Nutrients as a strong plant growth regulator

1.845: The terrestrial carbon cycle and ecosystem ecology

Civil and Environmental Engineering

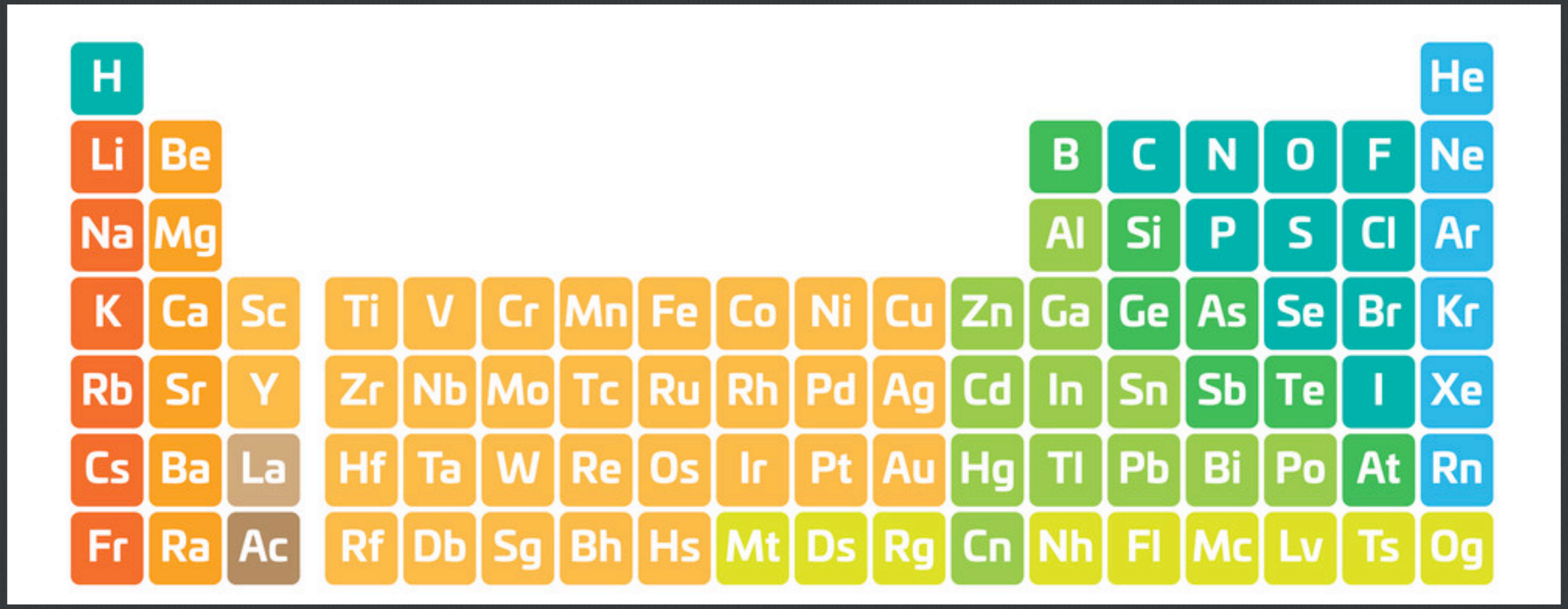
Helena Vallicrosa
helenavp@mit.edu

What are you going to learn?

