# Influence of tropical rivers on carbon and nitrogen fixation


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# Definition of "new production"
## Dugdale and Goering 1967



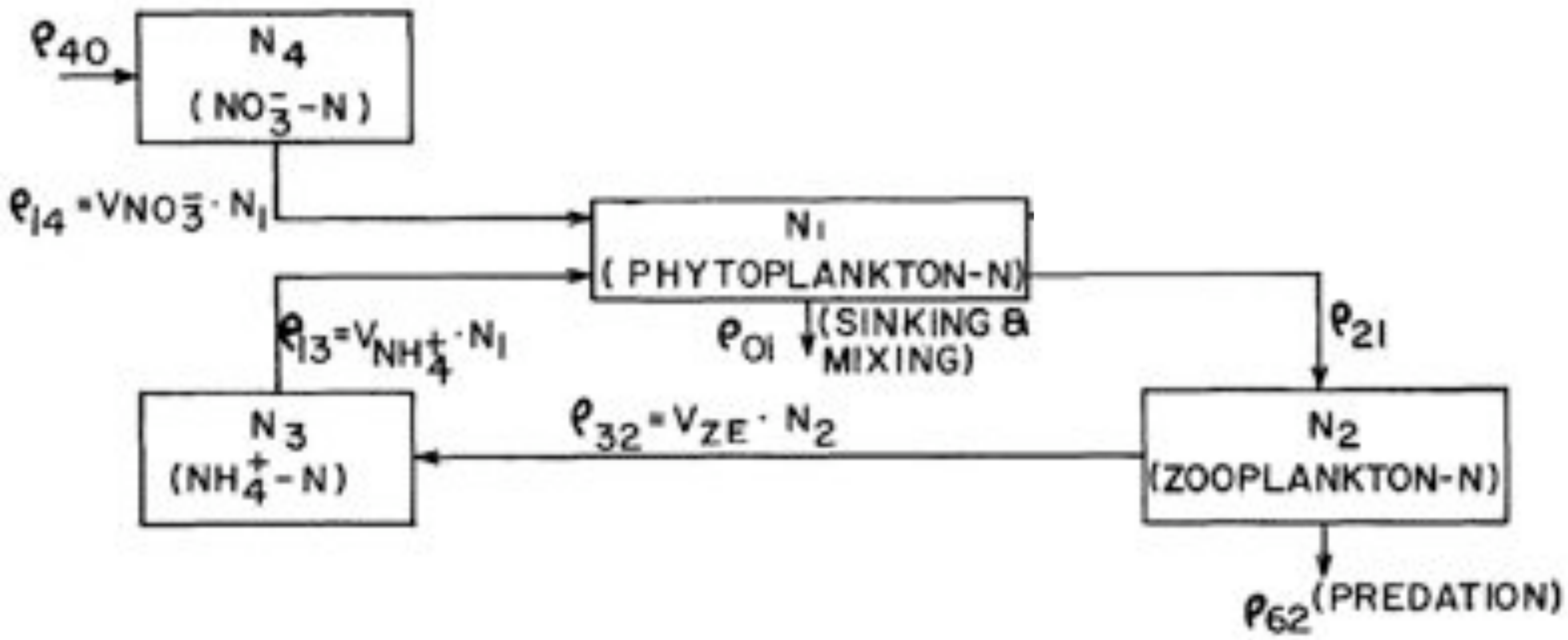



FIG. 1. Circulation of inorganic nitrogen through the euphotic zone ecosystem.

# Definition of "new production"
## Dugdale and Goering 1967



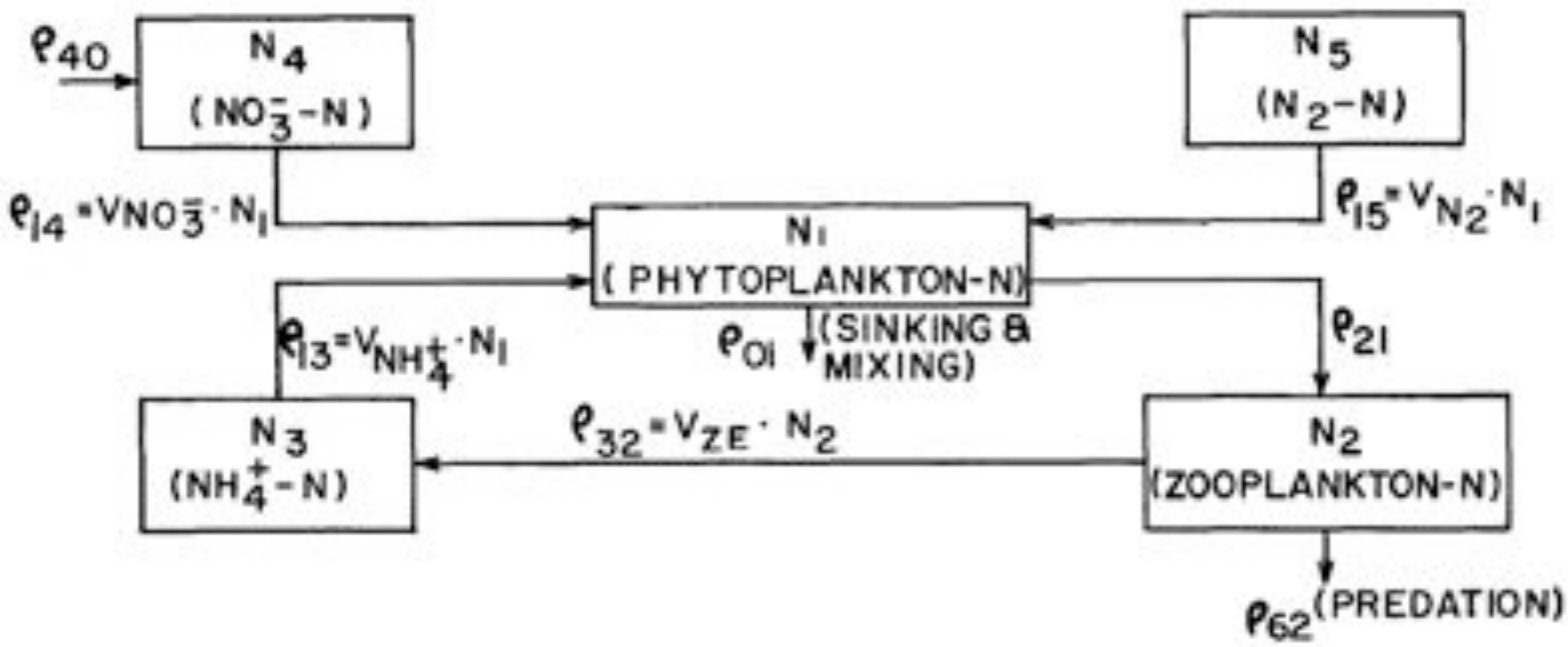
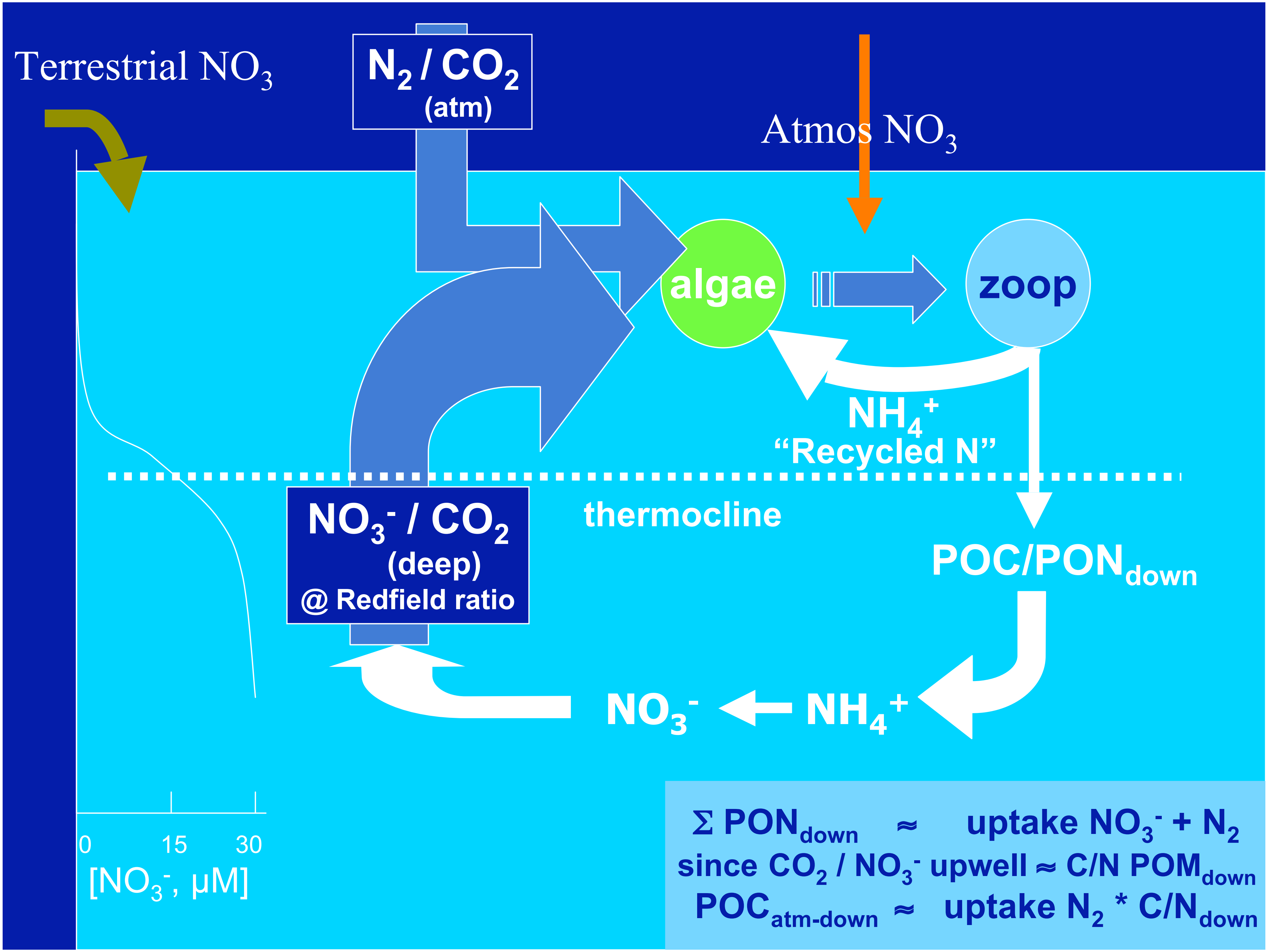



FIG. 1. Circulation of inorganic nitrogen through the euphotic zone ecosystem.

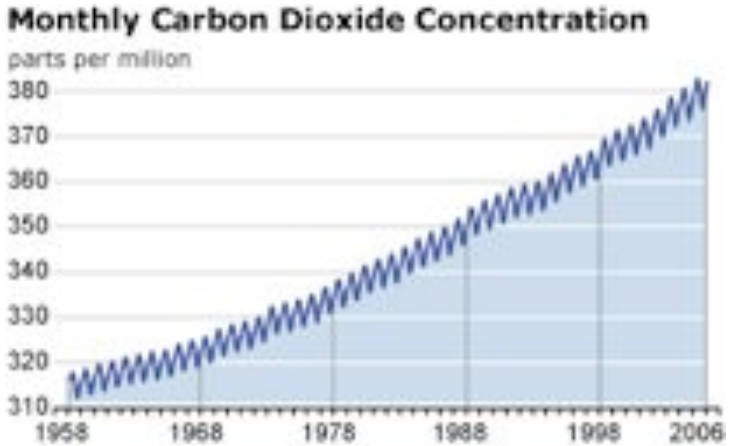
# And……

"only the sinking flux due to new production associated with nitrogen fixation and nutrient inputs from terrestrial and atmospheric sources can be identified as biologically-mediated transport of atmospheric CO2 to the deep ocean"

Eppley and Peterson, Nature 1979.

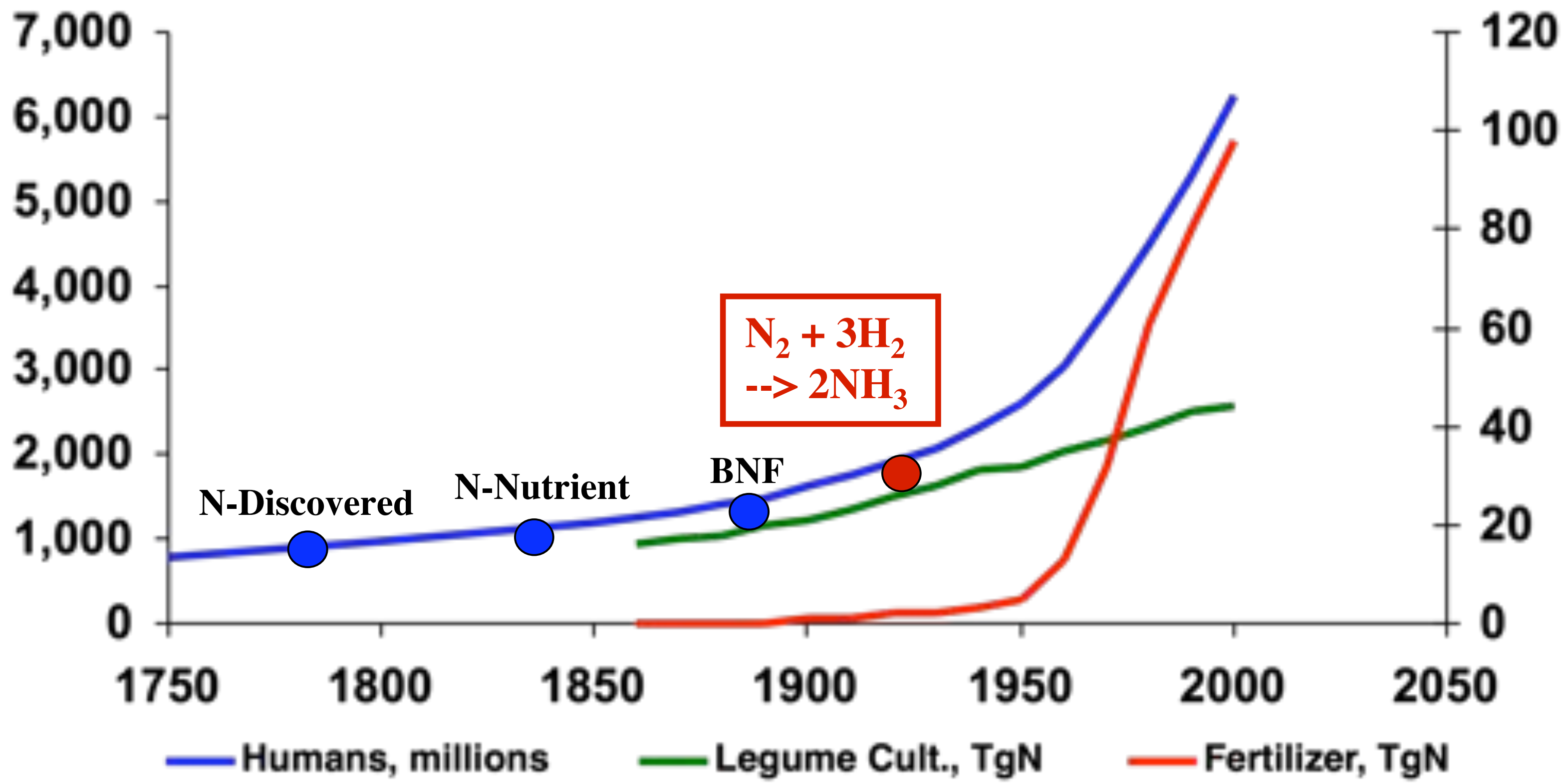


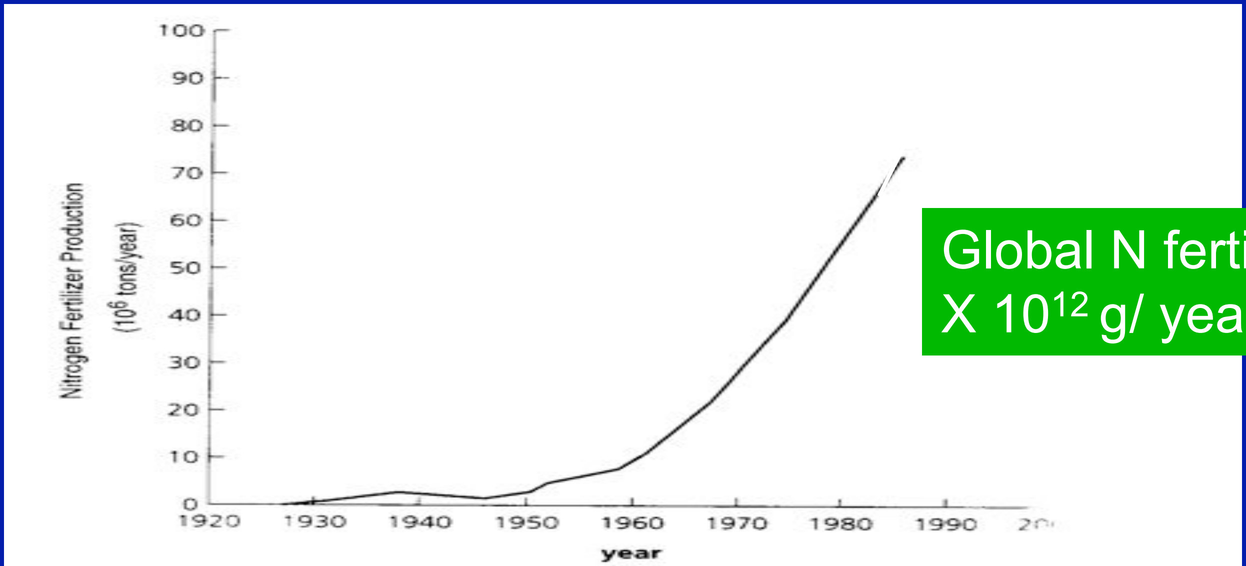
Terrestrial $NO_3$
$N_2$ / $CO_2$
(atm)
Atmos $NO_3$
algae
zoop
$NH_4^+$
"Recycled N"
thermocline
$NO_3^-$ / $CO_2$
(deep)
@ Redfield ratio
POC/$PON_{down}$
$NO_3^-$
$NH_4^+$
0
15
30
[$NO_3^-$, μM]
$\Sigma\ PON_{down} \approx$ uptake $NO_3^- + N_2$
since $CO_2$ / $NO_3^-$ upwell ≈ C/N $POM_{down}$
$POC_{atm\text{-}down}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




