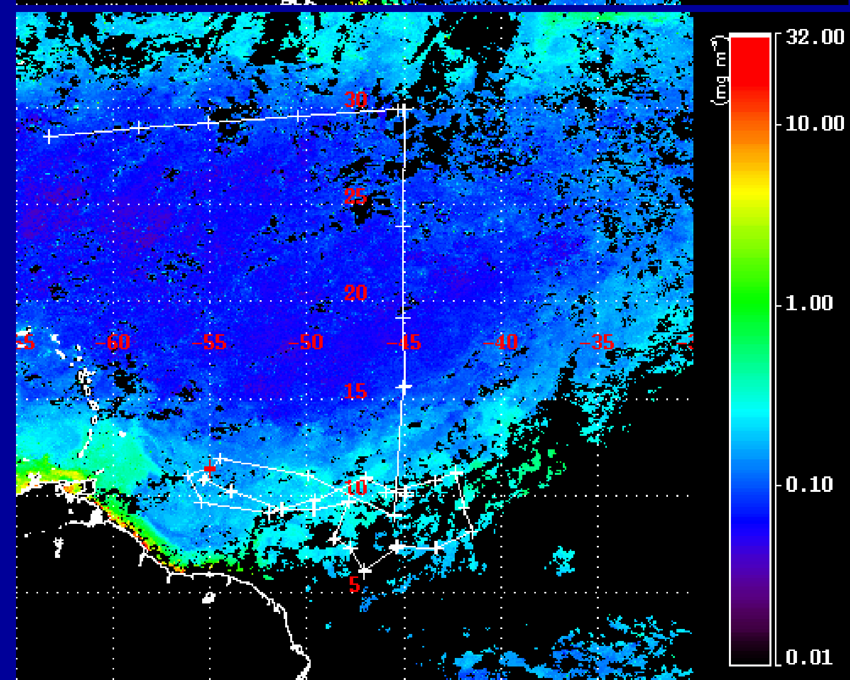
30
25
20
15
10
5
-60
-55
-50
-45
-40
-35
(mg m^-3)
32.00
10.00
1.00
0.10
0.01



30
25
20
15
10
5
-60
-55
-50
-45
-40
-35
(mg m^-3)
32.00
10.00
1.00
0.10
0.01

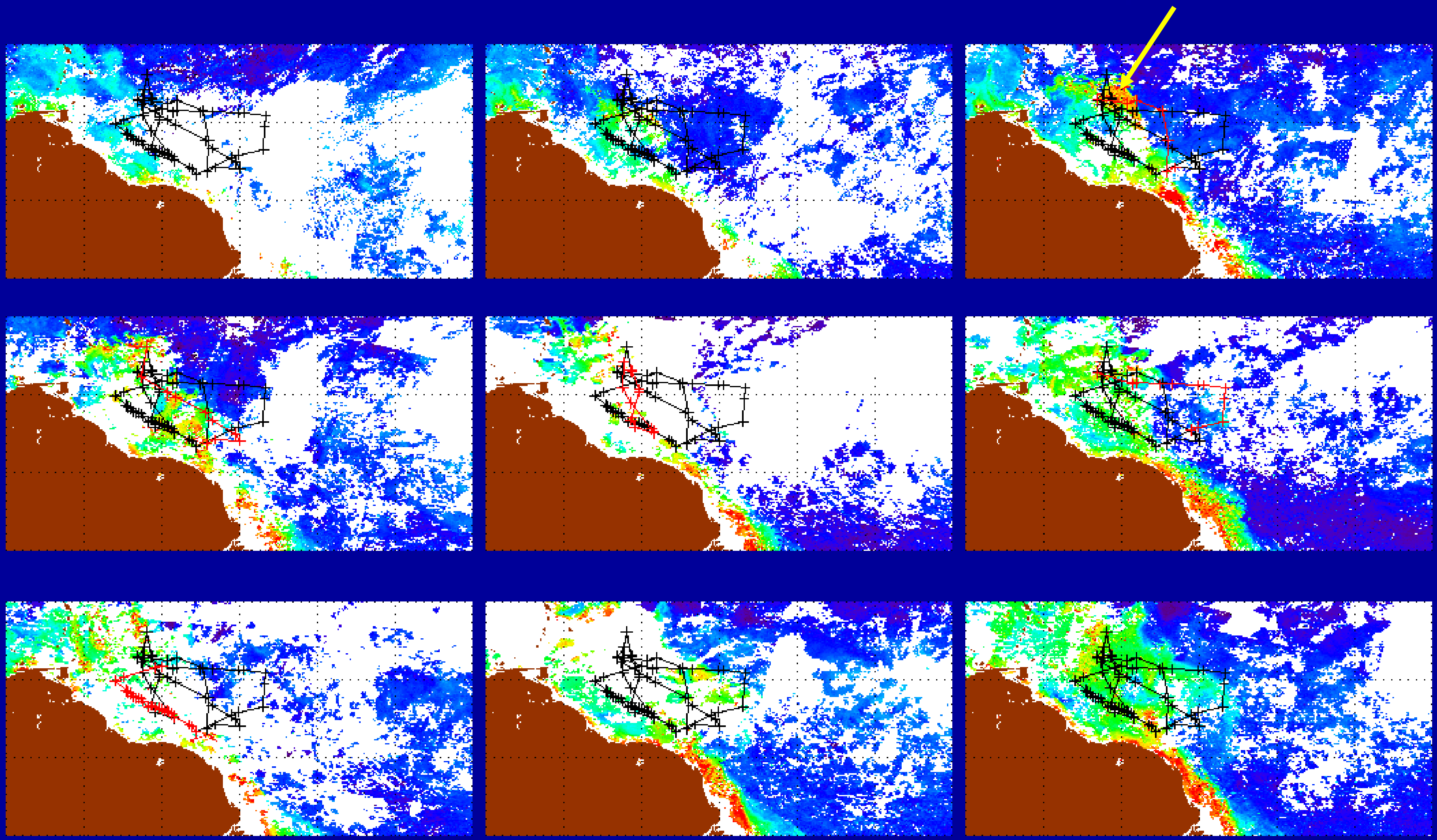


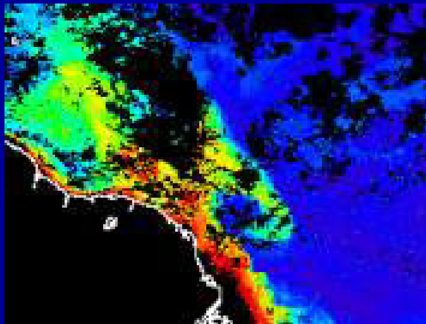
30
25
20
15
10
5
-60
-55
-50
-45
-40
-35
(mg m^-3)
32.00
10.00
1.00
0.10
0.01



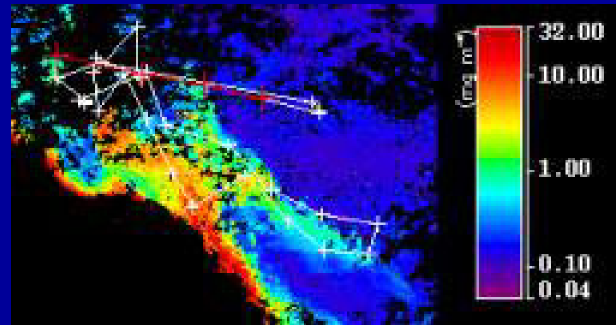
30
25
20
15
10
5
-60
-55
-50
-45
-40
-35
(mg m^-3)
32.00
10.00
1.00
0.10
0.01

