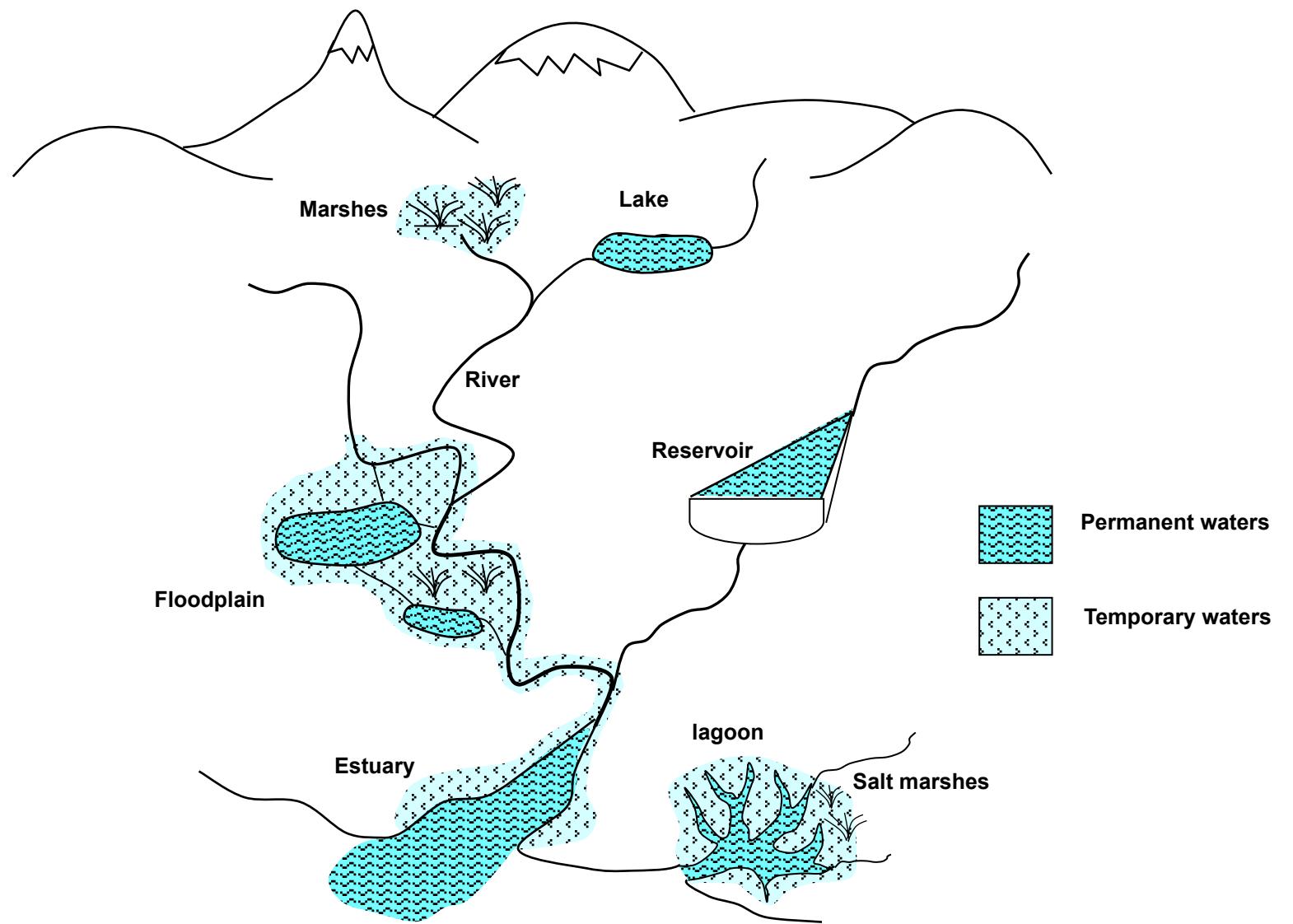


Contrôles du fonctionnement biogéochimique des eaux continentales par le milieu terrestre qui les entoure

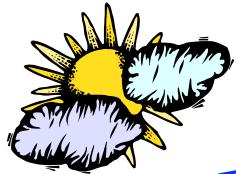
Gwenaël Abril

CNRS-EPOC

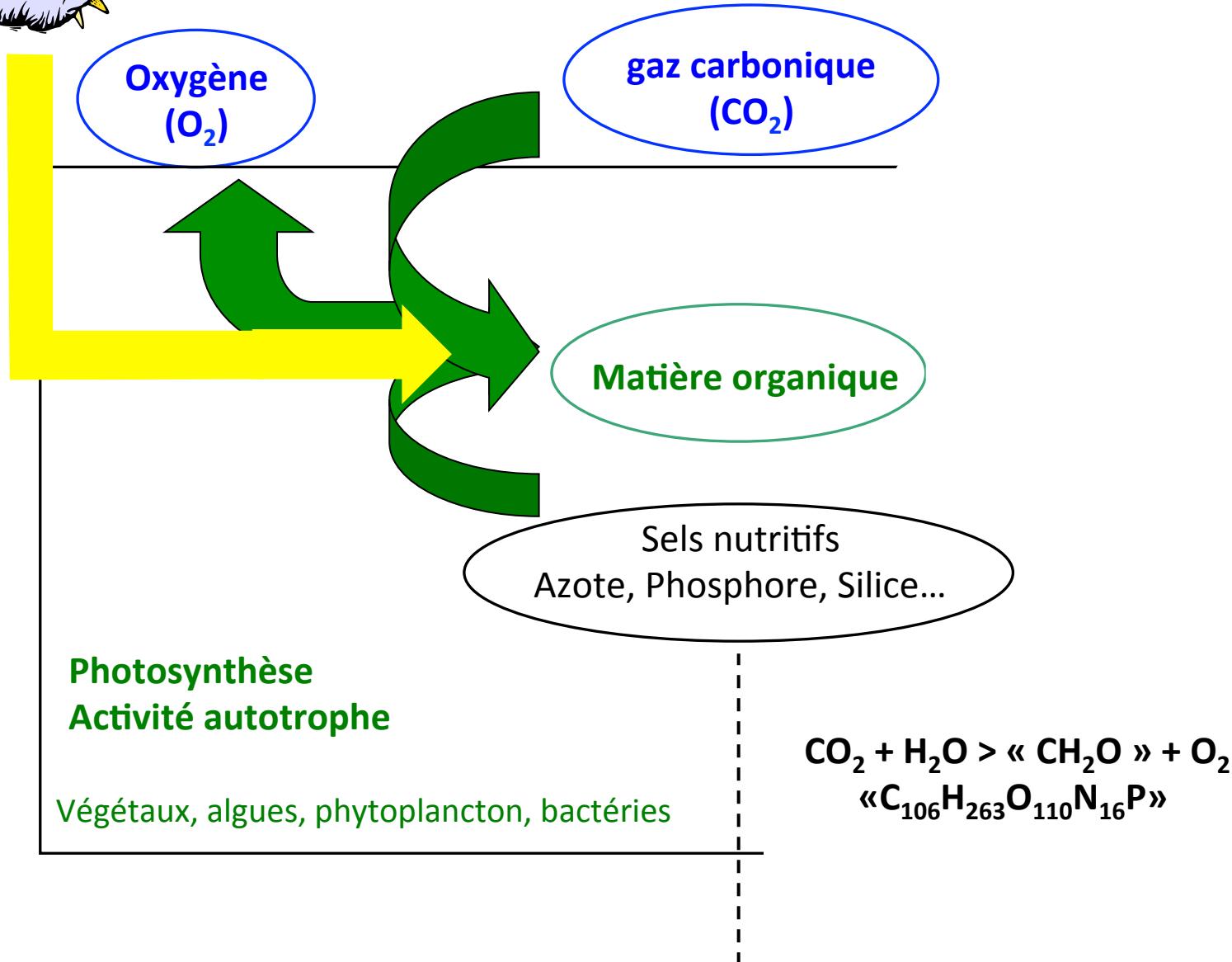
- Concepts en écologie fonctionnelle et biogéochimie
Cycle du C en milieu terrestre et aquatique
- Couplages Terrestre > Aquatique cas du Cycle du Carbone
Echelle globale
Hétérogénéité dans le paysage, connectivité terre-eau, zone humides, ripisylve...
- Couplages Terrestre > Aquatique : contrôle sur les populations biologiques
Trophique / écosystémique



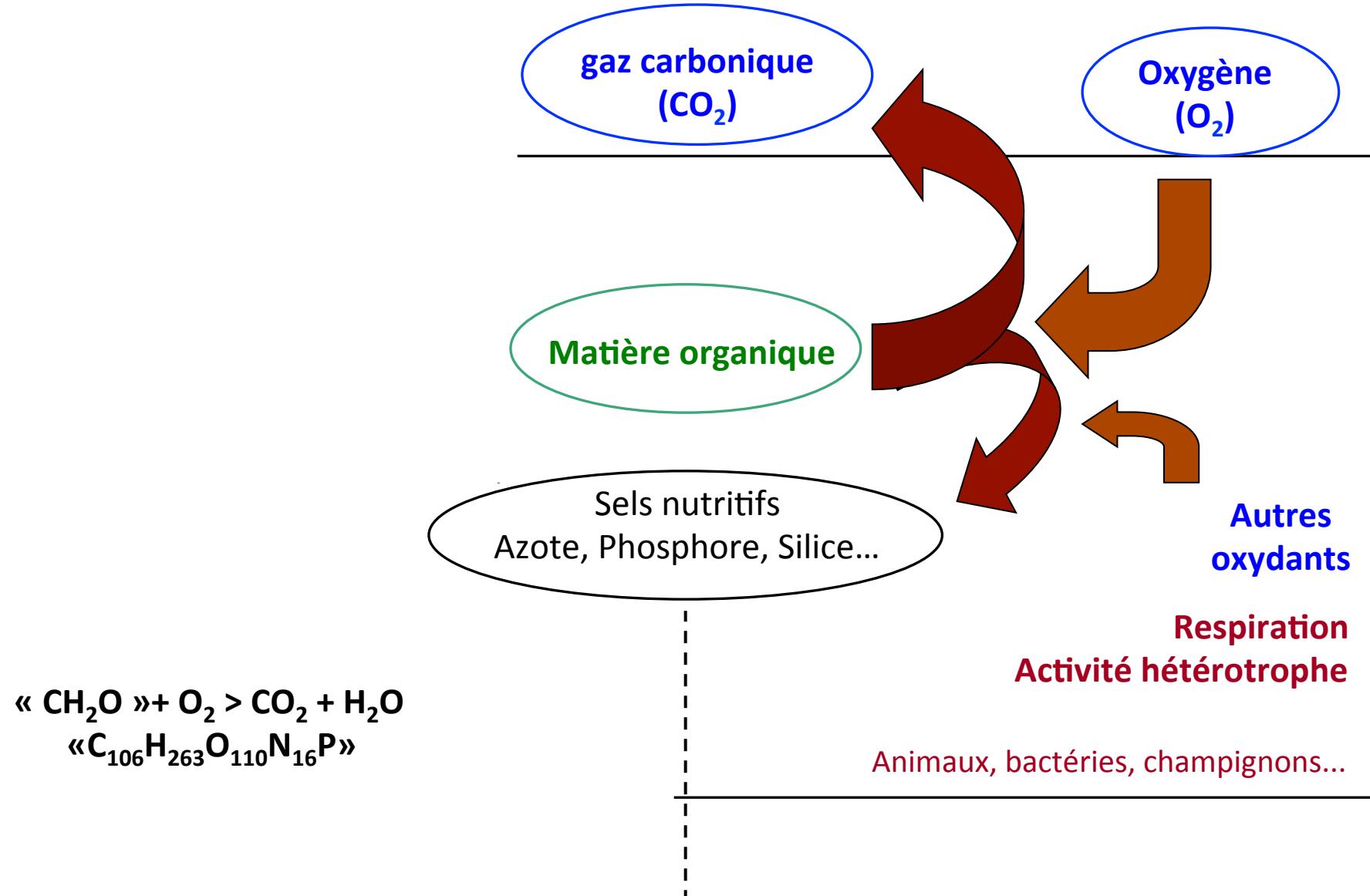
~15% de la surface des continents (Downing et al. 2007, L&O)