# The History of Nitrogen

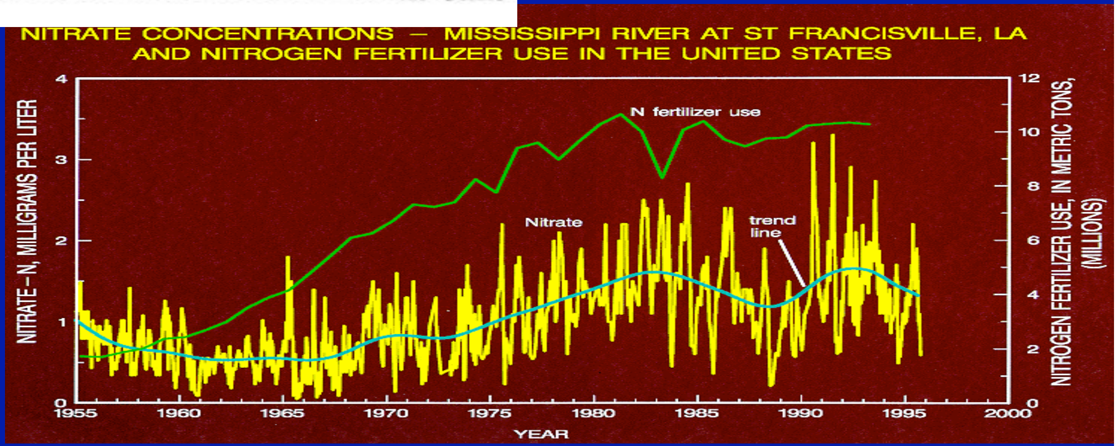
## *--Haber & Bosch!--*

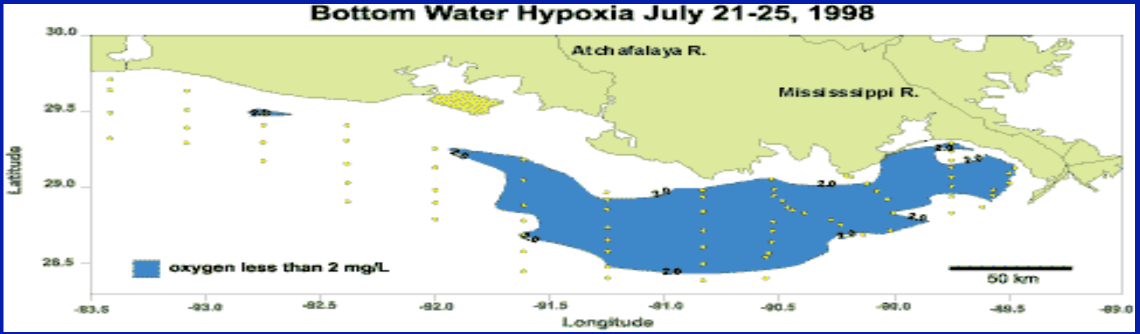





12.4 The global production of nitrogen fertilizer from 1920 to 198… from Smil

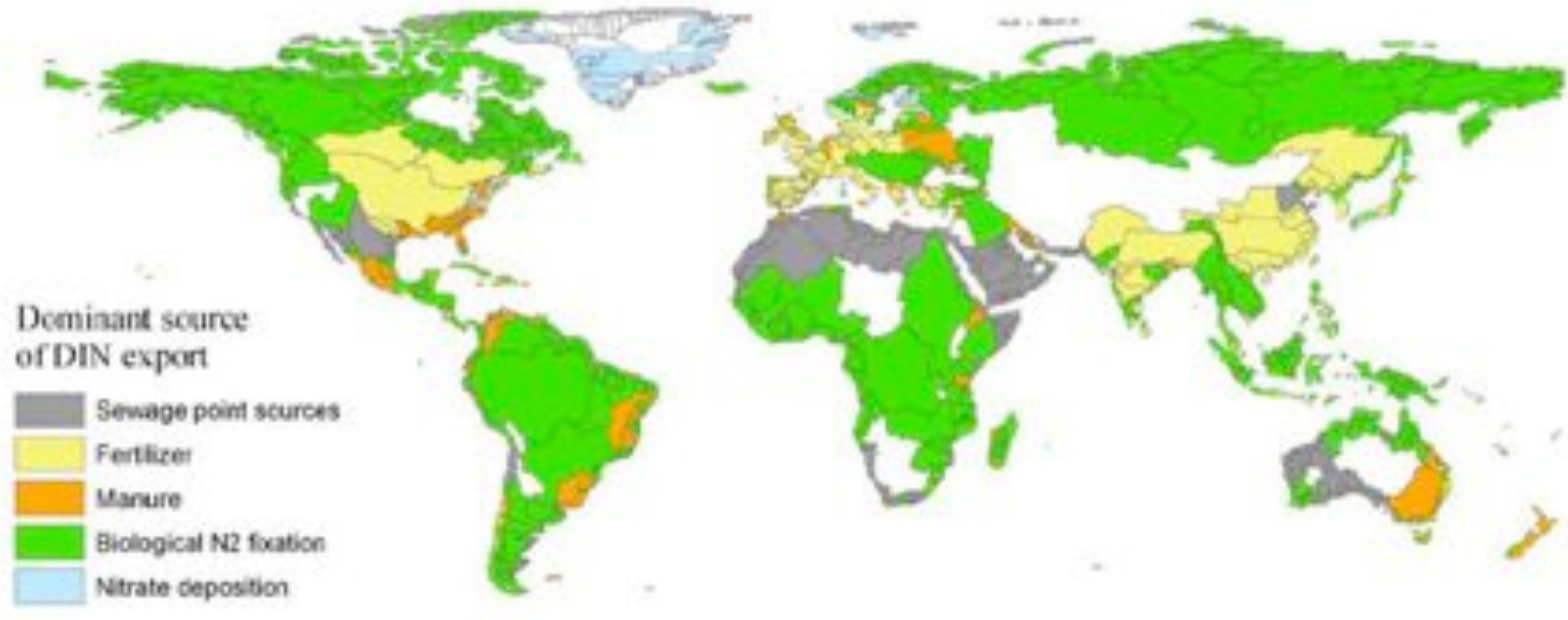
Global N fertilizer use
X $10^{12}$ g/ year



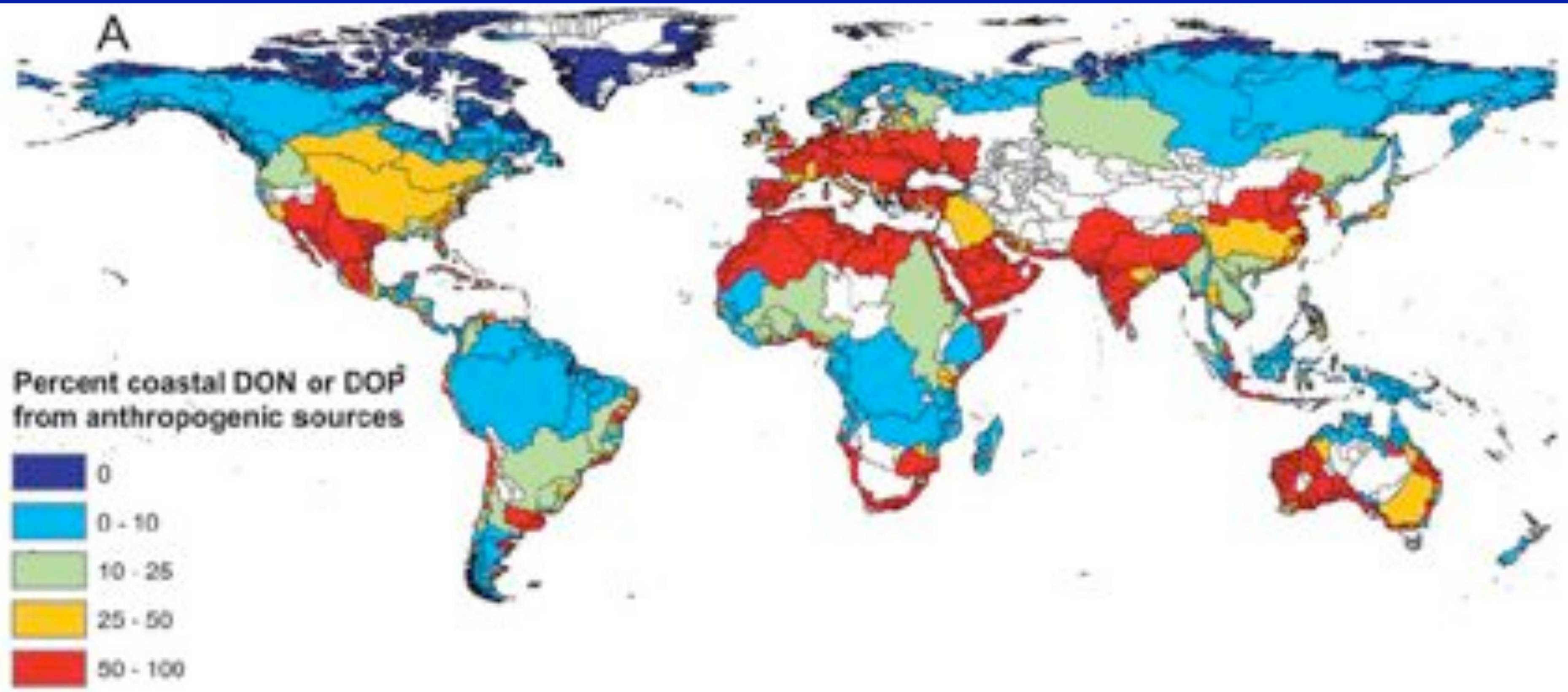

The Mississippi
plume “dead zone”

# NEWS-DIN-predicted dominant sources of DIN export



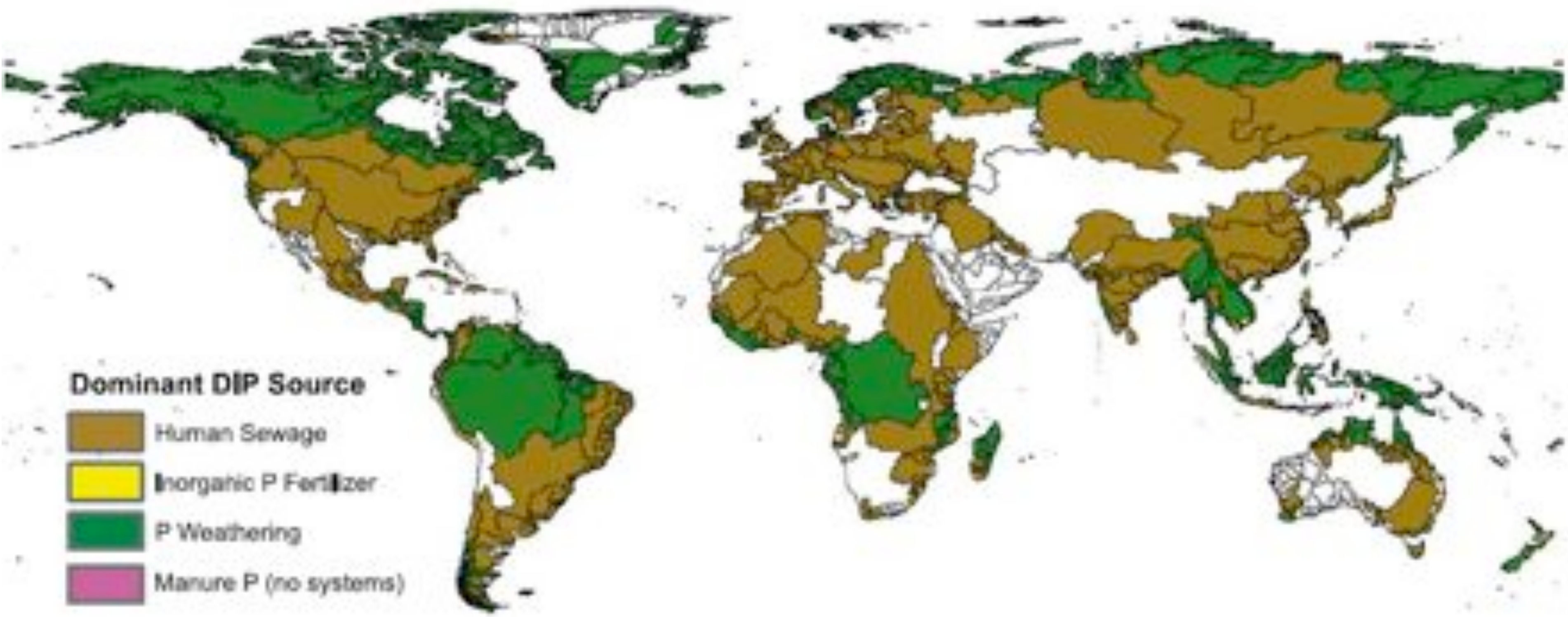

Dumont et al 2005 GBC

# DON/DOP – Percent from Anthropogenic Sources




Harrison et al 2005 GBC

# Dominant sources of DIP




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 | 5 | 7 | | | 90 | | | 8800 |
| Orinoco | 6.2 | | | | | | 90 | | | |
| Zamberi | 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 is not a source of N

