The phosphorus imbalance in Nature

Phosphorus **supply** to natural ecosystems **is limited**

- Ash and dust deposition
- Free-up inaccessible soil P
- Weathering of mineral P

All small & uncertain processes

Phosphorus **demand is growing** due to human activities

- **Increasing CO2**, global effect
- **Increasing N** deposition, mainly over industrialized regions
- **Climate change**, e.g. longer growing seasons in boreal areas

P Imbalance

The phosphorus imbalance in Nature

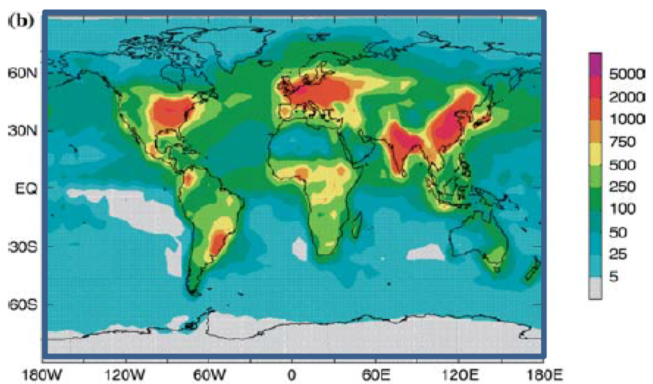
Phosphorus **supply** to natural ecosystems **is limited**

Phosphorus **demand is growing** due to human activities

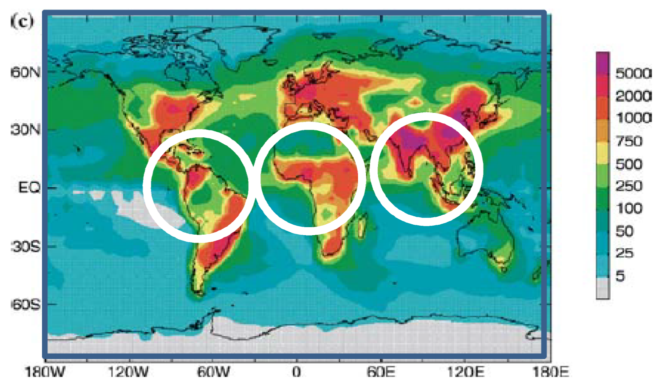
The P-imbalance will alter ecosystems, carbon sinks, and climate

The phosphorus imbalance in tropical areas

- During the 21st century:
  - N deposition will continue, but slow down, over northern areas.
  - N deposition will **increase dramatically over tropical areas.**



1990



2050

- This will cause the N to P deposition ratio to increase.
- Unlike northern ecosystems, most **tropical forests** are more limited by P than by N.

The phosphorus imbalance in tropical areas

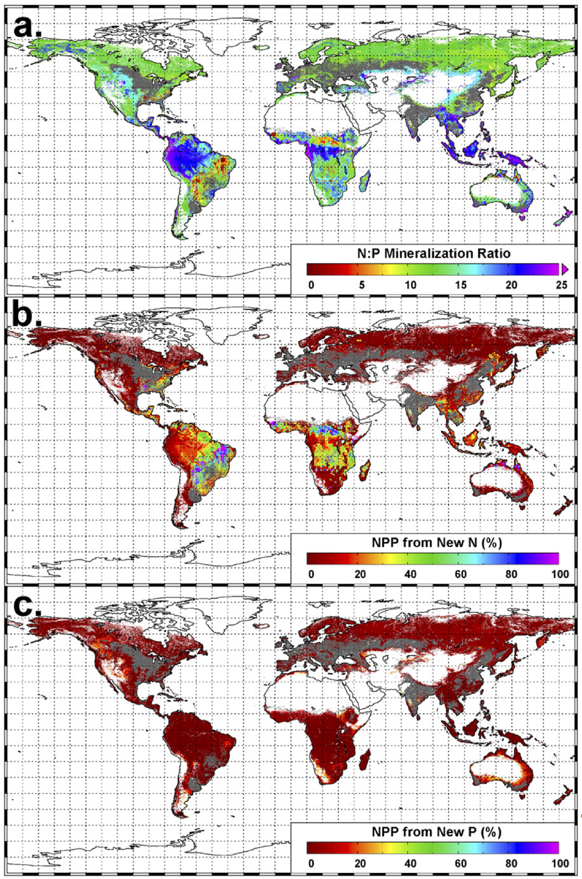
- During the 21st century:
  - N deposition will continue, but slow down, over northern areas.
  - N deposition will **increase dramatically over tropical areas.**