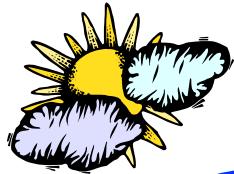


Métabolisme d'un écosystème

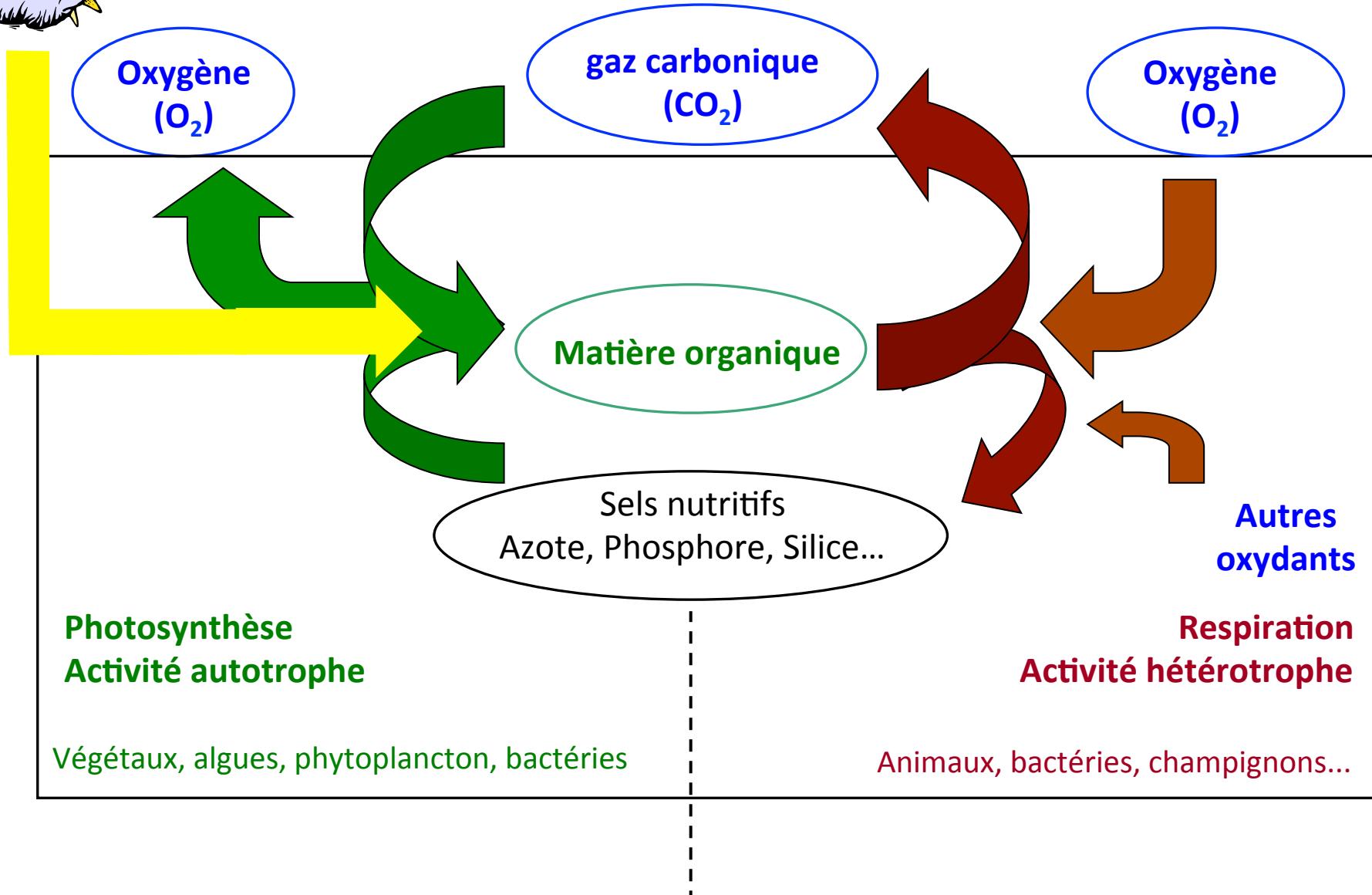


Métabolisme d'un écosystème





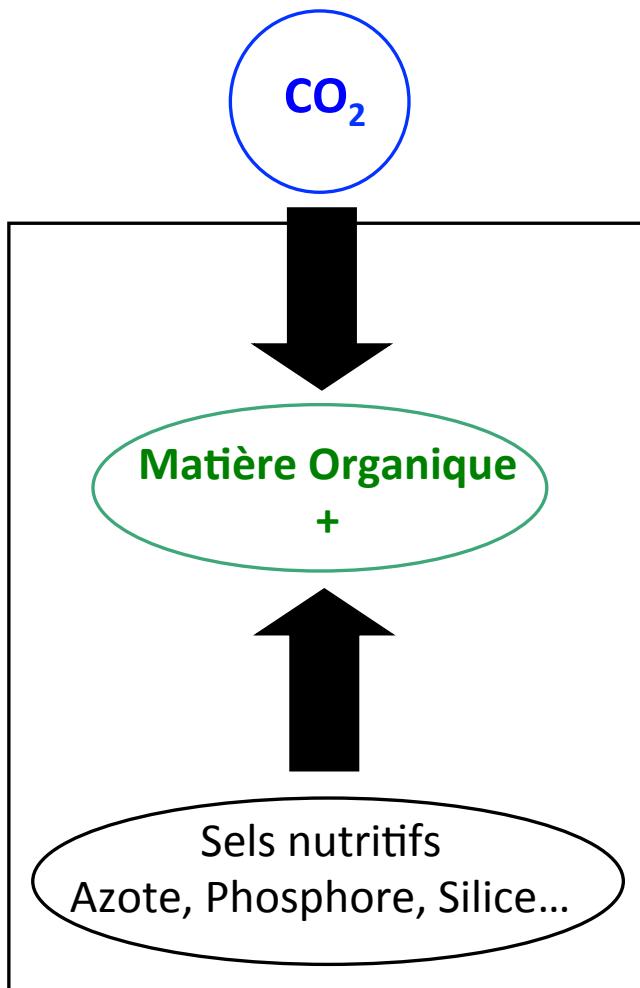
Métabolisme d'un écosystème



Métabolisme d'un écosystème

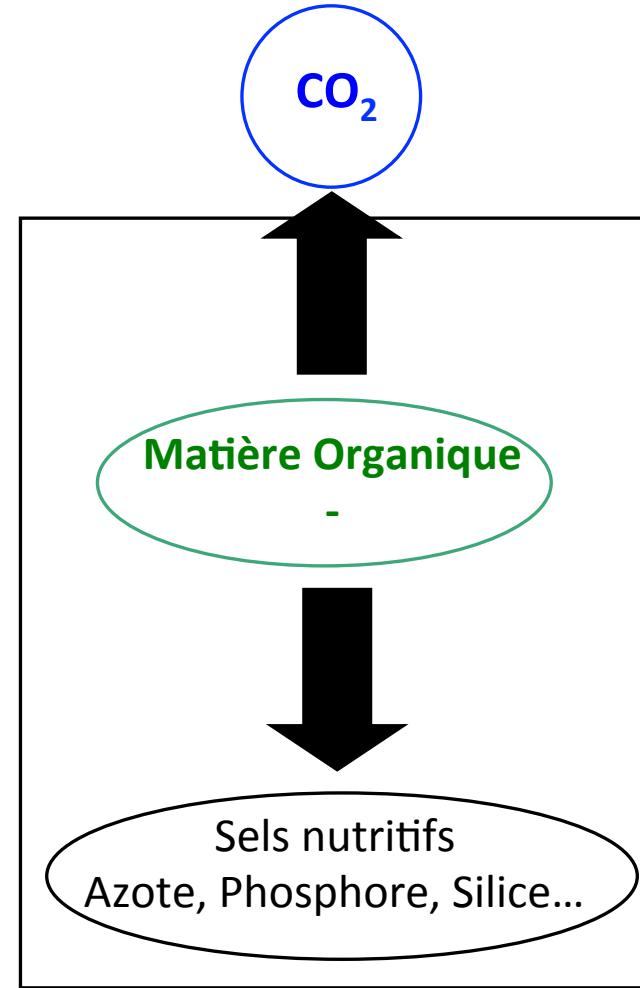
Net Autotrophe

- puits de CO₂
- Accumulateur/exportateur de MO



Net Hétérotrophe

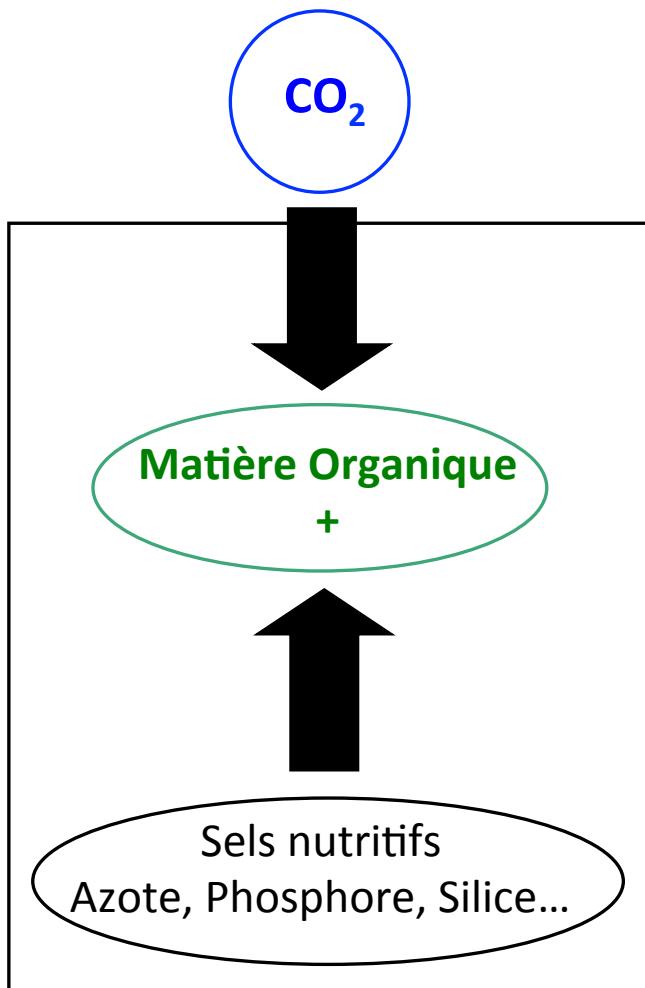
- source de CO₂
- Réceptacle/destructeur de MO



Métabolisme d'un écosystème

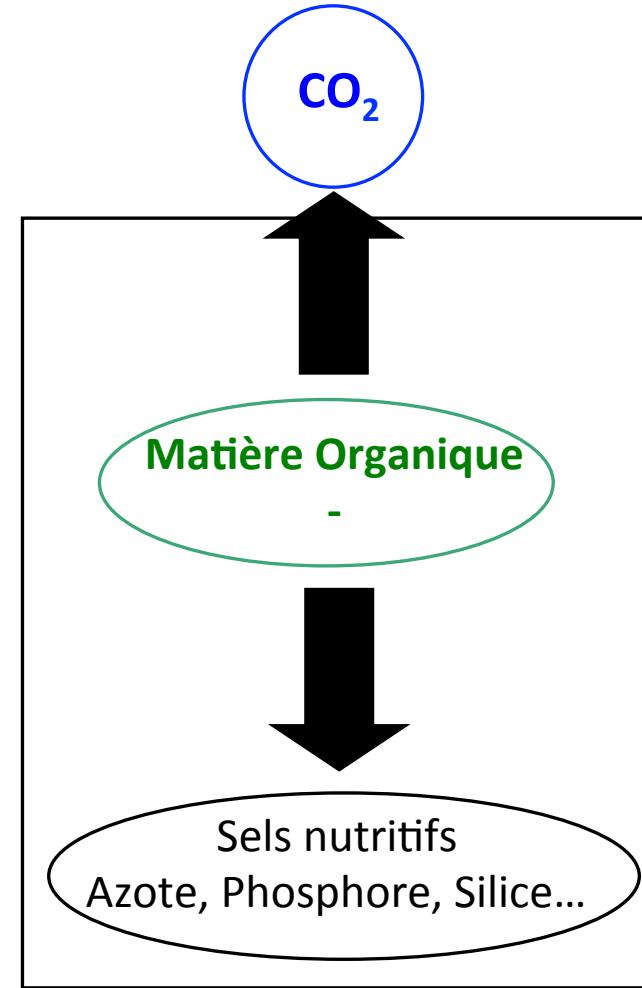
Net Autotrophe

- puits de CO₂
- Accumulateur/**exportateur** de MO

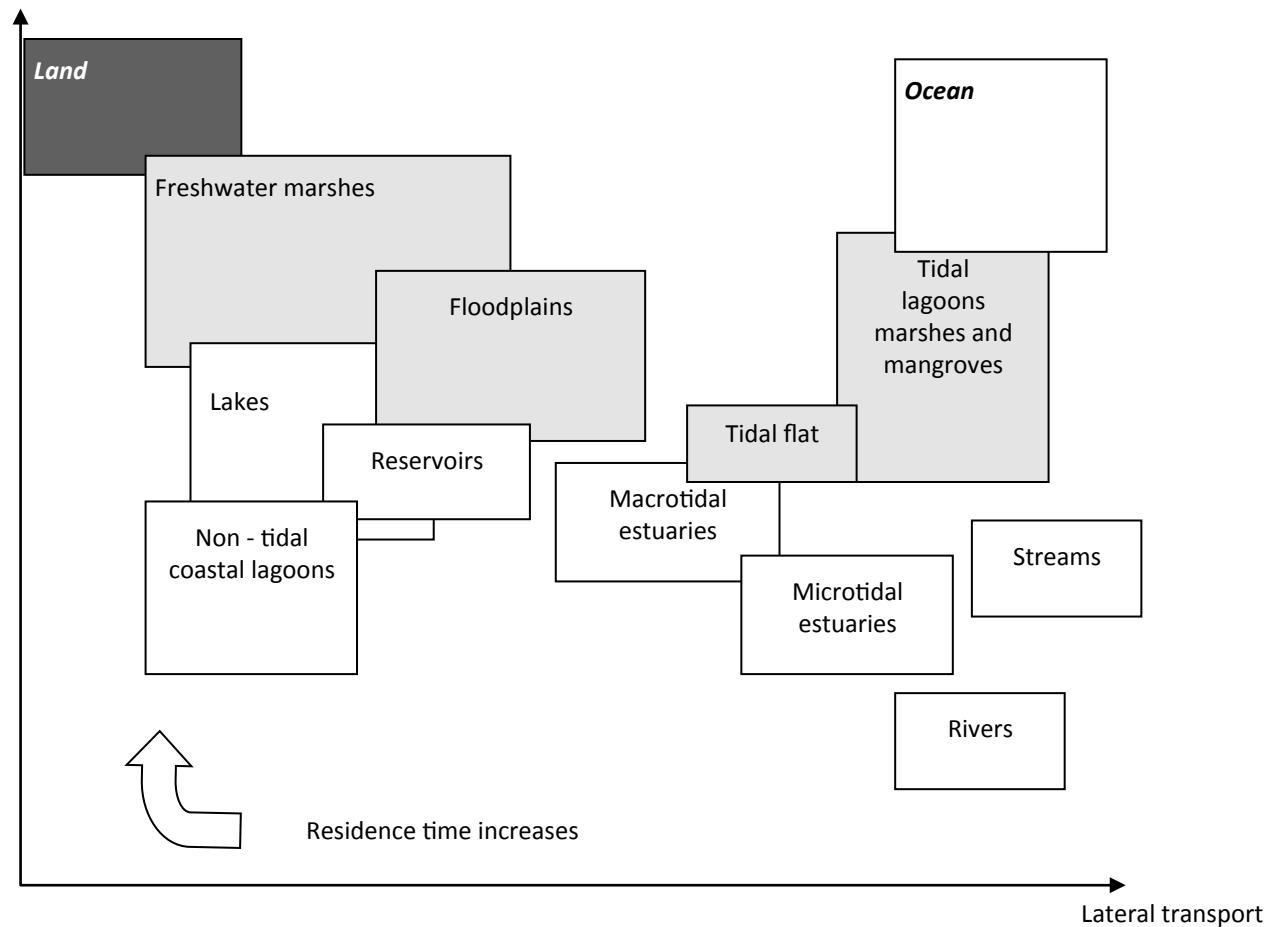


Net Hétérotrophe

- source de CO₂
- Réceptacle/**destructeur** de MO



Processing and vertical transport



COMMENTARY

Prevalence of Heterotrophy and Atmospheric CO₂ Emissions from Aquatic Ecosystems

Carlos M. Duarte,^{1*} and Yves T. Prairie²

¹IMEDEA (CSIC-UIB), Instituto Mediterráneo de Estudios Avanzados, Miquel Marqués 21, 07190 Esporles, Spain; ²Département des Sciences Biologiques, Université du Québec à Montréal, Case postale 8888, succ. Centre-Ville, Montréal H3C 3P8, Canada

1-Water pCO₂ > air pCO₂ (outgassing of CO₂ at the water-air interface)

2-Respiration > Gross Primary production (heterotrophic metabolism)

“The correspondence between aquatic metabolism and CO₂ emissions or uptake need to be explicitly tested and not only assumed, as there are processes (...) that may confound the relationship between aquatic metabolism and CO₂ emissions.”

outline

CO₂ emissions from inland waters (Streams, Rivers, Lakes and other flooded lands including wetlands) represent **3 PgC per year** = more than deforestation (1-2 PgC), equivalent to the uptake of CO₂ by forests in the northern hemisphere.

Ecosystems (2007) 10: 171–184
DOI: 10.1007/s10021-006-9013-8

ECOSYSTEMS

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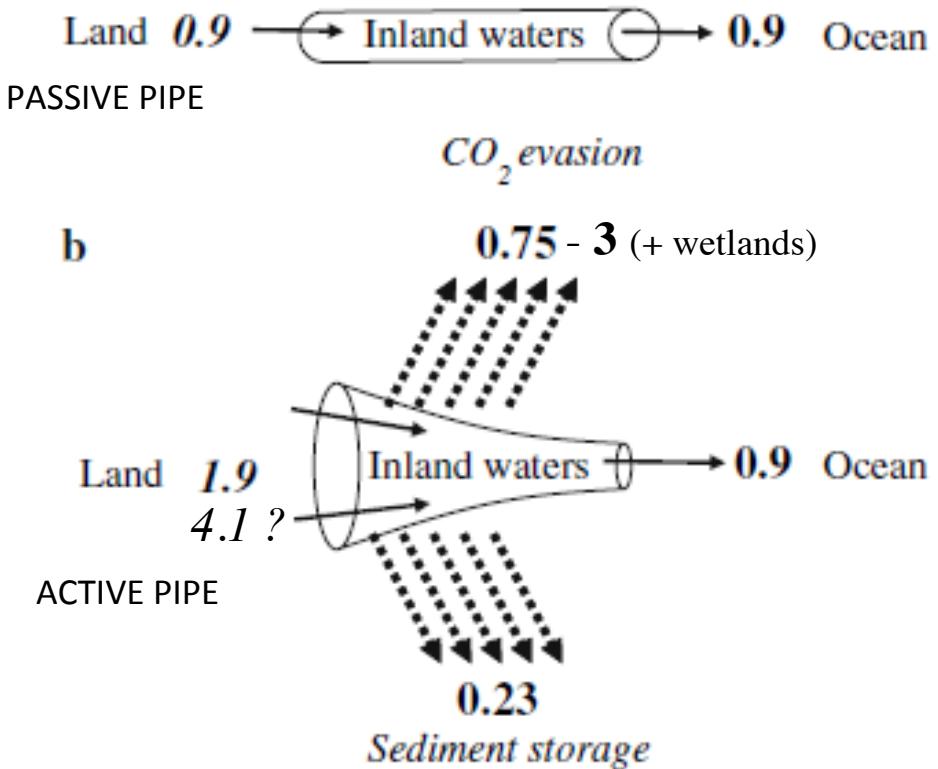
Plumbing the Global Carbon Cycle: Integrating Inland Waters into the Terrestrial Carbon Budget

J. J. Cole,¹ Y. T. Prairie,^{2,*} N. F. Caraco,¹ W. H. McDowell,³ L. J. Tranvik,⁴
R. G. Striegl,⁵ C. M. Duarte,⁶ P. Kortelainen,⁷ J. A. Downing,⁸
J. J. Middelburg,⁹ and J. Melack,¹⁰

COUPLED BIOGEOCHEMICAL CYCLES

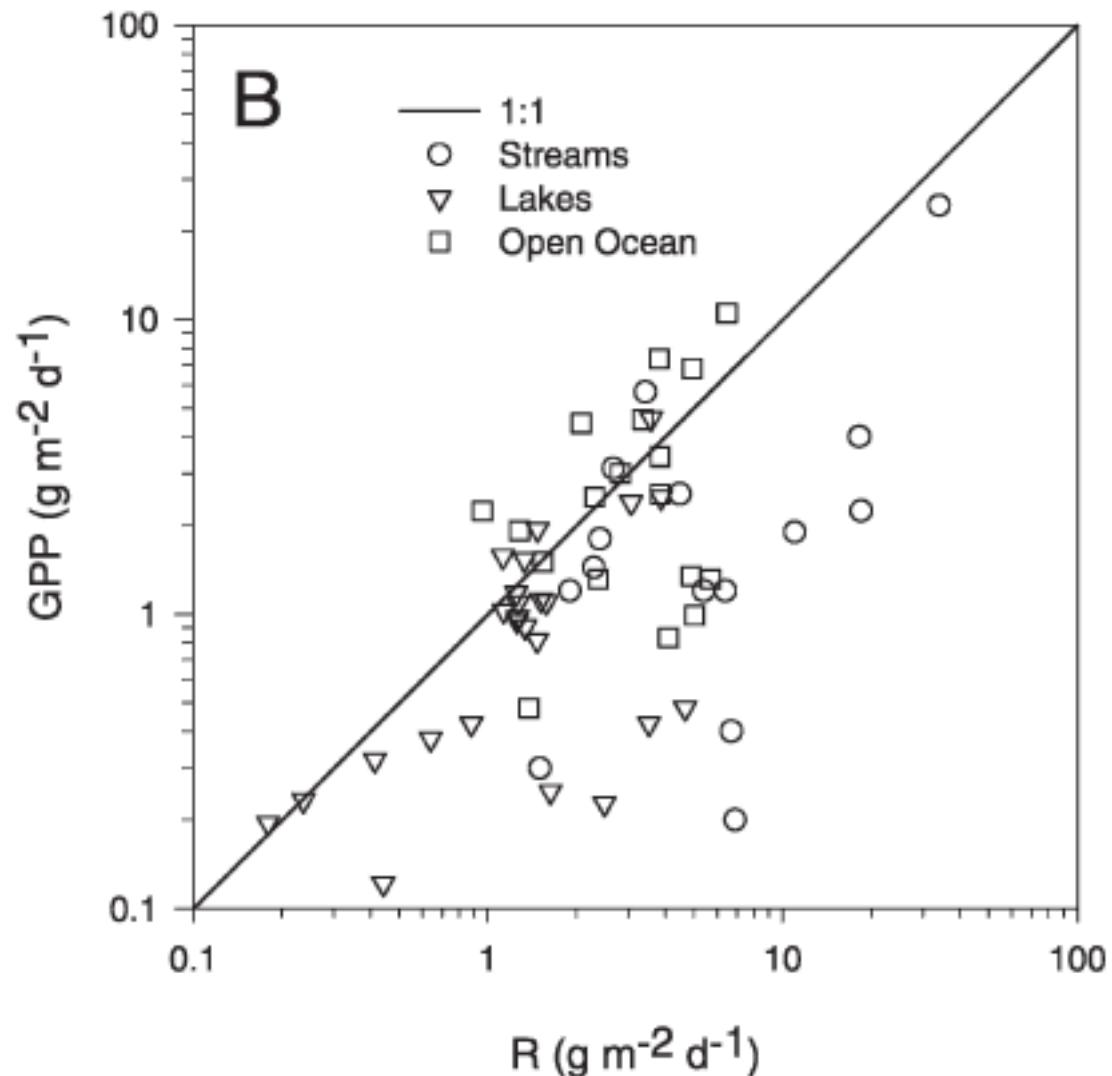
Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere

Anthony K Aufdenkampe^{1*}, Emilio Mayorga², Peter A Raymond³, John M Melack⁴, Scott C Doney⁵,
Simone R Alin⁶, Rolf E Aalto⁷, and Kyungsoo Yoo⁸



Expanding the concept of trophic state in aquatic ecosystems: It's not just the autotrophs

Walter K. Dodds^{1,*} and Jonathan J. Cole²



Biophysical controls on organic carbon fluxes in fluvial networks

TOM J. BATTIN^{1,2*}, LOUIS A. KAPLAN³,
 STUART FINDLAY⁴, CHARLES S. HOPKINSON⁵,
 EUGENIA MARTI⁶, AARON I. PACKMAN⁷,
 J. DENIS NEWBOLD³ AND FRANCESC SABATER⁸

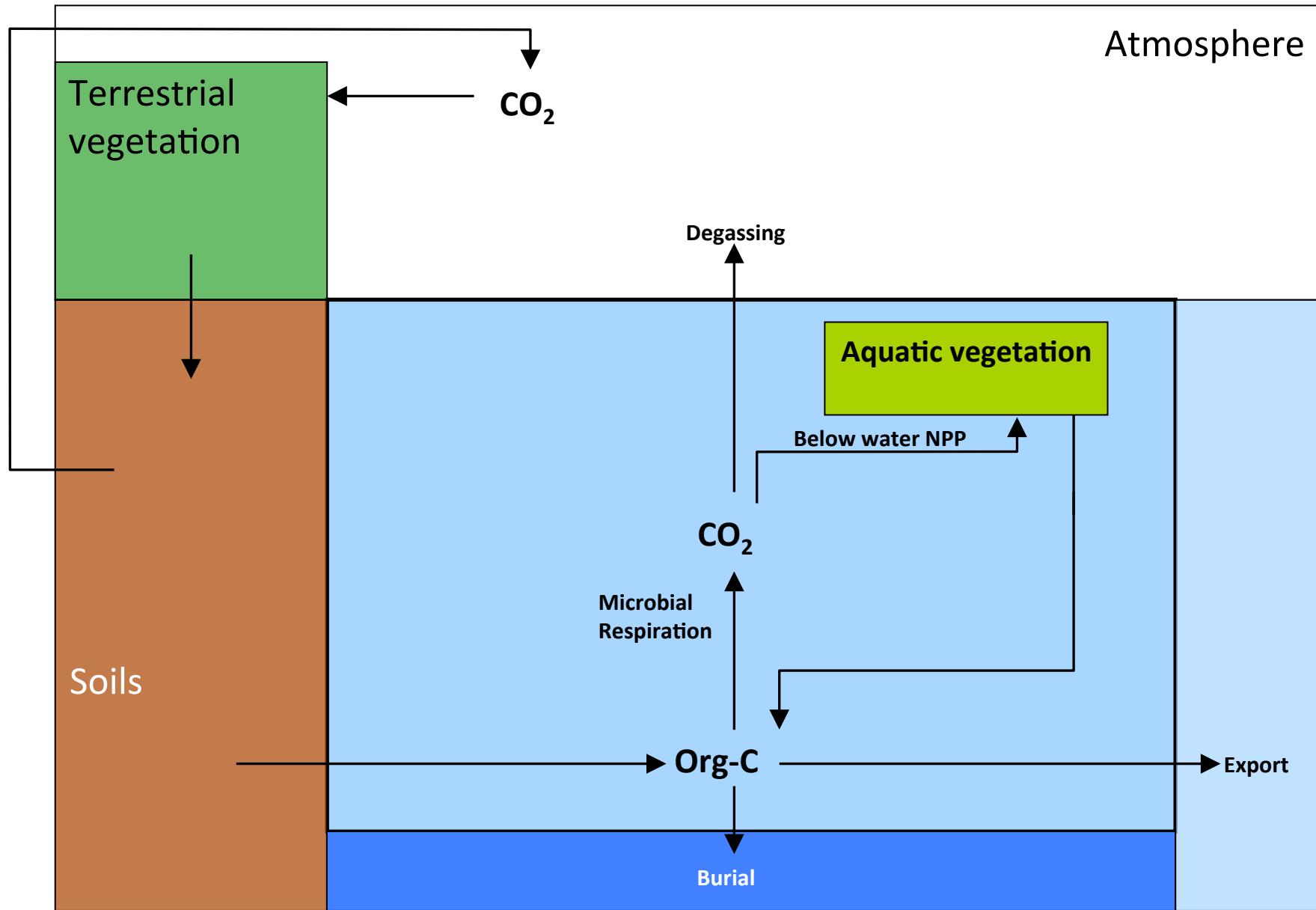
Table 1 Gross primary production (GPP), respiration (R) and net ecosystem production (NEP) in streams, rivers and estuaries as determined from whole-ecosystem metabolism measurements (see Supplementary Information S2), and global estimates of respiration and net heterotrophy.

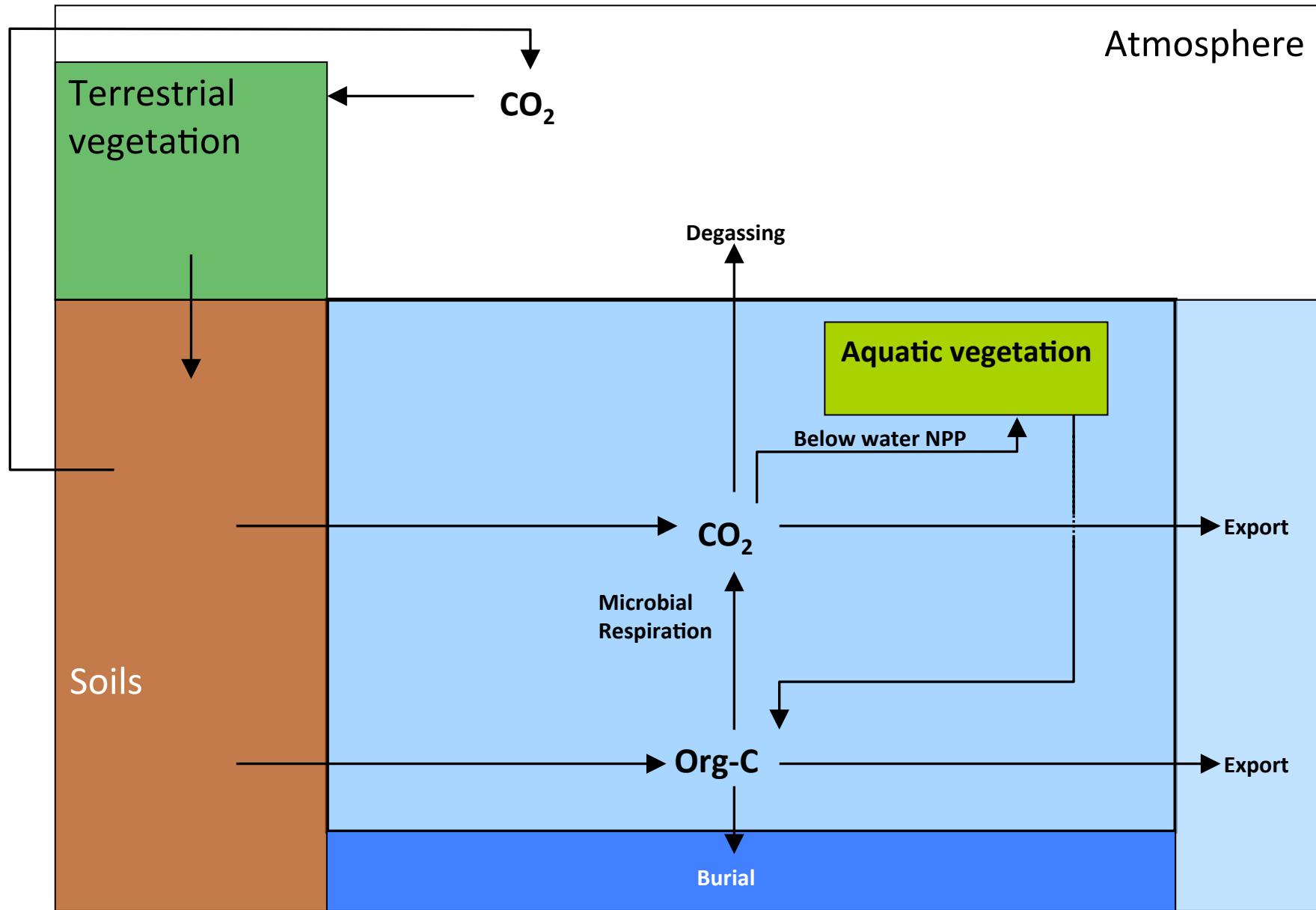
Ecosystem	GPP (g C m ⁻² d ⁻¹)	R (g C m ⁻² d ⁻¹)	NEP (g C m ⁻² d ⁻¹)	Global R (Pg C y ⁻¹)	Global net heterotrophy (Pg C y ⁻¹)
Streams (n = 62)	0.73 ± 0.14* (0.02–5.62)	1.93 ± 0.19* (0.29–8.16)	-1.20 ± 0.15* (-5.86–2.51)	0.19	0.12
River (n = 37)	0.91 ± 0.10† (0.06–2.28)	1.53 ± 0.15* (0.20–3.54)	-0.66 ± 0.11† (-2.06–1.60)	0.16	0.07
Estuaries (n = 31)	3.14 ± 0.41‡ (0.72–10.4)	3.51 ± 0.32† (0.83–7.58)	-0.39 ± 0.21† (-2.98–2.86)	1.20	0.13

Given is the mean ± s.e., and the minimum and maximum in brackets. For each metabolic parameter, ecosystems with the same superscript are not statistically different ($\alpha = 0.05$, one-way analysis of variance with a Scheffé post-hoc test, data were log-transformed). Rivers were defined as running waters with a discharge >500 l s⁻¹ or larger than 5th order. Global stream and river surface area were estimated at 0.275×10^6 km² and 0.295×10^6 km², respectively (Wilfred M. Wollheim personal communication); the global surface estimate of 0.94×10^6 km² for estuaries is from ref. 42 (see Supplementary Information S2).

$$\begin{aligned} \text{Total Net Heterotrophy (+Lakes)} &\approx 0.3 \text{ PgC.yr}^{-1} \\ \text{Total CO}_2 \text{ emissions} &\approx 0.75 - 3 \text{ PgC.yr}^{-1} \end{aligned}$$

Where is the additional C coming from ?







CO₂ efflux from Amazonian headwater streams represents a significant fate for deep soil respiration

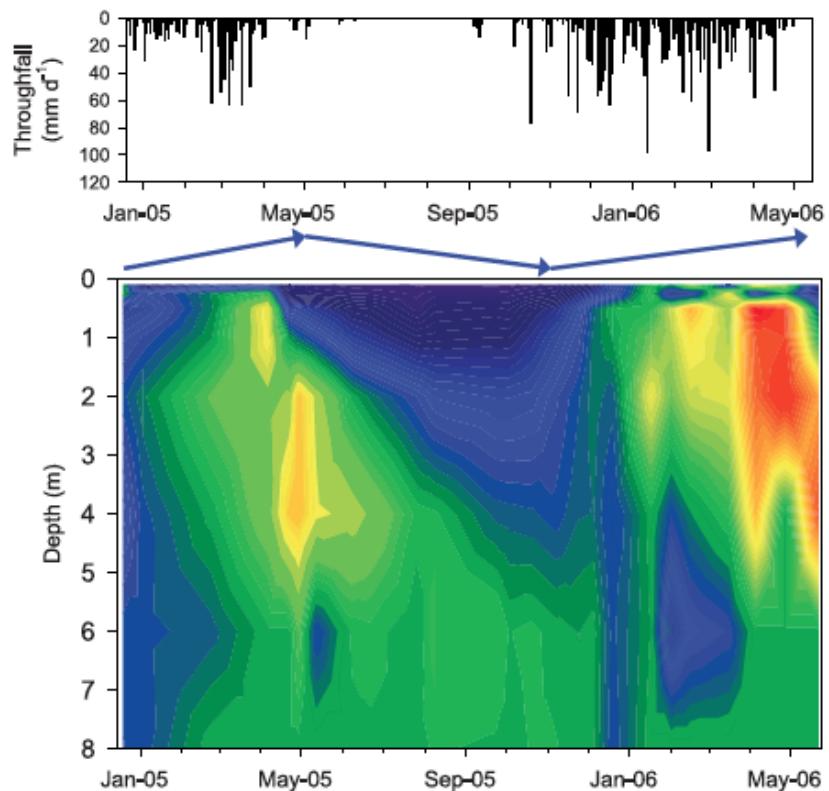
Mark S. Johnson,^{1,2} Johannes Lehmann,³ Susan J. Riha,⁴ Alex V. Krusche,⁵
Jeffrey E. Richey,⁶ Jean Pierre H. B. Ometto,^{5,7} and Eduardo Guimarães Couto⁸

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, G04005, doi:10.1029/2009JG001202, 2010

Dissolved CO₂ in small catchment streams of eastern Amazonia: A minor pathway of terrestrial carbon loss

Eric A. Davidson,¹ Ricardo O. Figueiredo,² Daniel Markewitz,³
and Anthony K. Aufdenkampe⁴

Received 2 November 2009; revised 12 May 2010; accepted 18 May 2010; published 5 October 2010.



GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L17401, doi:10.1029/2008GL034619, 2008

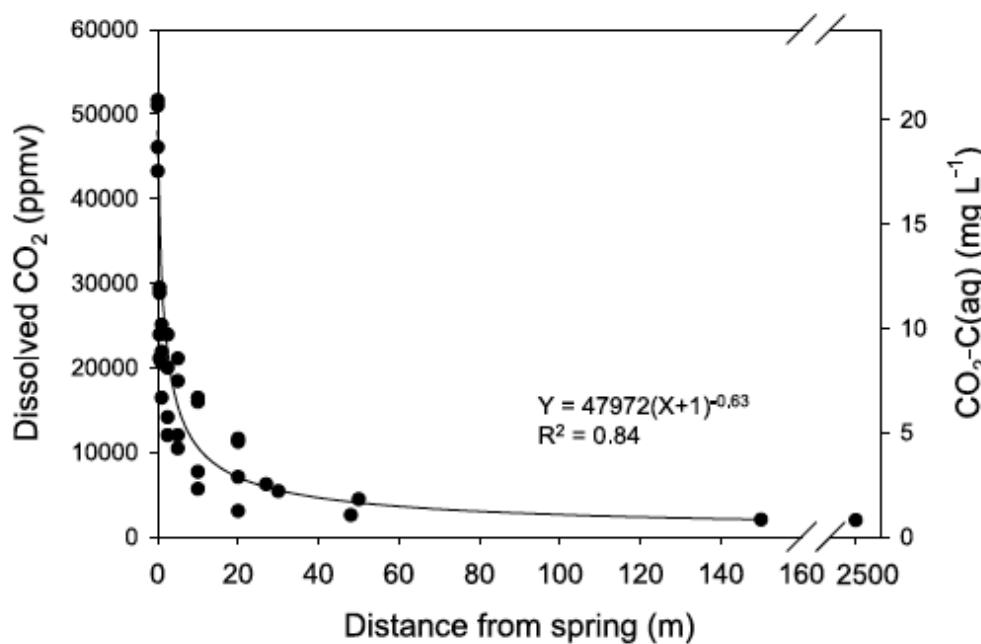
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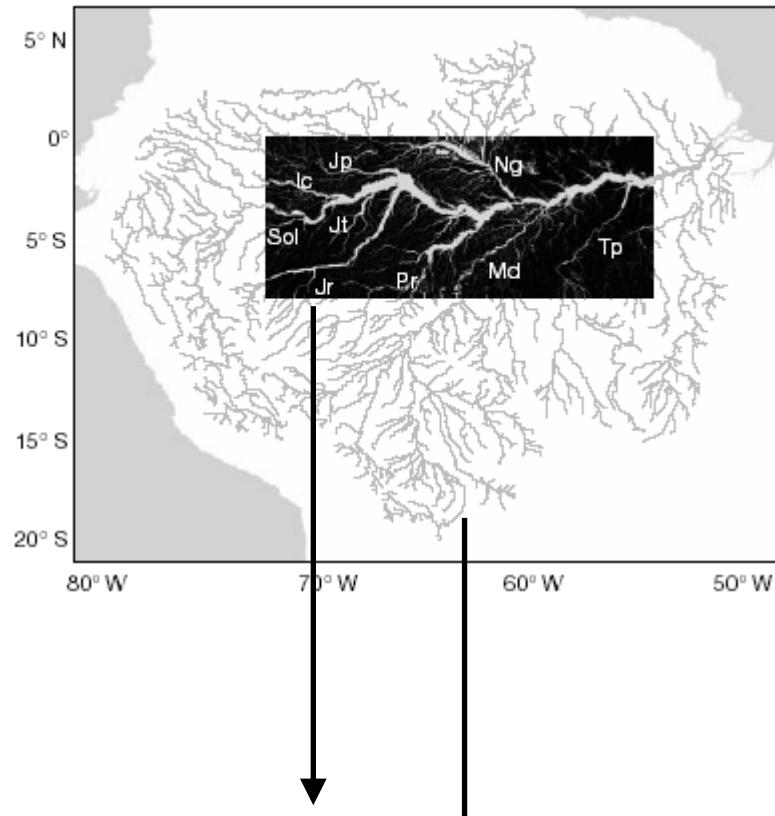
CO₂ efflux from Amazonian headwater streams represents a significant fate for deep soil respiration

Mark S. Johnson,^{1,2} Johannes Lehmann,³ Susan J. Riha,⁴ Alex V. Krusche,⁵ Jeffrey E. Richey,⁶ Jean Pierre H. B. Ometto,^{5,7} and Eduardo Guimarães Couto⁸

Gaseous CO₂ in the soil atmosphere (ppmv)

- 10,000
- 20,000
- 30,000
- 40,000
- 50,000
- 60,000
- 70,000
- 80,000
- 90,000





..... **letters to nature** 2002 .