**DeMaster and Pope 1996**

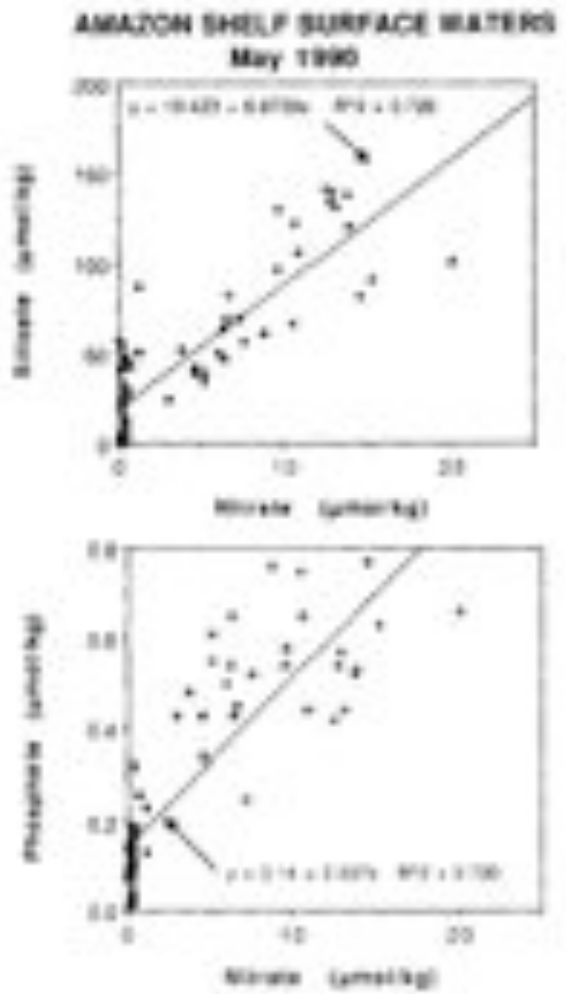
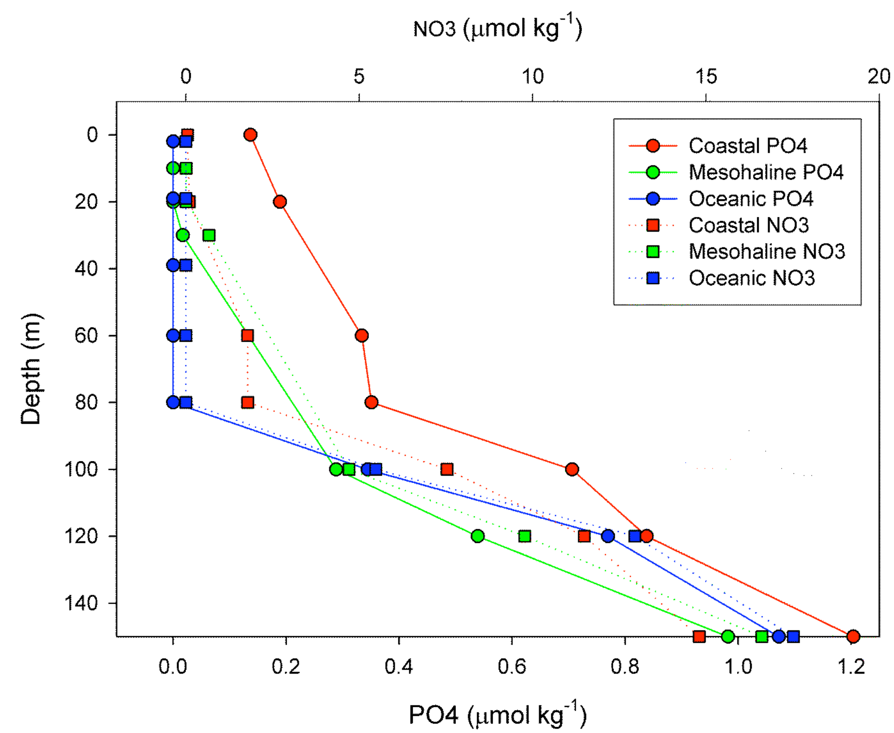



Fig. 7. Phosphate and silicate concentrations in Amazon shelf surface waters plotted as a function of nitrate concentration for AMASSEDS Cruise III (May 1990; high river discharge). In all four of the cruises the phosphate and the silicate intercept(s) at zero nitrate concentration were positive and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



# Source of P/ Si

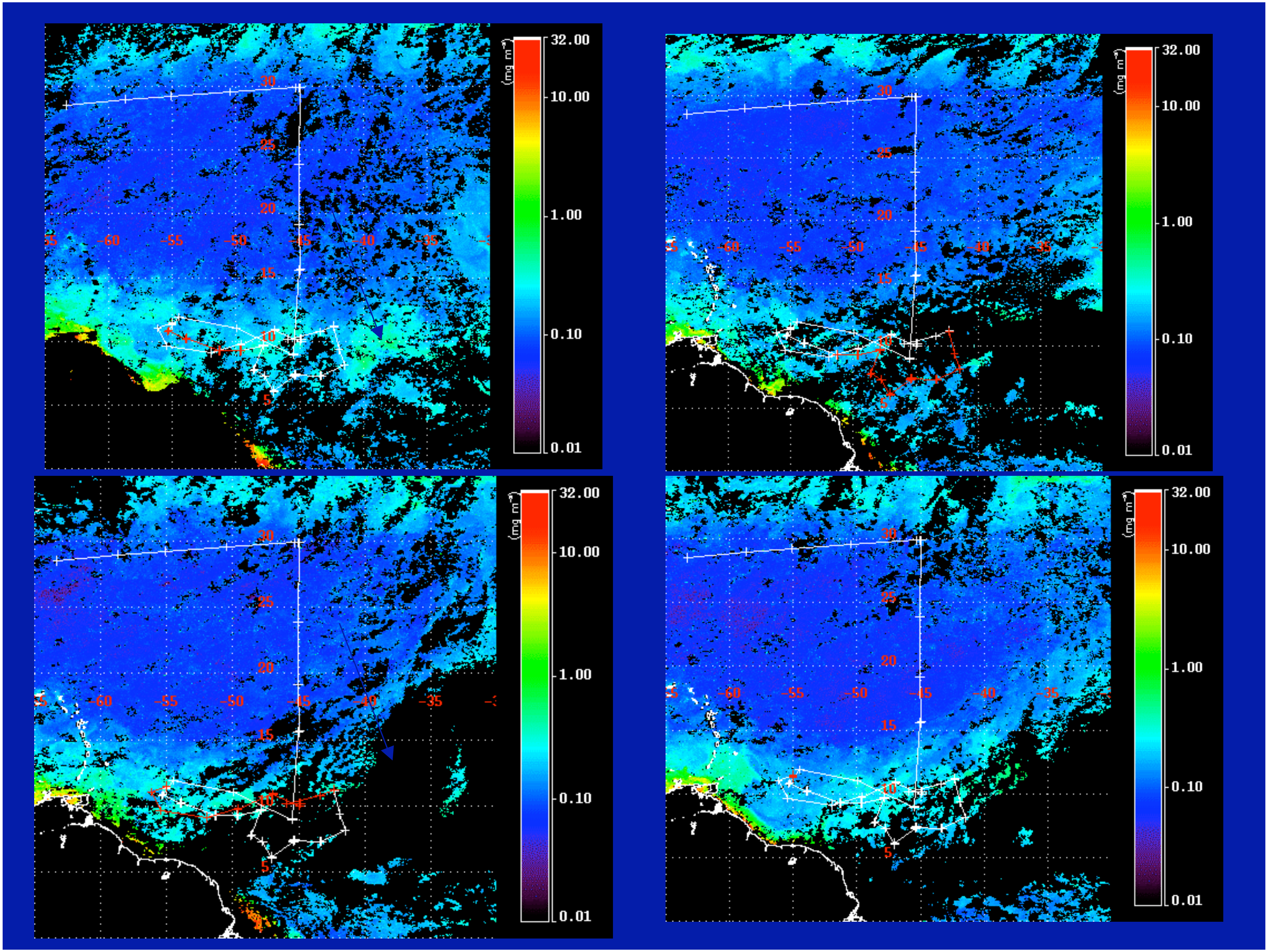
**DeMaster and Aller 2001**

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

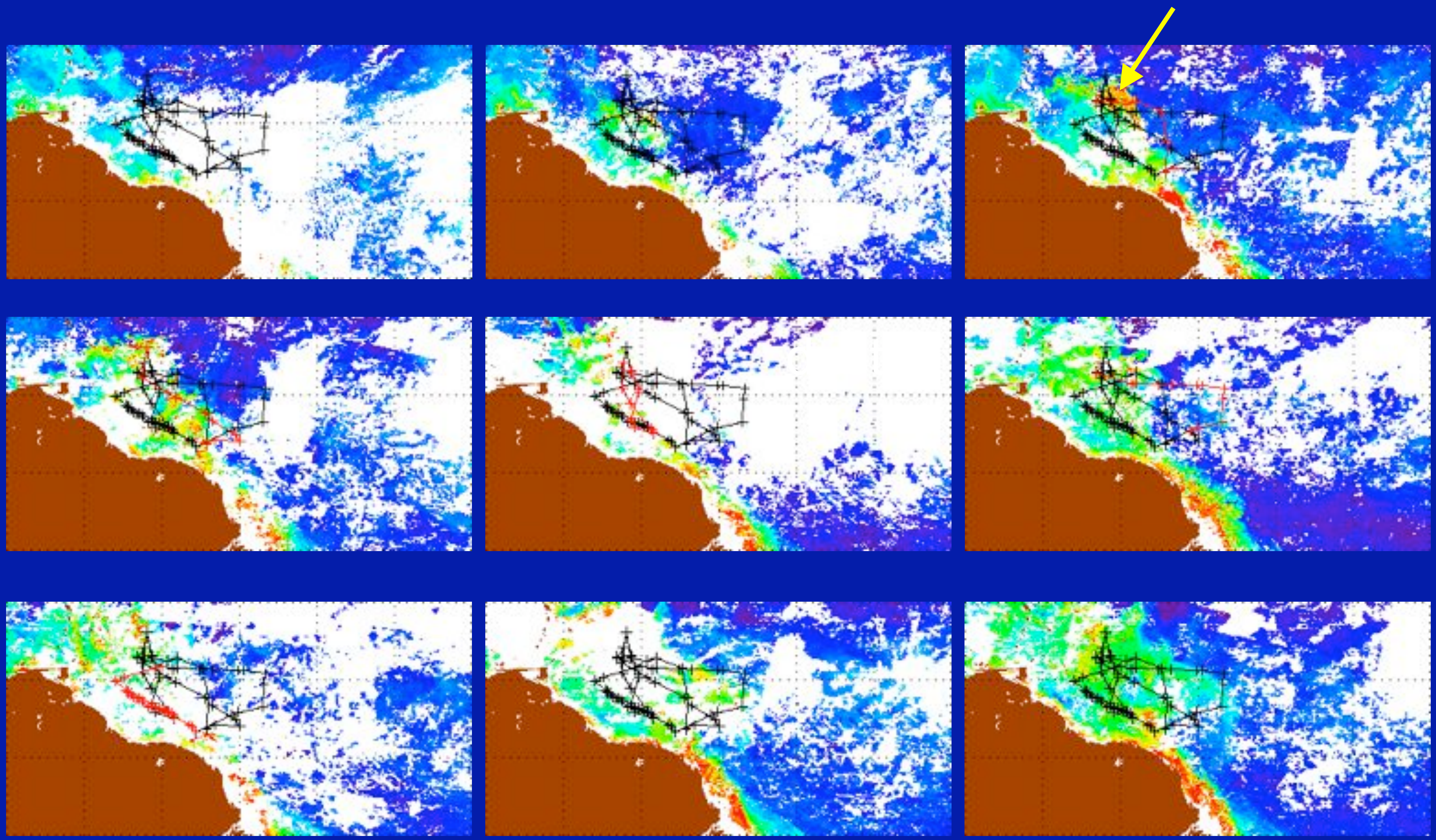
| | External Nutrient Supply* ($\times 10^{8}$ mol $d^{-1}$) | % of Ext. Nutrient Supply to Shelf from Rivers | Gross Production ($\times 10^{8}$ mol $d^{-1}$) | % of Gross Production from Recycling | % of Ext. Nutrient Supply that is Exported Offshore** |
|---|---|---|---|---|---|
| Si | 32 | 60% | 27 | 0% | 91-97% |
| P | 0.7-0.8 | 28% | 1.7 | 50% | 100% |
| N | 10-12 | 20-50% | 27 | 60% | 50% |

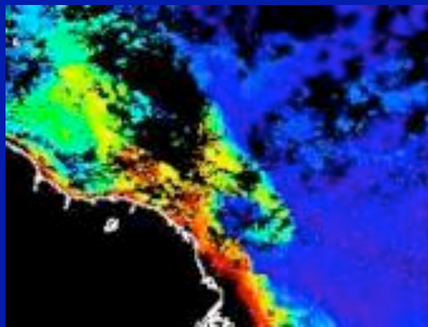
* External nutrient supply is defined as the supply of dissolved nutrient that is biologically available for shelf plankton. The sources of these nutrients are from the river and upwelled offshore waters, nitrogen fixation regenerated terrestrial organic matter, and absorbed material. The flux of P from 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 is 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 bioavailable, dissolved, externally supplied N to the shelf is exported in a form that is useable by marine biota.