8 Day SeaWiFS Chl Images 30 March – 9 June 2003

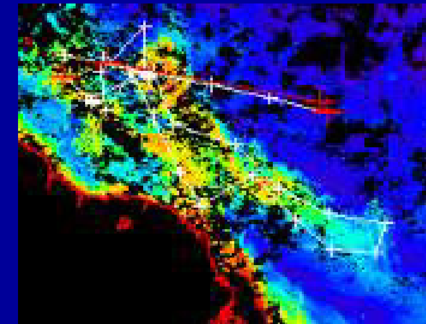




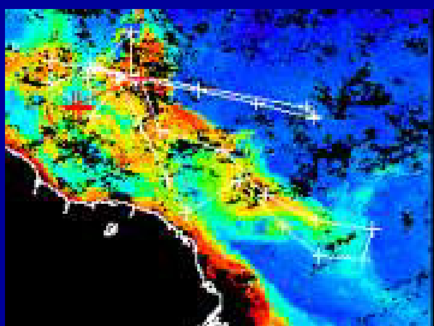
26 June - 3 July 2001



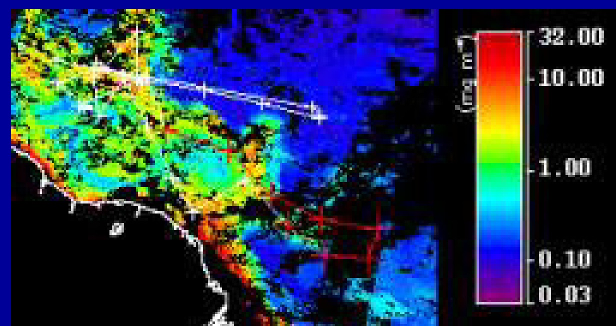
4 July - 12 July 2001



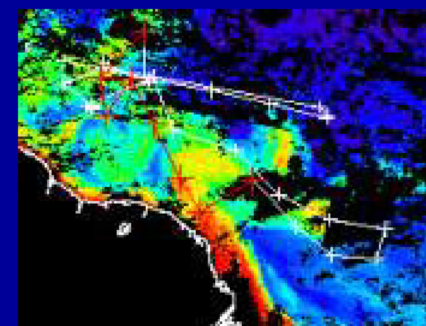
13 July - 19 July 2001



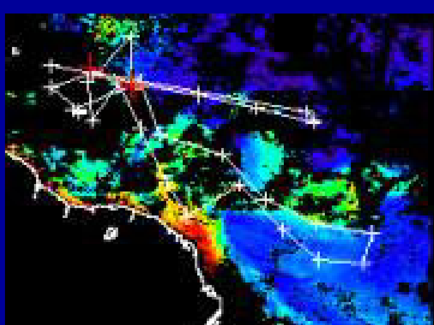
20 July - 27 July 2001



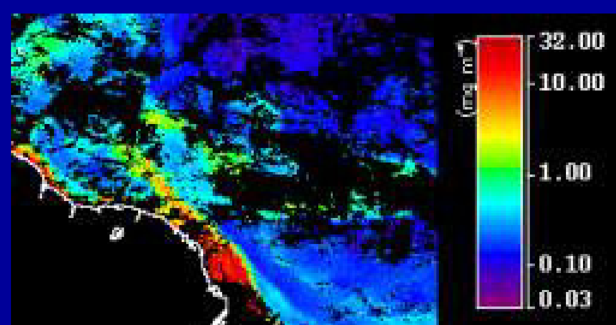
28 July - 4 August 2001



5 August - 12 August 2001

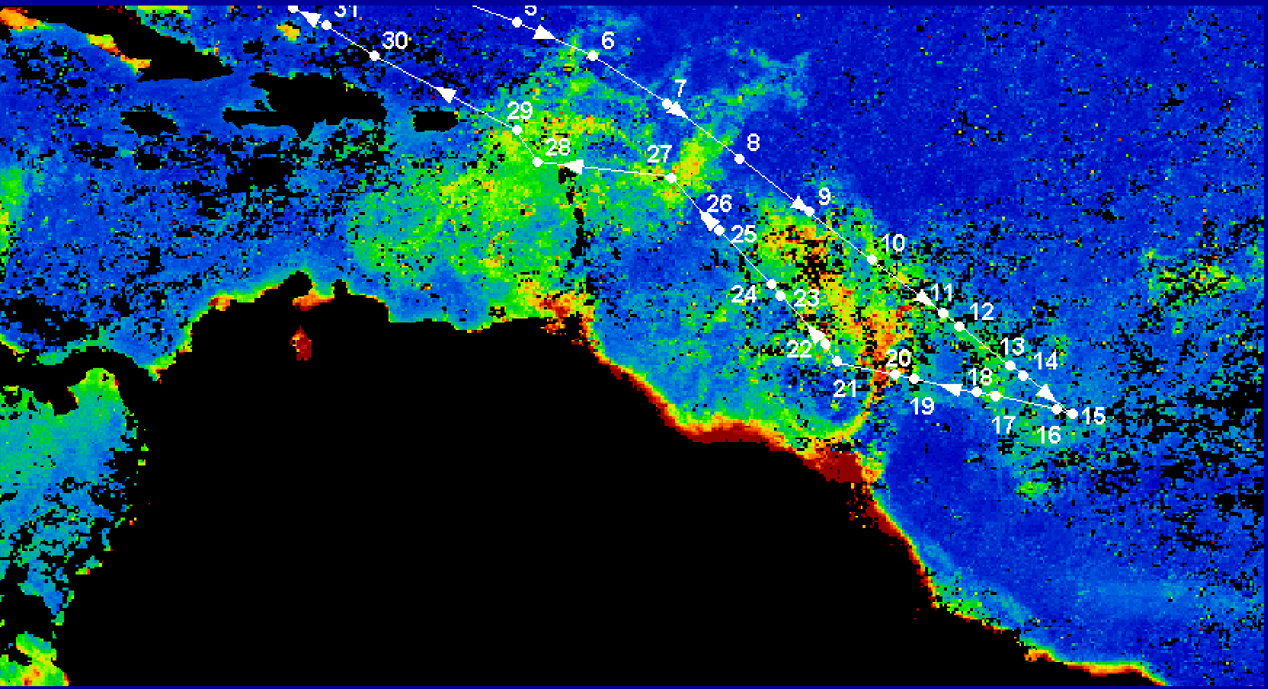


13 August - 20 August 2001



21 August -28 August 2001

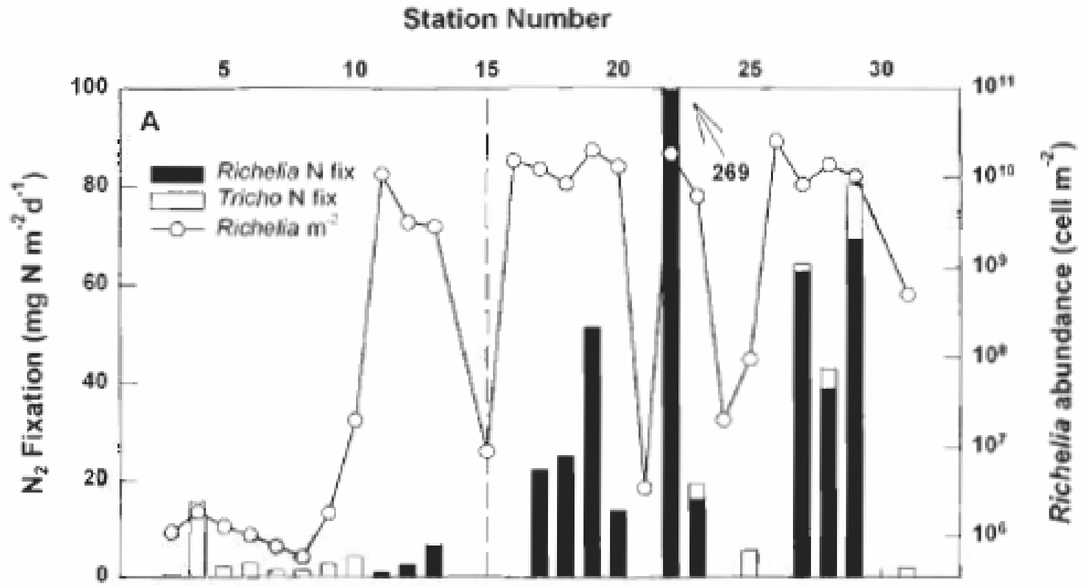
Oct/Nov 1996

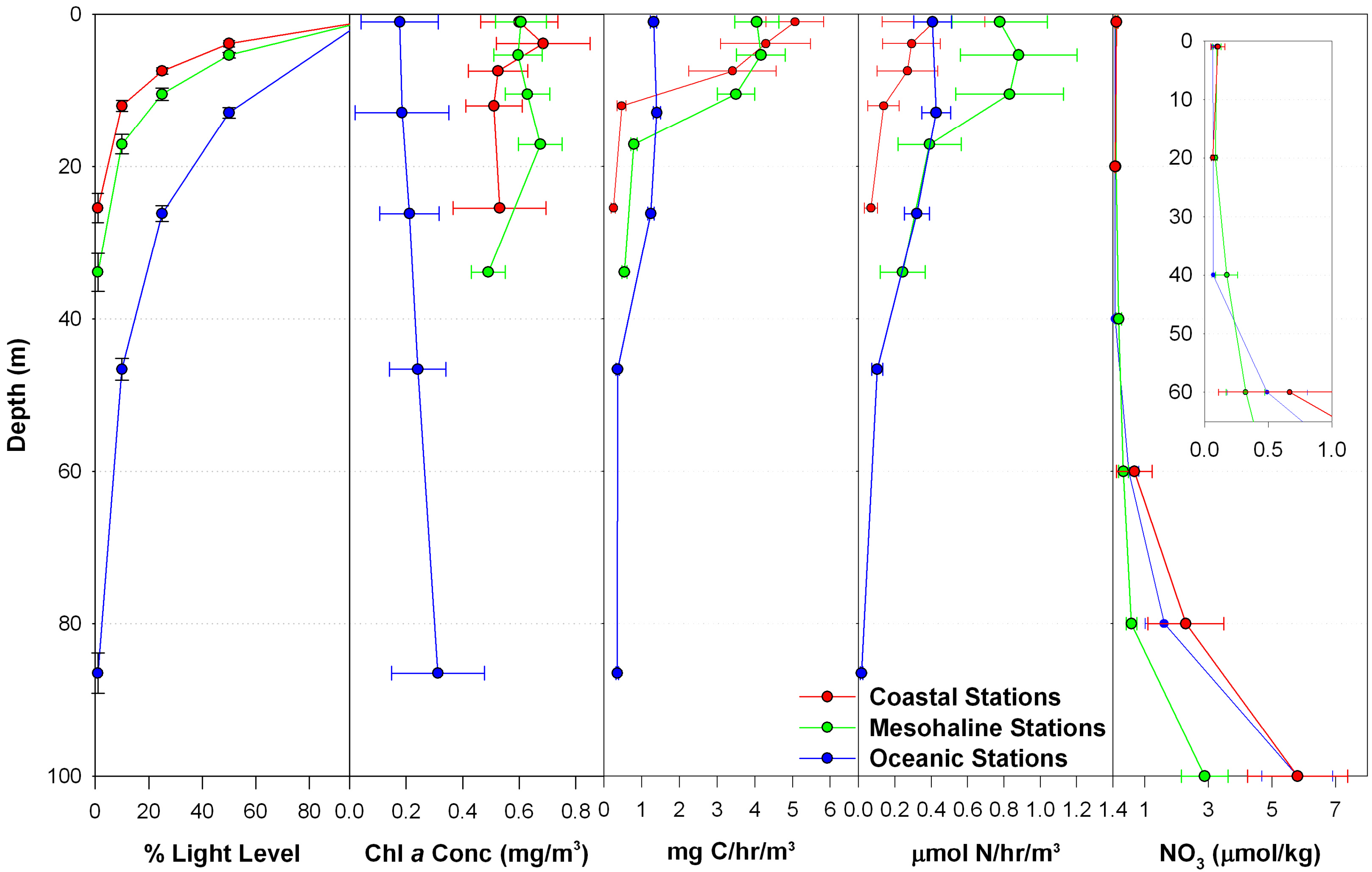


A major bloom of *Hemiaulus*/ *Richelia* in Oct. 1996 mapped using the OCTS satellite off the coast of South America, was found to extend all the way into the Caribbean and involved the Orinoco Plume as well (Carpenter et al. 1999)

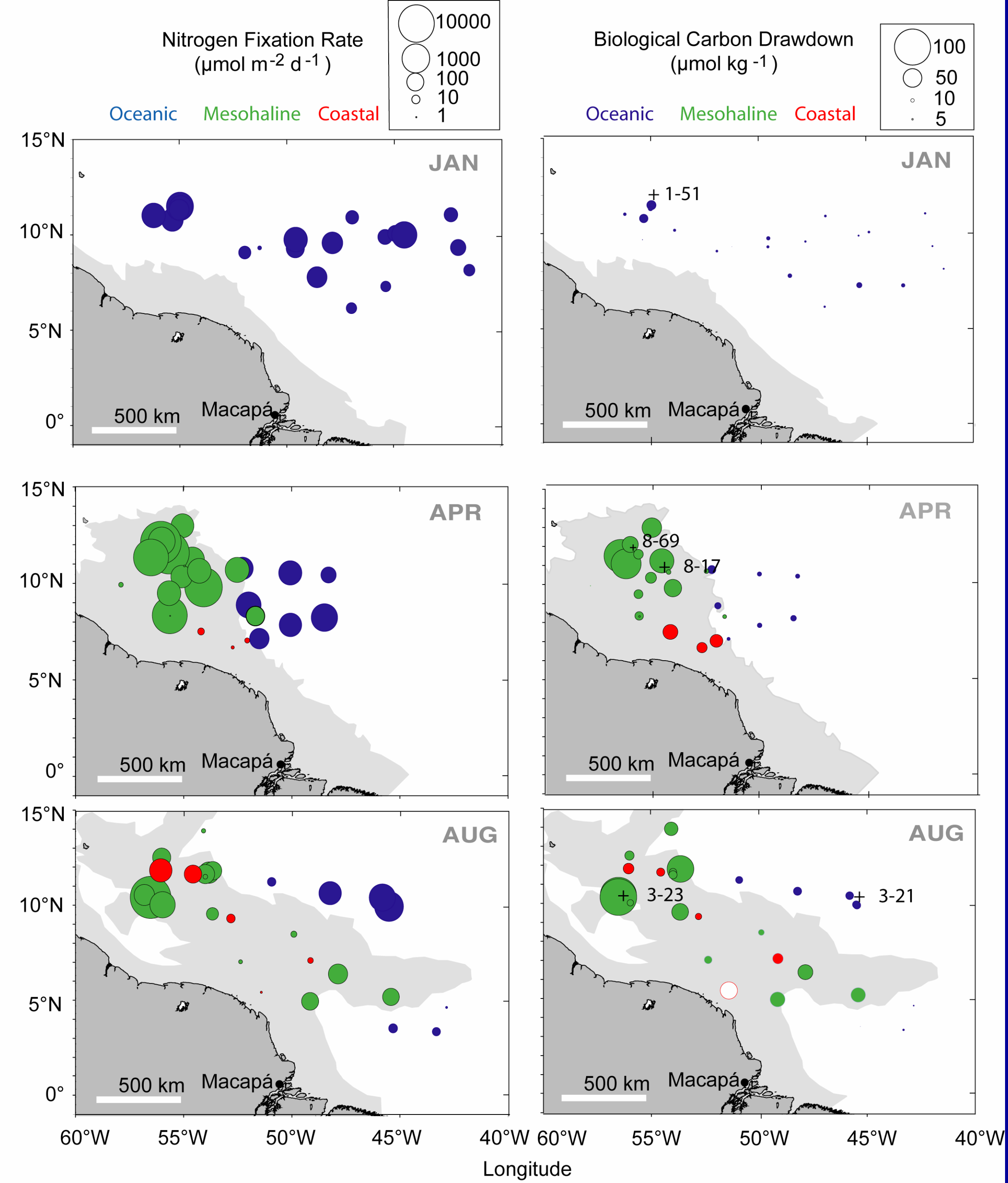
Table 2. Isotopic composition of *Trichodesmium*, concentrated suspensions of *Hemiaulus*, or concentrated suspensions of a mix of the 2 diazotrophs isolated from near-surface net tows

Sample type	No. of stations sampled		$\delta^{15}N$ (‰)
Trichodesmium (20 colonies)	13	Mean	−2.15
		SE	0.09
		n	36
Hemiaulus (100 ml concentrated suspension)	4	Mean	−1.24
		SE	0.25
		n	12
Trichodesmium & *Hemiaulus* mix (100 ml concentrated suspension)	3	Mean	−1.95
		SE	0.47
		n	6
Overall summary	20	Mean	−1.93
		SE	0.11
		n	54





Depth (m)
0
20
40
60
80
100
0 20 40 60 80
0.0 0.2 0.4 0.6 0.8
0 1 2 3 4 5 6
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
1 3 5 7
0.0 0.5 1.0
0 10 20 30 40 50 60
% Light Level
Chl a Conc (mg/m3)
mg C/hr/m3
µmol N/hr/m3
NO3 (µmol/kg)
Coastal Stations
Mesohaline Stations
Oceanic Stations



Nitrogen Fixation Rate
(μmol m-2 d-1)
10000
1000
100
10
1
Oceanic
Mesohaline
Coastal
Biological Carbon Drawdown
(μmol kg-1)
100
50
10
5
JAN
APR
AUG
1-51
8-69
8-17
3-23
3-21
500 km
Macapá
15°N
10°N
5°N
0°
60°W
55°W
50°W
45°W
40°W
Longitude

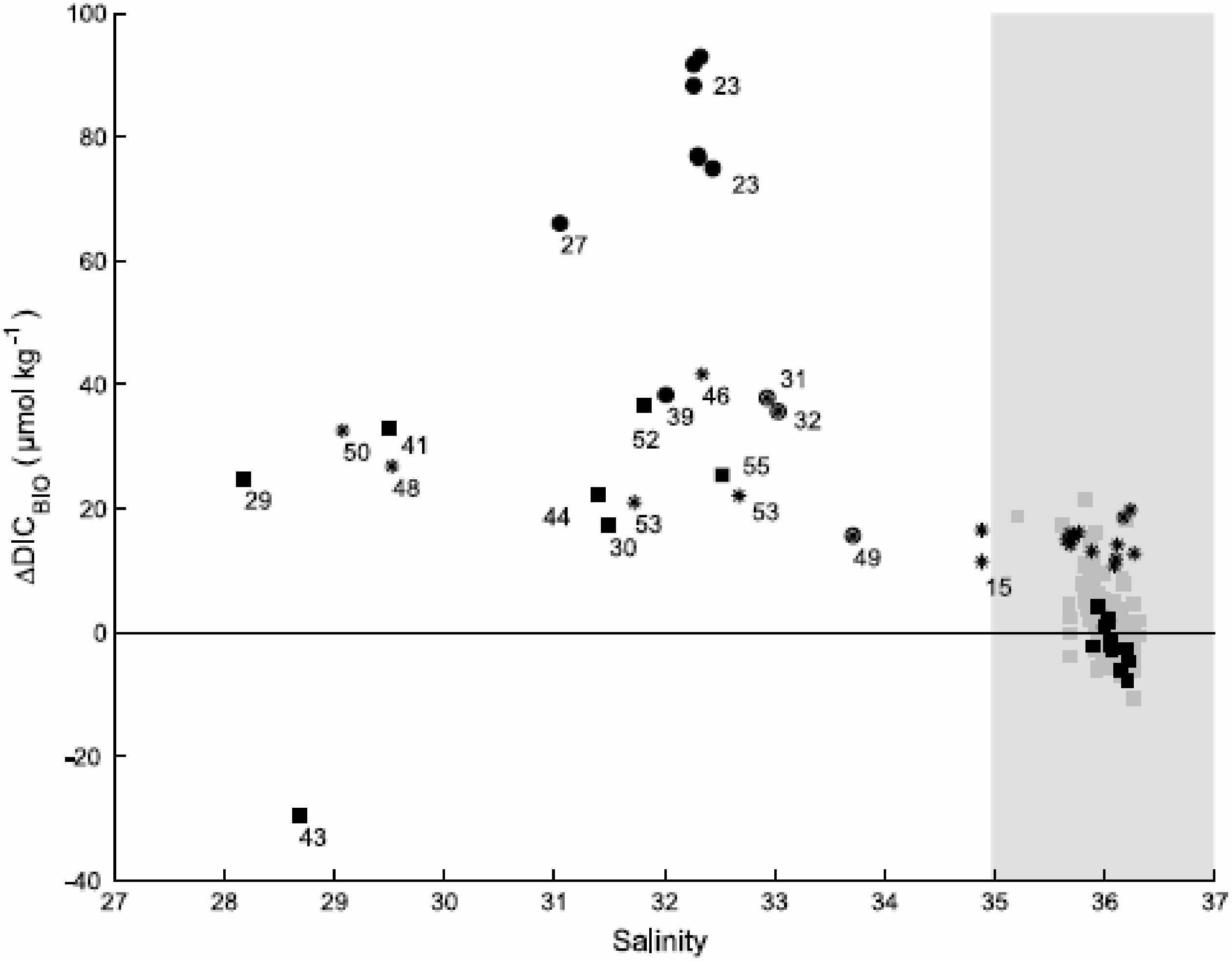


Figure 6. Community impact on DIC (ΔDIC_{BIO}), calculated with the mixing model, plotted against salinity. The 95% confidence interval error bars are within the size of the marker. Station numbers are shown for summer samples. Endmembers used to calculate ΔDIC_{BIO} included: $A_s = 2359.4 \pm 5.9$, $S_s = 36.07 \pm 0.10$, $DIC_s = 2024.5 \pm 6.8$, $S_r = 0 \pm 0$. The shaded region above salinity 35 indicates data outside the influence of the plume. Markers indicate the prevailing macroscopic nitrogen-fixing organisms observed at a station: square, none; circle, *Richelia*; asterisk, *Trichodesmium*; circle and star superimposed, *Richelia* and *Trichodesmium* together.