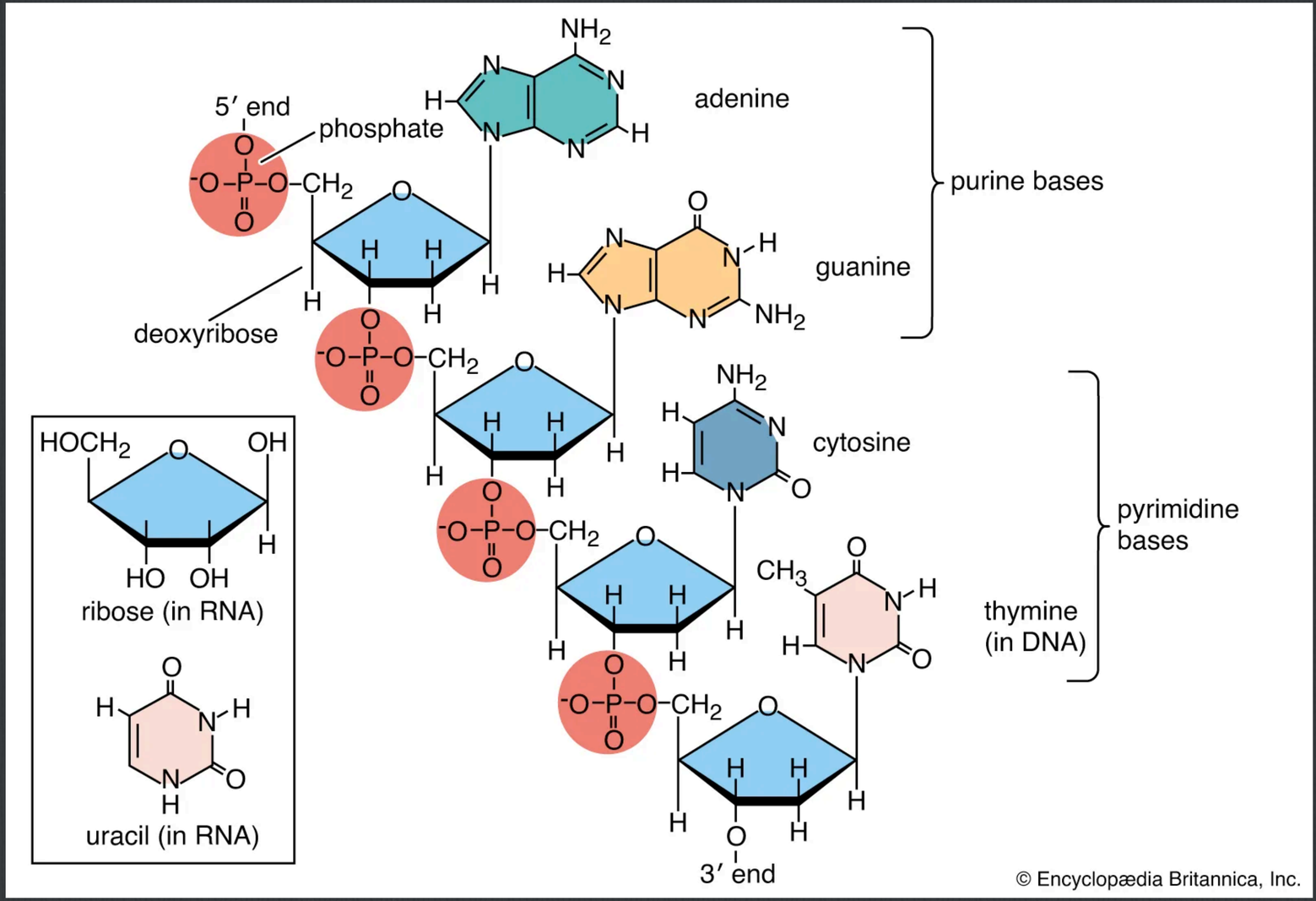
- ☐ <u>FROM MOLECULES TO ECOSYSTEMS</u>
  - ☐ Explain the importance of nutrients in plants and how they affect biological processes
  - ☐ Describe the concept of nutrient limitation and nutrient resorption
- ☐ <u>GLOBAL SCALE PATTERNS</u>
  - ☐ Describe global N and P cycle
  - ☐ Enumerate N and P cycle differences and how those translate to global scale
- ☐ <u>BIOGEOCHEMICAL DISRUPTION IN THE ANTHROPOCENE</u>
  - ☐ Describe how humans are affecting biogeochemical cycles and its implications in natural ecosystems
  - ☐ How N, P and nutrients in general affect C sink