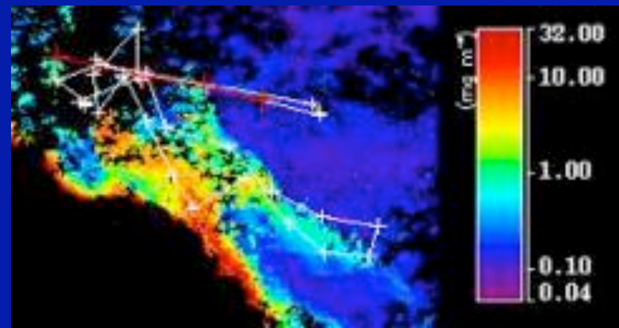

(mg m-3)
32.00
10.00
1.00
0.10
0.01
30
25
20
15
10
5
-60
-55
-50
-45
-40
-35

# 8 Day SeaWiFS Chl Images 30 March – 9 June 2003

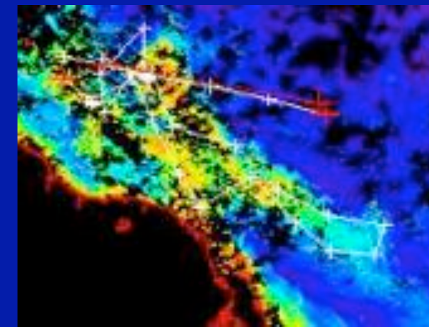




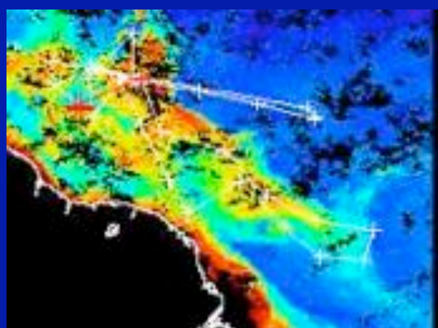
26 June - 3 July 2001



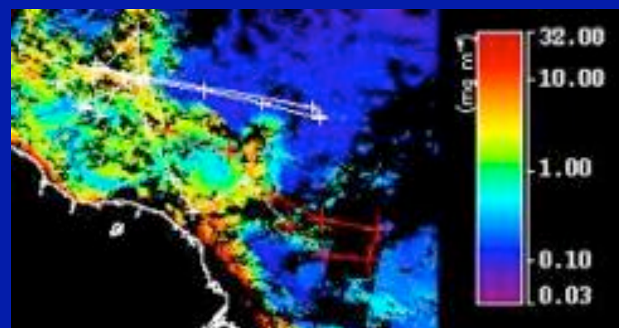

4 July - 12 July 2001



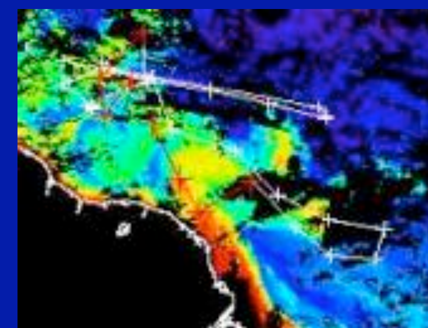
13 July - 19 July 2001



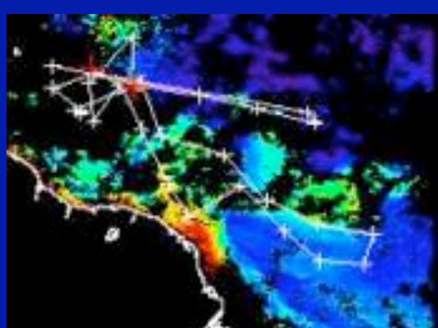
20 July - 27 July 2001



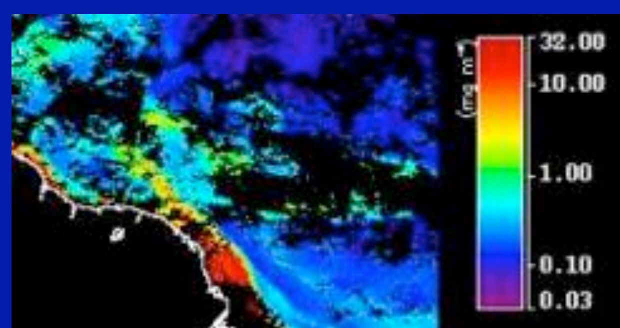

28 July - 4 August 2001



5 August - 12 August 2001

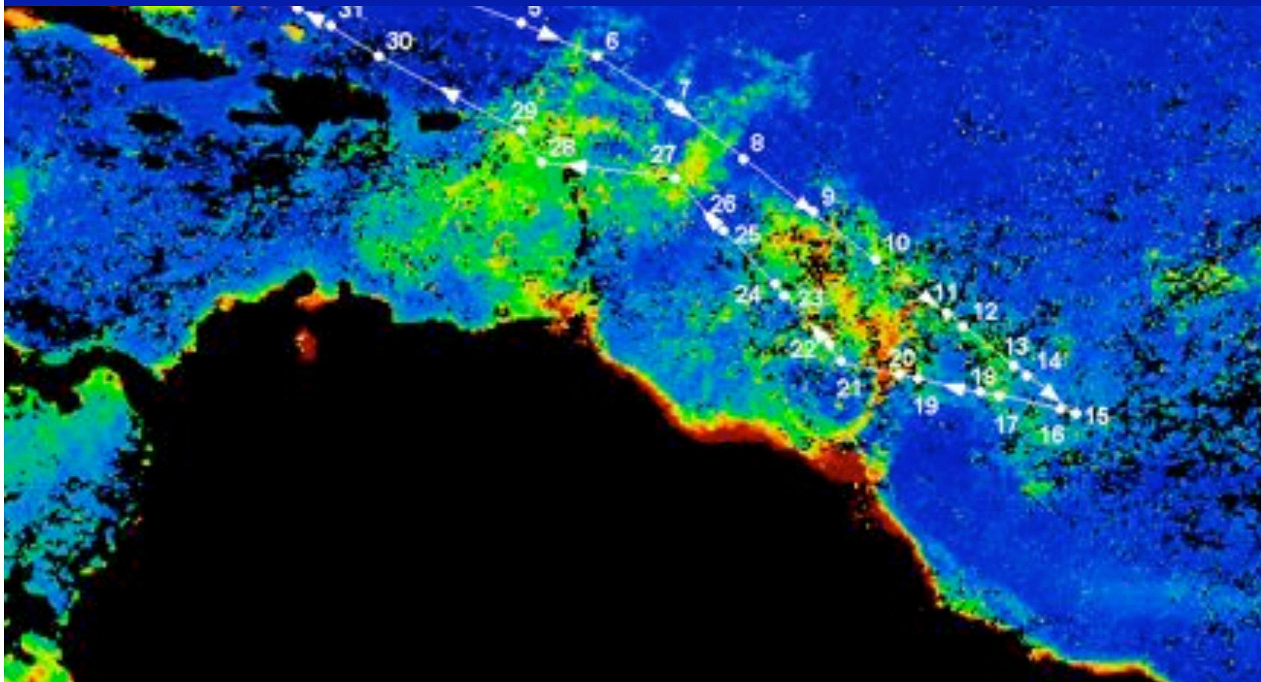


13 August - 20 August 2001




21 August -28 August 2001

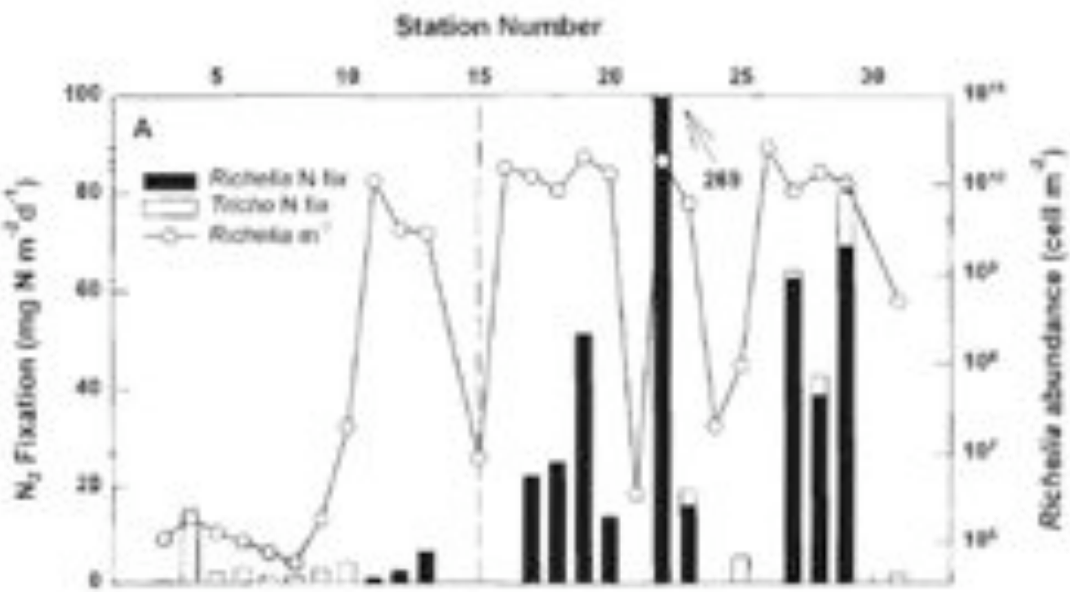
# Oct/Nov 1996

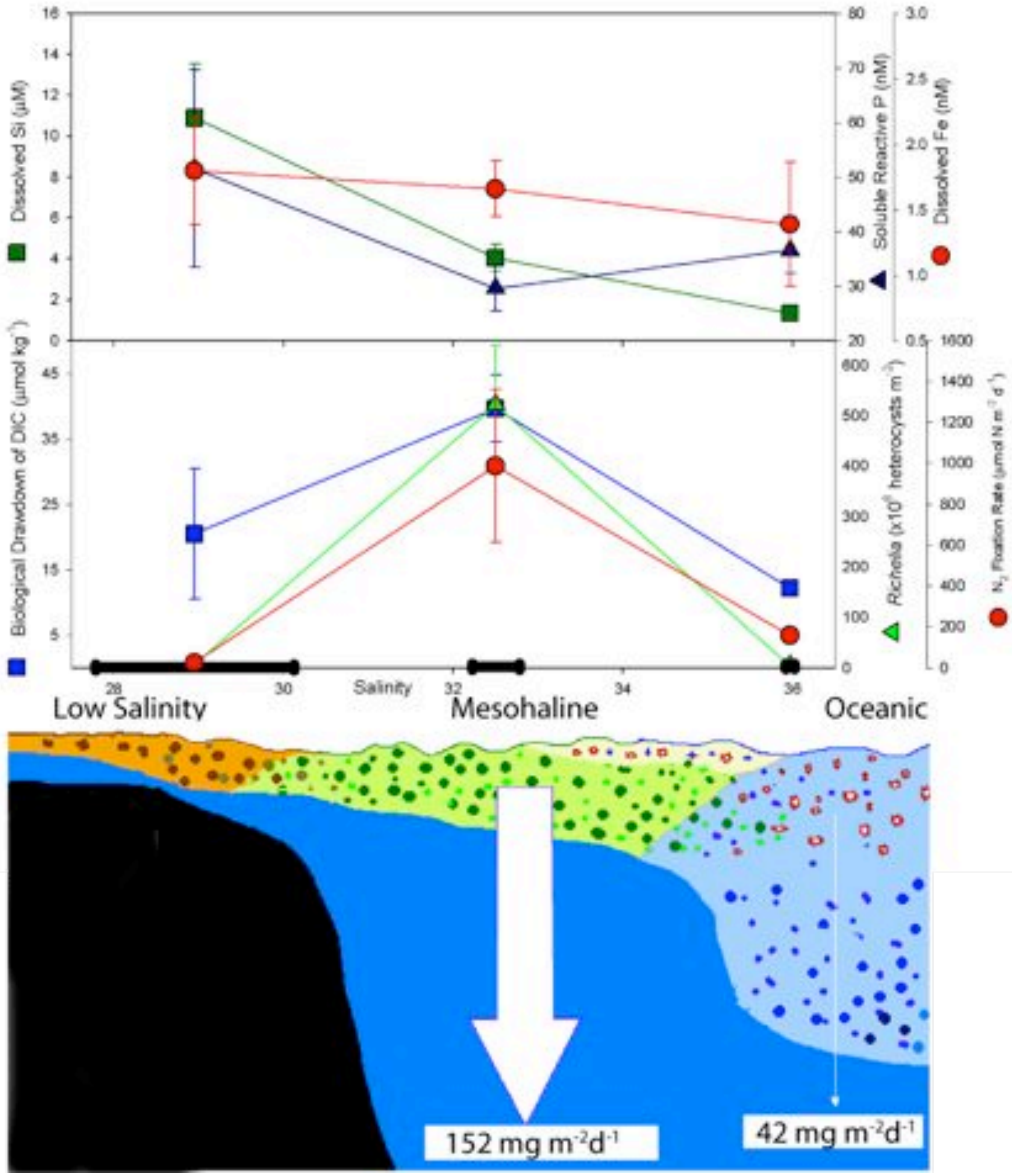


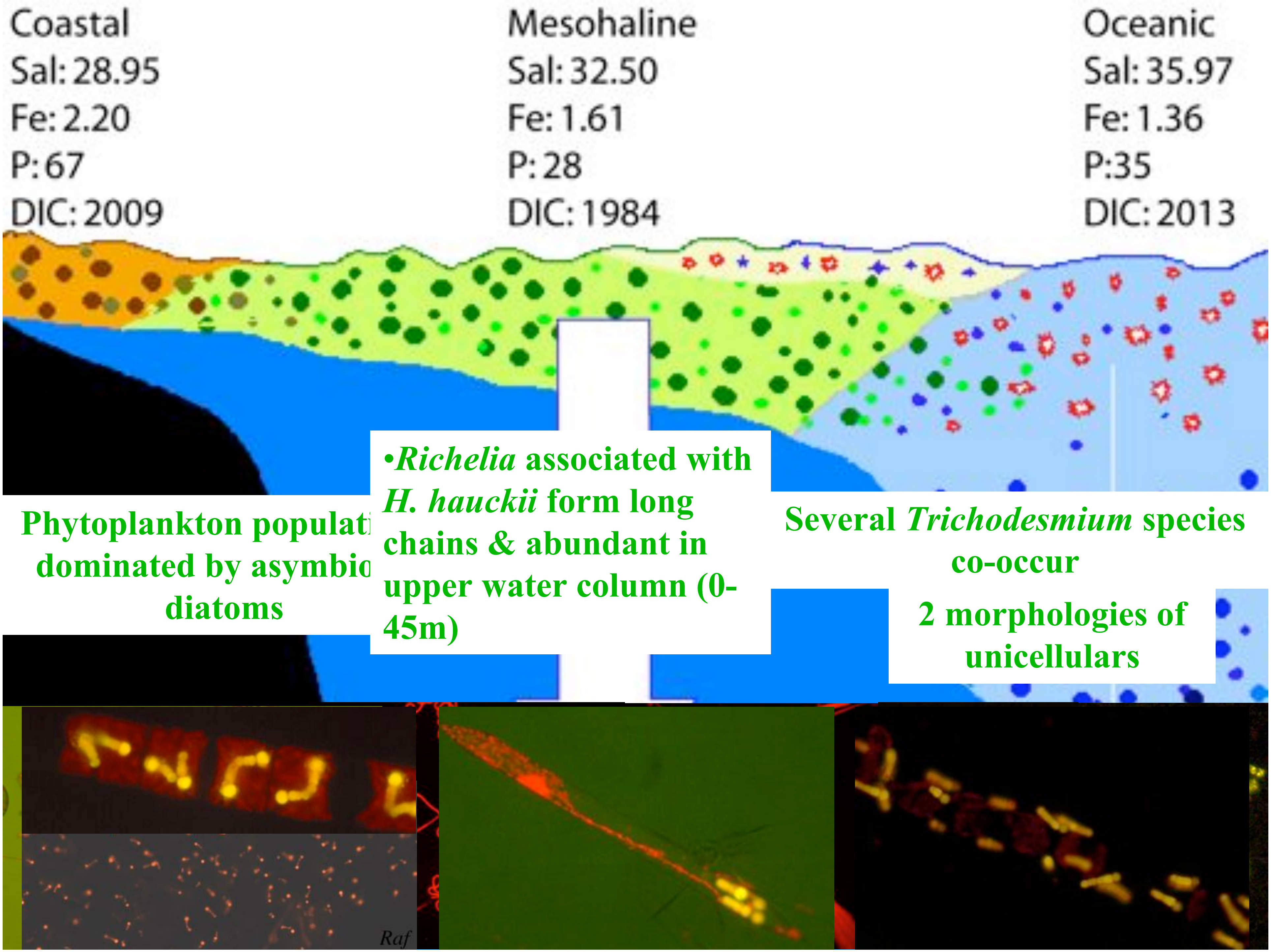

A major bloom of *Hemiaulus/ Richelia* in Oct. 1996 mapped using the OCTS satellite off the coast of South America, was found to extend all the way into the Caribbean and involved the Orinoco Plume as well (Carpenter et al. 1999)

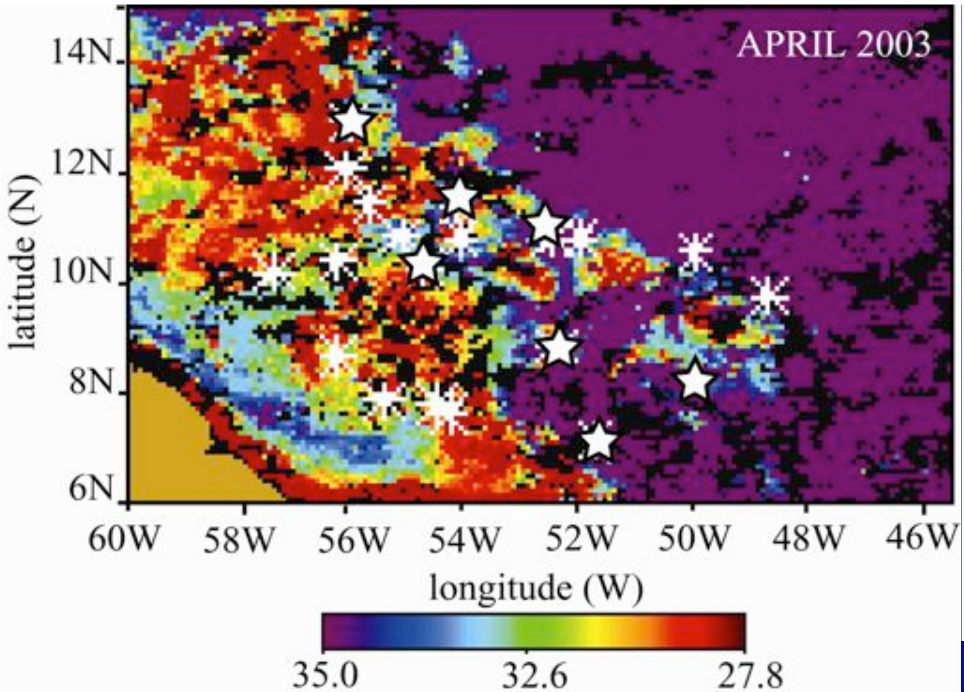
Table 2. Isotopic composition of *Trichodesmium*, concentrated suspensions of *Hemiaulus*, or concentrated suspensions of a mix of the 2 diazotrophs isolated from near-surface net tows

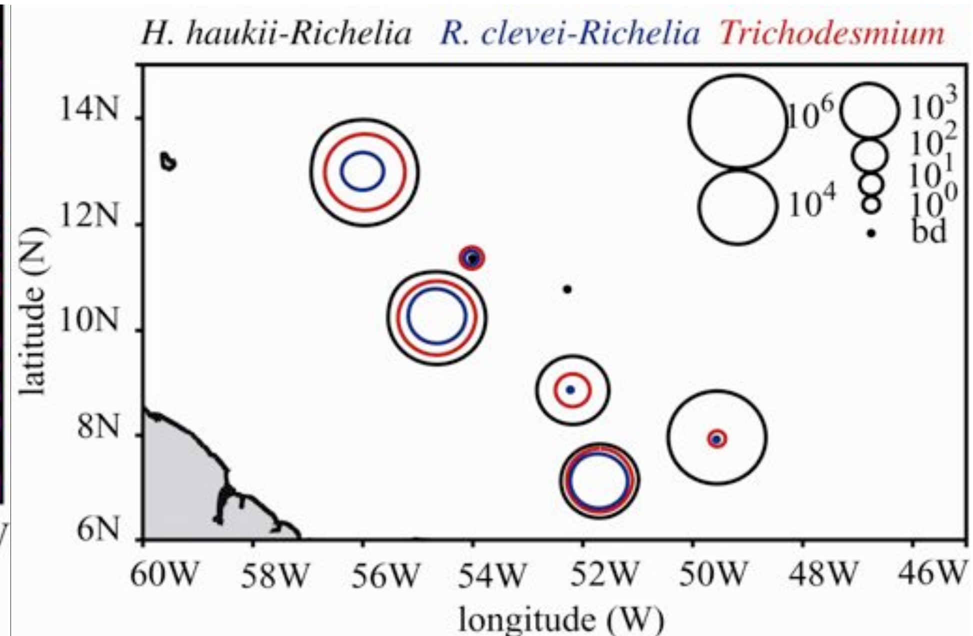
| Sample type | No. of stations sampled | | $\delta^{15}N$ (‰) |
|---|---|---|---|
| *Trichodesmium* (20 colonies) | 13 | Mean | −2.15 |
| | | SE | 0.09 |
| | | n | 36 |
| *Hemiaulus* (100 ml concentrated suspension) | 4 | Mean | −1.24 |
| | | SE | 0.25 |
| | | n | 12 |
| *Trichodesmium* & *Hemiaulus* 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 |