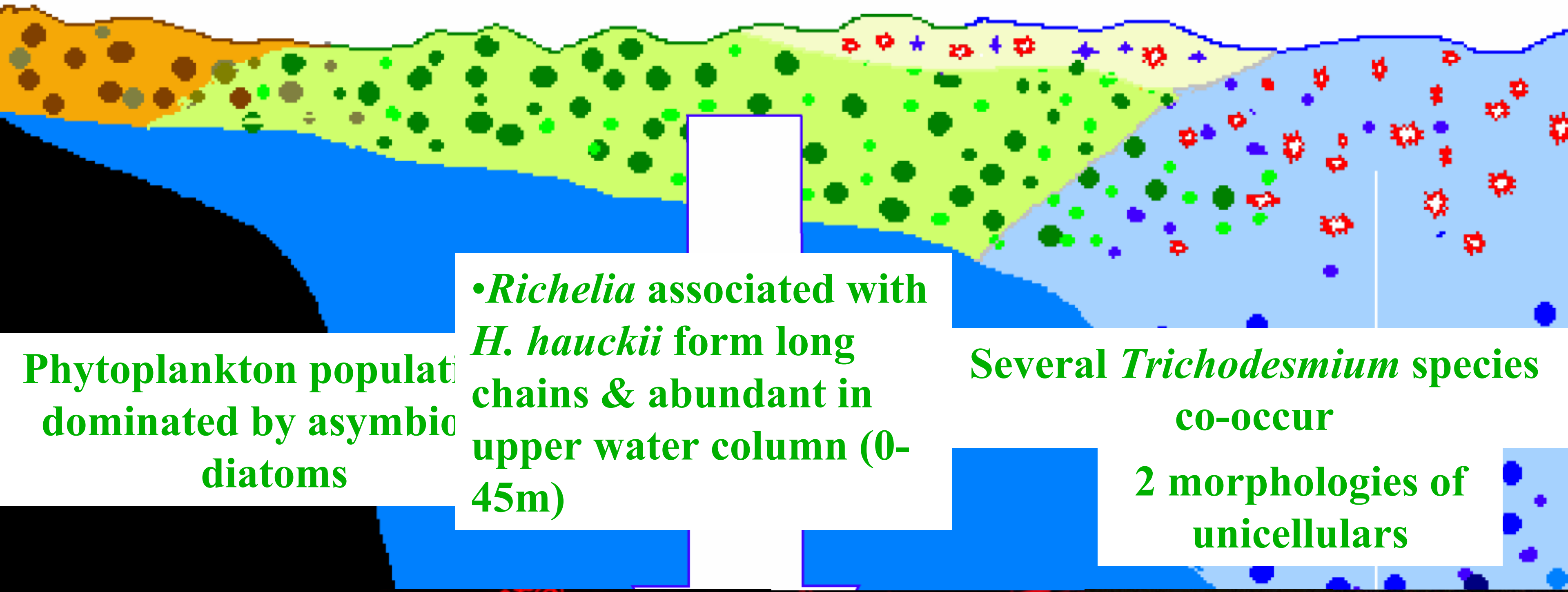
From Cooley SR, Yager PL (2006) Physical and biological contributions to the Western Tropical North Atlantic Ocean carbon sink formed by the Amazon River Plume. JGR C:111

Coastal
Sal: 28.95
Fe: 2.20
P: 67
DIC: 2009

Mesohaline
Sal: 32.50
Fe: 1.61
P: 28
DIC: 1984

P limitation?

Oceanic
Sal: 35.97
Fe: 1.36
P:35
DIC: 2013

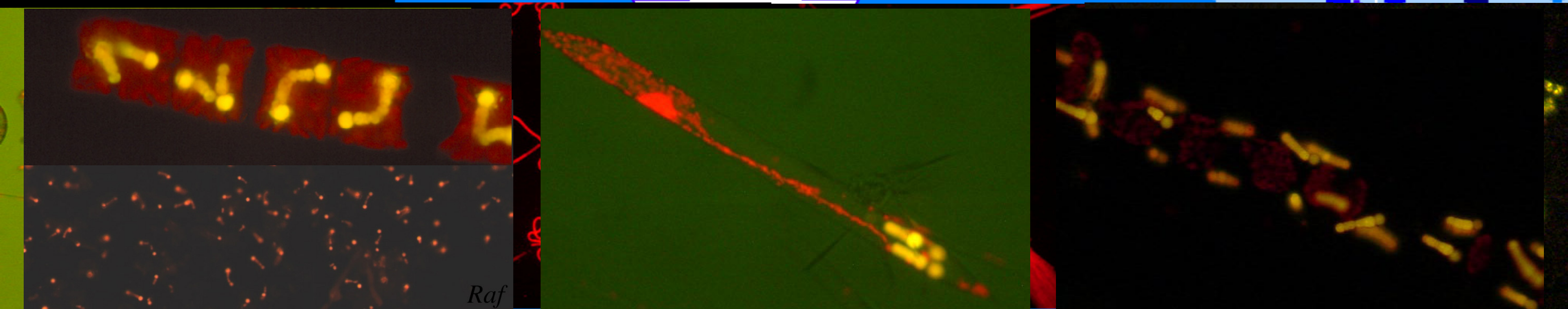


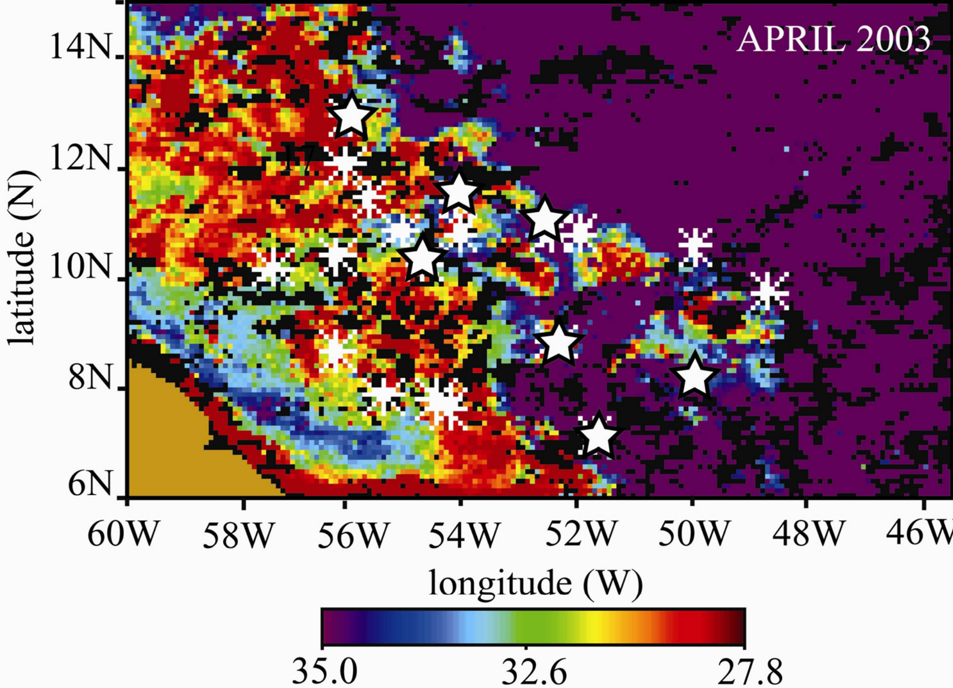
Phytoplankton populati dominated by asymbio diatoms

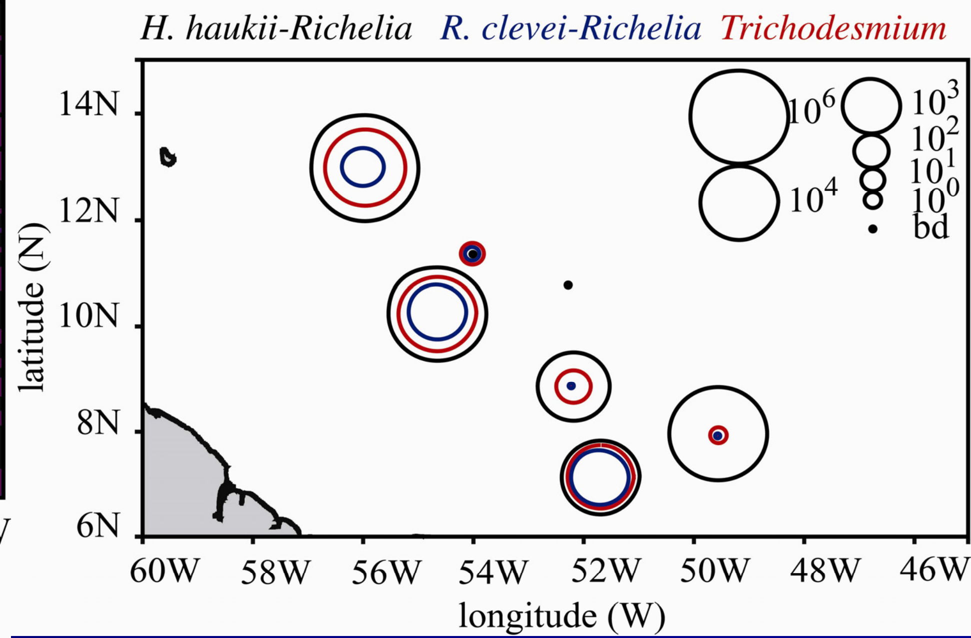
•*Richelia* associated with *H. hauckii* form long chains & abundant in upper water column (0-45m)

Several *Trichodesmium* species co-occur

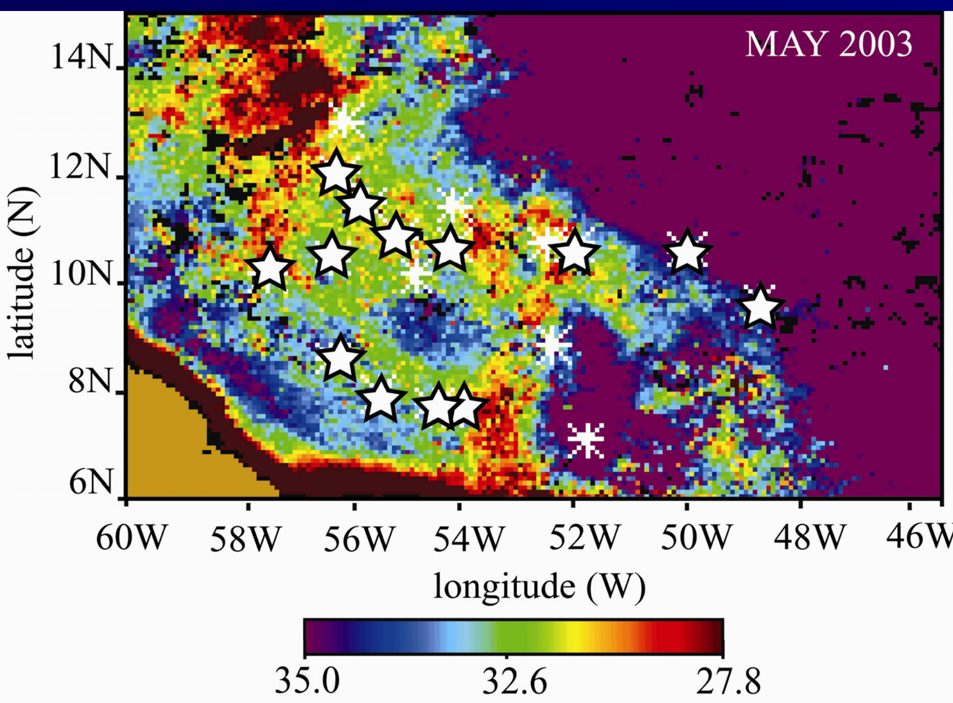
2 morphologies of unicellulars

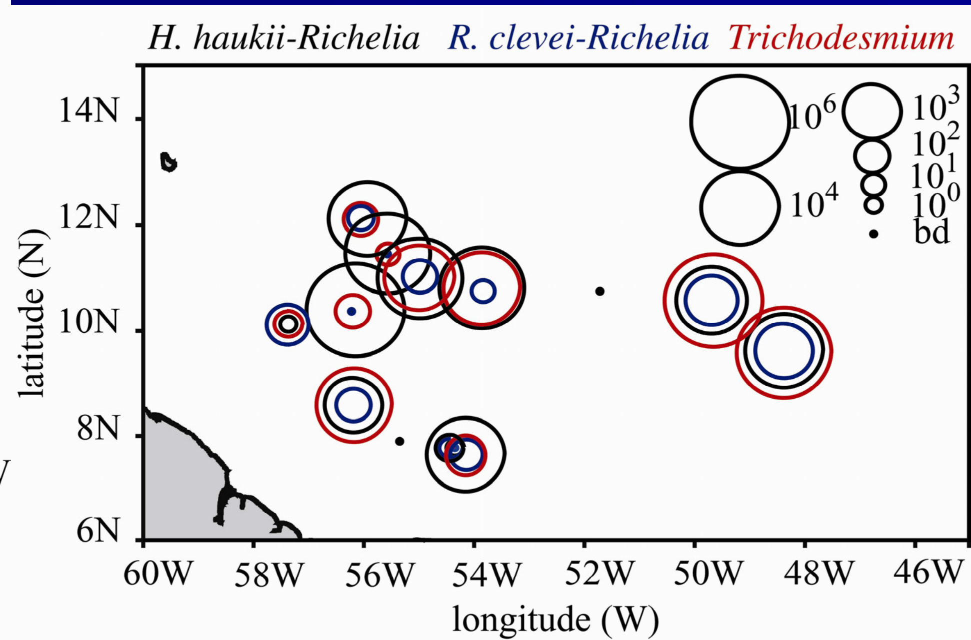


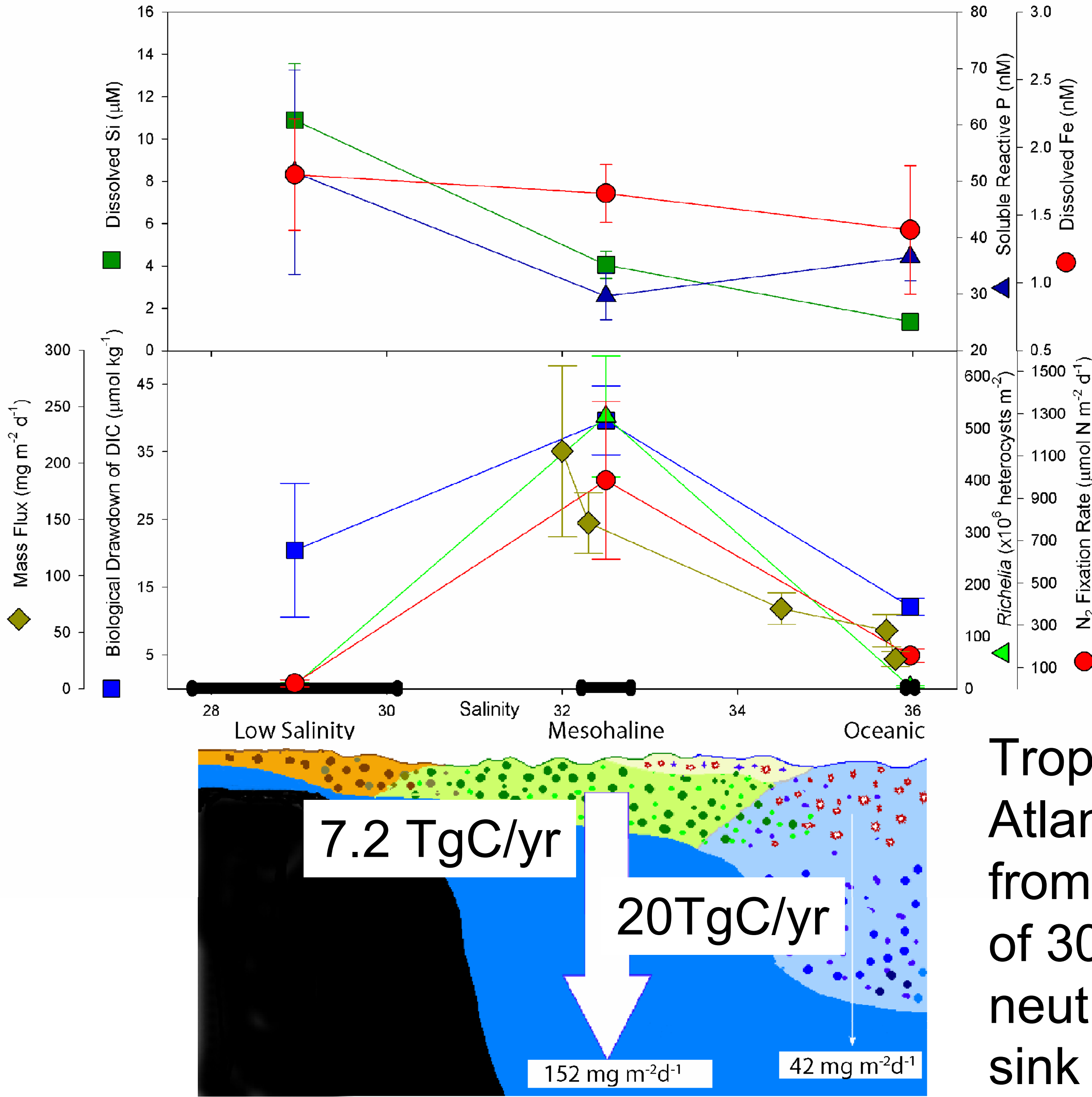




Foster et al., (2007) *L & O.*







Tropical North Atlantic goes from net source of 30 Tg C/yr to neutral or even a sink for C

Deuser et al. (1988). "Temporal variations of particle fluxes in the deep subtropical and tropical North Atlantic: eulerian versus lagrangian effects." Journal of Geophysical Research **93**(No. C6): 6857-6862.