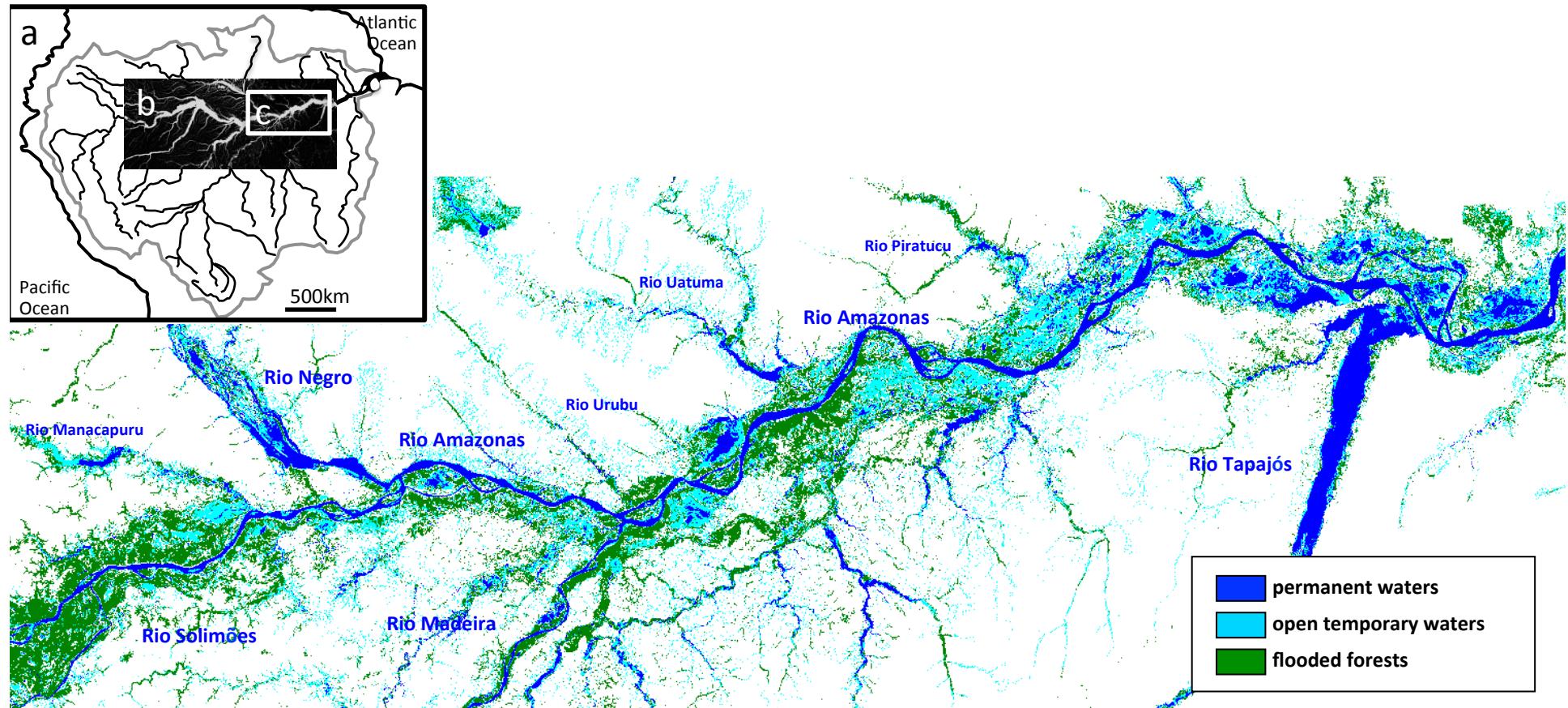
Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO₂

**Jeffrey E. Richey*, John M. Melack†, Anthony K. Aufdenkampe*,
Victoria M. Ballester‡ & Laura L. Hess†**

Central Amazon Reference quadrant, superficie 1 770 000 km²
CO₂ outgassing : 0.21 PgC per year i.e. 210 TgC per year

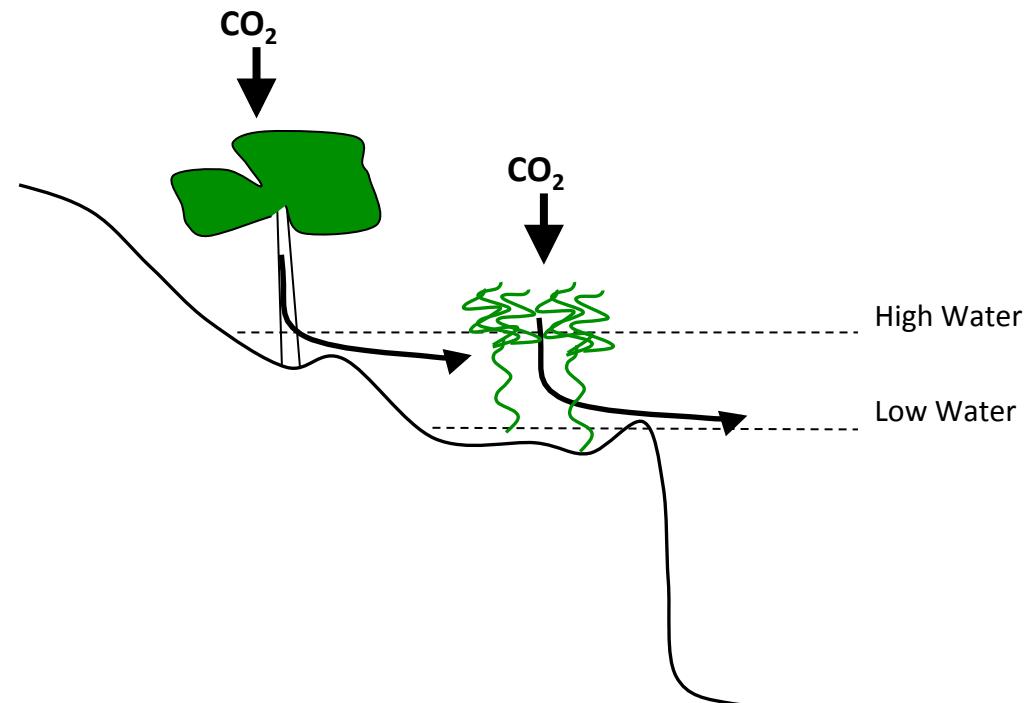
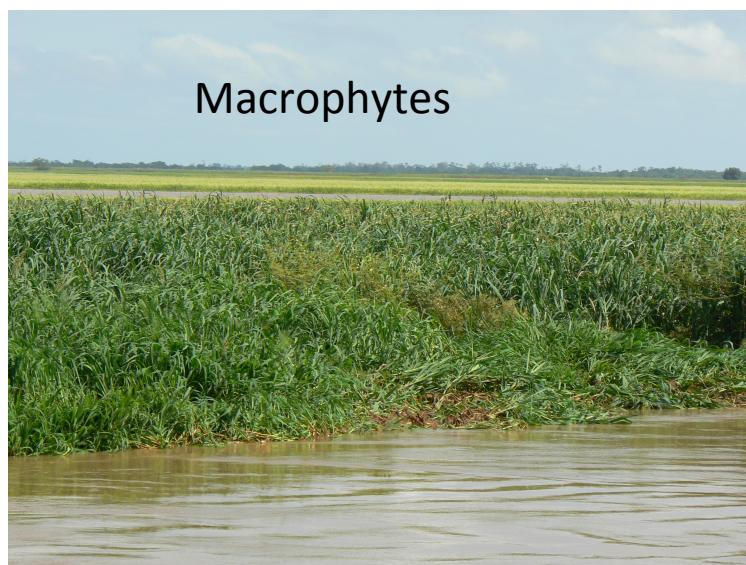
↓
Upscaling to the whole Amazon basin : 0.47 PgC per year i.e. 475 TgC per year

50% from river channels (25% of the surface area), 50% from the floodplain
(75% of the surface area)



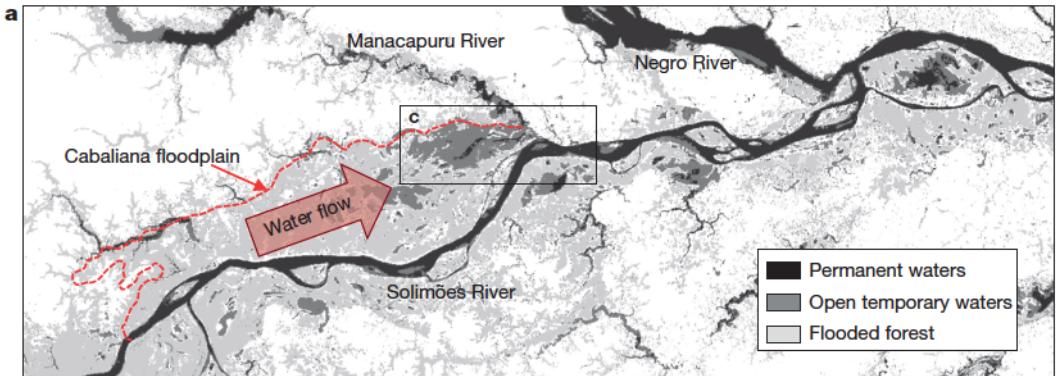
Flooded Forest

Open Lakes

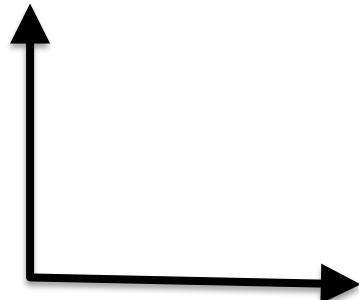


Amazon River carbon dioxide outgassing fuelled by wetlands

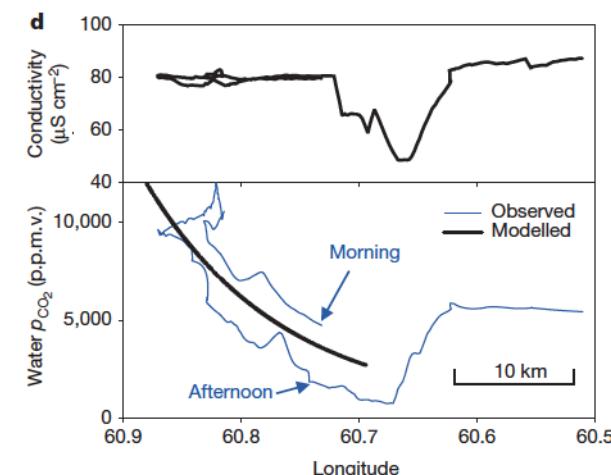
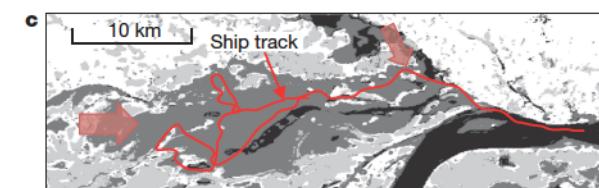
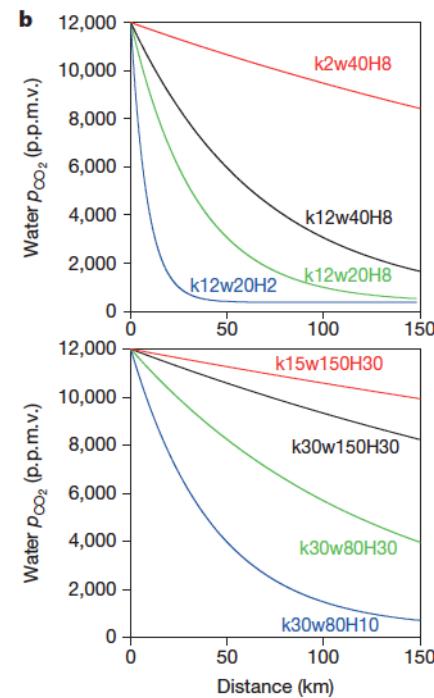
Gwenael Abril^{1,2}, Jean-Michel Martinez², L. Felipe Artigas³, Patricia Moreira-Turcq², Marc F. Benedetti⁴, Luciana Vidal⁵, Tarik Meziane⁶, Jung-Hyun Kim⁷, Marcelo C. Bernardes⁸, Nicolas Savoye¹, Jonathan Deborde¹, Edivaldo Lima Souza⁹, Patrick Albéric¹⁰, Marcelo F. Landim de Souza¹¹ & Fabio Roland⁵

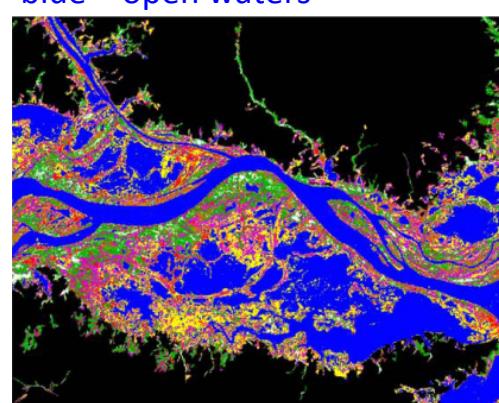


Gas exchange

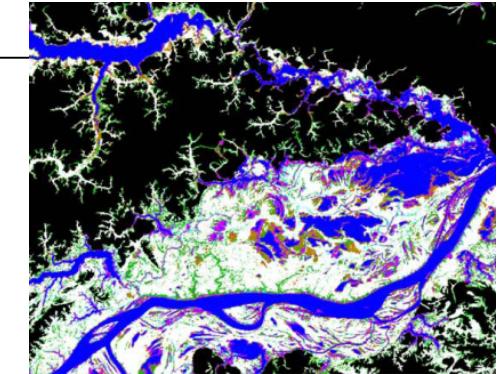
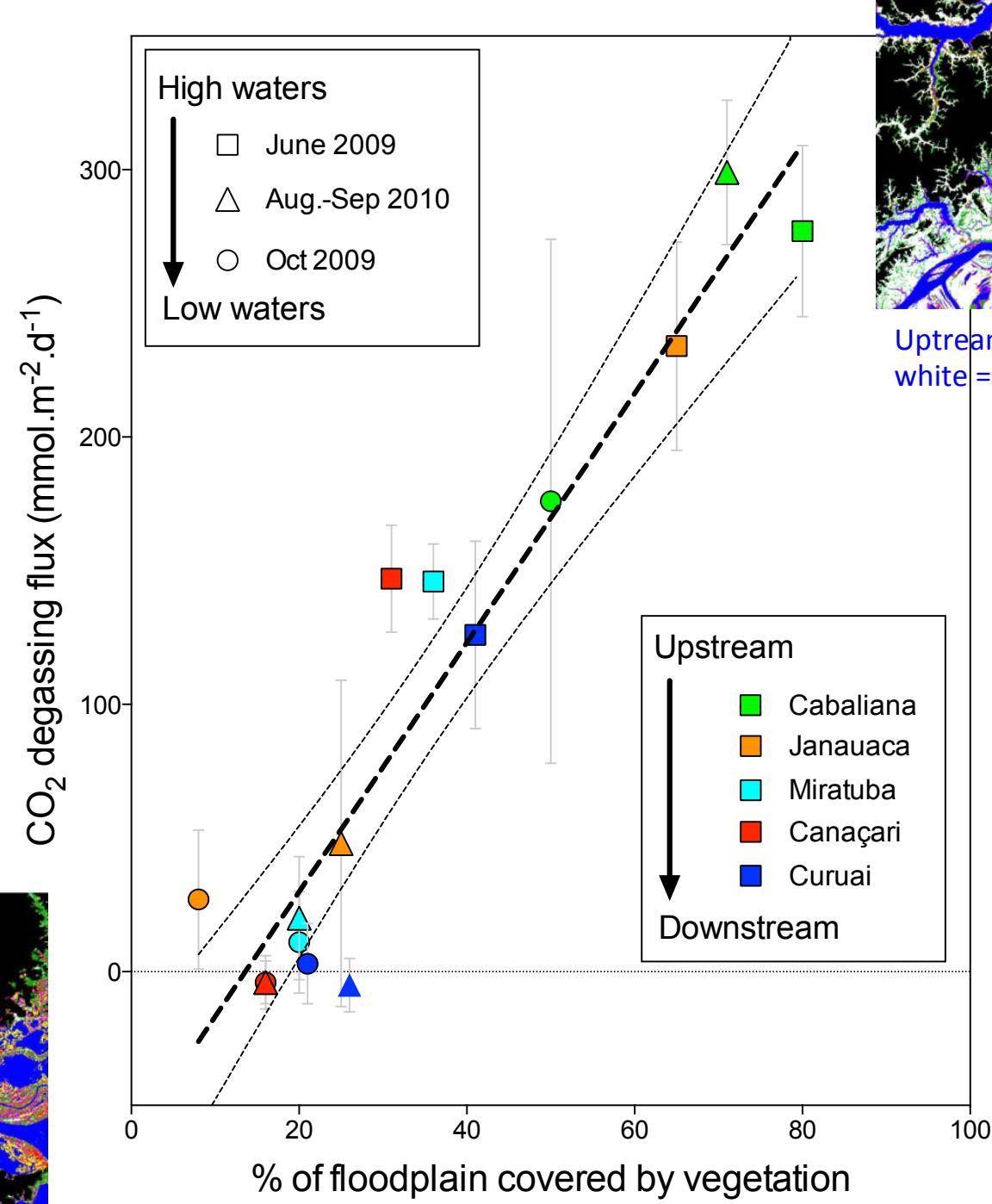