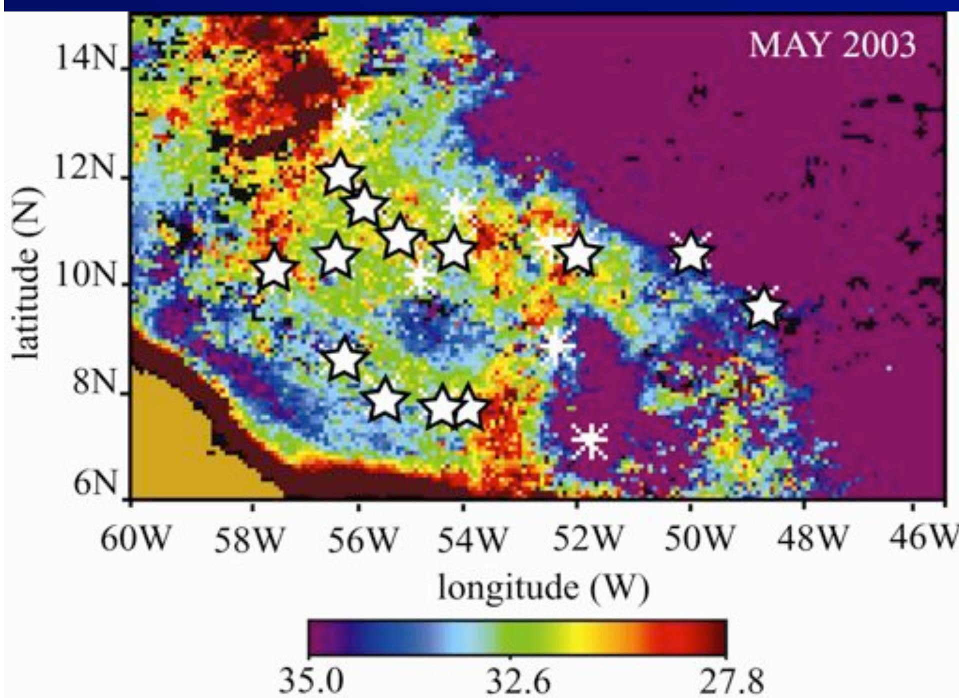

Dissolved Si (μM)
Soluble Reactive P (nM)
Dissolved Fe (nM)
Biological Drawdown of DIC (μmol kg$^{-1}$)
Salinity
Low Salinity
Mesohaline
Oceanic
152 mg m$^{-2}$d$^{-1}$
42 mg m$^{-2}$d$^{-1}$

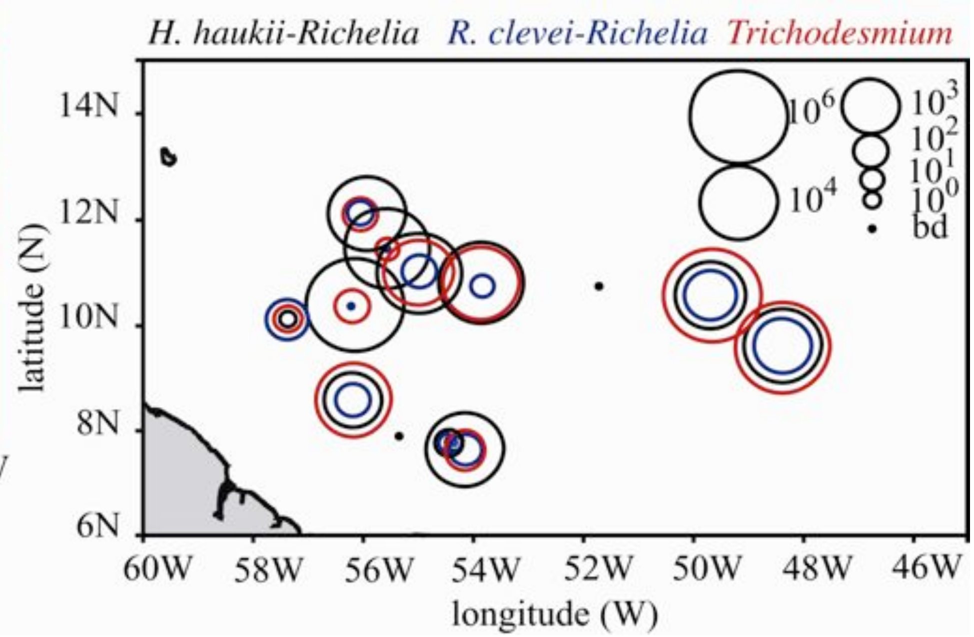

Coastal
Sal: 28.95
Fe: 2.20
P: 67
DIC: 2009
Mesohaline
Sal: 32.50
Fe: 1.61
P: 28
DIC: 1984
Oceanic
Sal: 35.97
Fe: 1.36
P:35
DIC: 2013
Phytoplankton populati
dominated by asymbio
diatoms
•*Richelia* associated with *H. hauckii* form long chains & abundant in upper water column (0-45m)
Several *Trichodesmium* species co-occur
2 morphologies of unicellulars
Raf

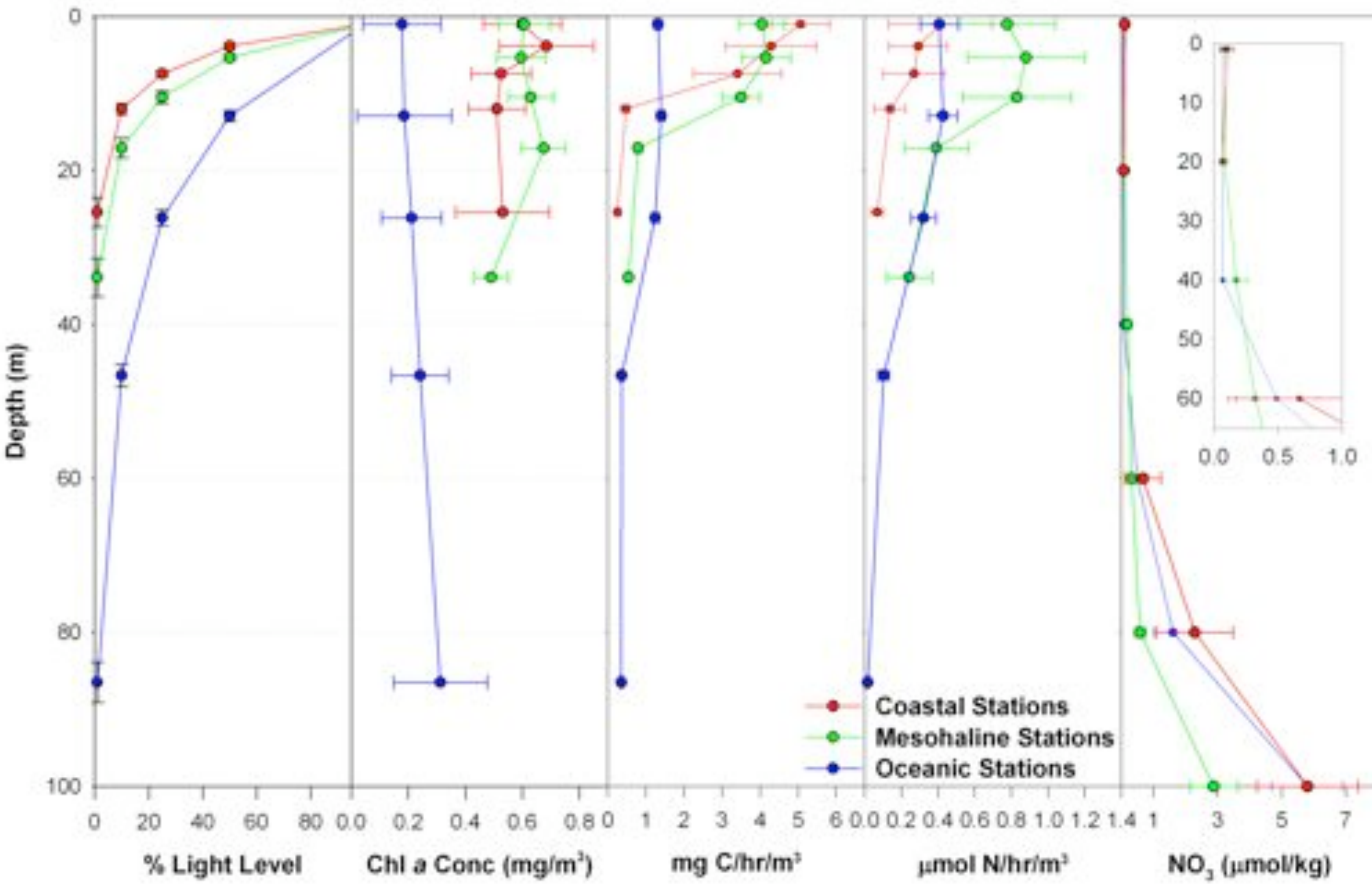



**Foster et al., (2007) *L & O.***





Depth (m)
% Light Level
Chl a Conc (mg/m³)
mg C/hr/m³
µmol N/hr/m³
NO₃ (µmol/kg)
Coastal Stations
Mesohaline Stations
Oceanic Stations

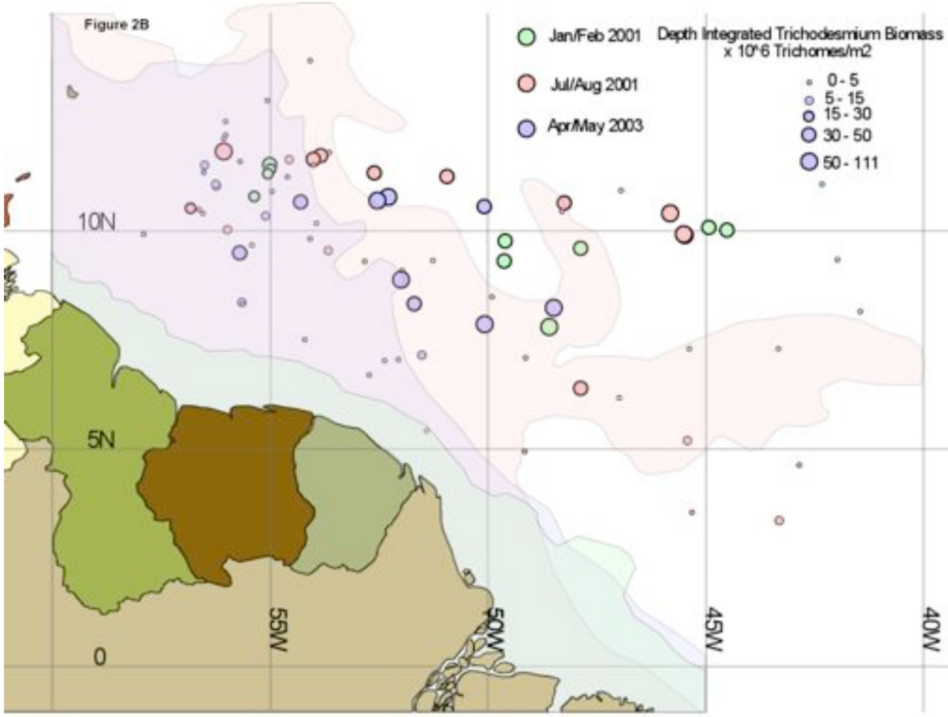


Figure 2B
Jan/Feb 2001
Jul/Aug 2001
Apr/May 2003
Depth Integrated Trichodesmium Biomass
x 10^6 Trichomes/m2
0 - 5
5 - 15
15 - 30
30 - 50
50 - 111
10N
5N
0
55W
50W
45W
40W

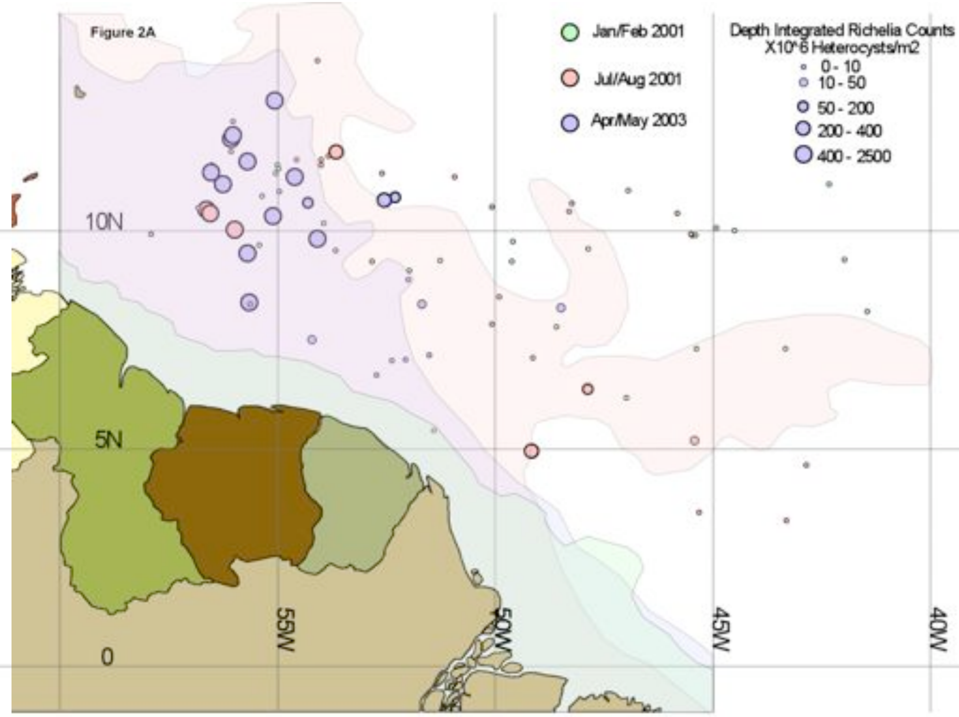
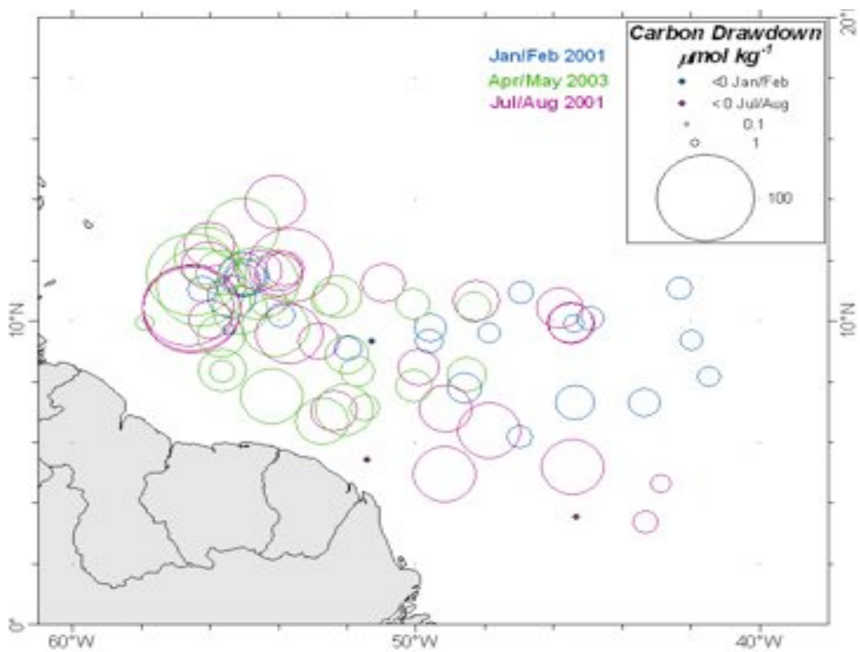
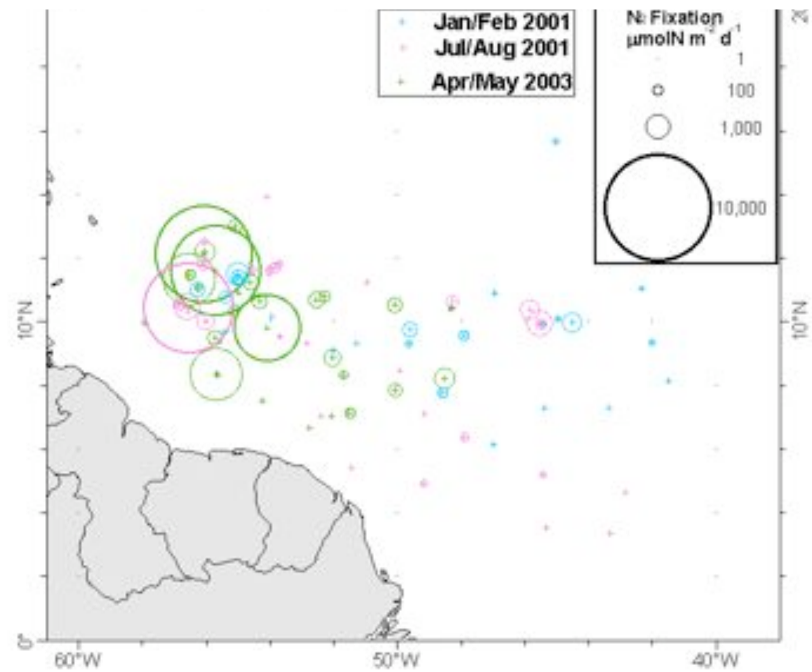