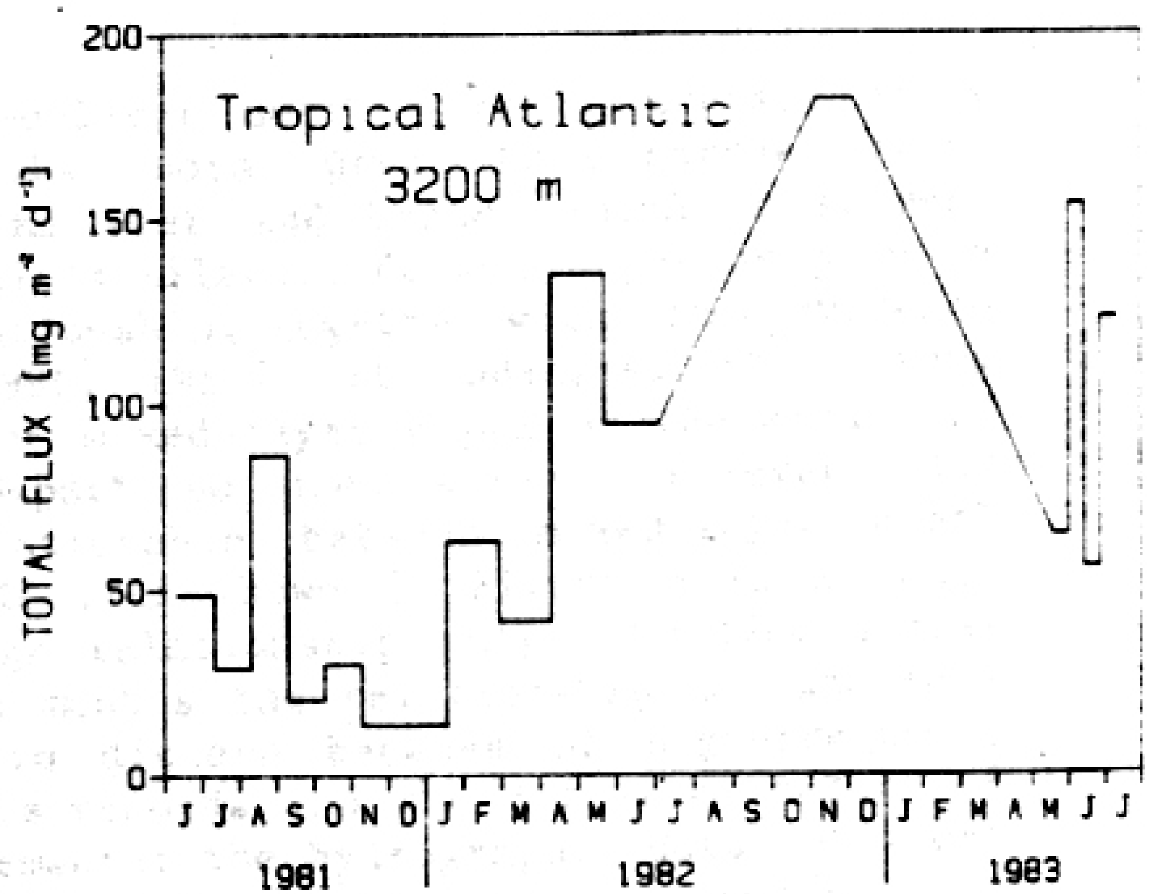
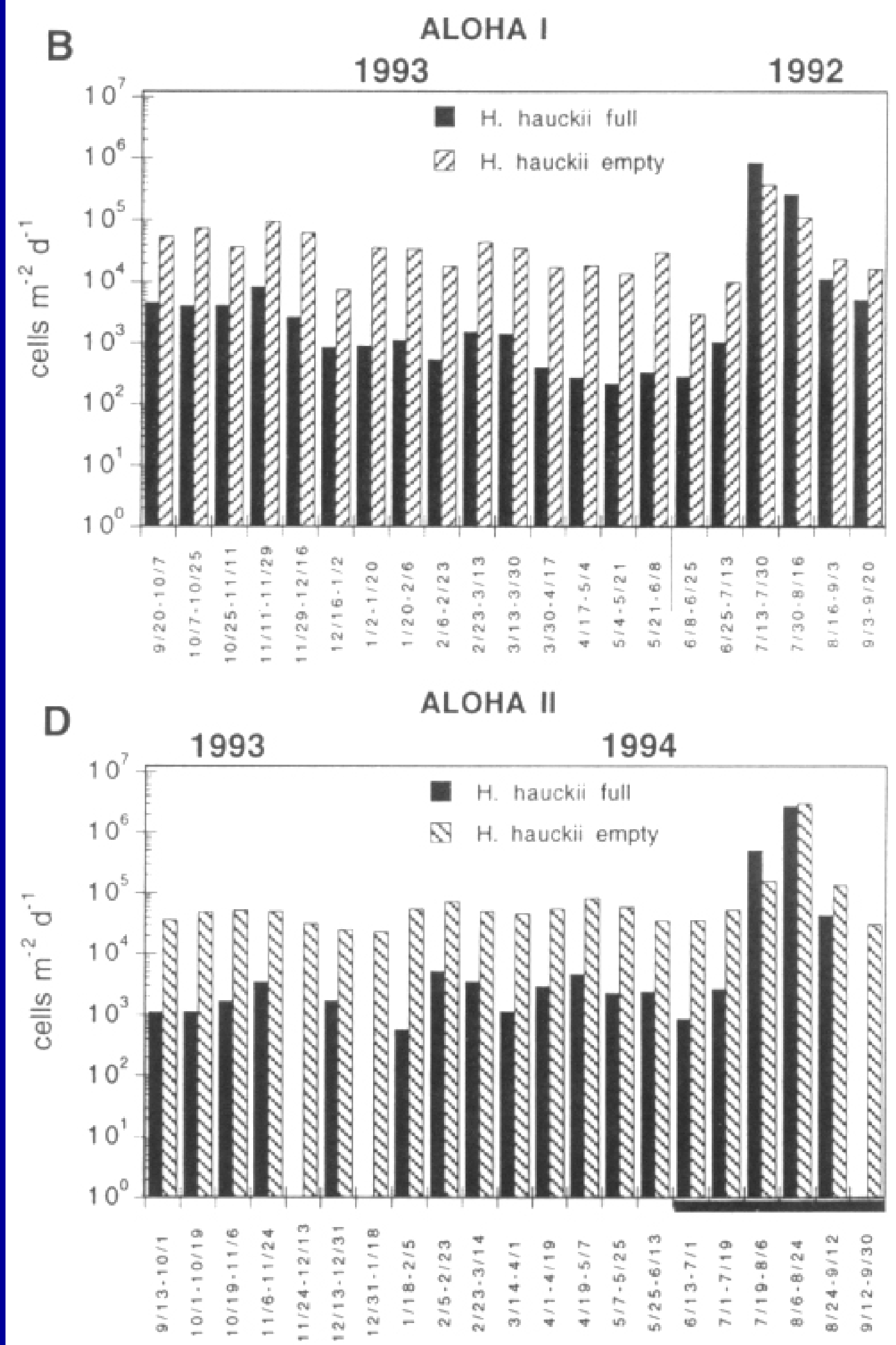


Fig. 2. Variations of total particle flux at a depth of 3200 m in the western tropical North Atlantic. Notation is as in Figure 1. The two gaps in the record (sloping lines) amount to 38% of the time between start and end of the series.

Flux at 2800m

Diatom fluxes to the deep sea in the oligotrophic North Pacific gyre at station ALOHA
Marine Ecology Progress Series, Vol 182:55-67, 1999

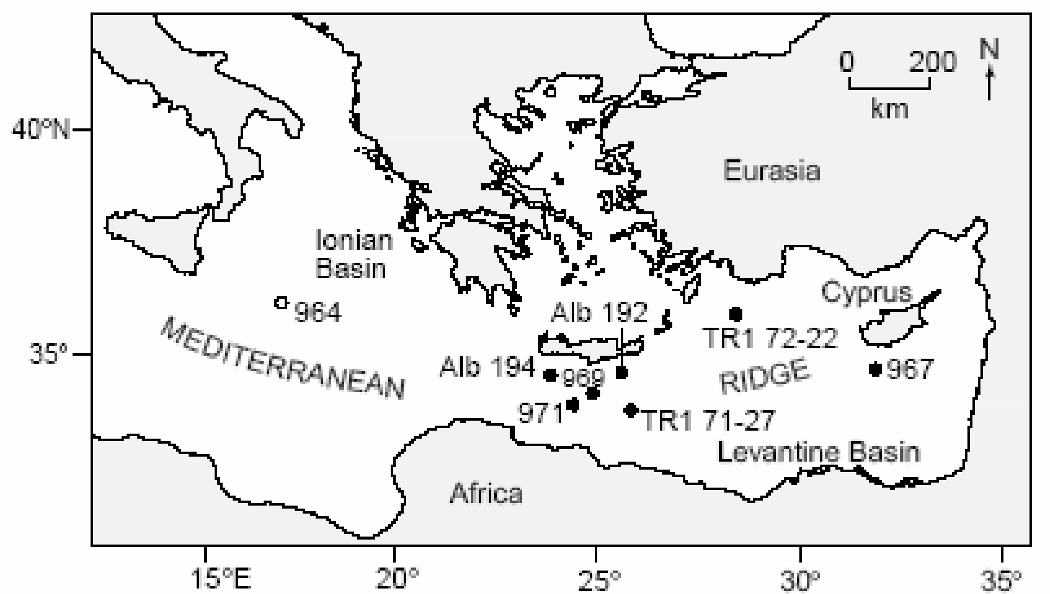
Flux at 4000m

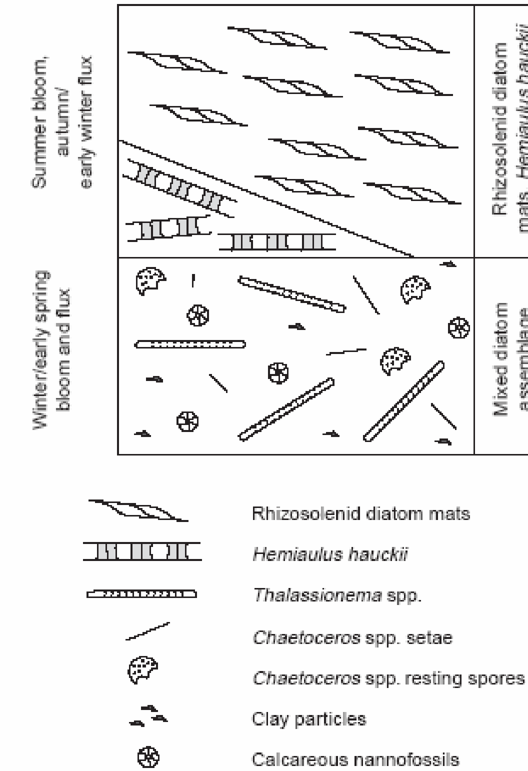


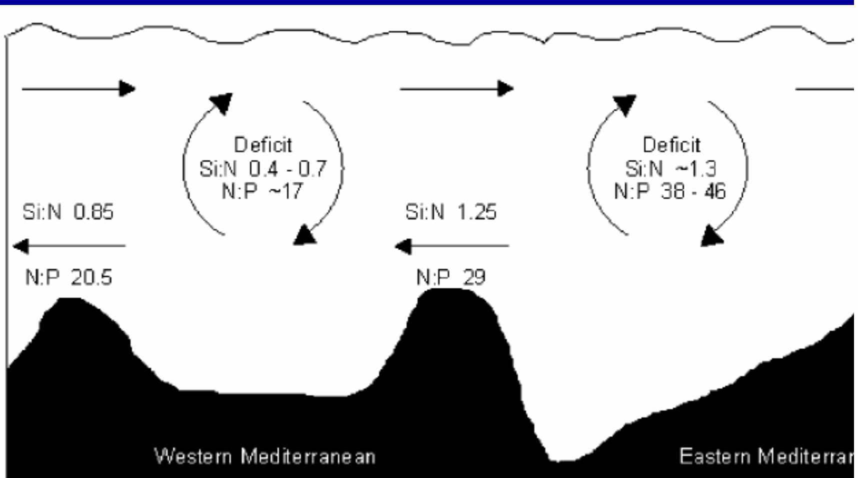
woodiana and *Hemiaulus hauckii* (cells m^{-2} d^{-1}, in logarithmic

The role of mat-forming diatoms in the formation of Mediterranean sapropels

Alan E. S. Kemp*, Richard B. Pearce*, Itaru Koizumi†, Jennifer Pike*‡ & S. Jae Rance*







JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. C9, 8106, doi:10.1029/2002JC001650, 2003