Water flow





Downstream at low water
blue = open waters



Upstream at high water
white = flooded forest

Quantitative aspects-

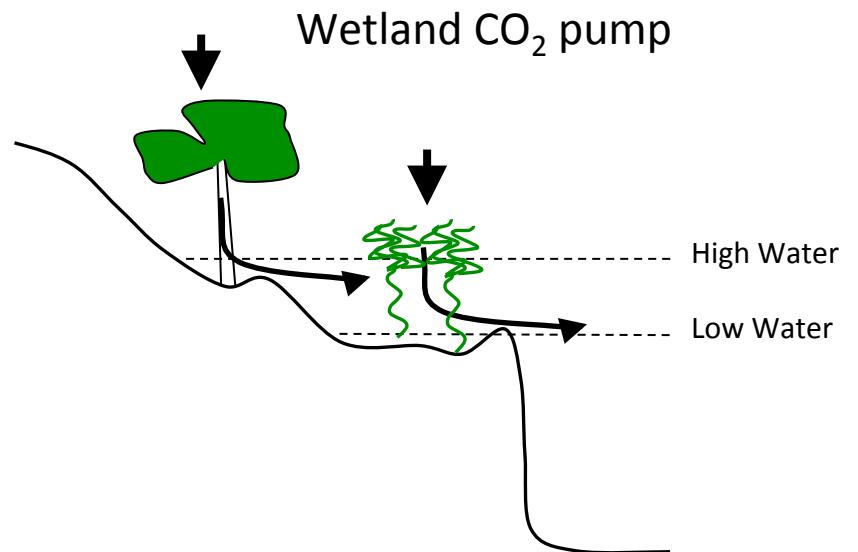
Combining literature data of primary production, litter fall, root respiration in Amazonian wetlands (Junk, Worbes, Piedade, et al...) with surface areas of flooded and floating vegetation, we estimate the quantity of C transferred from wetlands to waters as organic carbon and dissolved CO₂

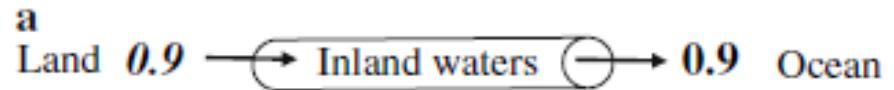
Amazonian wetlands export 50% of their GPP to waters, compared to 1-2% in strictly terrestrial systems.

For the central Amazon, this wetland export is **305 ± 120 TgC per year**

In the same area, waters outgas **210 ± 60 TgC per year as CO₂** (Richey et al. 2002)

Consequently, the net carbon balance between the atmosphere and the Central Amazon River-floodplain system is **neutral or maybe a small Carbon sink**.

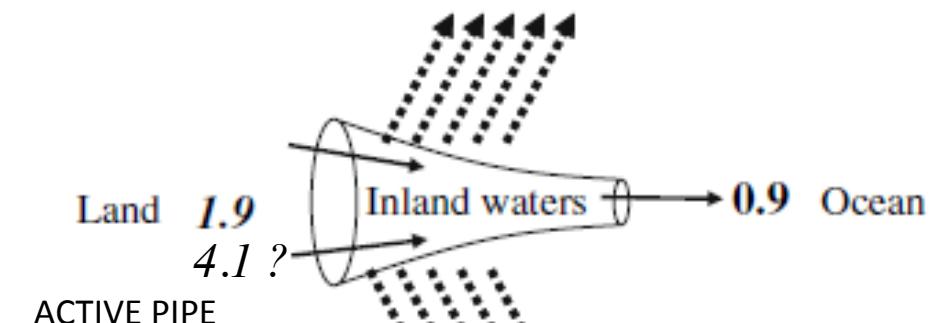




PASSIVE PIPE

CO₂ evasion

b **0.75 - 3** (+ wetlands)



ACTIVE PIPE

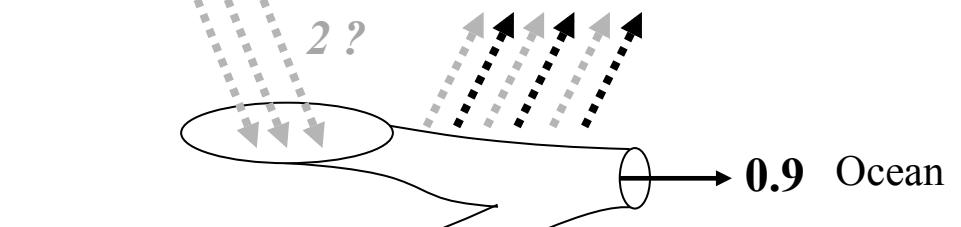
0.23

Sediment storage

Wetlands

0.75 - 3

2 ?



Land

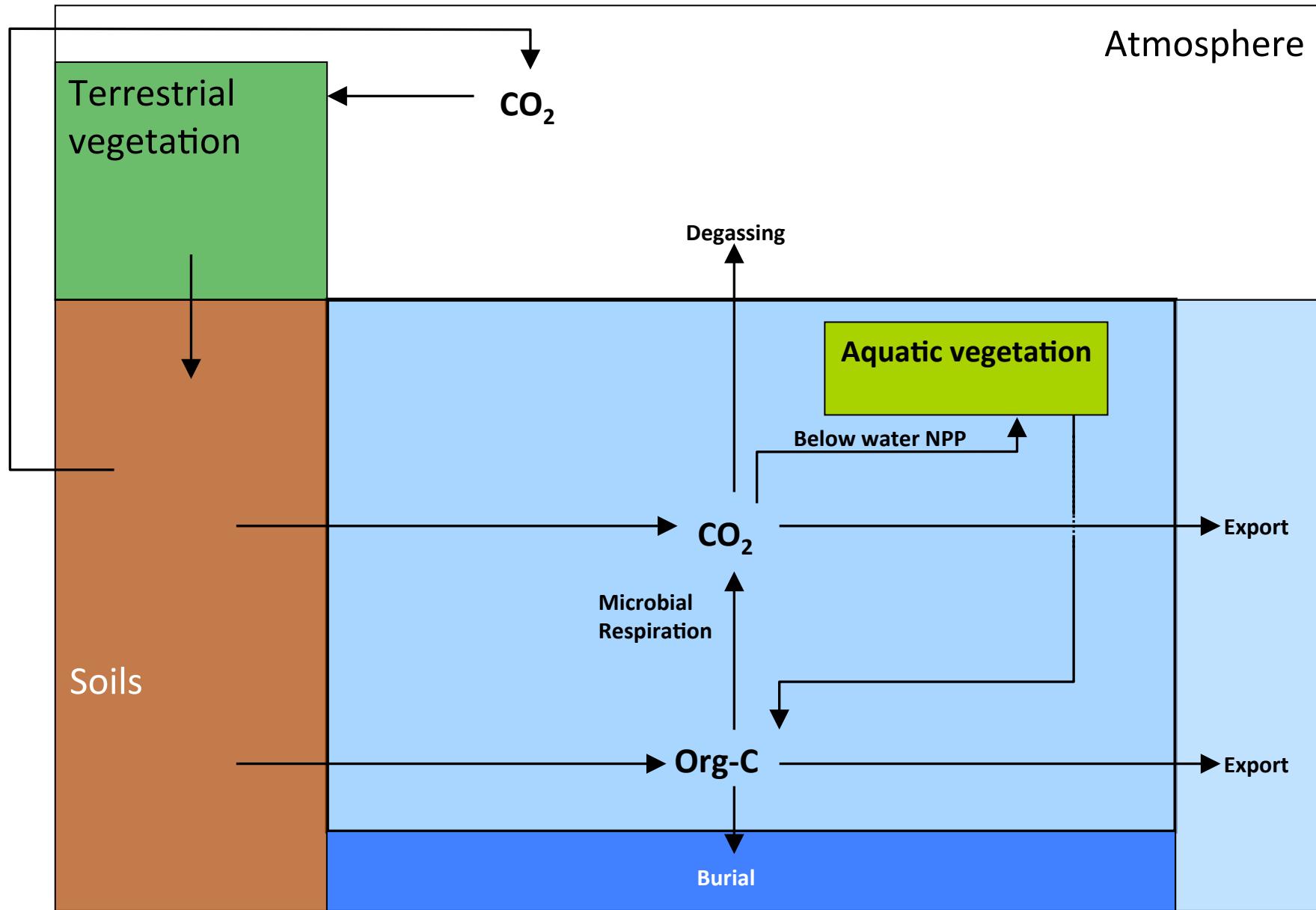
? →

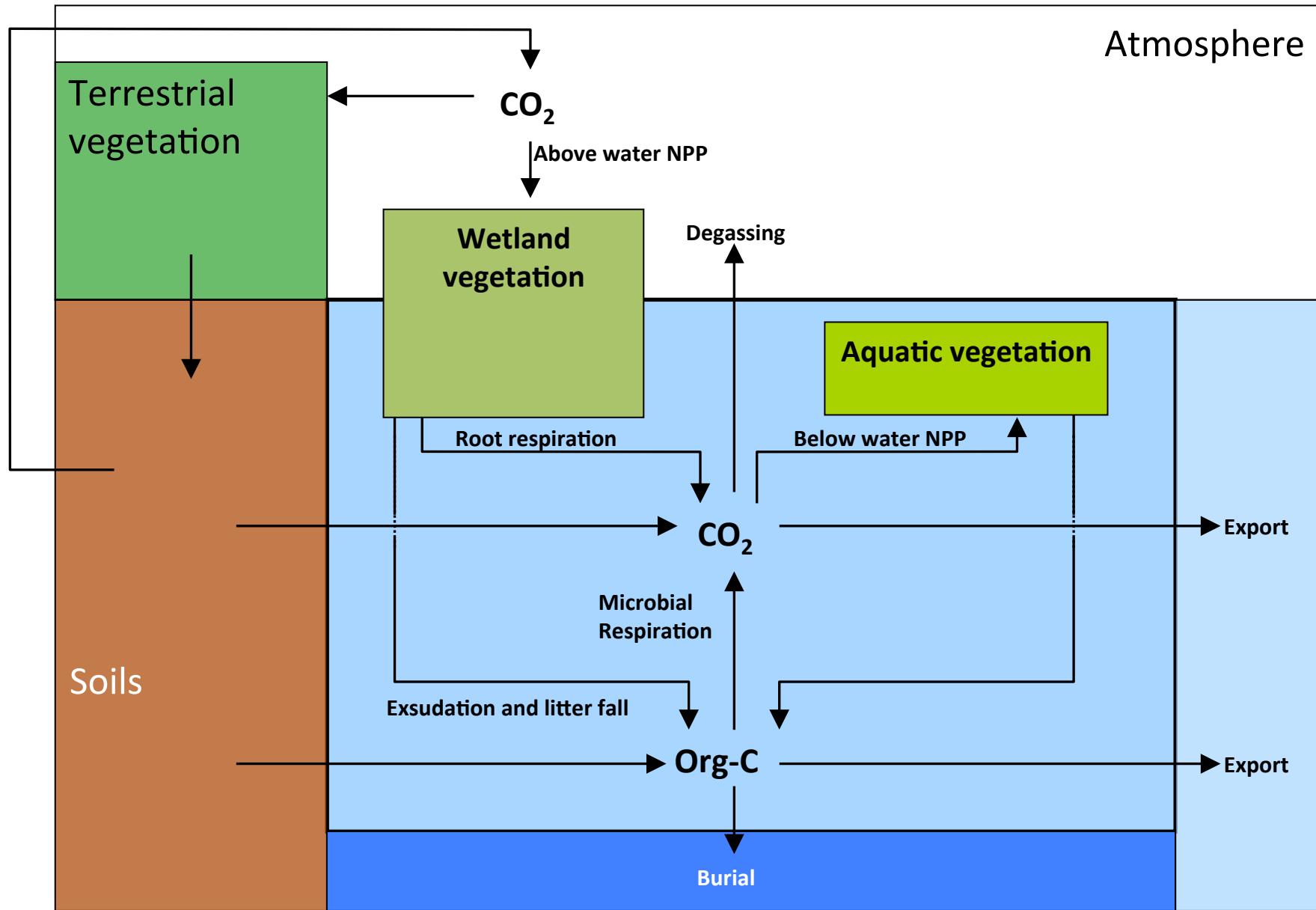
1.9 ?

SUPER ACTIVE PIPE

« TWO WAYS » ACTIVE PIPE

0.23





Disproportionate Contribution of Riparian Inputs to Organic Carbon Pools in Freshwater Systems

Trent R. Marwick,^{1*} Alberto Vieira Borges,² Kristof Van Acker,¹
François Darchambeau,² and Steven Bouillon¹