Figure 2A
Jan/Feb 2001
Jul/Aug 2001
Apr/May 2003
Depth Integrated Richelia Counts
X10^6 Heterocysts/m2
0 - 10
10 - 50
50 - 200
200 - 400
400 - 2500
10N
5N
0
55W
50W
45W
40W


Carbon Drawdown
μmol kg-1
Jan/Feb 2001
Apr/May 2003
Jul/Aug 2001
<0 Jan/Feb
< 0 Jul/Aug
0.1
1
100
10°N
0°
60°W
50°W
40°W


Jan/Feb 2001
Jul/Aug 2001
Apr/May 2003
N2 Fixation
μmolN m-2 d-1
1
100
1,000
10,000
10°N
0°
60°W
50°W
40°W

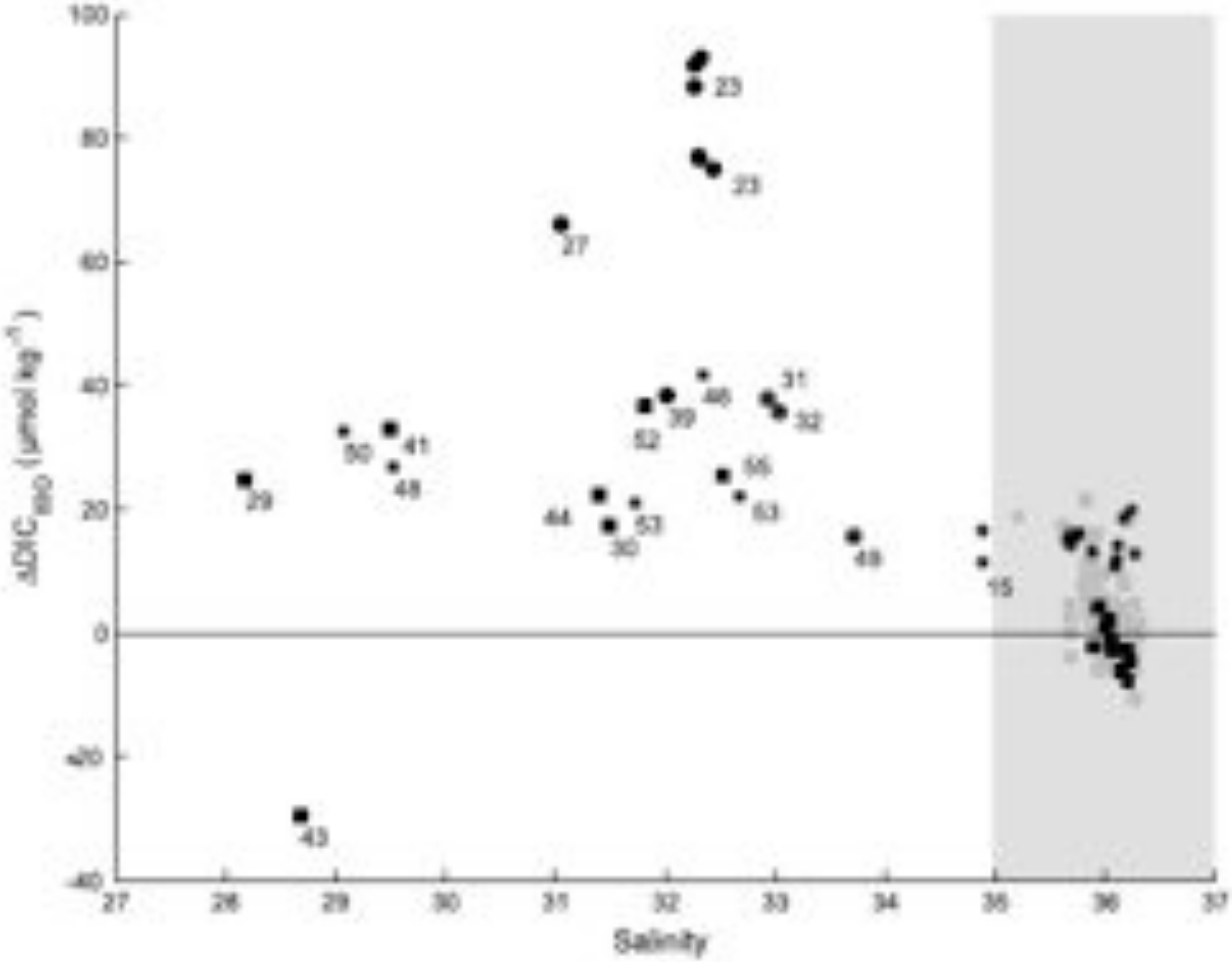



Figure 6. Community impact on DIC ($\Delta DIC_{BIO}$), calculated with the mixing model, plotted against salinity. The 95% confidence interval error bars are within the size of the marker. Station numbers are shown for summer samples. Endmembers used to calculate $\Delta DIC_{BIO}$ included: $A_s = 2359.4 \pm 5.9$, $S_s = 36.07 \pm 0.10$, $DIC_s = 2024.5 \pm 6.8$, $S_r = 0 \pm 0$. 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.

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.

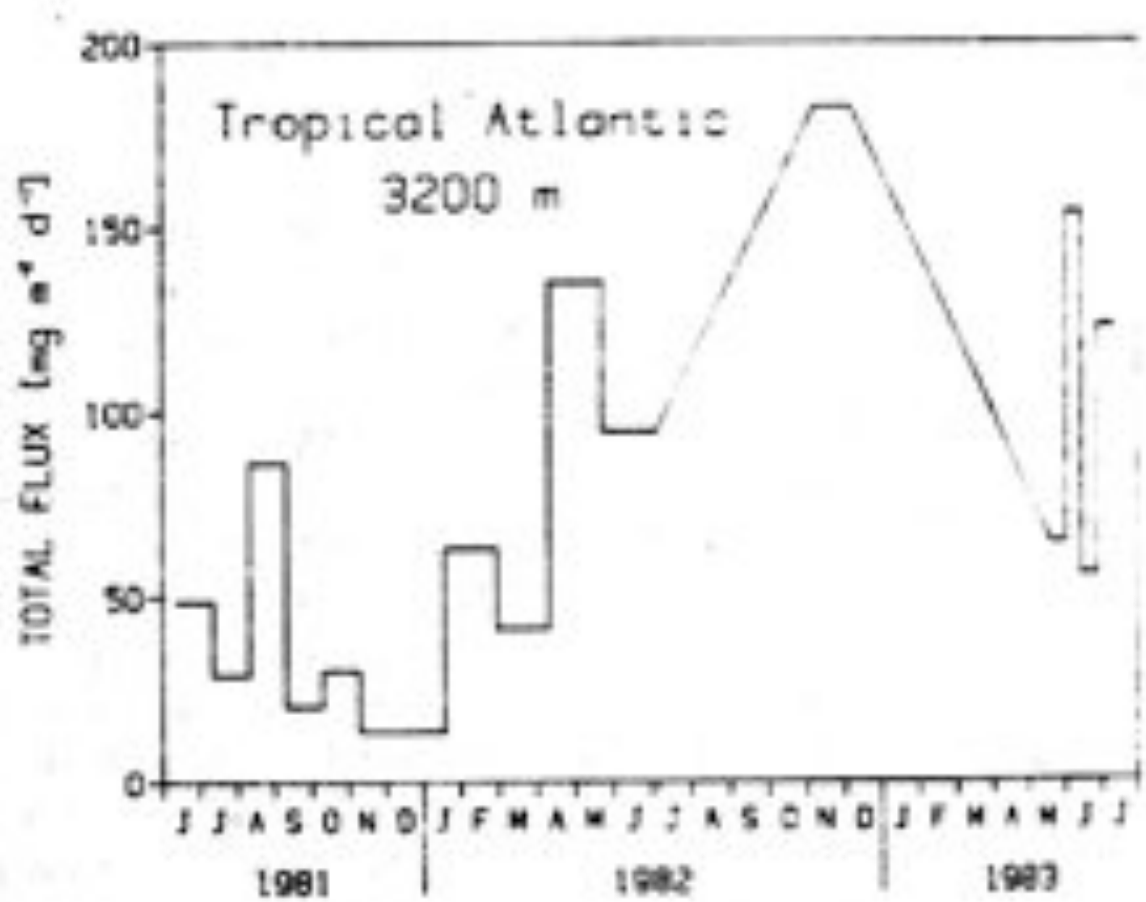
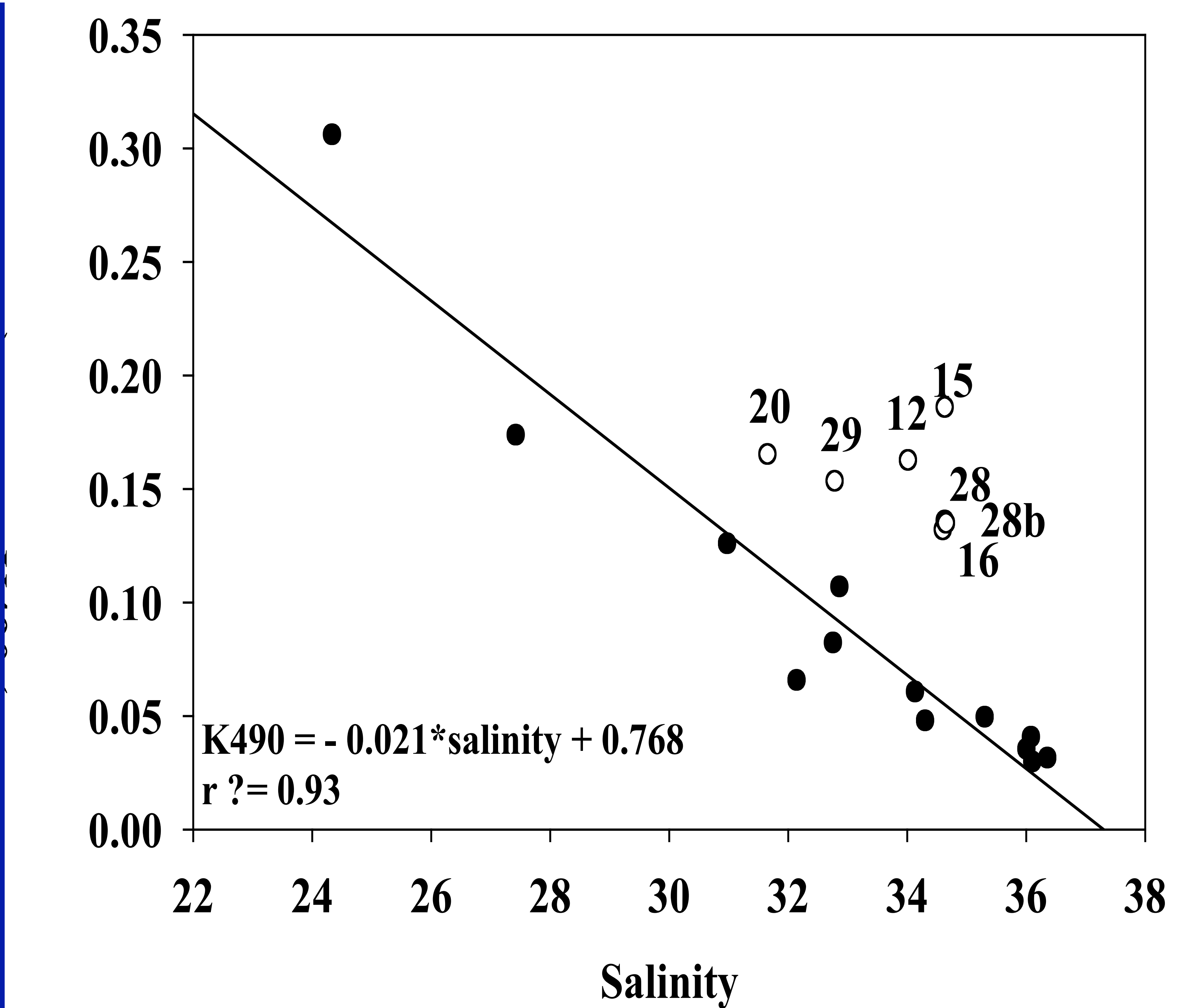
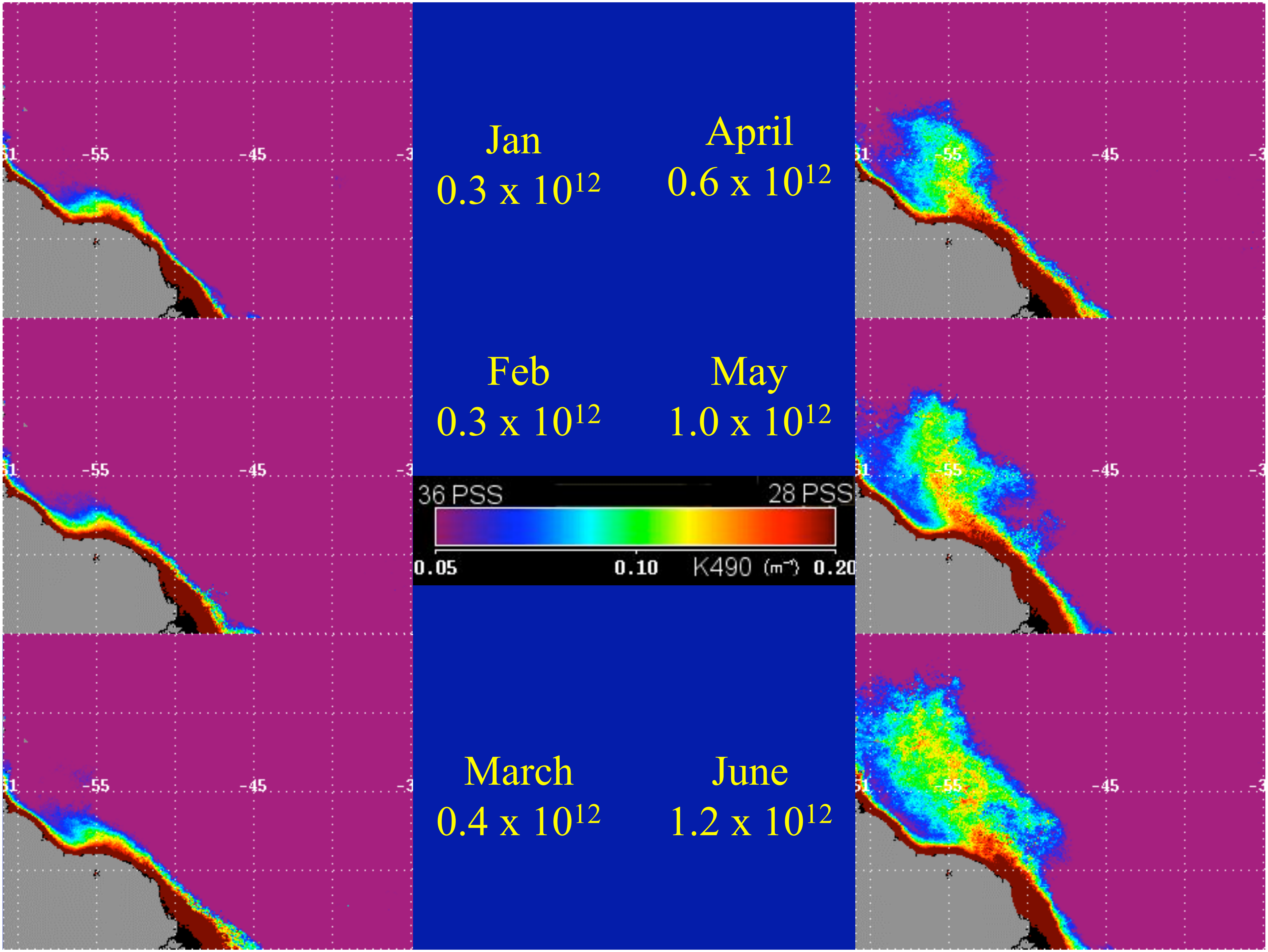
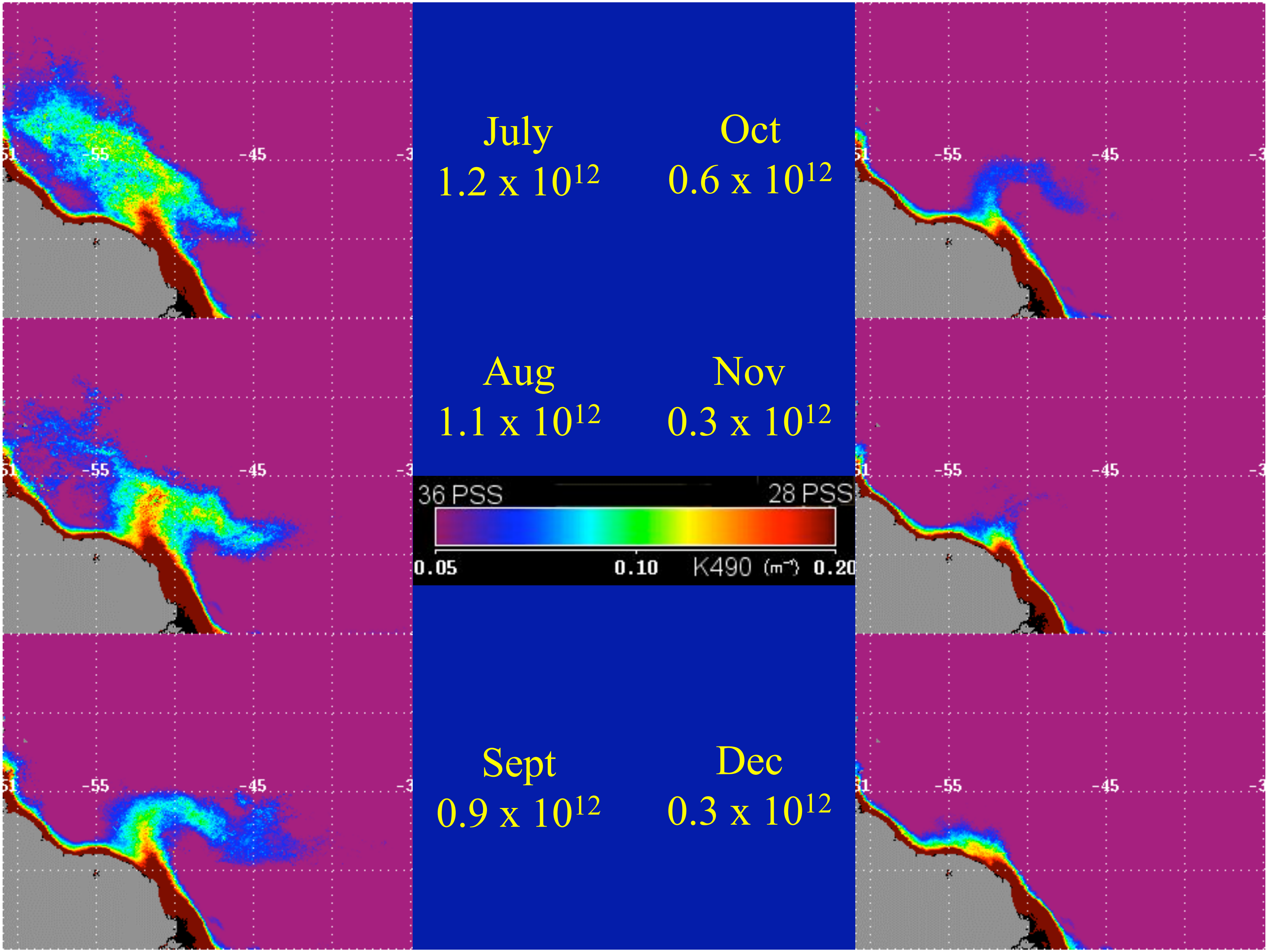