Nutrient ratios and fluxes hint at overlooked processes in the Mediterranean Sea

M. Ribera d'Alcalà,
Stazione Zoologica A. Dohrn, Laboratorio di Oceanografia Biologica, Naples, Italy

G. Civitarese
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F. Conversano and R. Lavezza
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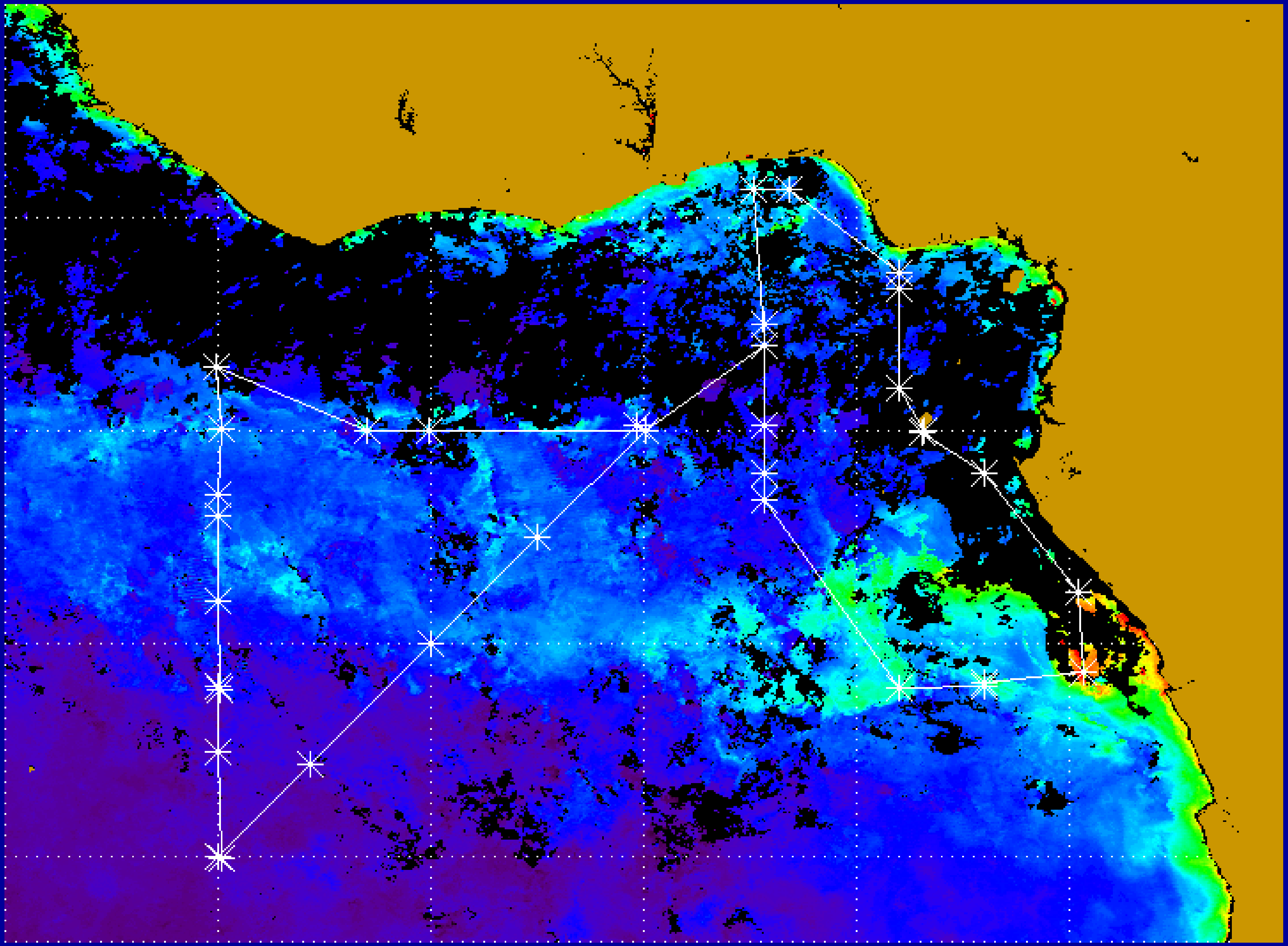
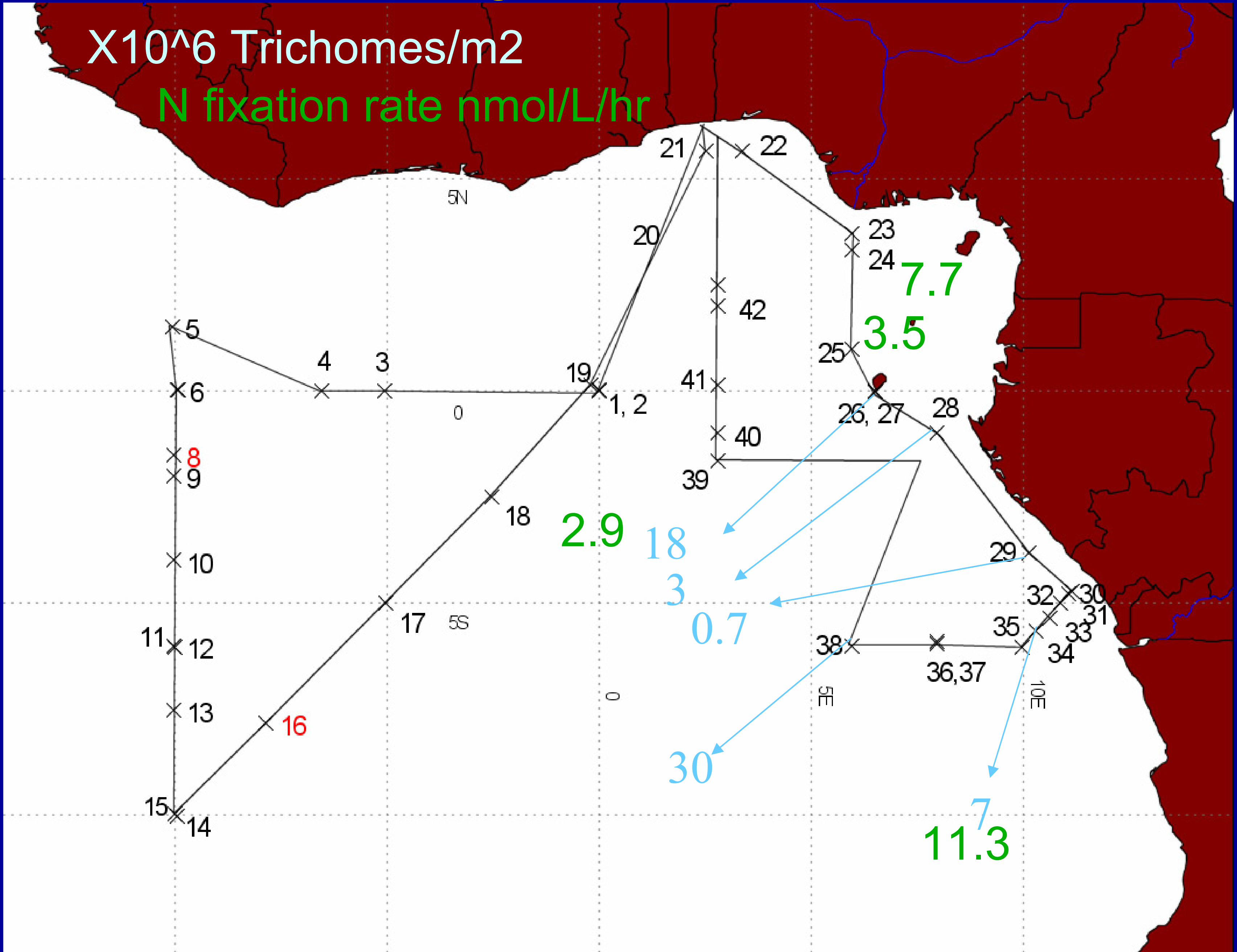
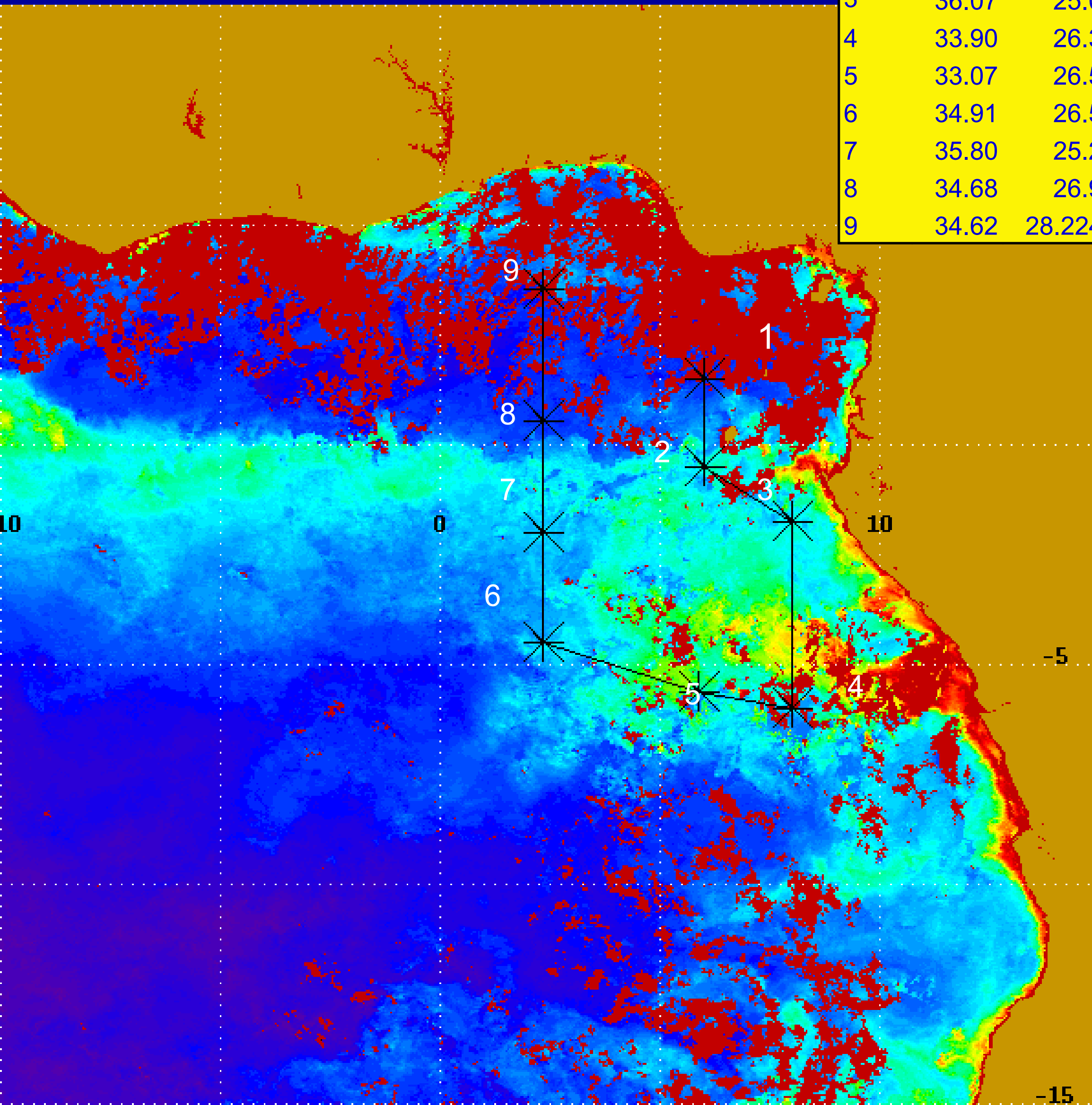