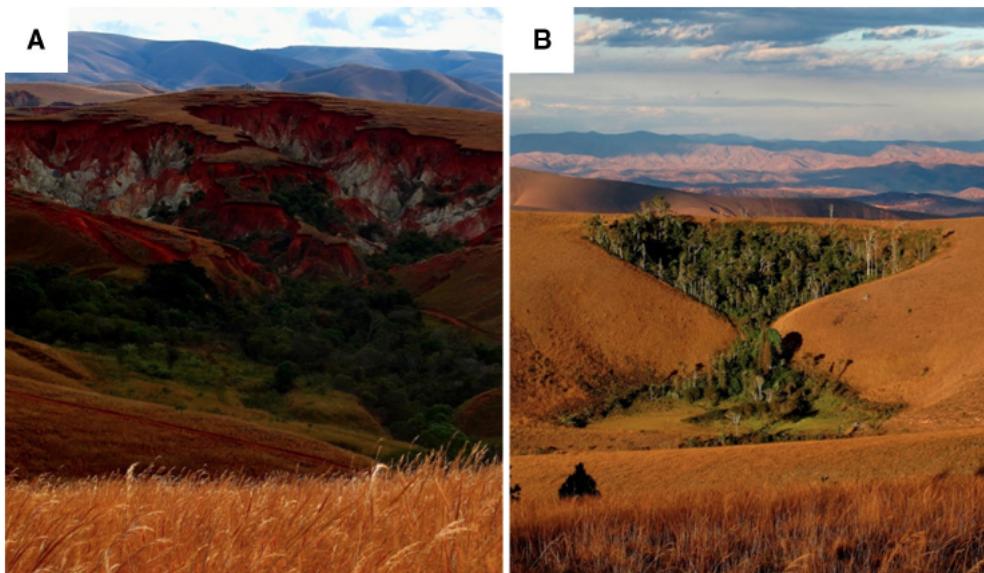
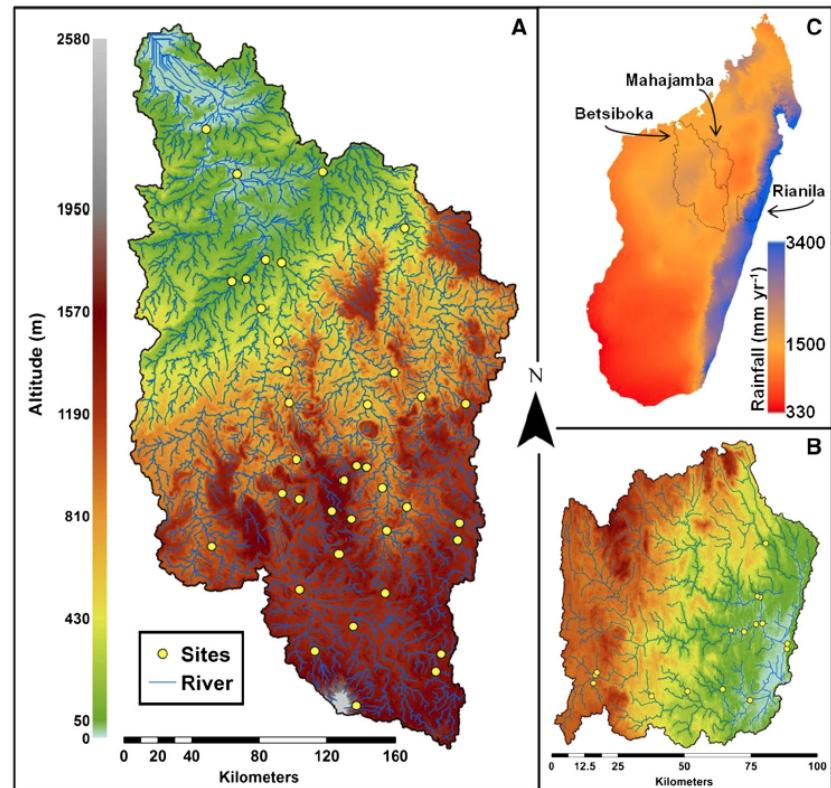
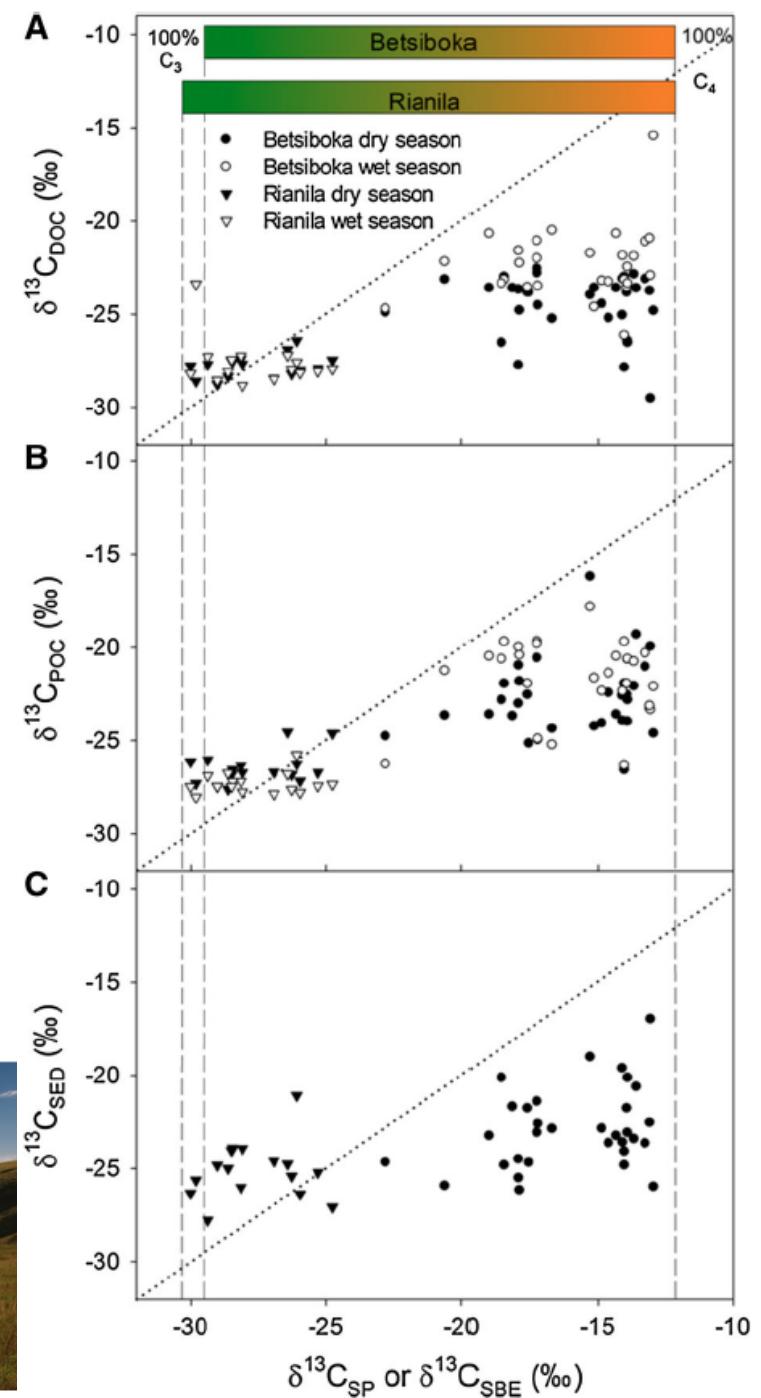
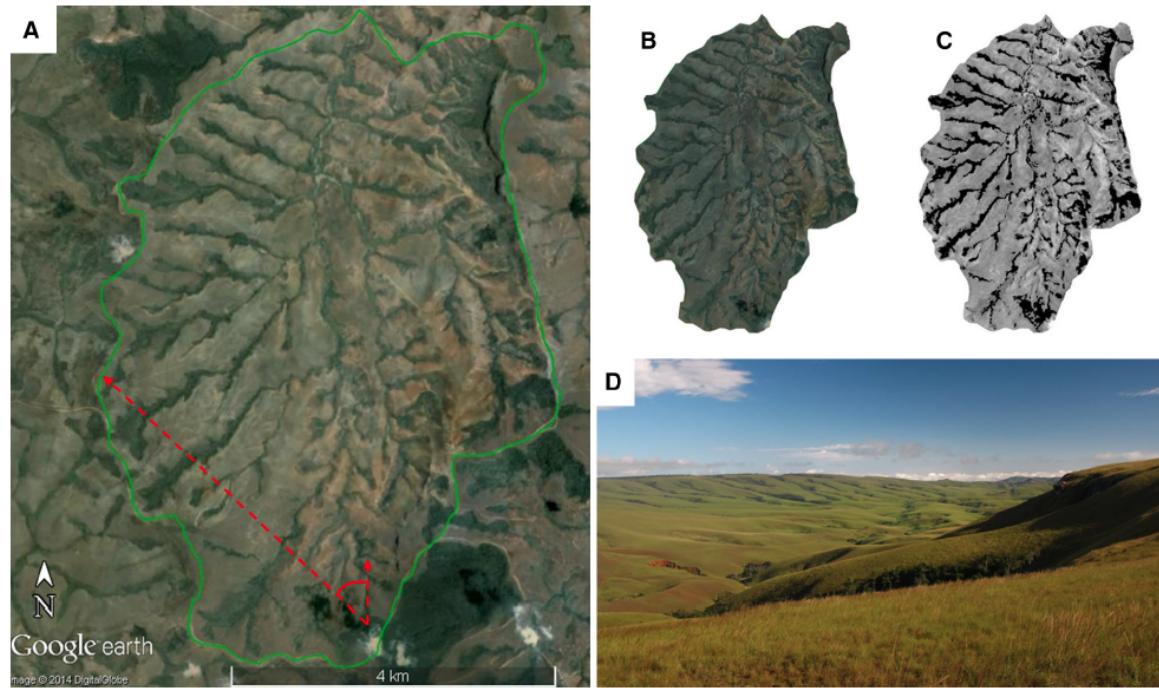


Figure 3. Examples of *lavakas* in the Hauts-Plateaux of central Madagascar. **A** With the collapse of the overlying lateritic soil layer, the more nutrient enriched saprolite layer becomes exposed. As *lavakas* evolve (**B**), often a C₃ dominant vegetation complex develops in response to increased nutrient and water availability (photos T.R.M.).

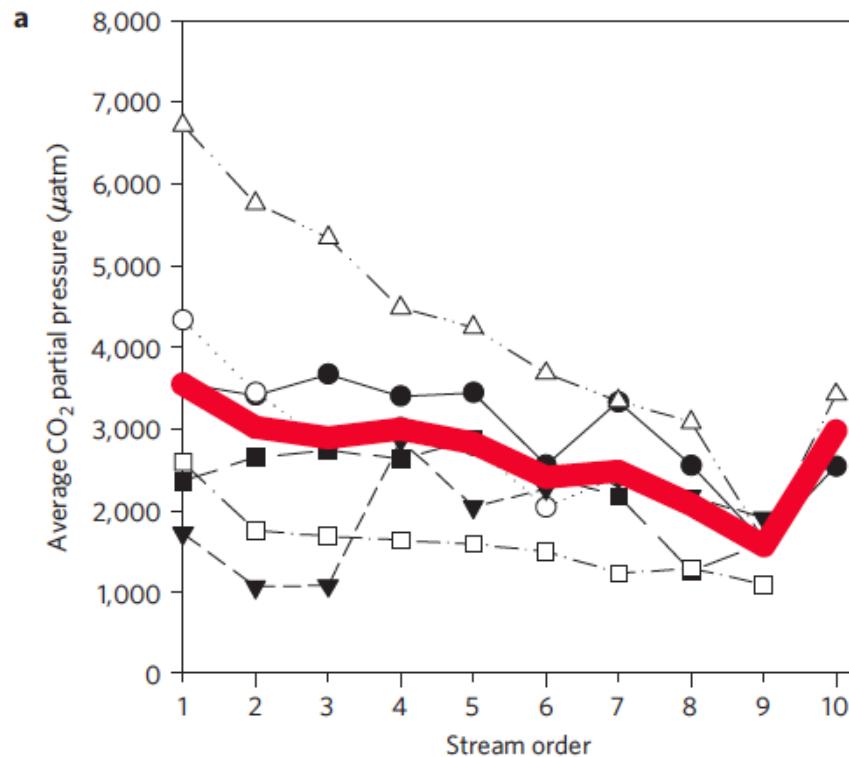
Disproportionate Contribution of Riparian Inputs to Organic Carbon Pools in Freshwater Systems

Trent R. Marwick,^{1,*} Alberto Vieira Borges,² Kristof Van Acker,¹
François Darchambeau,² and Steven Bouillon¹



Significant efflux of carbon dioxide from streams and rivers in the United States

David Butman* and Peter A. Raymond



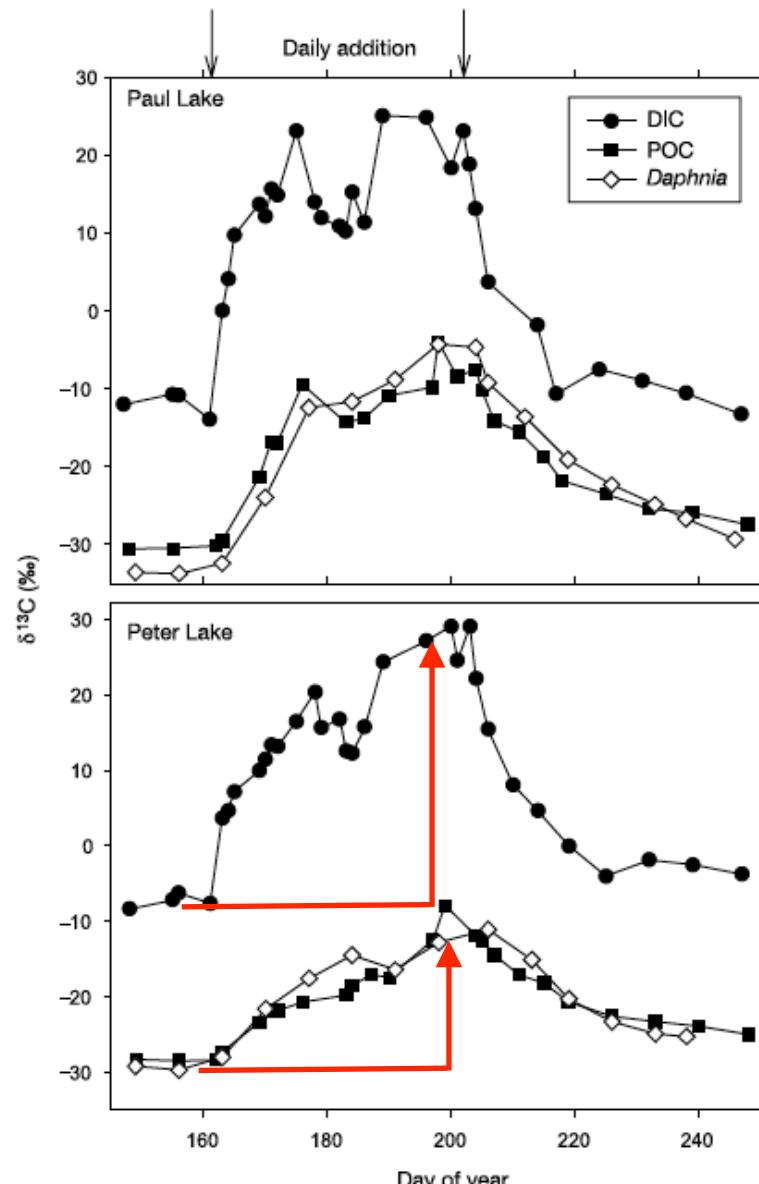
La ripsylve : source majeure de C pour les ruisseau d'ordre 1 ?

Whole-lake carbon-13 additions reveal terrestrial support of aquatic food webs

Michael L. Pace¹, Jonathan J. Cole¹, Stephen R. Carpenter²,
James F. Kitchell², James R. Hodgson³, Matthew C. Van de Bogert¹,
Darren L. Bade², Emma S. Kritzberg⁴ & David Bastviken⁵

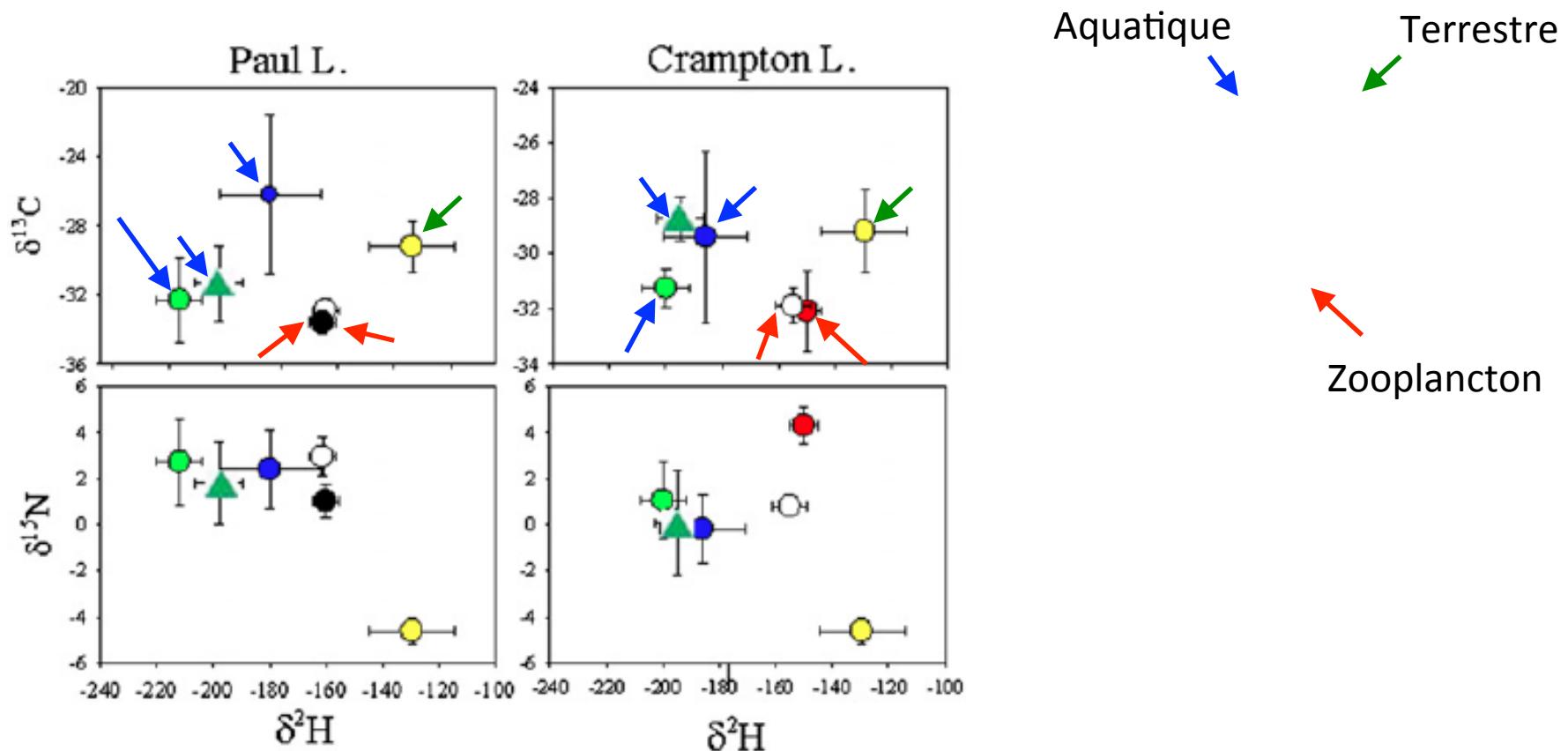
Table 1 Parameter values* for models of POC and *Daphnia* ^{13}C dynamics in Paul Lake and Peter Lake

POC	Model	ϵ_p	w	m	u	RSD	AIC
Paul Lake	1	17.8 ± 1.42				7.07	83.0
Paul Lake	2	9.5 ± 2.00	0.46 ± 0.047			3.21	66.1
Paul Lake	3	11.5 ± 0.90	0.40 ± 0.027	0.44 ± 0.071	8 ± 0.87	1.58	53.0
Peter Lake	1	21.6 ± 1.55				7.53	84.5
Peter Lake	2	10.2 ± 2.44	0.59 ± 0.042			2.49	59.9
Peter Lake	3	11.4 ± 1.25	0.55 ± 0.028	0.51 ± 0.116	9 ± 1.75	1.49	51.7
Daphnia							
Paul Lake	1	16.6 ± 1.94				7.45	56.8
Paul Lake	2	11.3 ± 3.21	0.38 ± 0.096			5.26	53.3
Paul Lake	3	14.5 ± 0.95	0.22 ± 0.045	0.56 ± 0.077	13 ± 1.07	2.22	43.5
Peter Lake	1	19.7 ± 1.89				7.03	49.2
Peter Lake	2	10.8 ± 3.06	0.55 ± 0.067			2.86	38.6
Peter Lake	3	12.5 ± 0.72	0.50 ± 0.020	0.92 ± 0.076	6 ± 0.48	0.83	25.2
Peter Lake	3	12.8 ± 1.08	0.48 ± 0.031	0.54 ± 0.073	$10\ddagger$	1.33	30.7