Fig. 2. Variations of total particle flux at a depth of 3200 m in the western tropical North Atlantic. Notation is as in Figure 1. The two gaps in the record (sloping lines) amount to 38% of the time between start and end of the series.


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



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

| | | | |
|---|---|---|---|
| Area | 0-20N | 35-61W | K490 = -0.0206*Salinity+0.7684 |
| K490 | 0.05-0.2 m-1 | | from Del Vecchio & Subramaniam (2004) |
| Salinity | 35 - 28 PSS | | |
| Total Area | 5509053 | | Total Flux per month |

| Month | Km2 | m2 | 150 mg/m2/d | 186 umol/m2/d |
|---|---|---|---|---|
| January | 335016 | 3.4E+11 | 1.6E+12 | 1.9E+09 |
| February | 317601 | 3.2E+11 | 1.3E+12 | 1.7E+09 |
| March | 372357 | 3.7E+11 | 1.7E+12 | 2.1E+09 |
| April | 634959 | 6.3E+11 | 2.9E+12 | 3.5E+09 |
| May | 957582 | 9.6E+11 | 4.5E+12 | 5.5E+09 |
| June | 1164051 | 1.2E+12 | 5.2E+12 | 6.5E+09 |
| July | 1181385 | 1.2E+12 | 5.5E+12 | 6.8E+09 |
| August | 1141371 | 1.1E+12 | 5.3E+12 | 6.6E+09 |
| September | 880389 | 8.8E+11 | 4.0E+12 | 4.9E+09 |
| October | 545130 | 5.5E+11 | 2.5E+12 | 3.1E+09 |
| November | 332343 | 3.3E+11 | 1.5E+12 | 1.9E+09 |
| December | 305208 | 3.1E+11 | 1.4E+12 | 1.8E+09 |

| | | |
|---|---|---|
| | Total Annual Flux (g/yr) | 3.7E+13 |
| Assuming | 40% Organic C (Tg C/yr) | 15 |
| Assuming | 40% Organic C (mol C/yr) | 2.E+10 |

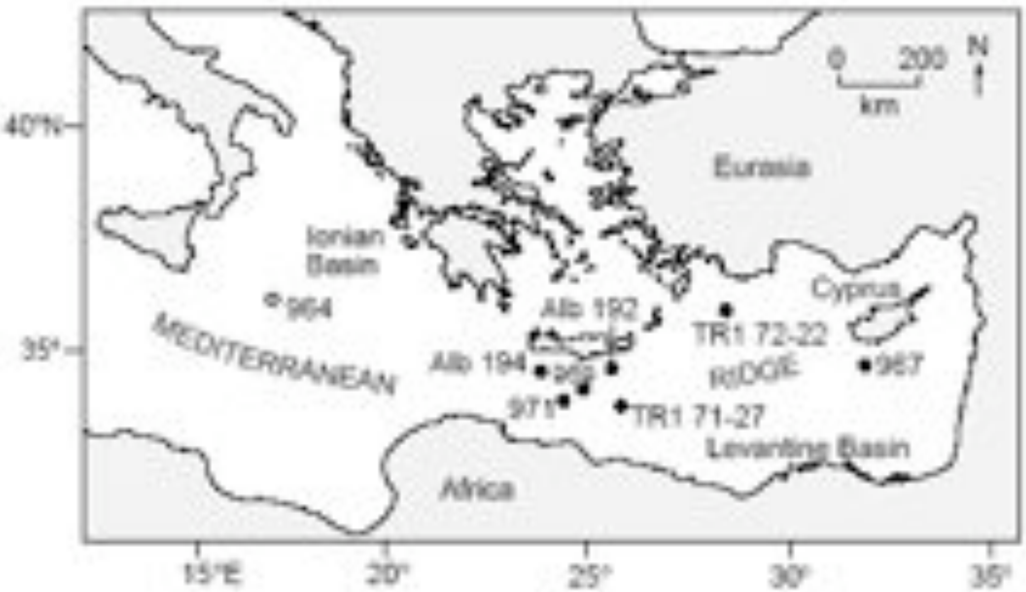
Organic Carbon makes up 5-40% of Total Flux i.e. 5-40% of 150 $mg/m^2/d$ = 7.5-60 $mg/m^2/d$. Over the area of the *Richelia* habitat, this could be as much as 15 Tg C $y^{-1}$

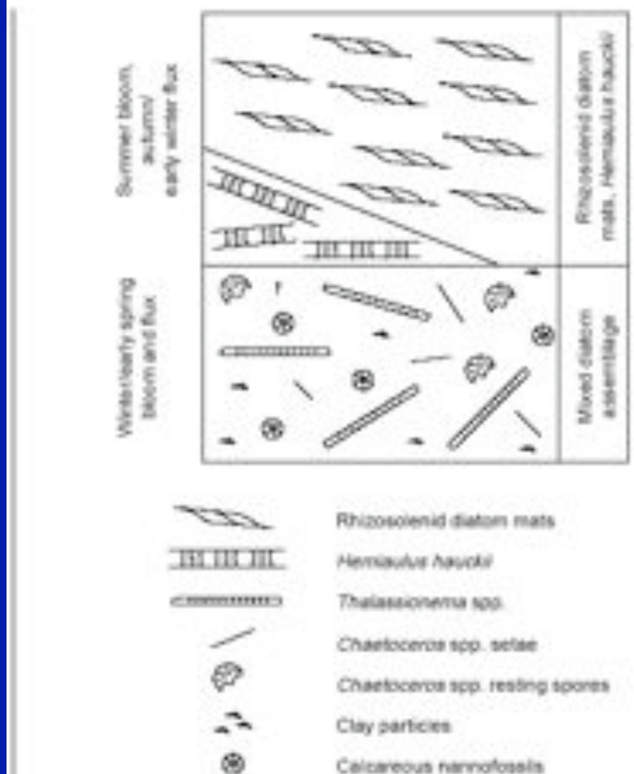
Using N fixation rates, we calculate new carbon fixed in the plume to be 15 - 20 Tg C $y^{-1}$

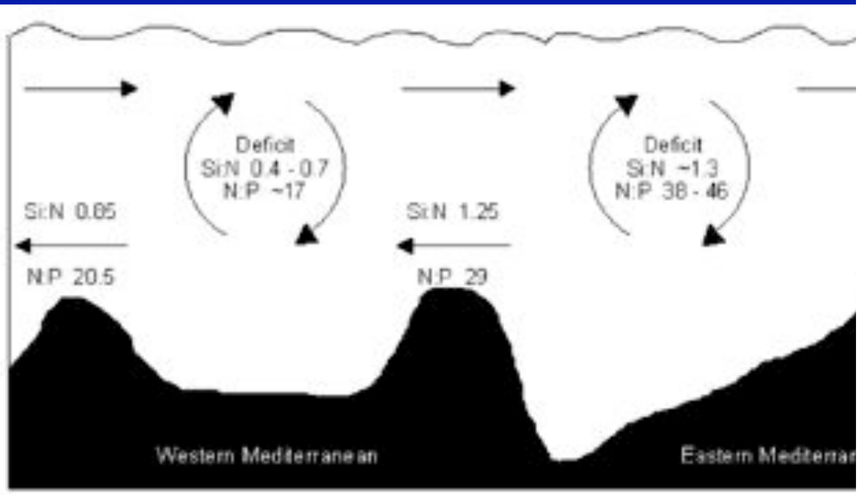
# The role of mat-forming diatoms in the formation of Mediterranean sapropels

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

letters to nature

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

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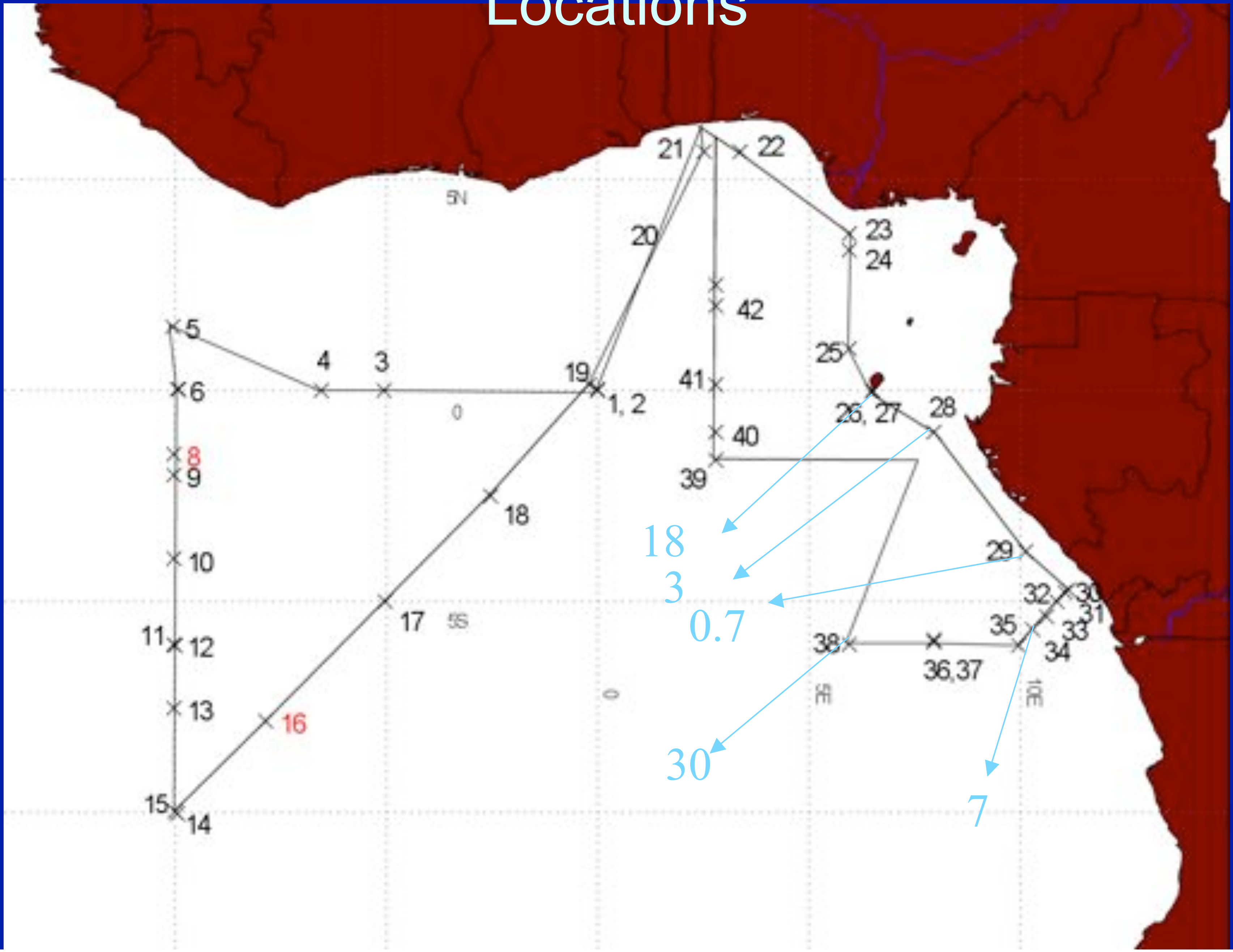
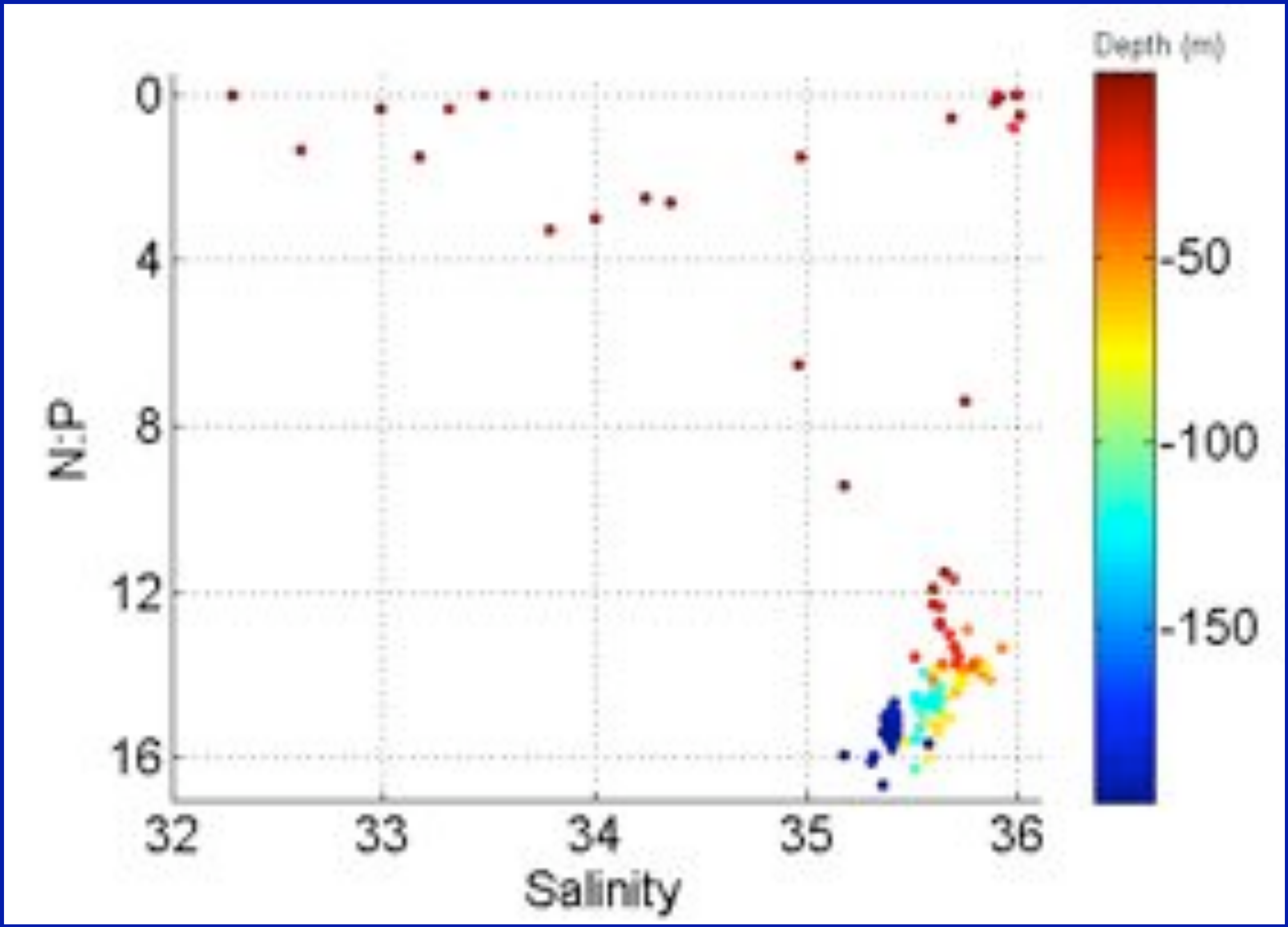
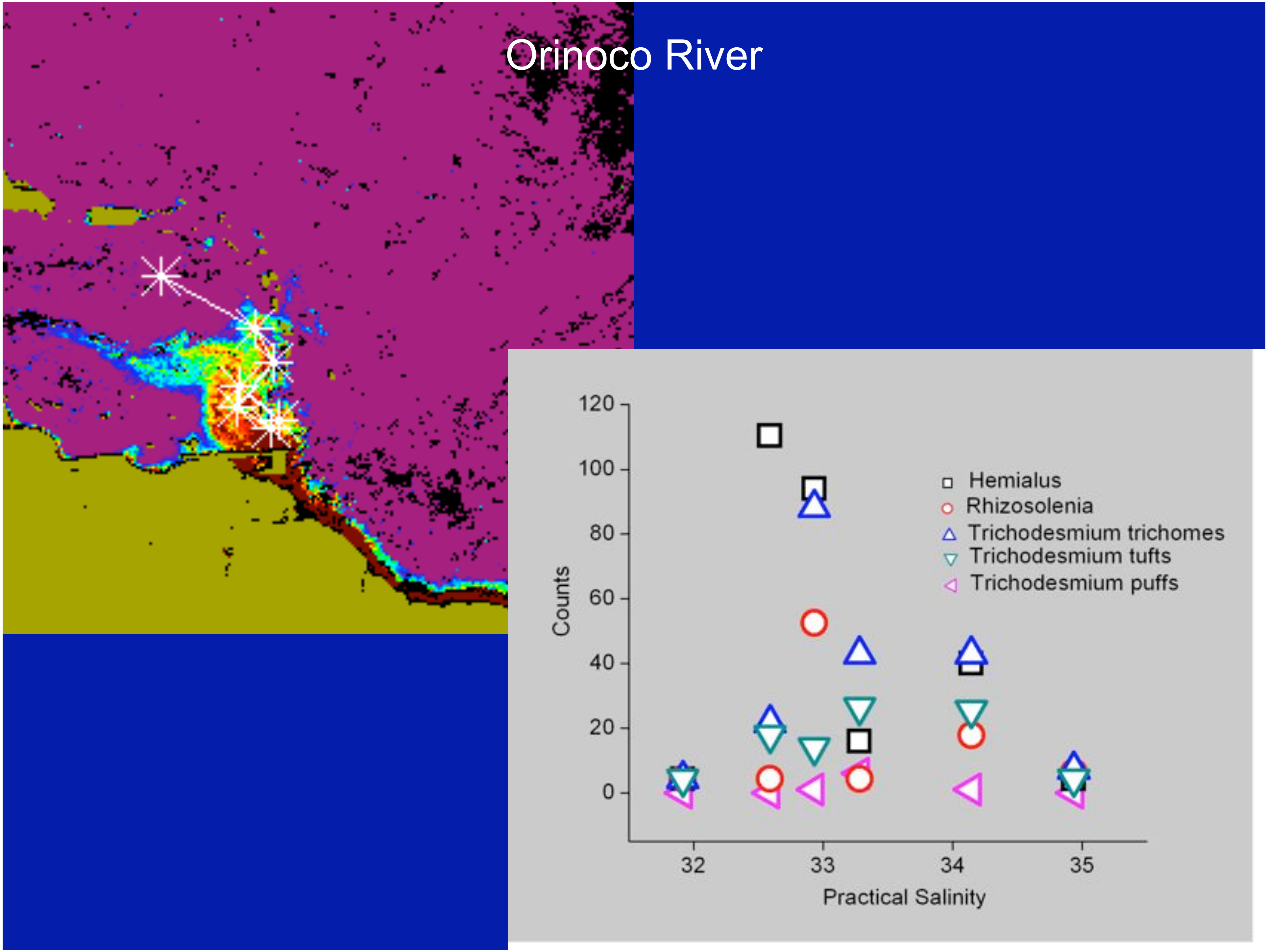
# Optical and Biogeochemical Station Locations