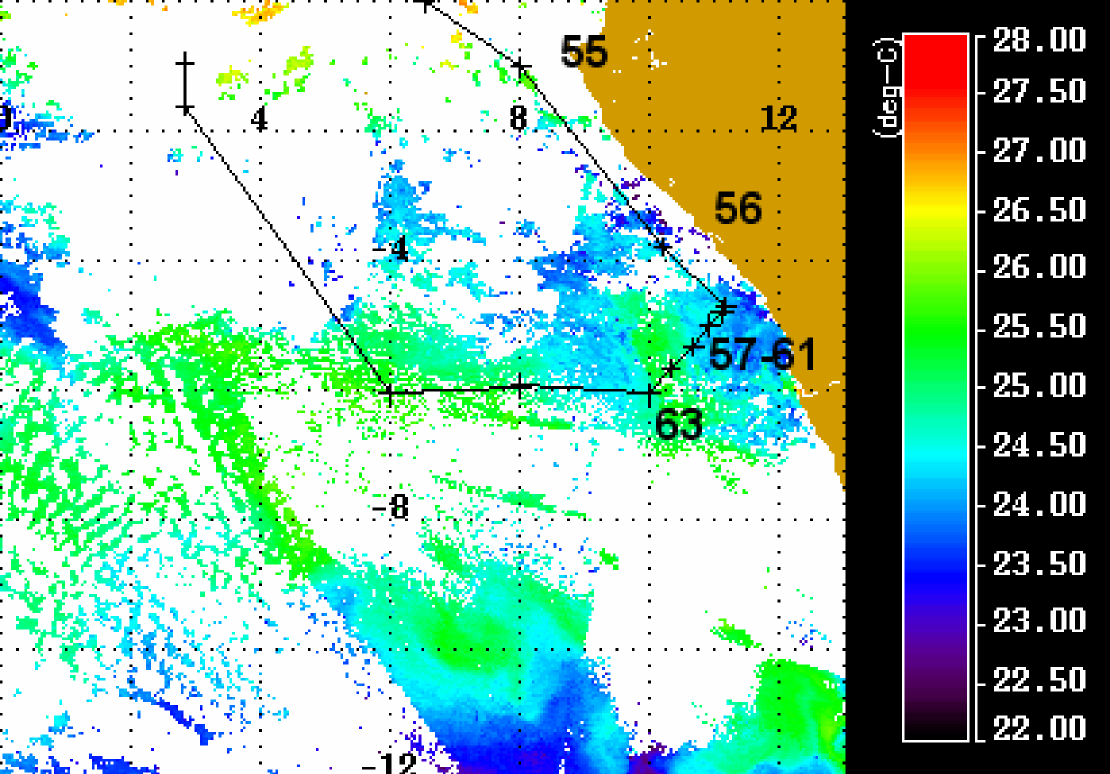
Congo River 2006

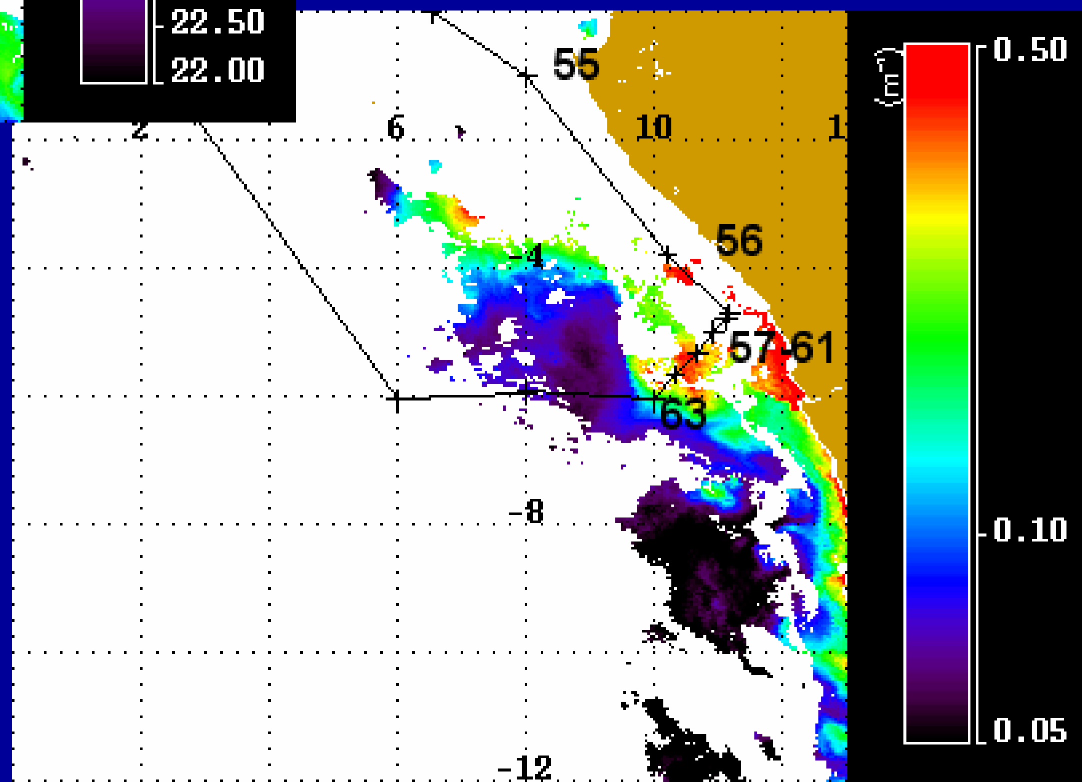


Congo River 2007

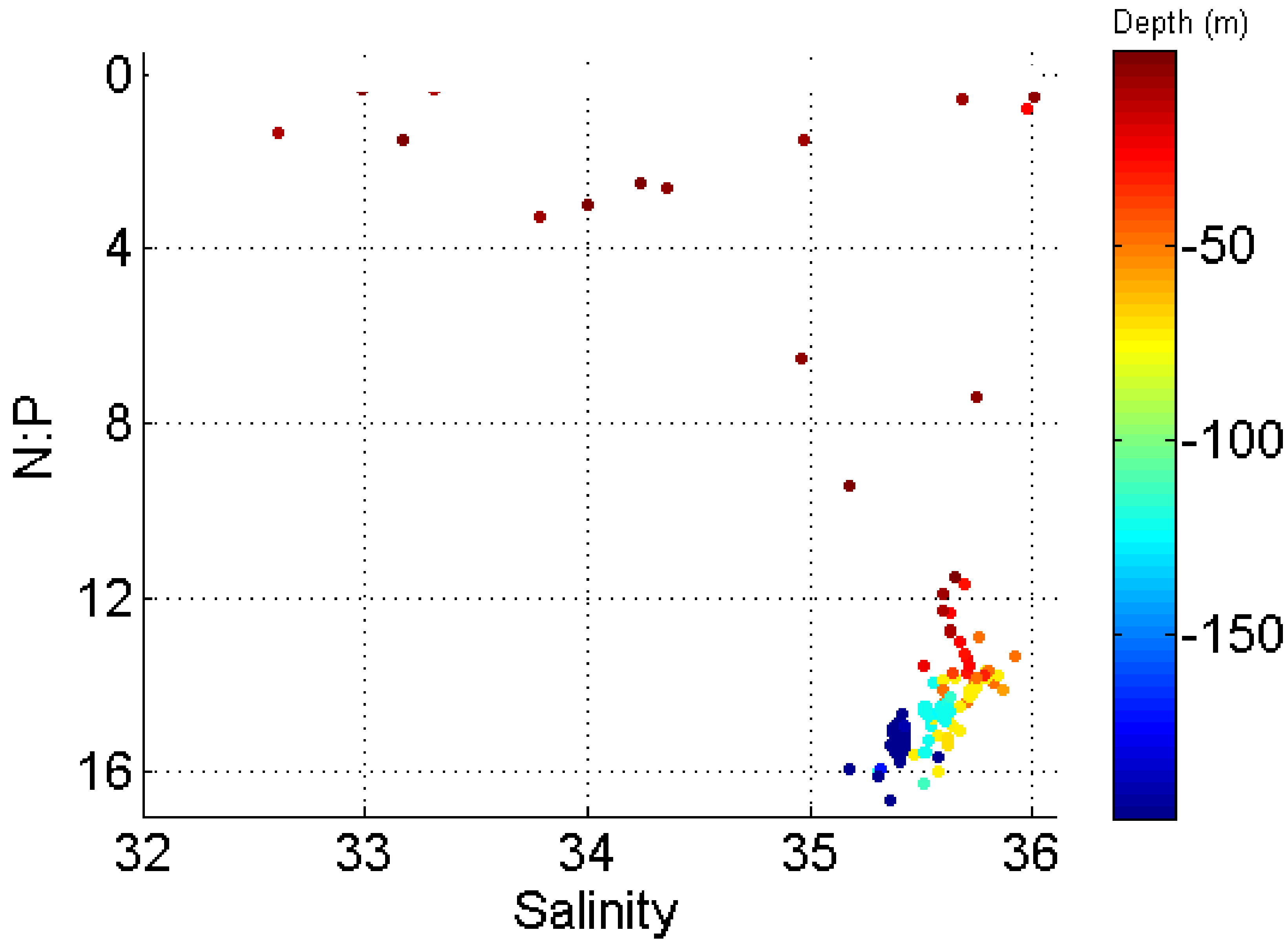
Station	salinity	temperature	*Tricho*	het-1	het-2	het-3	Total Rich
Niger			nd	det, not q	51400	nd	10280
1	33.39	28.04	nd	det, not q	82400	det, not q	16480
2	35.64	25.64	nd	nd	95900	det, not q	19180
2	36.20	21.99	3810	518	94600	149000	48824
3	36.07	25.09	det, not q	2010	2080	nd	818
4	33.90	26.35	8020	det, not q	nd	3490	698
5	33.07	26.51	85000	15800	3190	2180	4234
6	34.91	26.53	35600	2590	det, not q	1280	774
7	35.80	25.27	314000	det, not q	det, not q	det, not q	
8	34.68	26.95	90000	det, not q	1230	det, not q	246
9	34.62	28.2241	674000	det, not q	91800	24600	23280



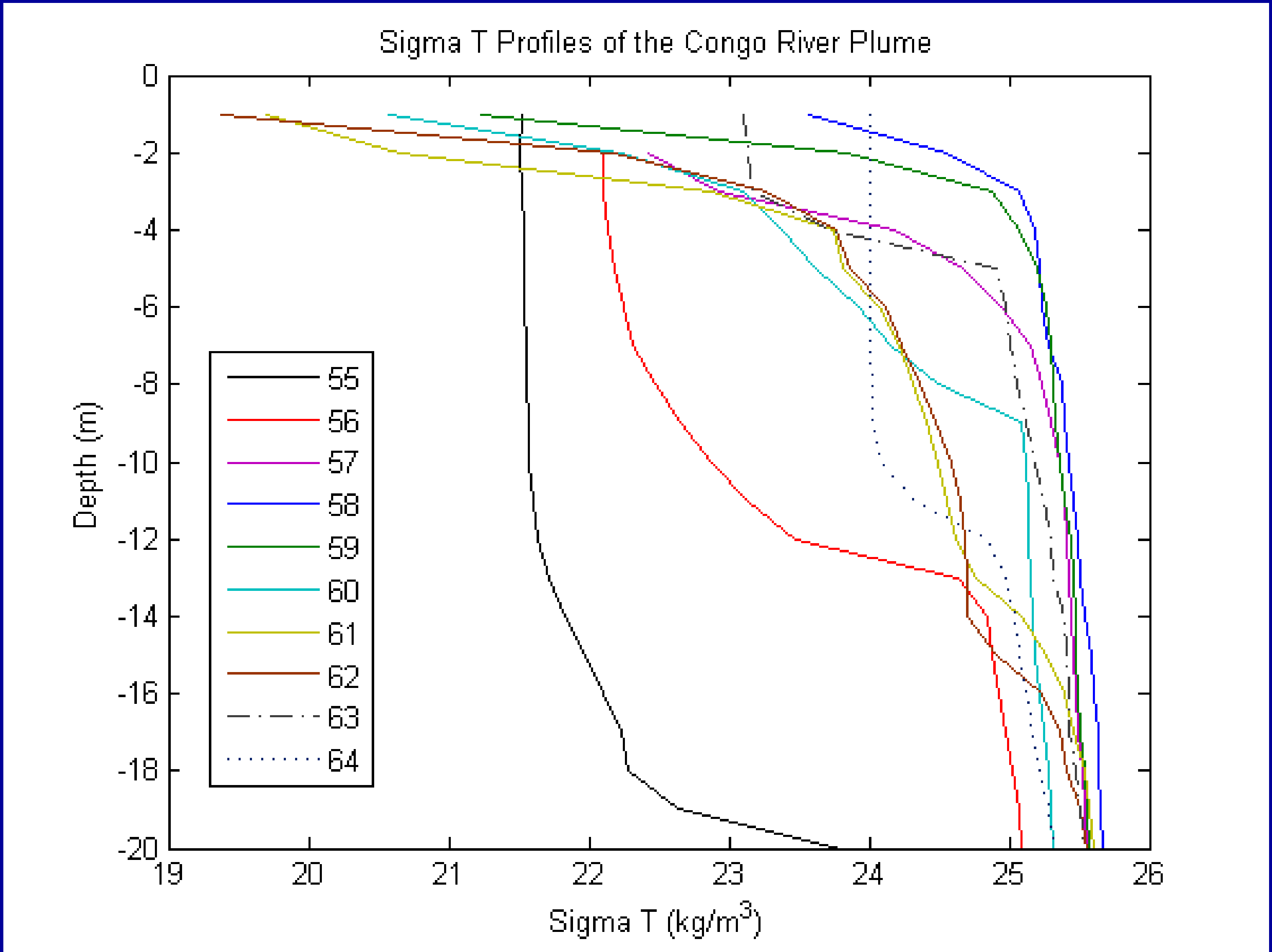

55
56
57-61
63
4
8
12
-4
-8
-12
(deg-C)
28.00
27.50
27.00
26.50
26.00
25.50
25.00
24.50
24.00
23.50
23.00
22.50
22.00