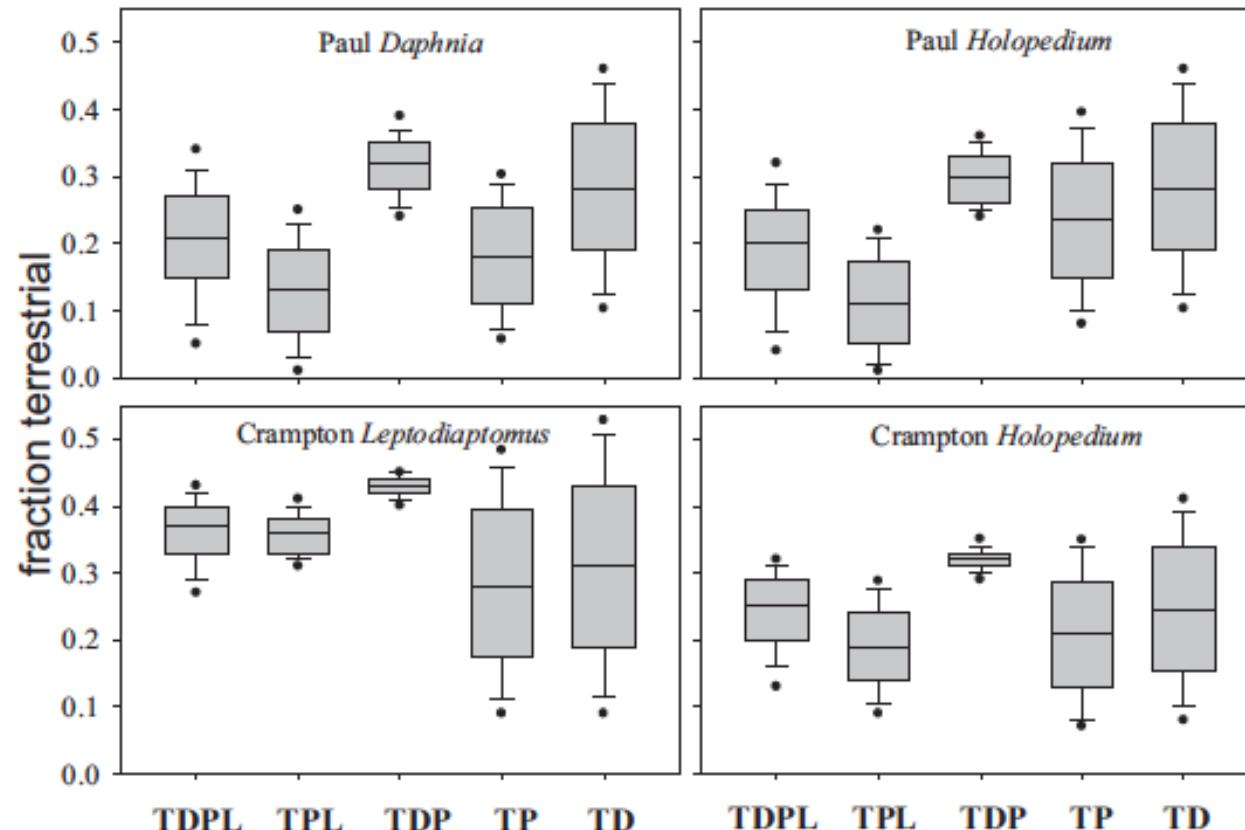
Strong evidence for terrestrial support of zooplankton in small lakes based on stable isotopes of carbon, nitrogen, and hydrogen

PNAS | February 1, 2011 | vol. 108 | no. 5 | 1975–1980

Jonathan J. Cole^{a,1}, Stephen R. Carpenter^b, Jim Kitchell^b, Michael L. Pace^c, Christopher T. Solomon^d, and Brian Weidel^e^aCary Institute of Ecosystem Studies, Millbrook, NY 12545; ^bCenter for Limnology, University of Wisconsin, Madison, WI 53706; ^cDepartment of Environmental Science, University of Virginia, Charlottesville, VA 22904; ^dDepartment of Natural Resource Sciences, McGill University, Sainte Anne de Bellevue, QC, Canada H9X 3V9; and ^eLake Ontario Biological Station, US Geological Survey, Oswego, NY 13126

Strong evidence for terrestrial support of zooplankton in small lakes based on stable isotopes of carbon, nitrogen, and hydrogen

PNAS | February 1, 2011 | vol. 108 | no. 5 | 1975–1980

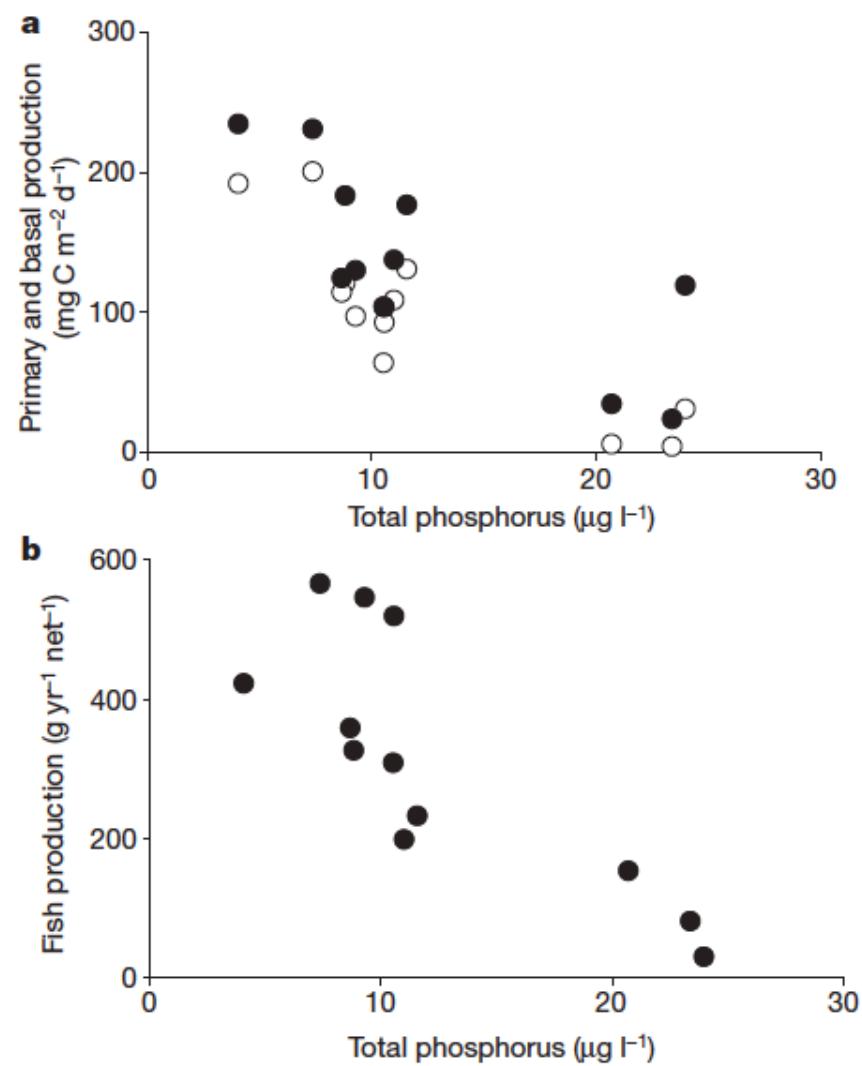
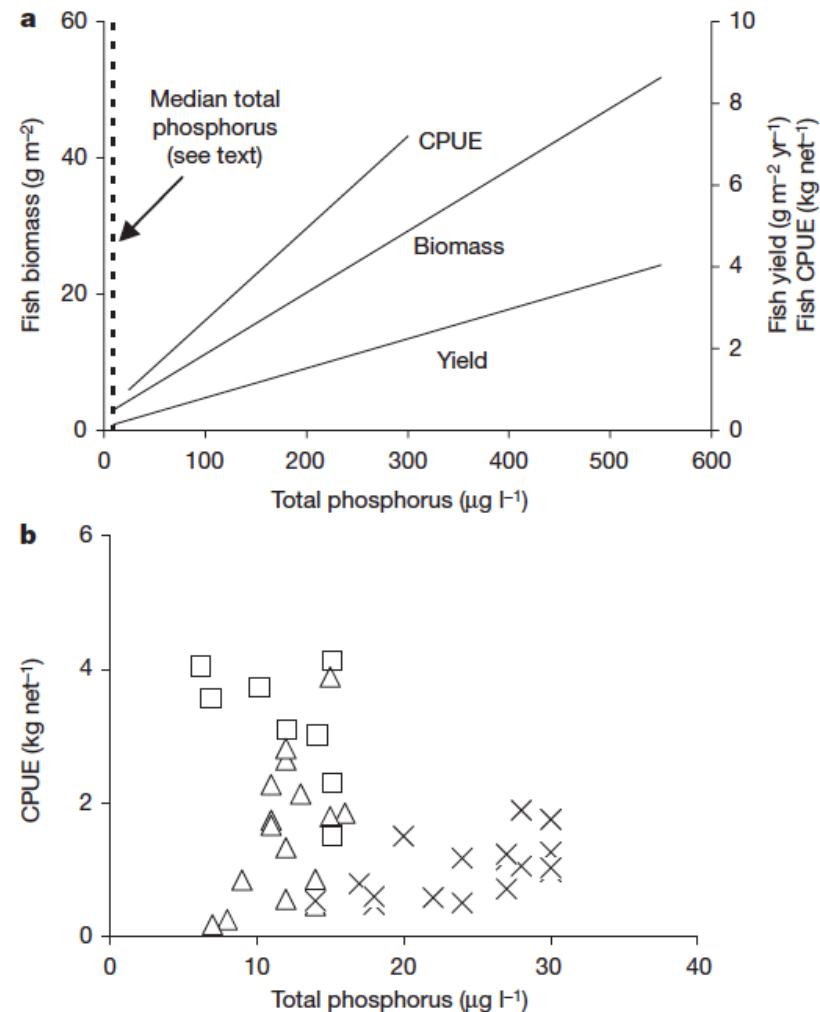
Jonathan J. Cole^{a,1}, Stephen R. Carpenter^b, Jim Kitchell^b, Michael L. Pace^c, Christopher T. Solomon^d, and Brian Weidel^e^aCary Institute of Ecosystem Studies, Millbrook, NY 12545; ^bCenter for Limnology, University of Wisconsin, Madison, WI 53706; ^cDepartment of Environmental Science, University of Virginia, Charlottesville, VA 22904; ^dDepartment of Natural Resource Sciences, McGill University, Sainte Anne de Bellevue, QC, Canada H9X 3V9; and ^eLake Ontario Biological Station, US Geological Survey, Oswego, NY 13126

of possible sources: T, terrestrial; P, phytoplankton in the upper mixed layer; D, phytoplankton at the chlorophyll max in oxic water; L, benthic algae.

LETTERS

Light limitation of nutrient-poor lake ecosystems

Jan Karlsson¹, Pär Byström², Jenny Ask², Per Ask², Lennart Persson² & Mats Jansson²



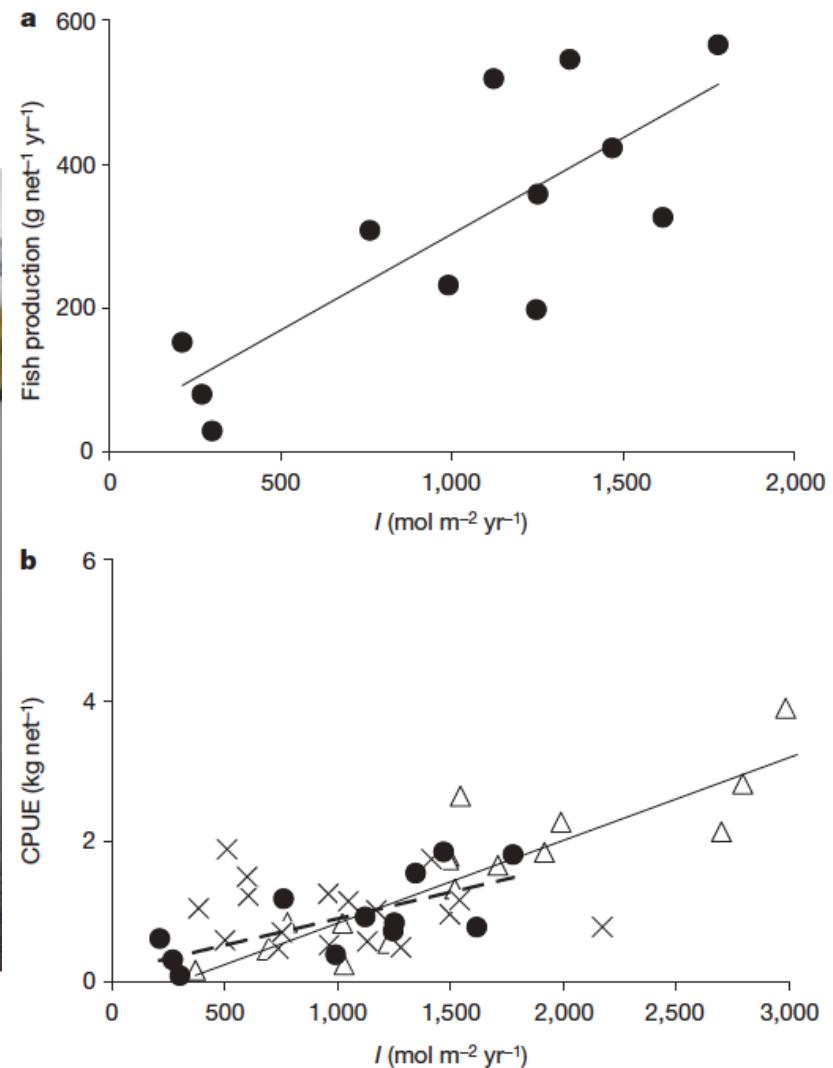
LETTERS

Light limitation of nutrient-poor lake ecosystems

Jan Karlsson¹, Pär Byström², Jenny Ask², Per Ask², Lennart Persson² & Mats Jansson²



Figure 1 | Clear difference. This example of a subarctic lake is nutrient-poor but productive because of a high-light climate stemming from the clear and shallow water¹.



Conclusions

Sur les continents, le milieu terrestre conditionne non seulement les flux biogéochimiques à travers les écosystèmes aquatiques, mais il influence aussi leur métabolisme et leur capacité trophique et contribue largement à structurer le fonctionnement de l'écosystème aquatique.

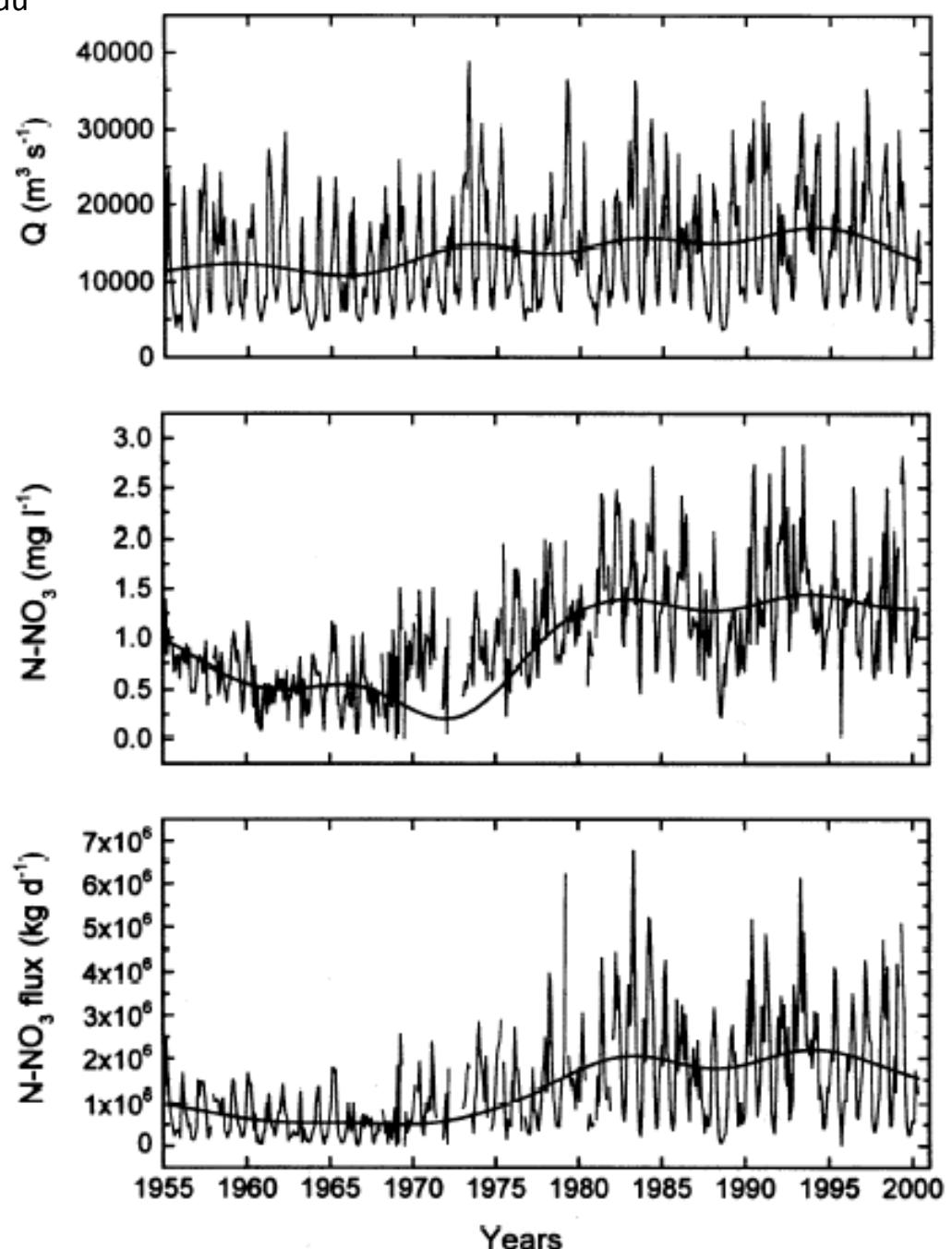
Même si elles ne représentent que 15% des continents au maximum, les surfaces inondées sont des zones de transit et de transformation préférentielles des éléments biogénés (hotspot) largement significatives à l'échelle globale. Elles se caractérisent aussi par une hétérogénéité spatio-temporelle extrême.

