Tropical rivers enhance carbon and nitrogen fixation

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Tropical Rivers Help Store Carbon

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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

Figure 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.
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.

$\sum PON_{down} \approx \text{uptake } \text{NO}_3^- + N_2$

since $CO_2 / \text{NO}_3^-$ upwell $\approx C/N \text{POM}_{down}$

$POC_{atm-down} \approx \text{uptake } N_2 * C/N_{down}$
The History of Nitrogen
--Haber & Bosch!--

\[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]

Monthly Carbon Dioxide Concentration
parts per million

Humans, millions
Legume Cult., TgN
Fertilizer, TgN
Global N fertilizer use
$X \times 10^{12}$ g/ year

The Mississippi plume “dead zone”
<table>
<thead>
<tr>
<th>River</th>
<th>Discharge</th>
<th>Cumulative %</th>
<th>Drainage area</th>
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<tbody>
<tr>
<td>Amazon</td>
<td>6300</td>
<td>18</td>
<td>6.15</td>
</tr>
<tr>
<td>Zaire</td>
<td>1250</td>
<td>22</td>
<td>3.82</td>
</tr>
<tr>
<td>Orinoco</td>
<td>1200</td>
<td>25</td>
<td>0.99</td>
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<tr>
<td>Ganges-Brahmaputra</td>
<td>970</td>
<td>28</td>
<td>1.48</td>
</tr>
<tr>
<td>Chiang Jiang</td>
<td>900</td>
<td>31</td>
<td>1.94</td>
</tr>
<tr>
<td>Yenisey</td>
<td>630</td>
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<td>2.58</td>
</tr>
<tr>
<td>Mississippi</td>
<td>530</td>
<td>34</td>
<td>3.27</td>
</tr>
<tr>
<td>Lena</td>
<td>510</td>
<td>36</td>
<td>2.49</td>
</tr>
<tr>
<td>Mekong</td>
<td>470</td>
<td>37</td>
<td>0.79</td>
</tr>
<tr>
<td>Parana</td>
<td>470</td>
<td>38</td>
<td>2.83</td>
</tr>
<tr>
<td>All others</td>
<td>21168</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
January: $0.3 \times 10^{12}$

February: $0.3 \times 10^{12}$

March: $0.4 \times 10^{12}$

April: $0.6 \times 10^{12}$

May: $1.0 \times 10^{12}$

June: $1.2 \times 10^{12}$
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
Devol (1991) found that Amazon alone is responsible for 30% of the global transport of SRP.
Fig. 7. Phosphate and silicate concentrations in Amazon shelf surface waters plotted as a function of nitrate concentration for AMASEDS 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.
Tricho can use DOP but P limitation still occurs
8 Day SeaWiFS Chl Images 30 March – 9 June 2003
Highly elevated apparent "chlorophyll" and Retroflection well developed.
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)
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 ± 5.9, S_s = 36.07 ± 0.10, DIC_s = 2024.5 ± 6.8, S_r = 0 ± 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
Several Trichodesmium species co-occur.

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

<table>
<thead>
<tr>
<th></th>
<th>Coastal</th>
<th>Mesohaline</th>
<th>Oceanic</th>
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<td>28.95</td>
<td>32.50</td>
<td>35.97</td>
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<tr>
<td>Fe</td>
<td>2.20</td>
<td>1.61</td>
<td>1.36</td>
</tr>
<tr>
<td>P</td>
<td>67</td>
<td>28</td>
<td>35</td>
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<tr>
<td>DIC</td>
<td>2009</td>
<td>1984</td>
<td>2013</td>
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</tbody>
</table>

**P limitation?**

Phytoplankton populations dominated by asymbiotic diatoms.
Tropical North Atlantic goes from net source of 30 Tg C/yr to neutral or even a sink for C.
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.
Diatom fluxes to the deep sea in the oligotrophic North Pacific gyre at station ALOHA
Marine Ecology Progress Series, Vol 182:55-67, 1999
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*

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

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Congo River 2006

X10^6 Trichomes/m²
N fixation rate nmol/L/hr
<table>
<thead>
<tr>
<th>Station</th>
<th>Salinity</th>
<th>Temperature</th>
<th>Tricho</th>
<th>het-1</th>
<th>het-2</th>
<th>het-3</th>
<th>Total Rich</th>
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<tr>
<td>Niger</td>
<td>nd</td>
<td>det, not q</td>
<td>51400</td>
<td>nd</td>
<td>10280</td>
<td></td>
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<td>1</td>
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<td>82400</td>
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<td>16480</td>
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<td>nd</td>
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<td>36.20</td>
<td>21.99</td>
<td>3810</td>
<td>518</td>
<td>94600</td>
<td>149000</td>
<td>48824</td>
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<tr>
<td>3</td>
<td>36.07</td>
<td>25.09</td>
<td>det, not q</td>
<td>2010</td>
<td>2080</td>
<td>nd</td>
<td>818</td>
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<tr>
<td>4</td>
<td>33.90</td>
<td>26.35</td>
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<td>nd</td>
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<td>698</td>
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<td>33.07</td>
<td>26.51</td>
<td>85000</td>
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<td>26.53</td>
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<td>1280</td>
<td>774</td>
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<td>35.80</td>
<td>25.27</td>
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<td>91800</td>
<td>24600</td>
<td>23280</td>
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</table>
N:P Ratio for CTDs 57-63 in the Congo plume and coastal cold tongue
Density structure of the Congo Plume

Sigma T Profiles of the Congo River Plume

Implications for diurnal heating and air/sea gas exchange
Temperature and Salinity from the Ship’s flowthrough system (4m)

TSG 25-26 June 2006

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

- CO2 mer
- CO2 air
- S
- SST+7

Upwelling côtier

Congo
Orinoco River

Cruise data from September 2006 from Corredor, Morrel, Cabrera
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.

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>
<thead>
<tr>
<th>Bloom date</th>
<th>Lat (°N)</th>
<th>Long (°E)</th>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Silicate</th>
<th>Primary production (mgC m⁻² d⁻¹)</th>
<th>Zooplankton biomass (ml 100m⁻³)</th>
</tr>
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<tbody>
<tr>
<td>11 April 2001</td>
<td>10° 58’</td>
<td>81°50’</td>
<td>0.05</td>
<td>0.9</td>
<td>2.2</td>
<td>2160</td>
<td>22.8</td>
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<tr>
<td>25 April 2001</td>
<td>19°44’</td>
<td>89°04’</td>
<td>0.14</td>
<td>0.56</td>
<td>—</td>
<td>1740</td>
<td>17.7</td>
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</table>
Zambezi River too?

STS036-073-056 Bazaruto Island, Mozambique March 1990

Tricho?
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

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

Future
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)
\[ K_{490} = -0.021 \times \text{salinity} + 0.768 \]

\[ r^2 = 0.93 \]

\[ a_{\text{CDOM}(490)} = 0.704 \times K_{490} - 0.026 \]

\[ r^2 = 0.98 \]

\[ a_{\text{CDOM}(490)} = 0.623 \times K_{490} - 0.058 \]

\[ r^2 = 0.77 \]