55
56
57-61
63
2
6
10
-4
-8
-12
(m⁻¹)
0.50
0.10
0.05

N:P Ratio for CTDs 57-63 in the Congo plume and coastal cold tongue

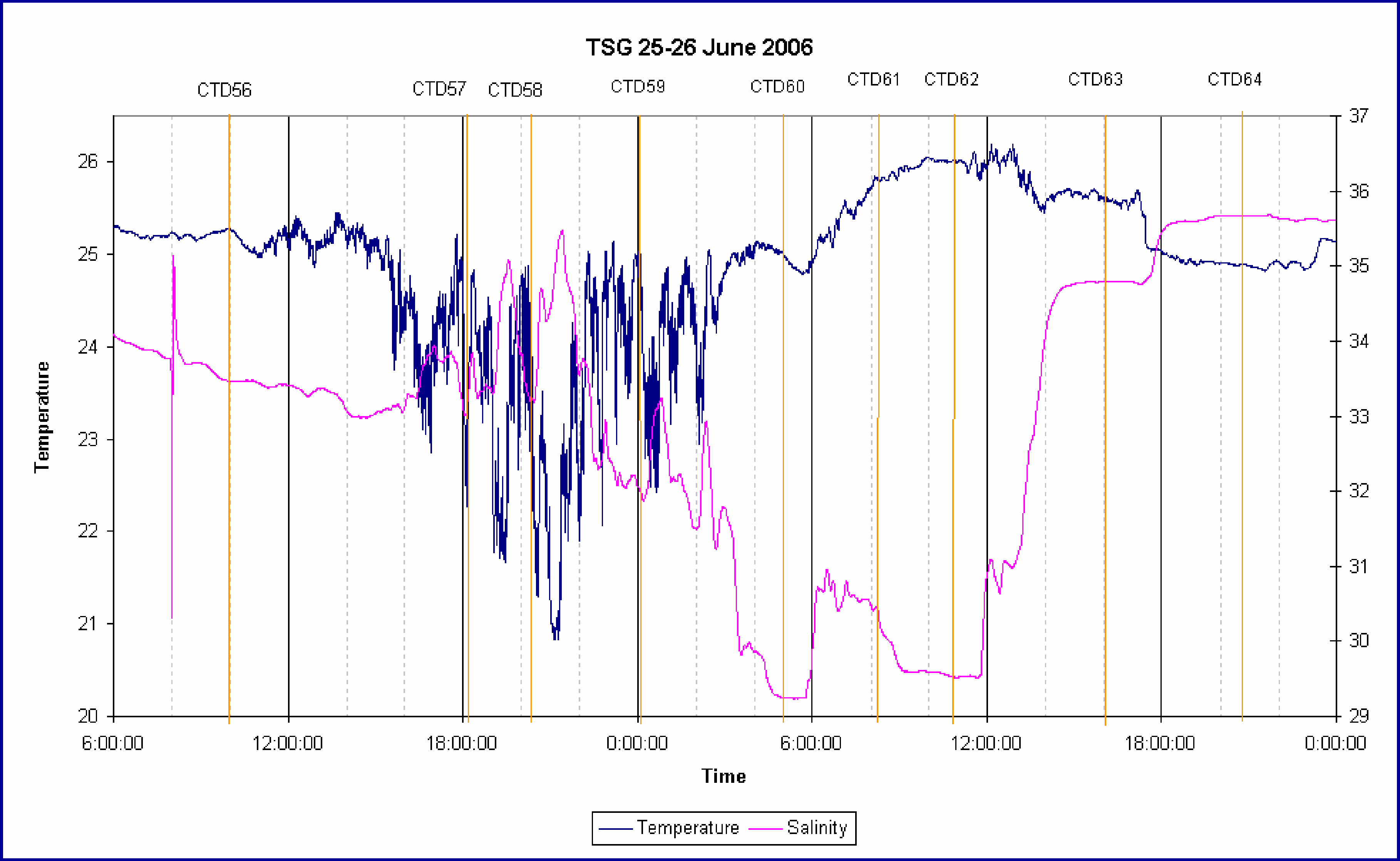


Density structure of the Congo Plume

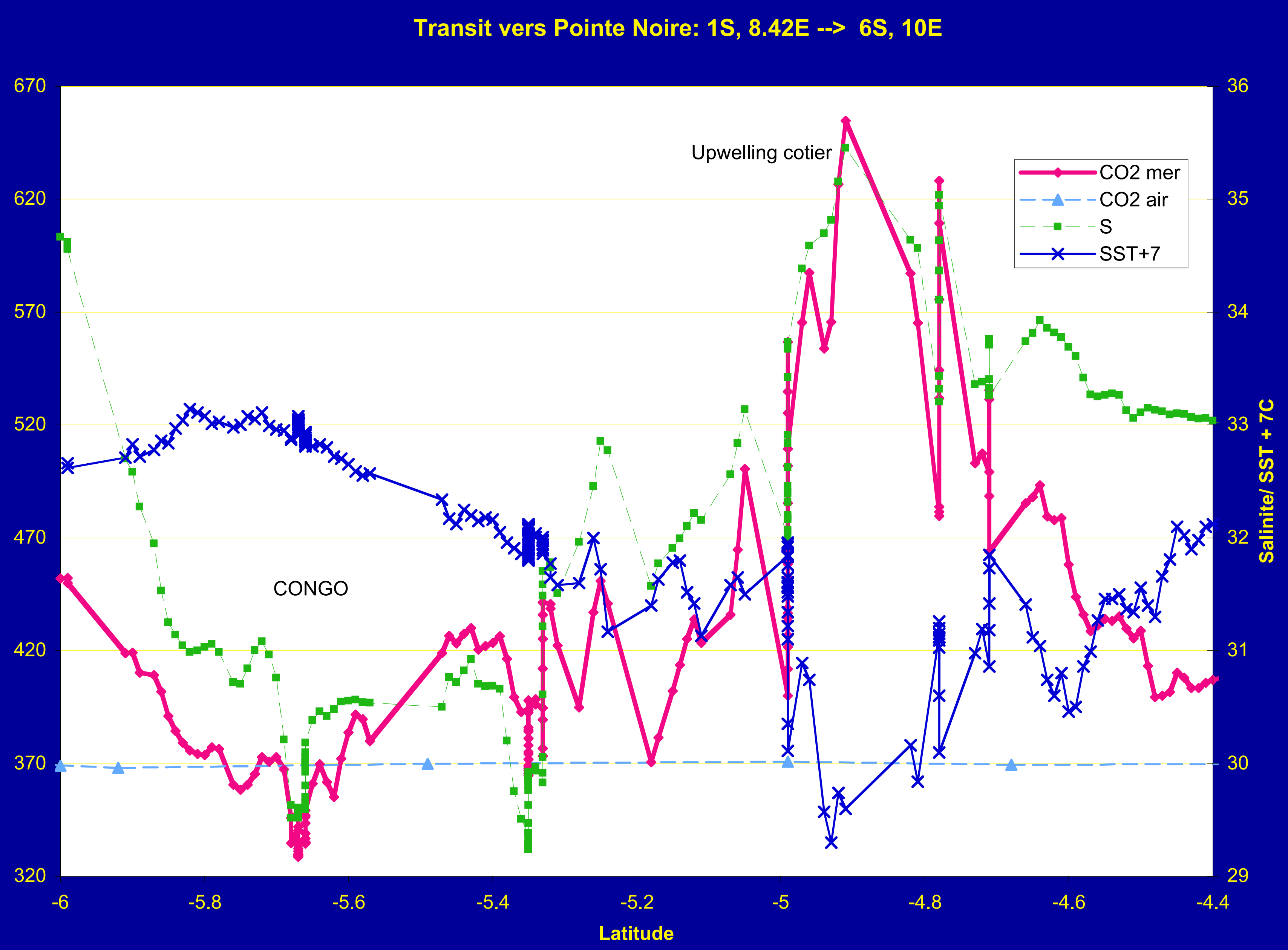


Implications for diurnal heating and air/sea gas exchange

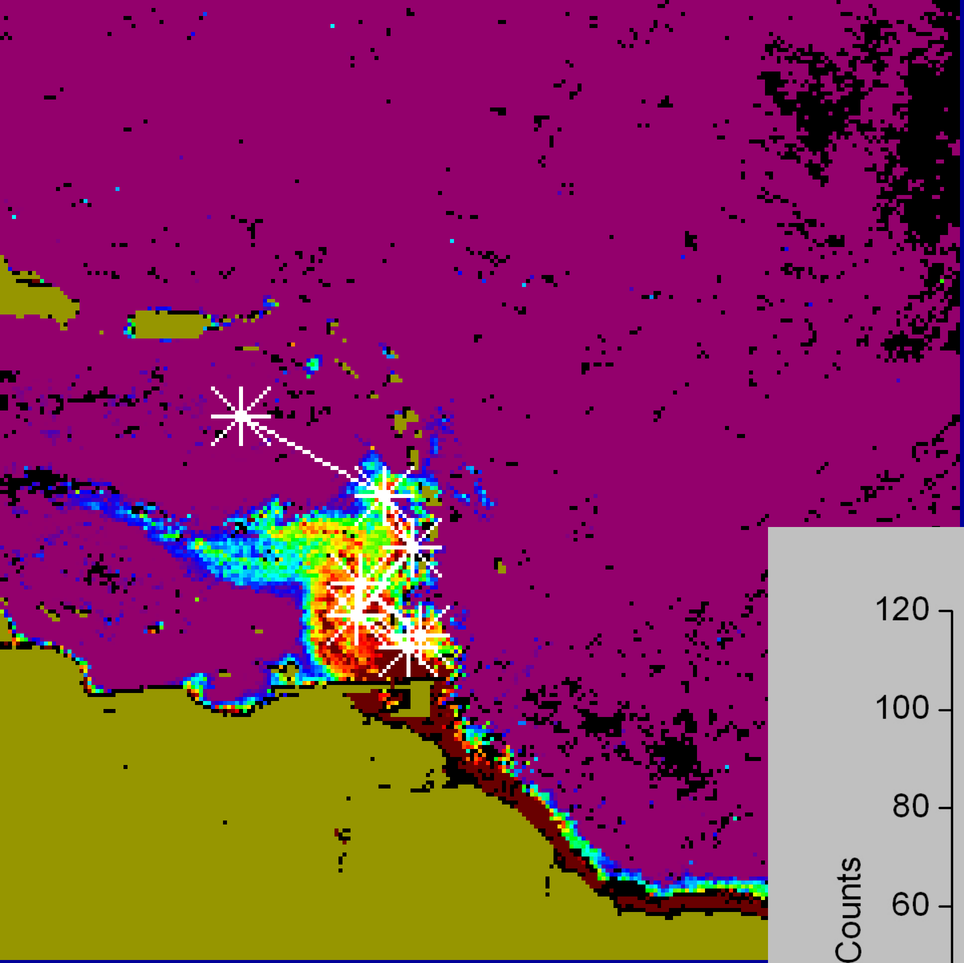
Temperature and Salinity from the Ship's flowthrough system (4m)

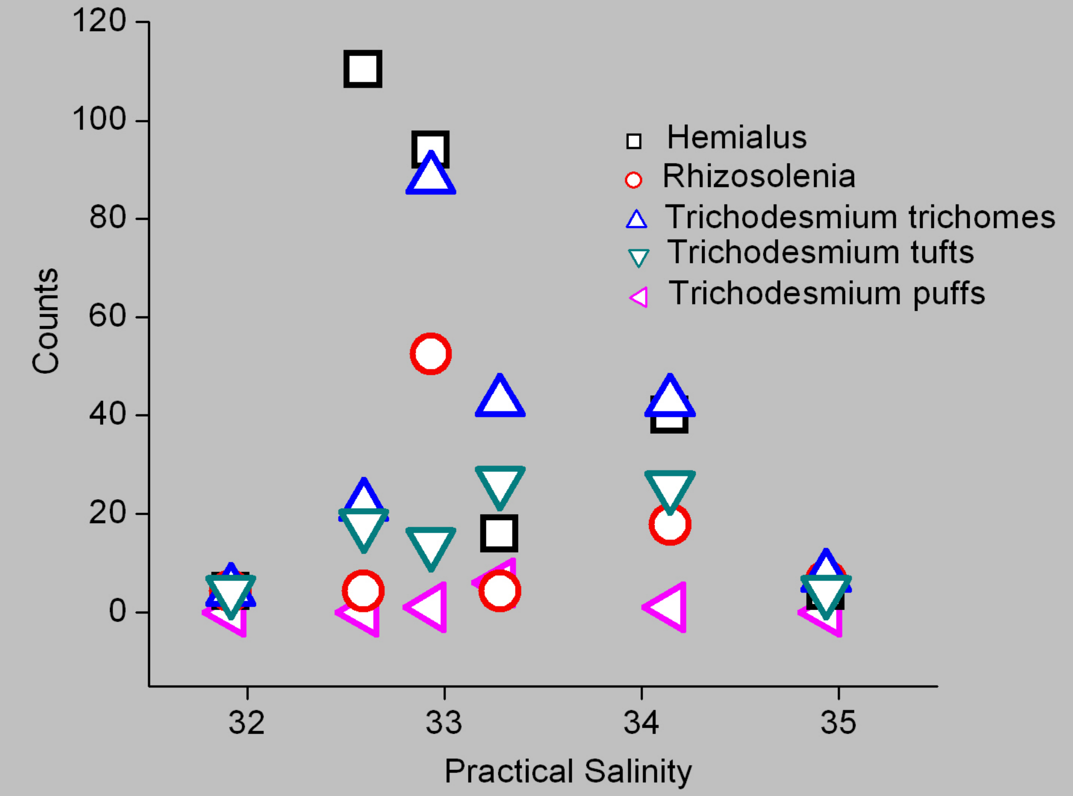


Have to be careful in using ships of opportunity to validate salinity and temperature in the Congo Plume, especially large container ships with deep intakes.


Transit vers Pointe Noire: 1S, 8.42E --> 6S, 10E
670
620
570
520
470
420
370
320
36
35
34
33
32
31
30
29
Upwelling cotier
CONGO
CO2 mer
CO2 air
S
SST+7
Salinite/ SST + 7C
-6
-5.8
-5.6
-5.4
-5.2
-5
-4.8
-4.6
-4.4
Latitude

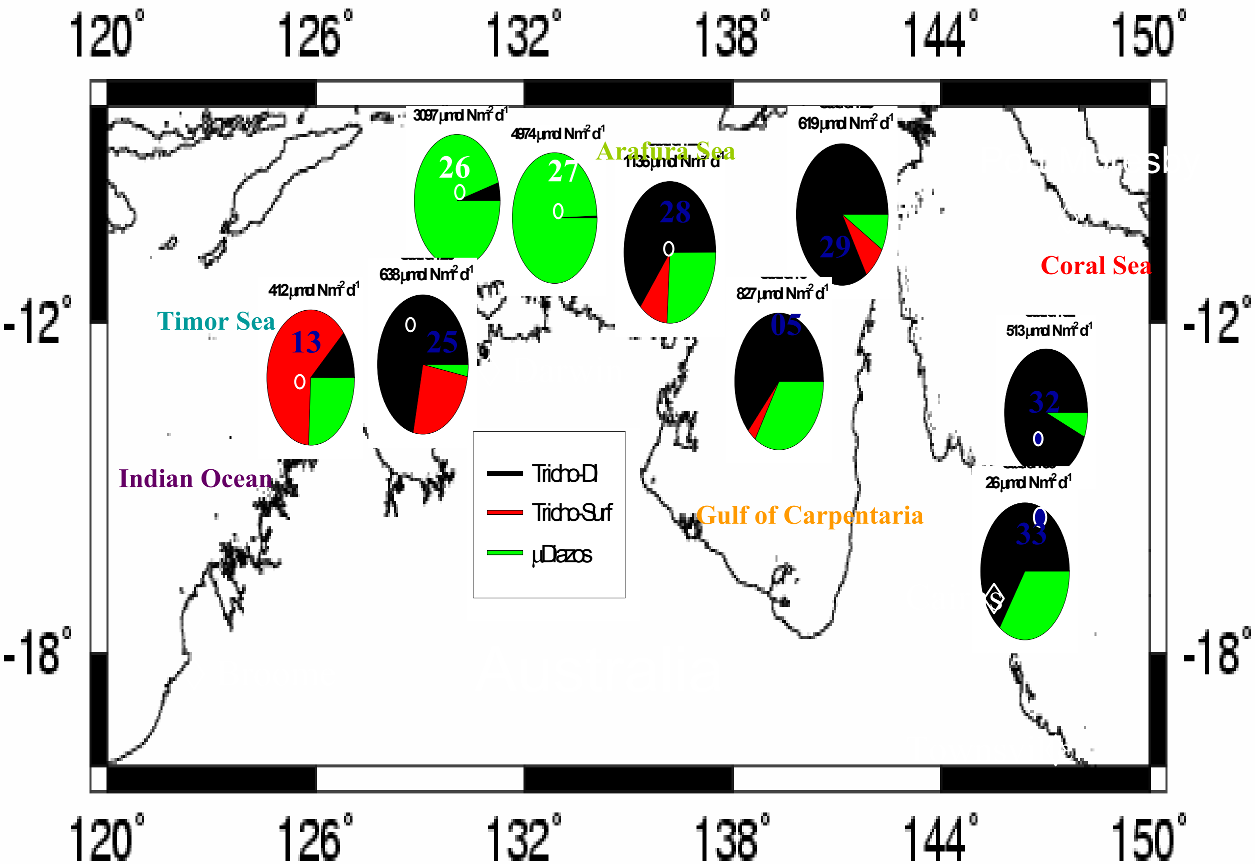
Orinoco River



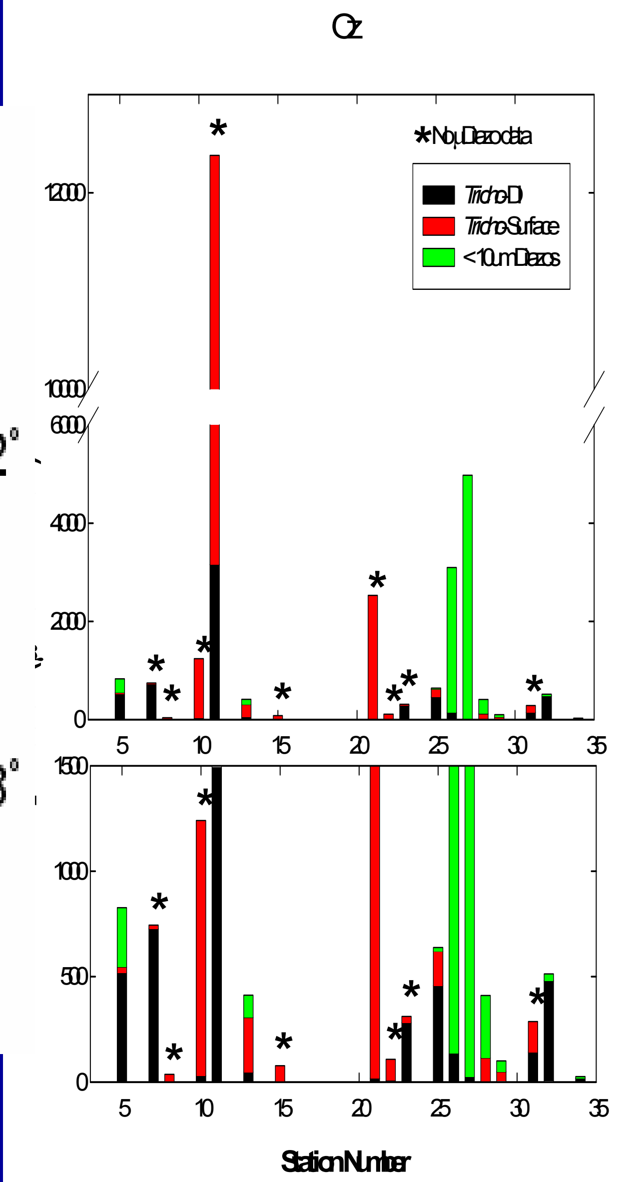


Cruise data from September 2006
from Corredor, Morrel, Cabrera

Fly River

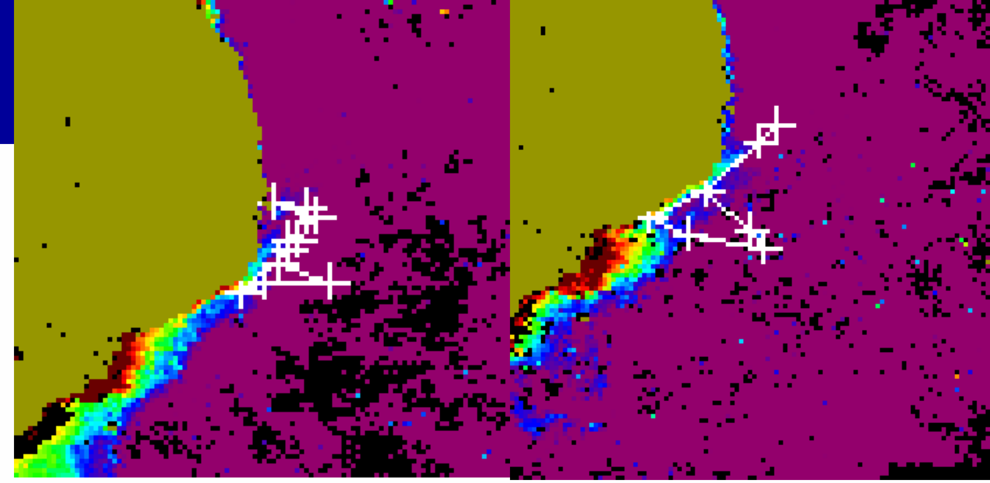


120°
126°
132°
138°
144°
150°
-12°
-18°
Timor Sea
Indian Ocean
Arafura Sea
Coral Sea
Gulf of Carpentaria
26
27
28
29
13
25
05
32
33
Tricho-D
Tricho-Surf
μDiazos