There exist no measurement of the phosphorus imbalance of tropical forests and its consequences

- This will cause the N to P deposition ratio to increase.
- Unlike northern ecosystems, most **tropical forests** are more limited by P than by N.

NPP limited by nutrients

Global N:P mineralization



%NPP from new N

%NPP from new P

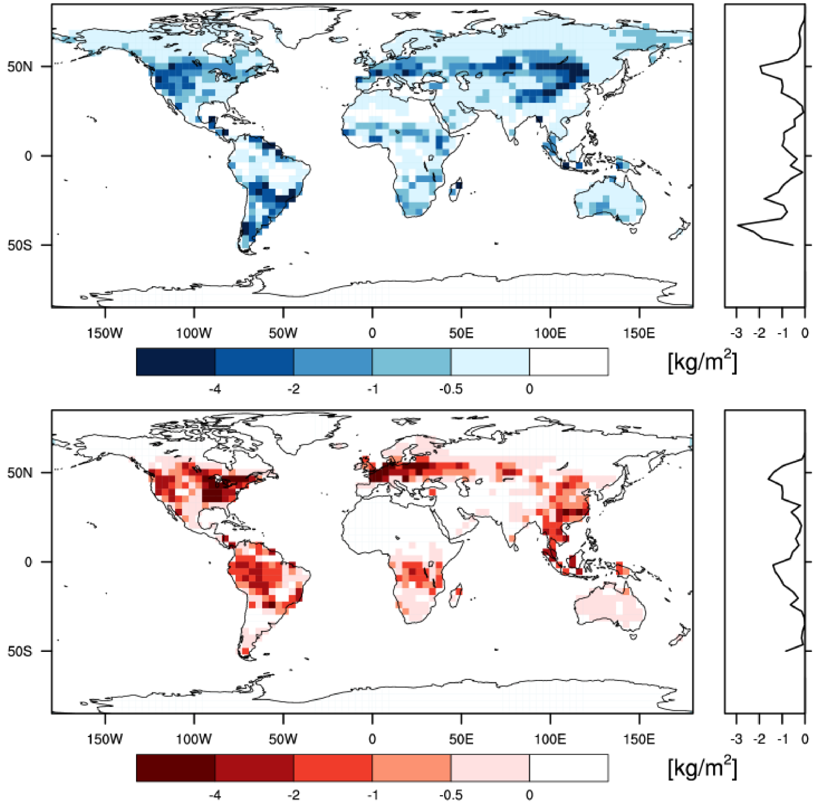
Biome	Area, Mkm^2	Total NPP, Pg·C·y^{-1}	NPP from new N: Pg·C·y^{-1}	NPP from new N: % Total	NPP from new P: Pg·C·y^{-1}	NPP from new P: % Total
ENF	6.17	2.86	0.07 (0.07–0.09)	2.6 (2.3–3.1)	0.12 (0.07–0.13)	4.1 (2.5–4.5)
EBF	16.21	17.49	3.06 (2.01–4.15)	17.5 (11.5–23.7)	0.08 (0.07–0.16)	0.5 (0.4–0.9)
DNF	1.62	0.56	0.02 (0.02–0.02)	2.9 (2.9–2.9)	0.03 (0.03–0.03)	5.7 (5.2–5.7)
DBF	1.12	0.71	0.16 (0.05–0.31)	21.9 (6.4–43.4)	0.01 (0.01–0.02)	2.0 (1.0–2.2)
MIX	7.46	4.30	0.23 (0.08–0.42)	5.5 (1.9–9.7)	0.14 (0.07–0.14)	3.3 (1.7–3.3)
SHB	26.98	4.75	0.20 (0.11–0.38)	4.2 (2.4–8.0)	0.23 (0.21–1.05)	4.9 (4.4–22.1)
WSV	7.71	4.94	1.30 (0.12–2.14)	26.3 (2.5–43.2)	0.06 (0.04–0.09)	1.2 (0.7–1.7)
SVN	10.78	6.23	1.88 (0.18–3.36)	30.1 (2.9–53.9)	0.10 (0.04–0.14)	1.7 (0.7–2.3)
GRS	11.15	2.52	0.04 (0.01–0.13)	1.6 (0.5–5.1)	0.11 (0.09–0.24)	4.2 (3.6–9.5)
Total	88.20	44.35	6.87 (2.73–10.98)	15.7 (6.0–24.8)	0.89 (0.62–2.00)	2.0 (1.4–4.5)