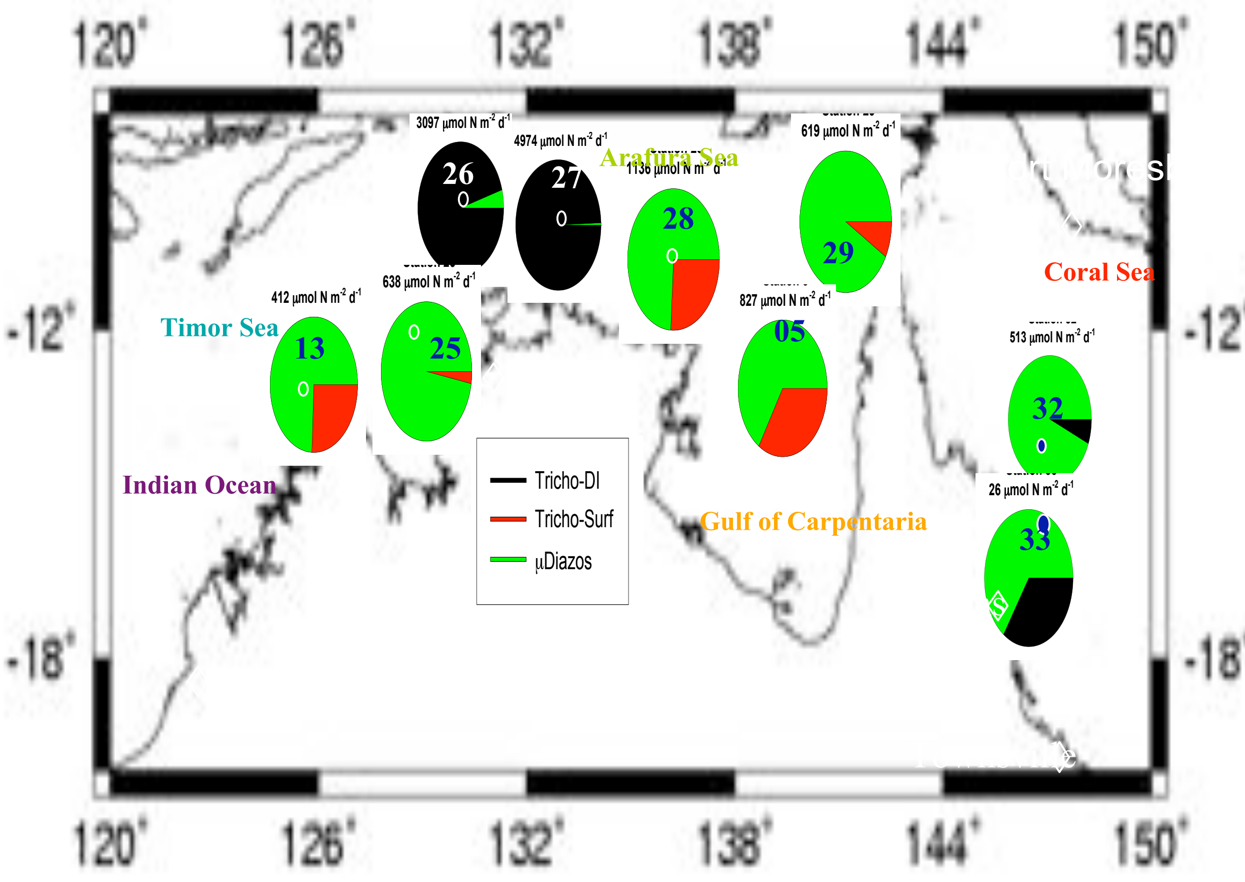



# N:P Ratio for stations 30-35

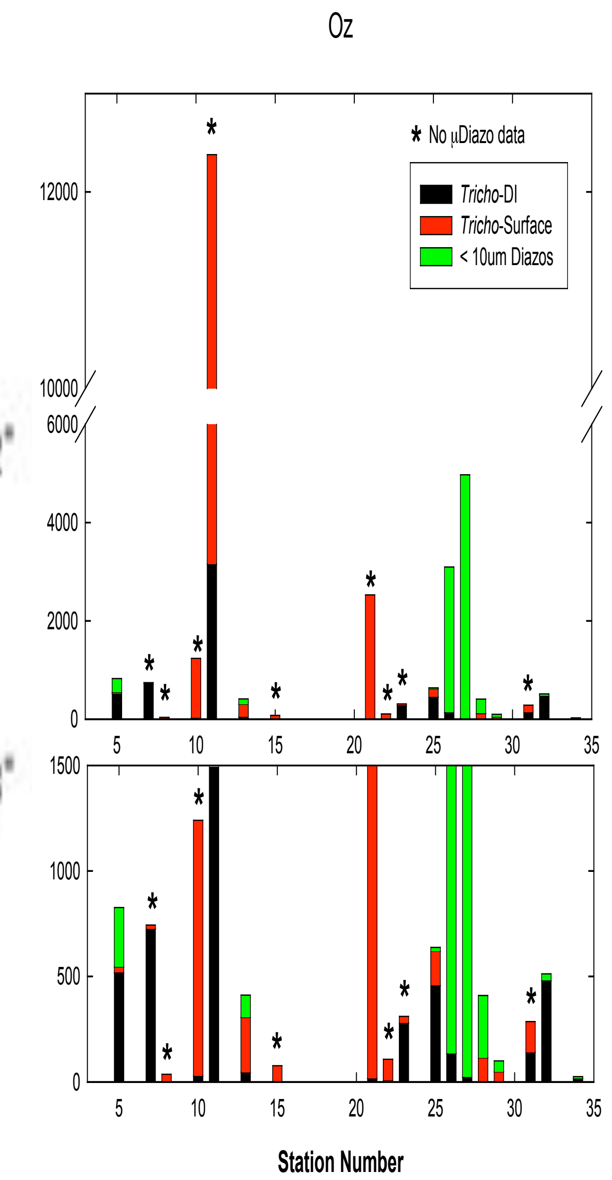



Orinoco River
120
100
80
60
40
20
0
Counts
32
33
34
35
Practical Salinity
Hemialus
Rhizosolenia
Trichodesmium trichomes
Trichodesmium tufts
Trichodesmium puffs

# Fly River

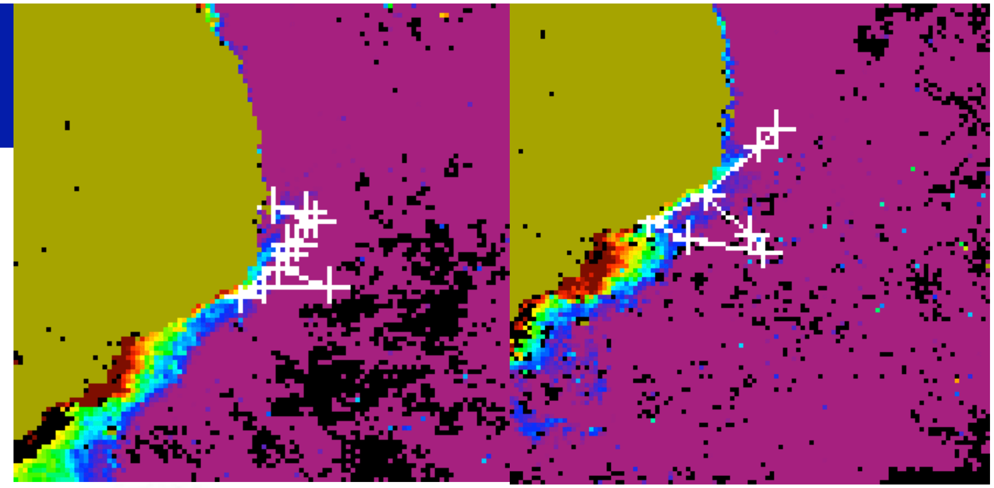


120° 126° 132° 138° 144° 150°
-12° -18°
3097 µmol N m-2 d-1
4974 µmol N m-2 d-1
1136 µmol N m-2 d-1
619 µmol N m-2 d-1
412 µmol N m-2 d-1
638 µmol N m-2 d-1
827 µmol N m-2 d-1
513 µmol N m-2 d-1
26 µmol N m-2 d-1
26
27
28
29
13
25
05
32
33
Arafura Sea
Timor Sea
Coral Sea
Indian Ocean
Gulf of Carpentaria
Tricho-DI
Tricho-Surf
µDiazos

Oz
* No µDiazo data
Tricho-DI
Tricho-Surface
< 10um Diazos
12000
10000
6000
4000
2000
0
1500
1000
500
5 10 15 20 25 30 35
Station Number

# Mekong River



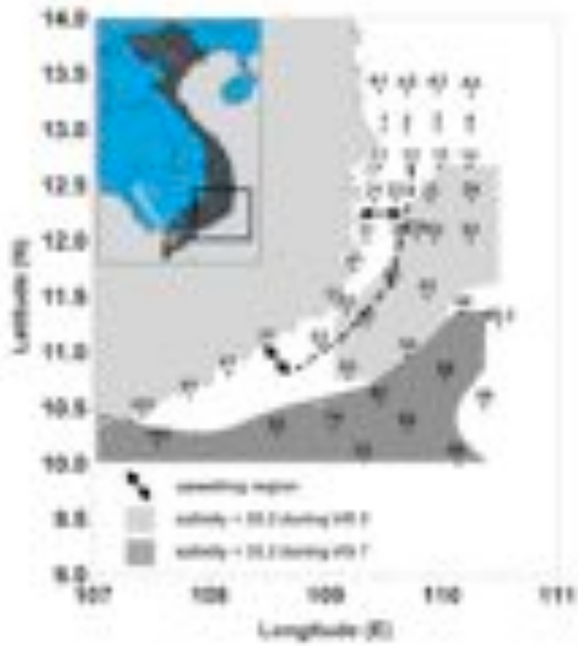



**Figure 1.** Map of the South China Sea off Vietnam with all CTD stations, the insert shows SE Asia. ($N_2$-fixation was measured at the 28 stations). Stations A1 to A4 and 1 to 4 were only visited during VG4, stations 62 to 65 only during VG7. The shaded area denotes Mekong river influence and the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

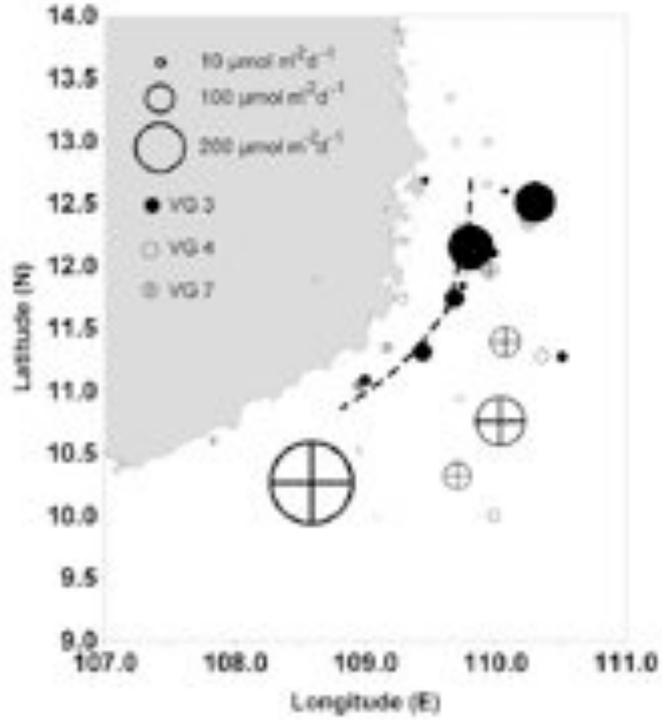



**Figure 2.** $N_2$-fixation rates, symbols are scaled linearly proportional to the measured values. The line visualises the offshore limitation of the upwelling area.

Zambezi River

STS036-073-056 Bazaruto Island, Mozambique March 1990

# Thank You