Si on a aujourd'hui une relativement bonne connaissance (retour d'expérience) de l'impact de l'usage des terres par l'Homme sur les écosystèmes aquatiques (eutrophisation), leur réponse au changement climatique est mal connu.

Combinaison d'effets directs sur le milieu aquatique (ex. température, cycle de l'eau et inondations), et indirects sur le milieu terrestre (ex. déstabilisation des sols et exportation de CDOM limitant le milieu aquatique en lumière)

Anthropisation des eaux continentales : 1^{er} témoin du
contrôle terrestre > aquatique

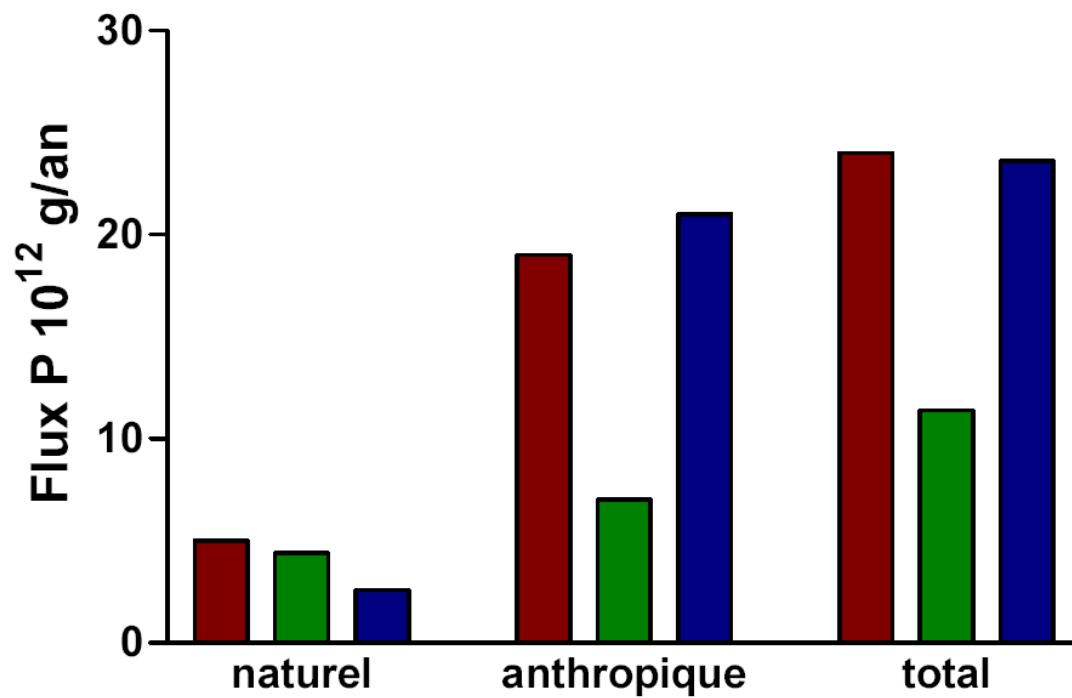
Mississippi



Justic et al 2002 Ecol. Model.

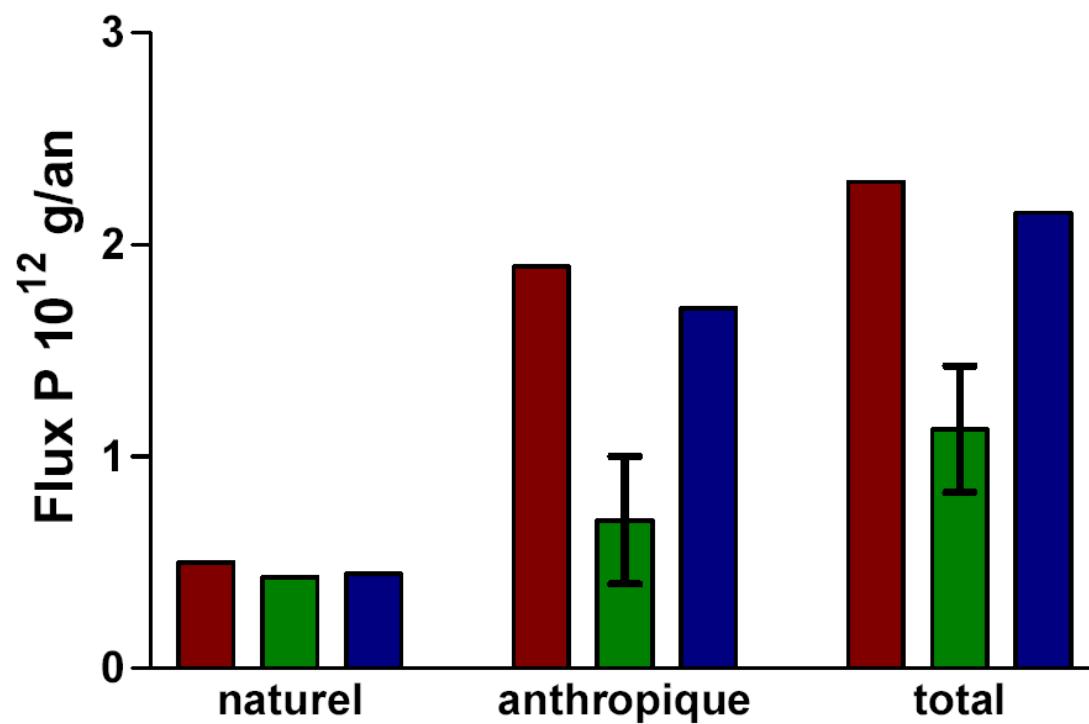
- Van Bennekom & Salomon 1981
- Meybeck 1982
- Wollast 1983

Transport de Nitrate et ammonium par les fleuves mondiaux

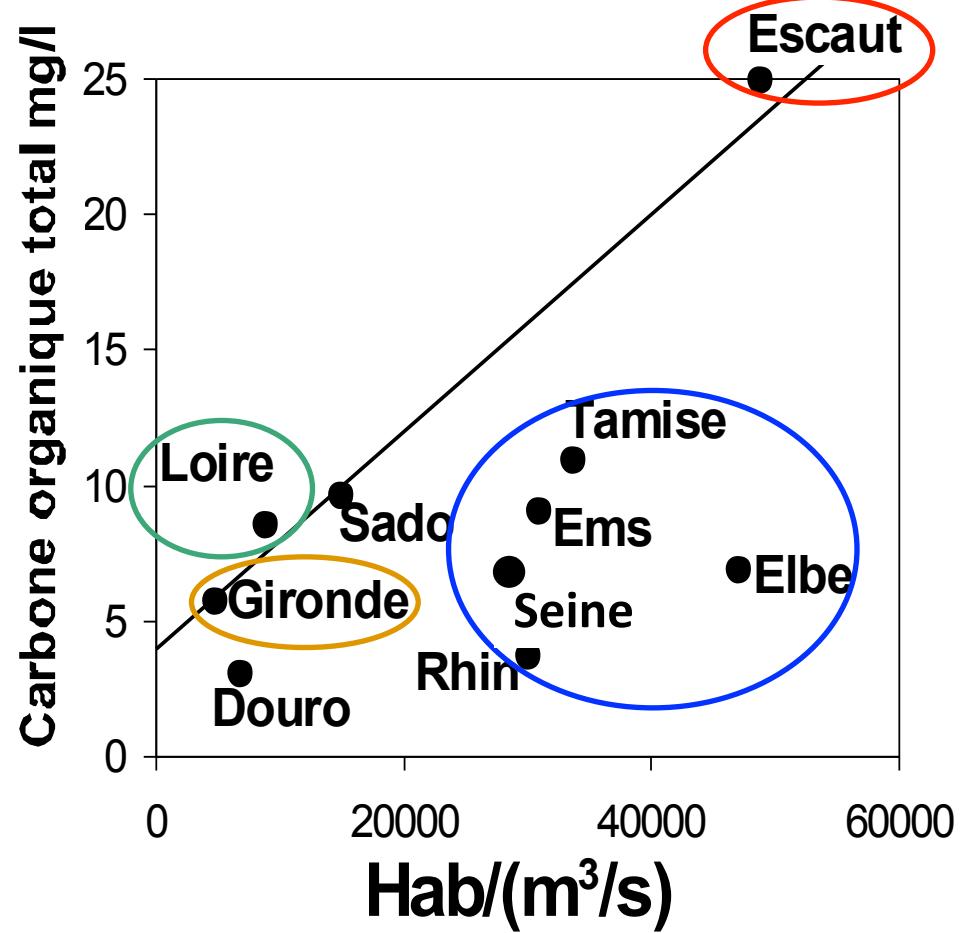


- Van Bennekom & Salomon
- Meybeck 1982
- Wollast 1983

Transport de Phosphates par les fleuves mondiaux

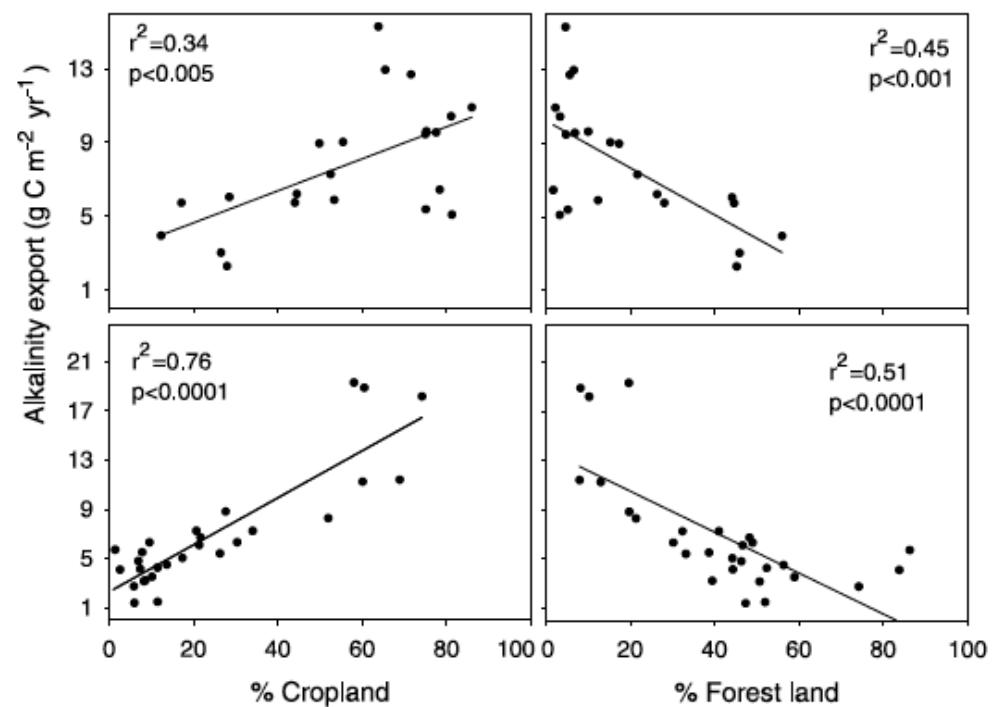
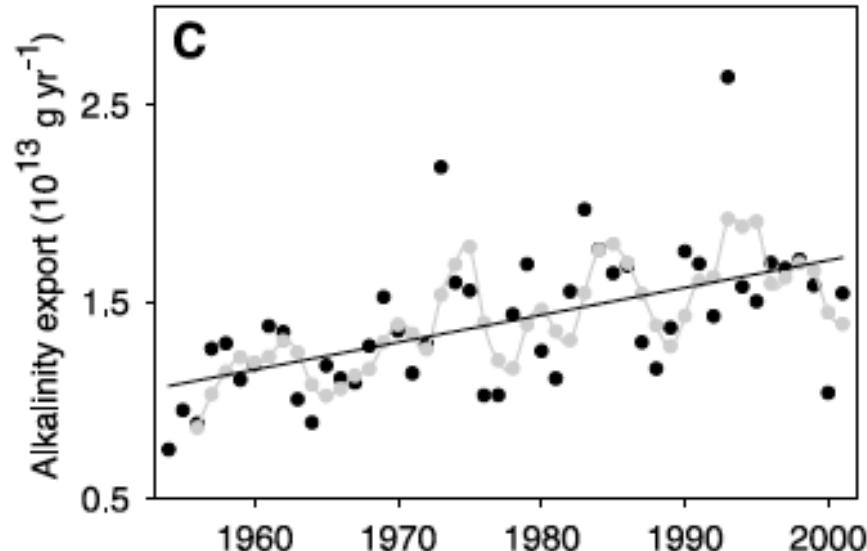


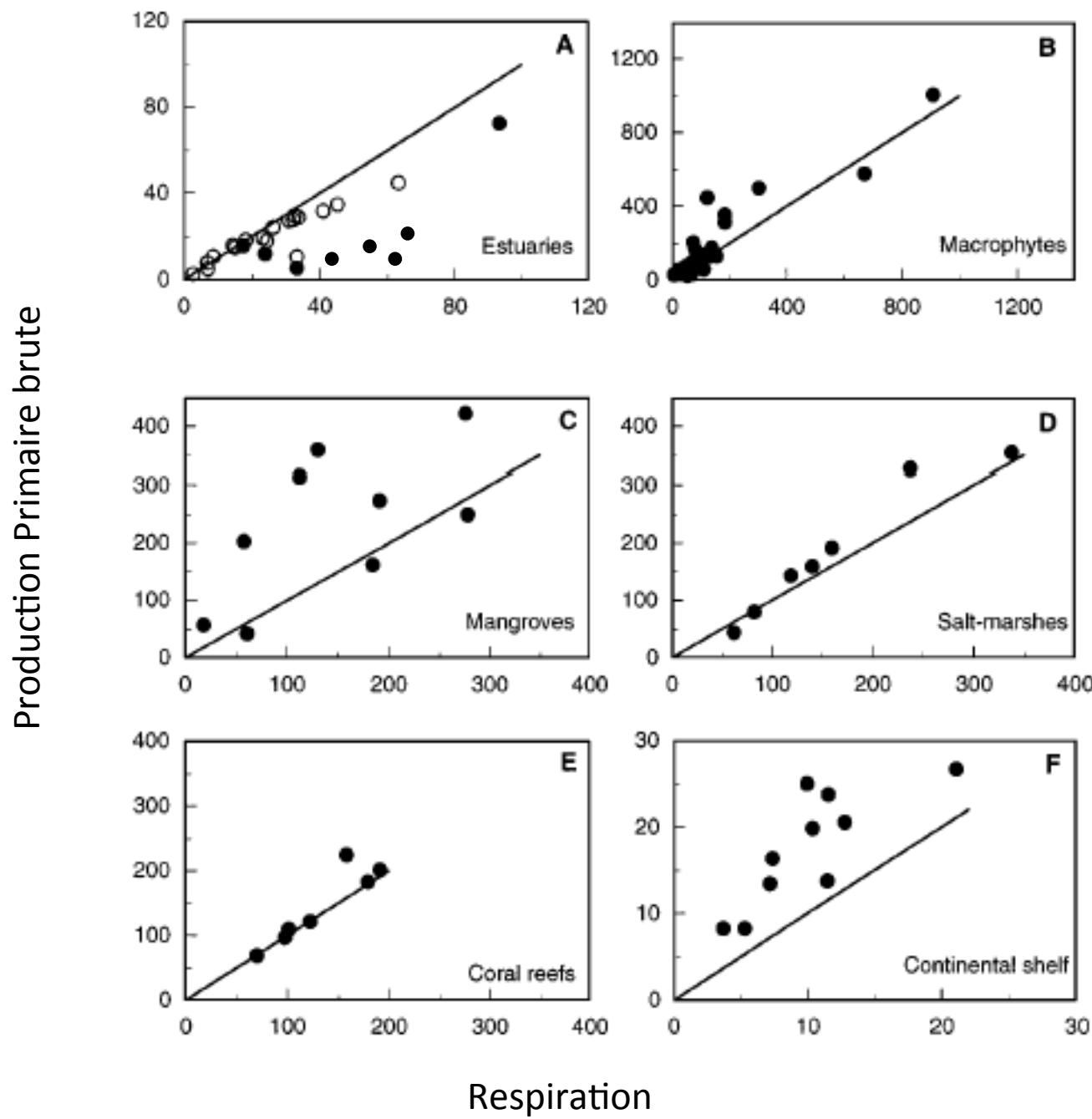
Carbone organique dans les fleuves



Increase in the Export of Alkalinity from North America's Largest River

Peter A. Raymond^{1*} and Jonathan J. Cole²





Gattuso et al
1998 *Ann Rev.
Ecol. Syst.*