The median values of within-biome spatial variability are reported for NPP from new nutrients. Values in parentheses represent the within-biome interquartile range in spatial variability. These estimates integrate the spatial variability observed in all internal and external nutrient inputs (Figs. S2 and S4). DBF, deciduous broadleaf forest; DNF, deciduous needleleaf forest; EBF, evergreen broadleaf forest; ENF, evergreen needleleaf forest; GRS, grassland; MIX, mixed forest; SHB, closed shrublands; SVN, savannas; and WSV, woody savannas.

Leaf N:P ratio in tropical forest = 50-68
Leaf N:P ratio in temperate forest = 30

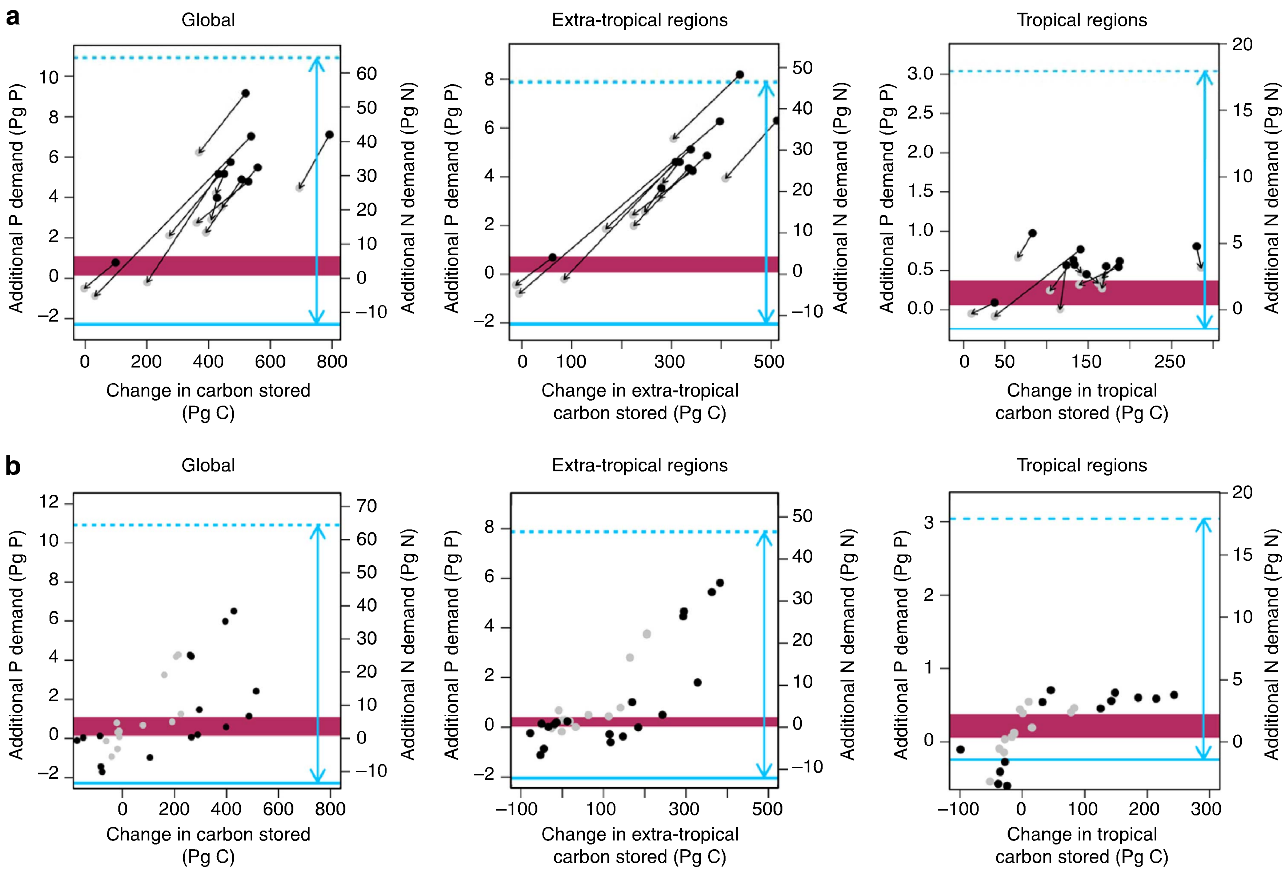
Cleveland et al. PNAS 2014

Reduction in C storage by nutrient limitation by end of 21st Century



Goll et al. Biogeosciences 2012

Tropical and global N and P limitations to carbon storage in C4MIP and CMIP5 models