From molecules to systems

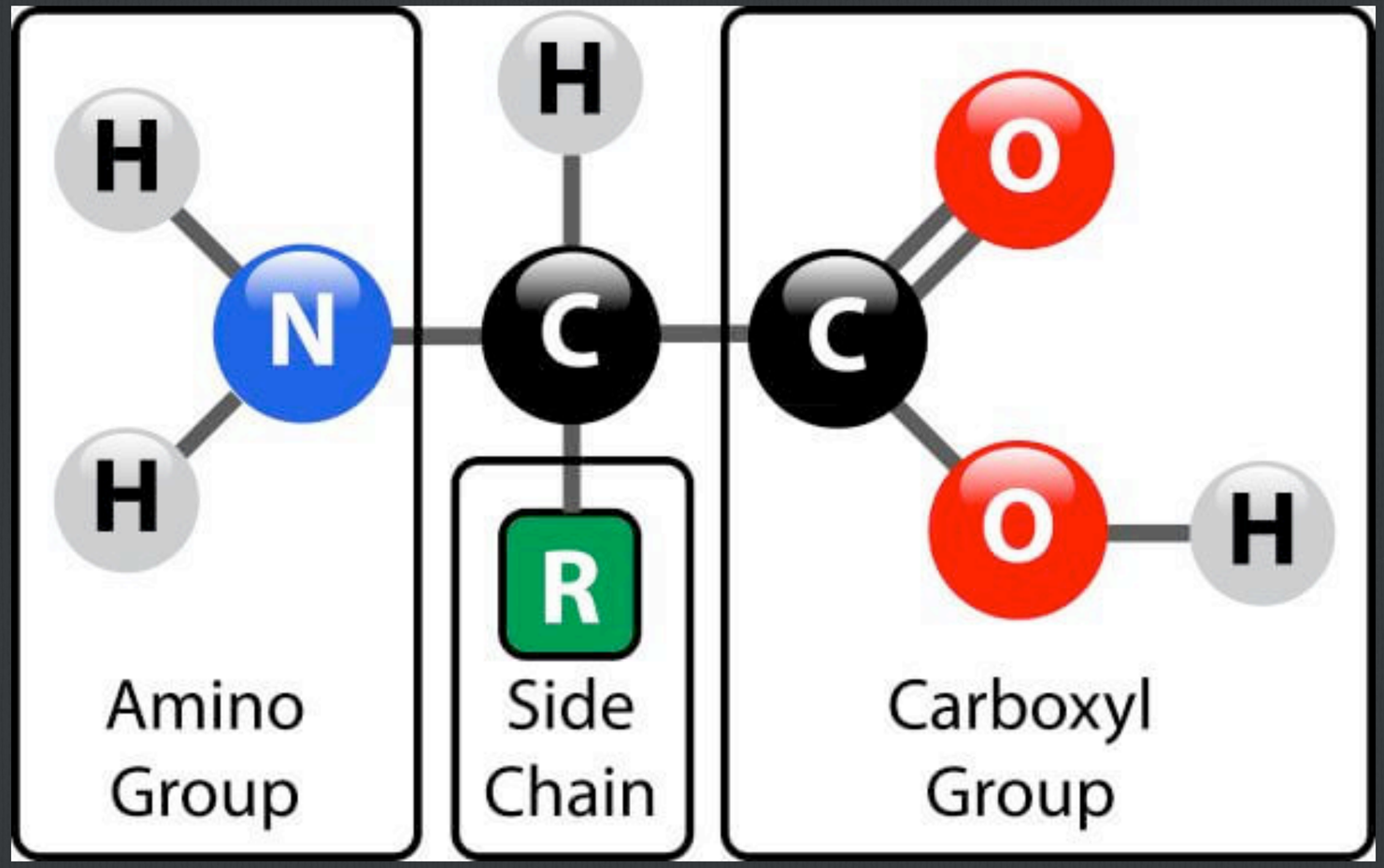
Context in BGC: Reactive non-metals



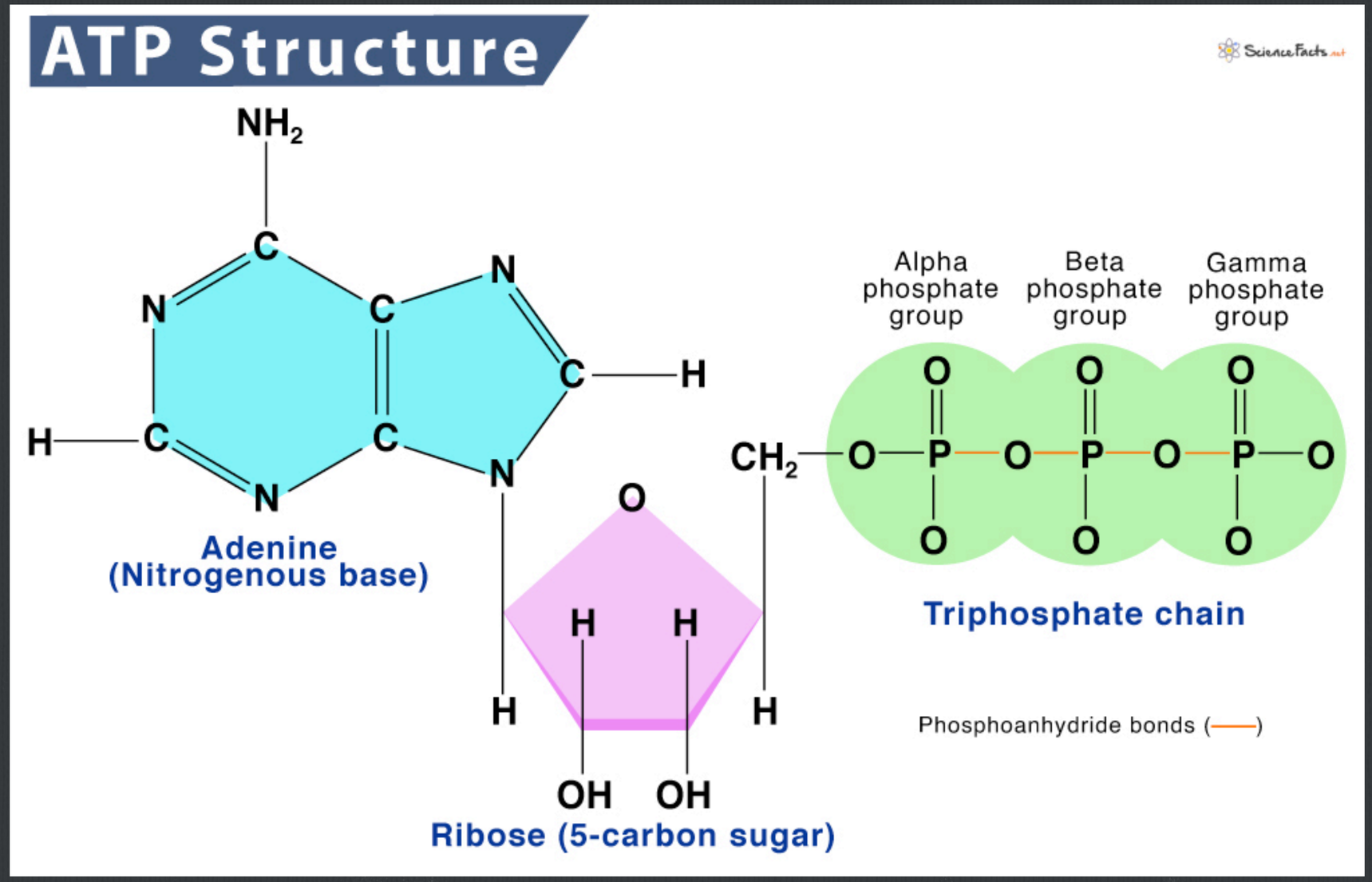
Context in BGC: DNA-RNA