Oz
* No μDiazo data
Tricho-D
Tricho Surface
<10um Diazos
Station Number

Mekong River



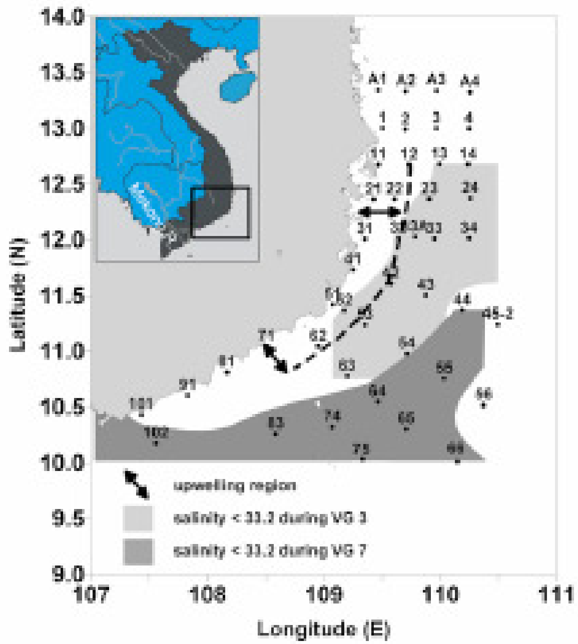
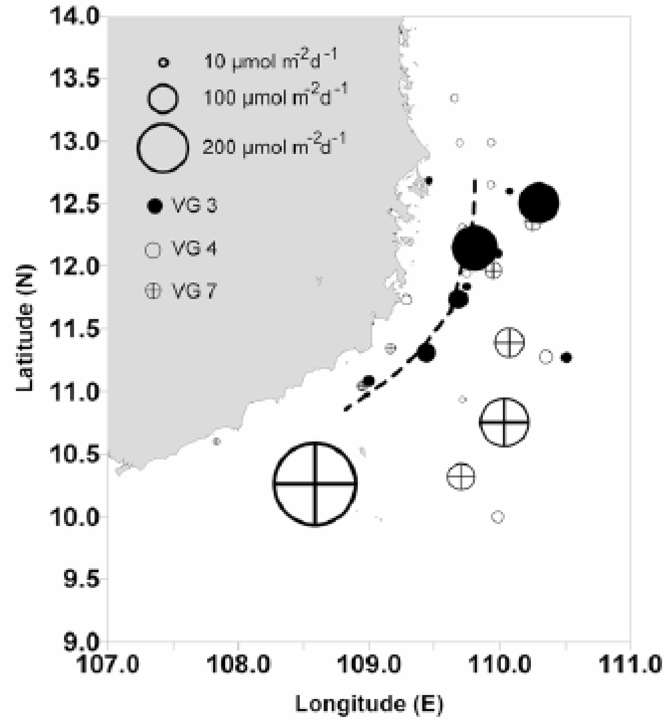


Figure 1. Map of the South China Sea off Vietnam with all CTD stations, the insert shows SE Asia. (N_2-fixation was measured at the 28 stations). Stations A1 to A4 and 1 to 4 were only visited during VG4, stations 62 to 65 only during VG7. The shaded area denotes Mekong river influence and the line the extension of the upwelling region from the coast.



Voss M, Bombar D, Loick N, Dippner J (2006) Riverine influence on nitrogen fixation in the upwelling region off Vietnam, South China Sea. GRL 33

Figure 2. N_2-fixation rates, symbols are scaled linearly proportional to the measured values. The line visualises the offshore limitation of the upwelling area.

Indian Ocean Rivers - the great unknowns

Bay of Bengal
Ganges/Brahmaputra/Irrawady/Salween

Intense blooms of *Trichodesmium erythraeum* (Cyanophyta) in the open waters along east coast of India

*R. Jyothibabu, N. V. Madhu, Nuncio Murukesh, P. C. Haridas, K. K.C.Nair & P. Venugopal

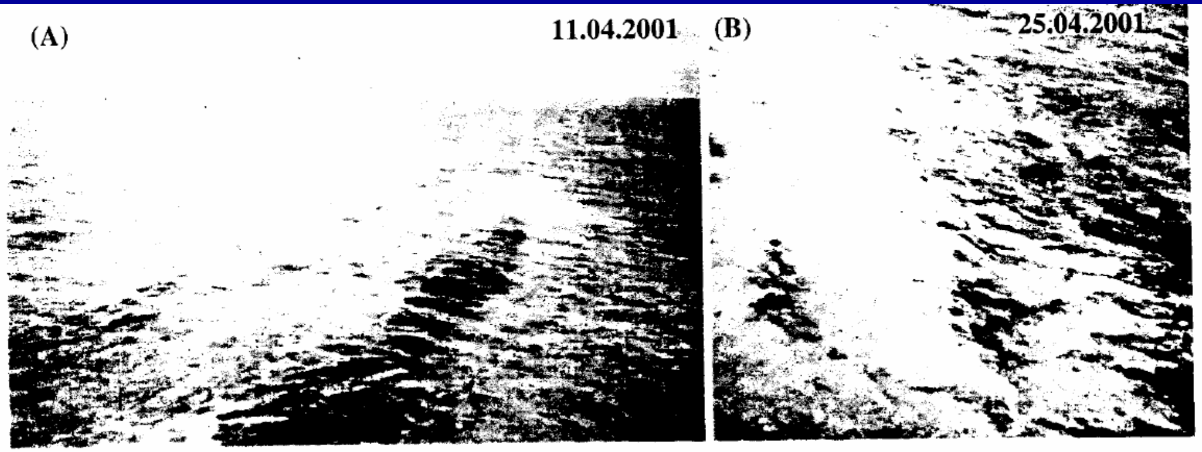


Fig. 2 — *Trichodesmium erythraeum* bloom observed (A) off Karaikkal, (B) off south of Calcutta

Table 1 — Details of the location, nutrients, primary production and mesozooplankton biomass of the bloom regions in the Bay of Bengal

Bloom date	Lat (°N)	Long (°E)	Nutrients (μ mol.l^{-1})			Primary production (mgC m^{-2} d^{-1})	Zooplankton biomass (ml 100m^{-3})
			Nitrate	Phosphate	Silicate		
11 April 2001	10° 58'	81°50'	0.05	0.9	2.2	2160	22.8
25 April 2001	19°44'	89°04'	0.14	0.56	—	1740	17.7

Zambezi River too?

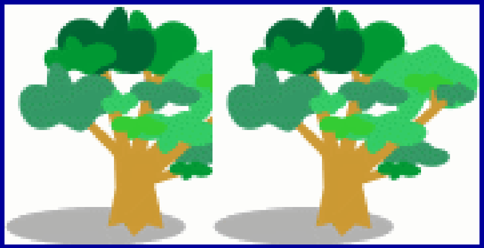
Tricho?

STS036-073-056 Bazaruto Island, Mozambique March 1990

Take home messages

To Understand the controls on the efficiency of the biological pump, we need to

- Need to understand the processes (go beyond pCO2 surveys)
- Understand the change in biotic structure
- Understand the influence of anthropogenic activity



Pre Industrial

Future

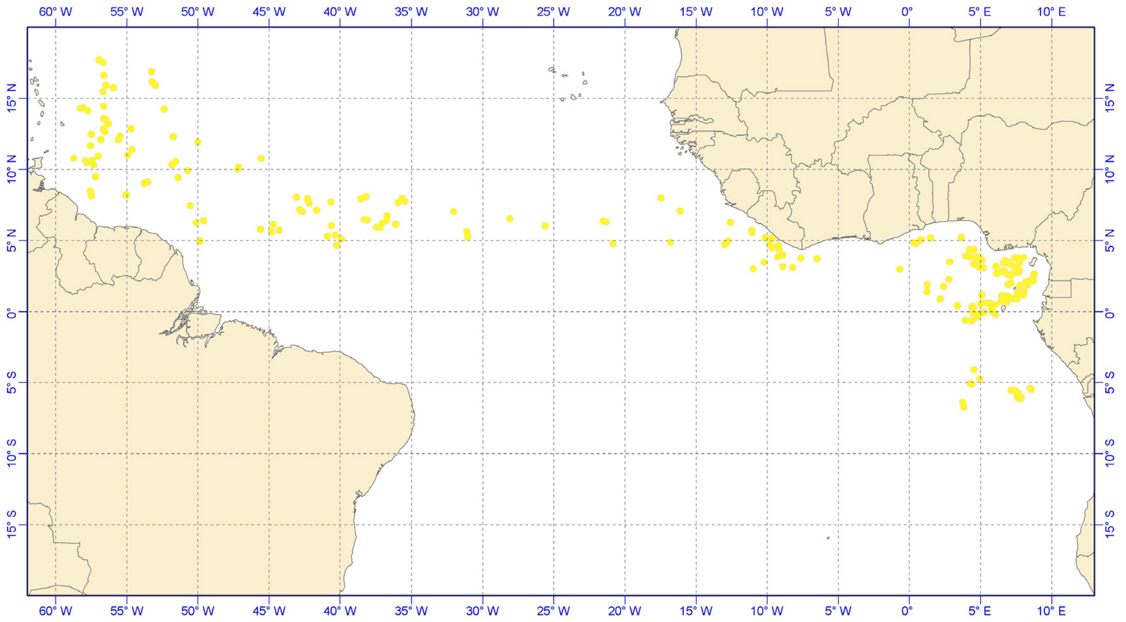
Amazon
Relatively Undisturbed
Low N:P
Source of P to the ocean
Major sink of carbon

Mekong
Rapidly changing
Dams, fertilizers
A model system for the future

Mississippi
Anthropogenically altered
High N:P
Perhaps P limited
Anoxia/denitrification
The future is here already

Discussion Points

- Either better define terms like export and new production or stop using them
- Need to know river fluxes at the mouth and just outside (like Amaseds) on a monthly basis
- Need to know biology of the DDAs (rates, limitation, DOP uptake, obligate symbiosis, host-symbiont transfers etc)



Salinity (ppt)

Legend

salinity

29.430000 - 32.000000

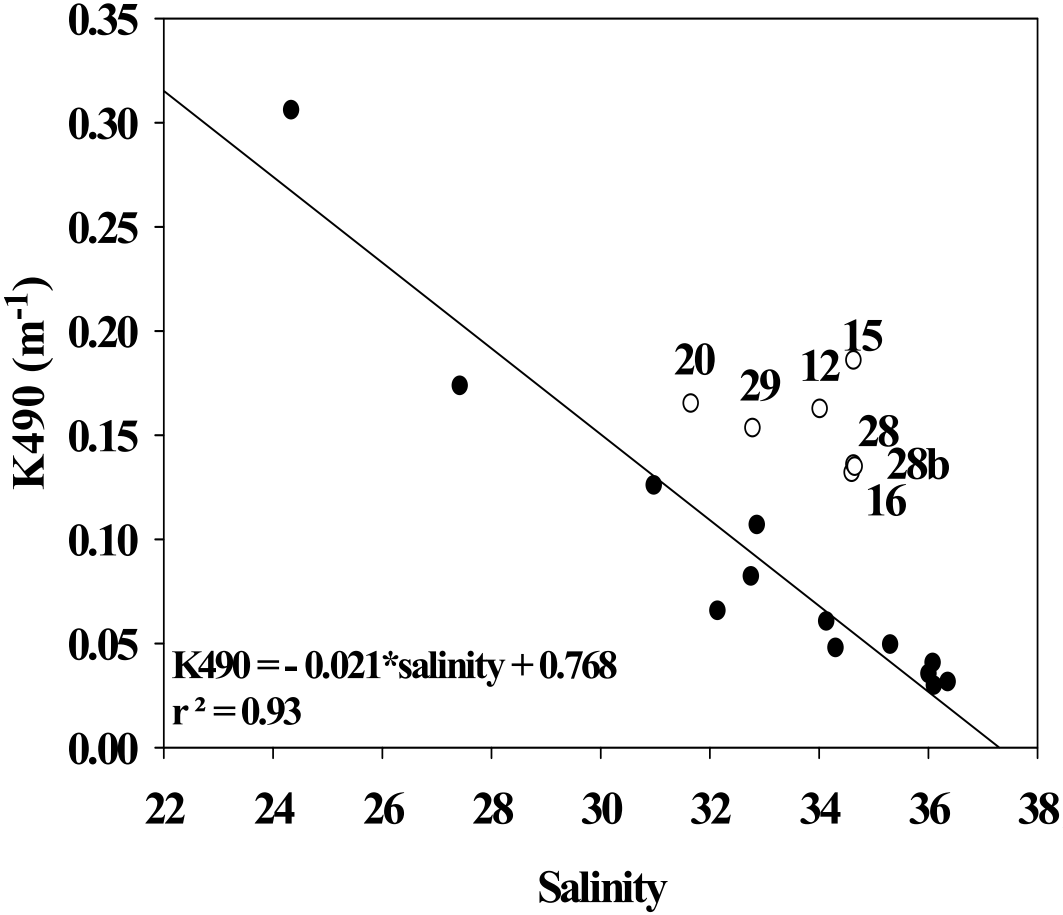
32.000001 - 34.000000

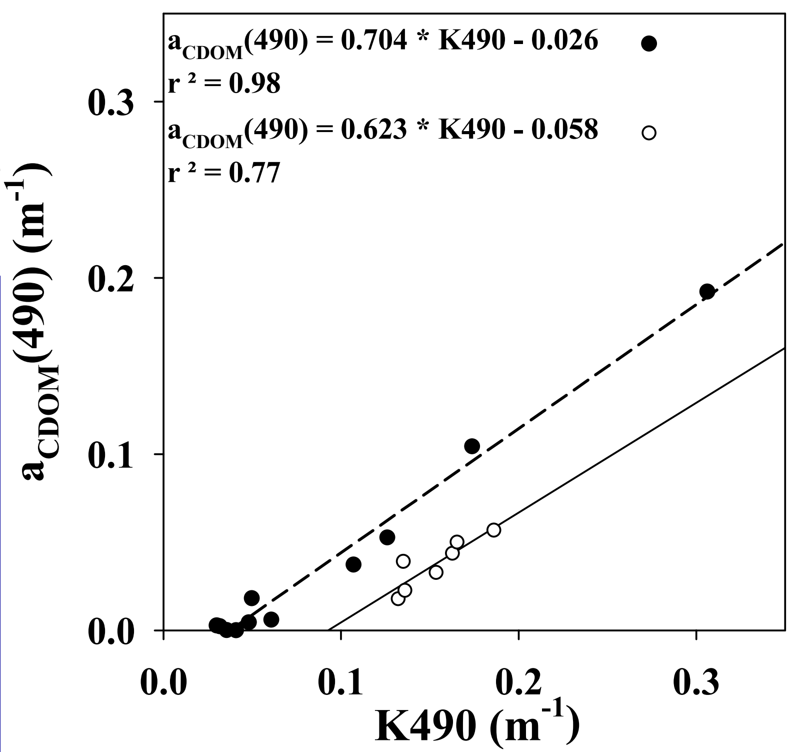
34.000001 - 36.000000

36.000001 - 38.000000

38.000001 - 40.000000

countryhighres


0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
K490 (m-1)
20
29
12
15
28
28b
16
K490 = - 0.021*salinity + 0.768
r ² = 0.93
22 24 26 28 30 32 34 36 38
Salinity


aCDOM(490) = 0.704 * K490 - 0.026
r ² = 0.98
aCDOM(490) = 0.623 * K490 - 0.058
r ² = 0.77
aCDOM(490) (m-1)
0.3
0.2
0.1
0.0
0.0 0.1 0.2 0.3
K490 (m-1)