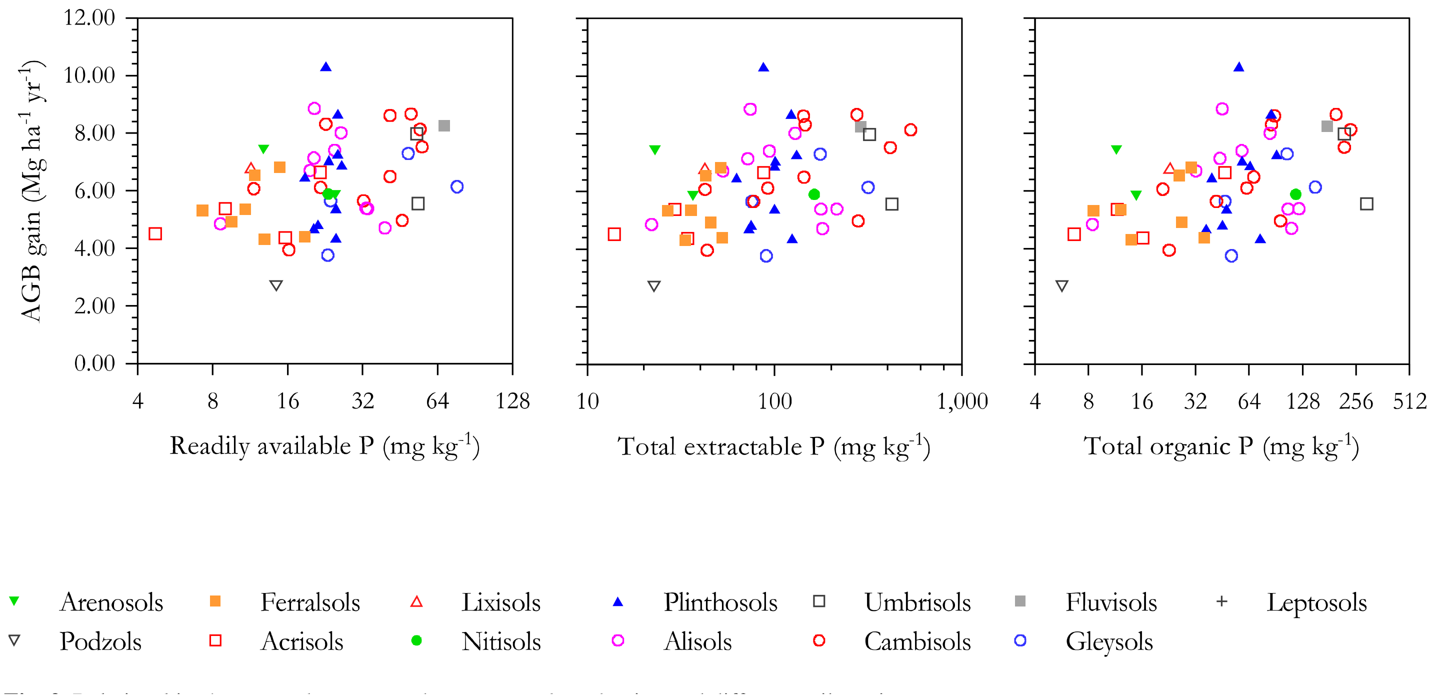


C4MIP

CMIP5

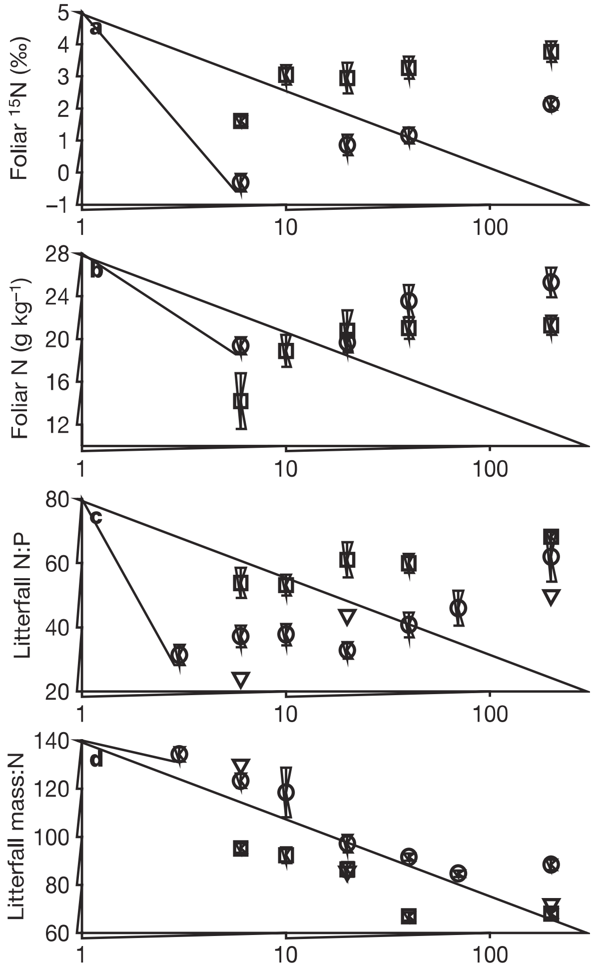
Penuelas et al. Nature Com 2013

Background P limitations of Amazon forest above-ground wood production



Quesada et al. Biogeosciences 2012

Shift from N to P limitation in Amazon regrowing secondary forests



15N enrichment indicates leaky N cycle through denitrification fractionation

Increasing N availability with age

N:P ratio increase indicates shift from N economy to P economy

Litter mass:N ratio decreases with age (early values similar to N-limited temperate forest)