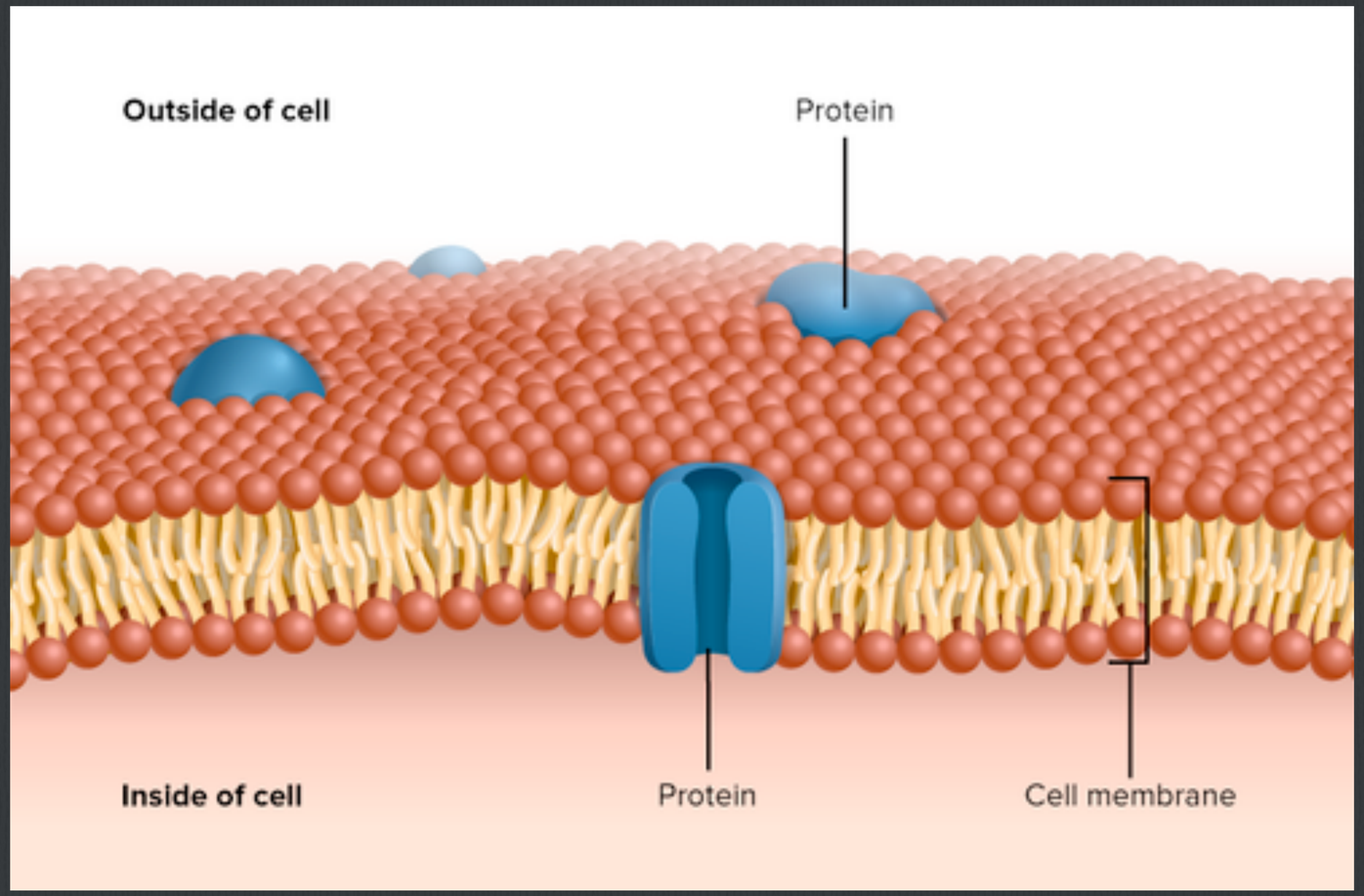
Context in BG: Proteins and amino-acids

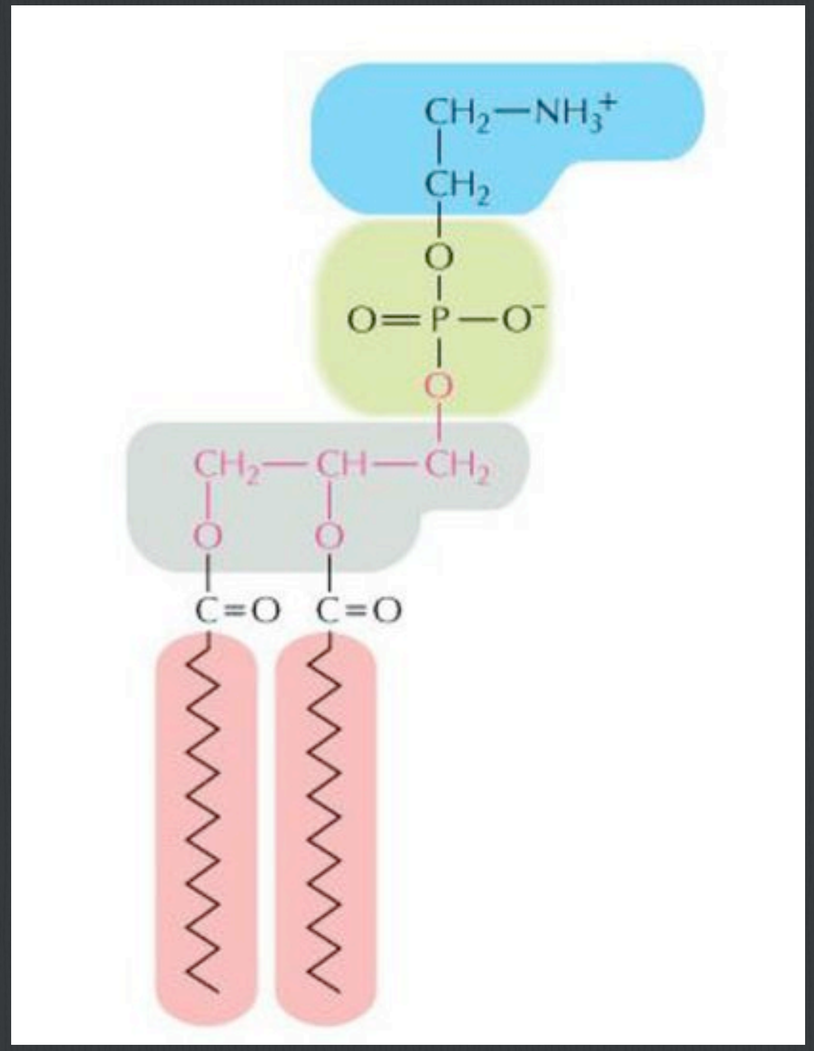


Context in BGC: ATP

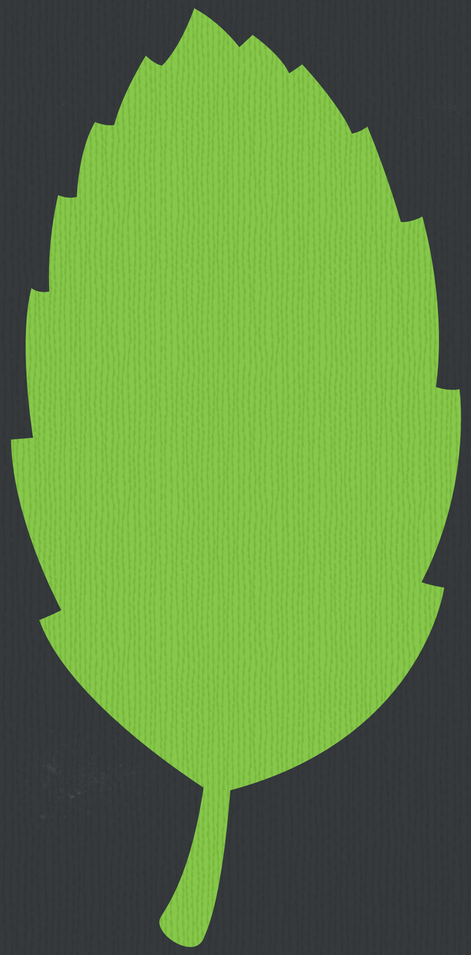


Context in BGQ: Phospholipid





Plant individual level



Article | Published: 04 January 2021

Empirical support for the biogeochemical niche hypothesis in forest trees

Jordi Sardans, Helena Vallicrosa, Paolo Zuccarini, Gerard Farré-Armengol, Marcos Fernández-Martínez, Guille Peguero, Albert Gargallo-Garriga, Philippe Ciais, Ivan A. Janssens, Michael Obersteiner, Andreas Richter & Josep Peñuelas