Davidson et al. Nature 2007

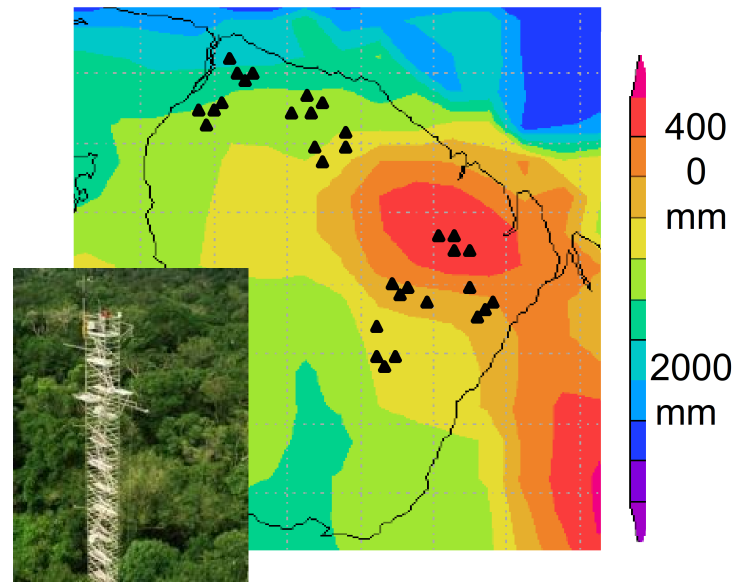
Imbalance P

① Experiments in French Guiana?

Species level: 5000 trees (700 species)

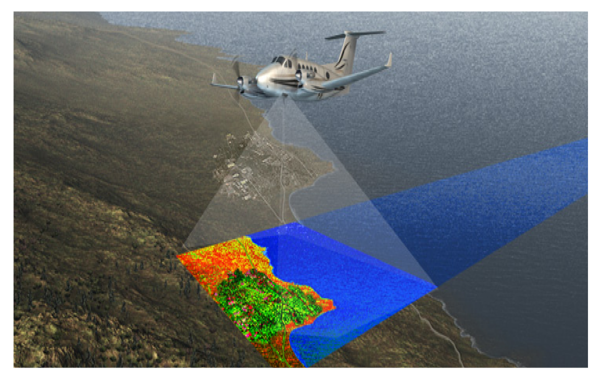
Community & Ecosystem level

- 40 forest plots
- Each with 15N deposition treatment
- Two with eddy covariance



Regional level: aircraft campaigns

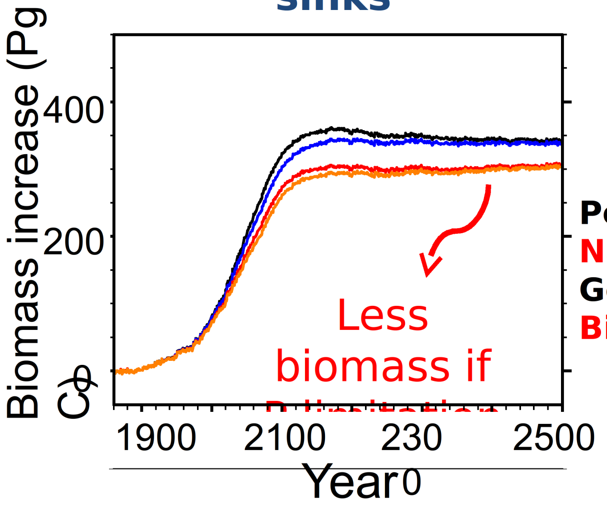
- Greenhouse gas fluxes
- Atmospheric composition
- Airborne remote sensing of biomass and photosynthesis



② Earth System & Climate response

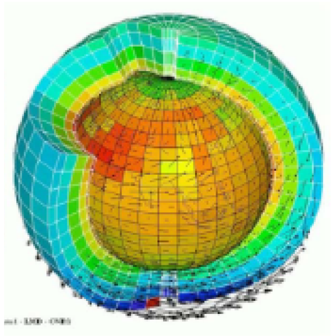
We will build phosphorus interactions in the IPSL Earth System model to quantify P feedbacks on climate.

P-imbalance will have a BIG reduction effect on carbon sinks



Penuelas et al. Nature Comm. 2013
Goll et al. Biogeociences 2013

But global models have ignored P-processes so far



- 30 climate models in the World
- 8 with carbon climate interactions
- 3 with nitrogen imbalance
- **No Earth System model with phosphorus imbalance.**

Imbalance

ERC Synergy Grant 2013

Quantify the responses of ecosystems and society in a world increasingly rich in N and C but limited in Phosphorus

P.Ciais, I.Janssens, M.Obersteiner, J.Peñuelas