Nature Ecology & Evolution **5**, 184–194 (2021) | Cite this article

2654 Accesses | **22** Citations | **12** Altmetric | Metrics

Tansley review

N : P ratios in terrestrial plants: variation and functional significance

Sabine Güsewell

Geobotanical Institute ETH, Zürichbergstrasse 38, 8044 Zürich, Switzerland

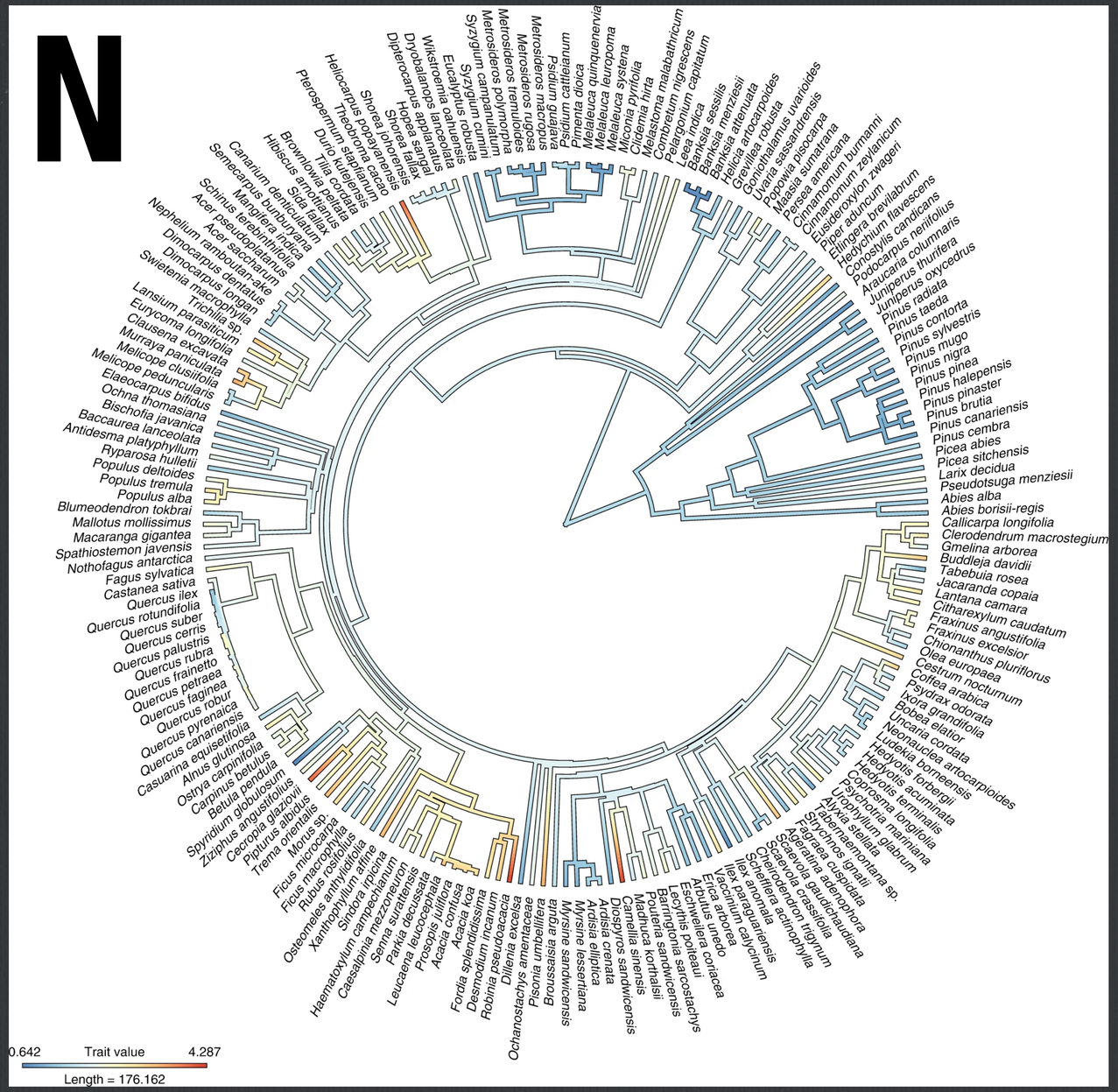
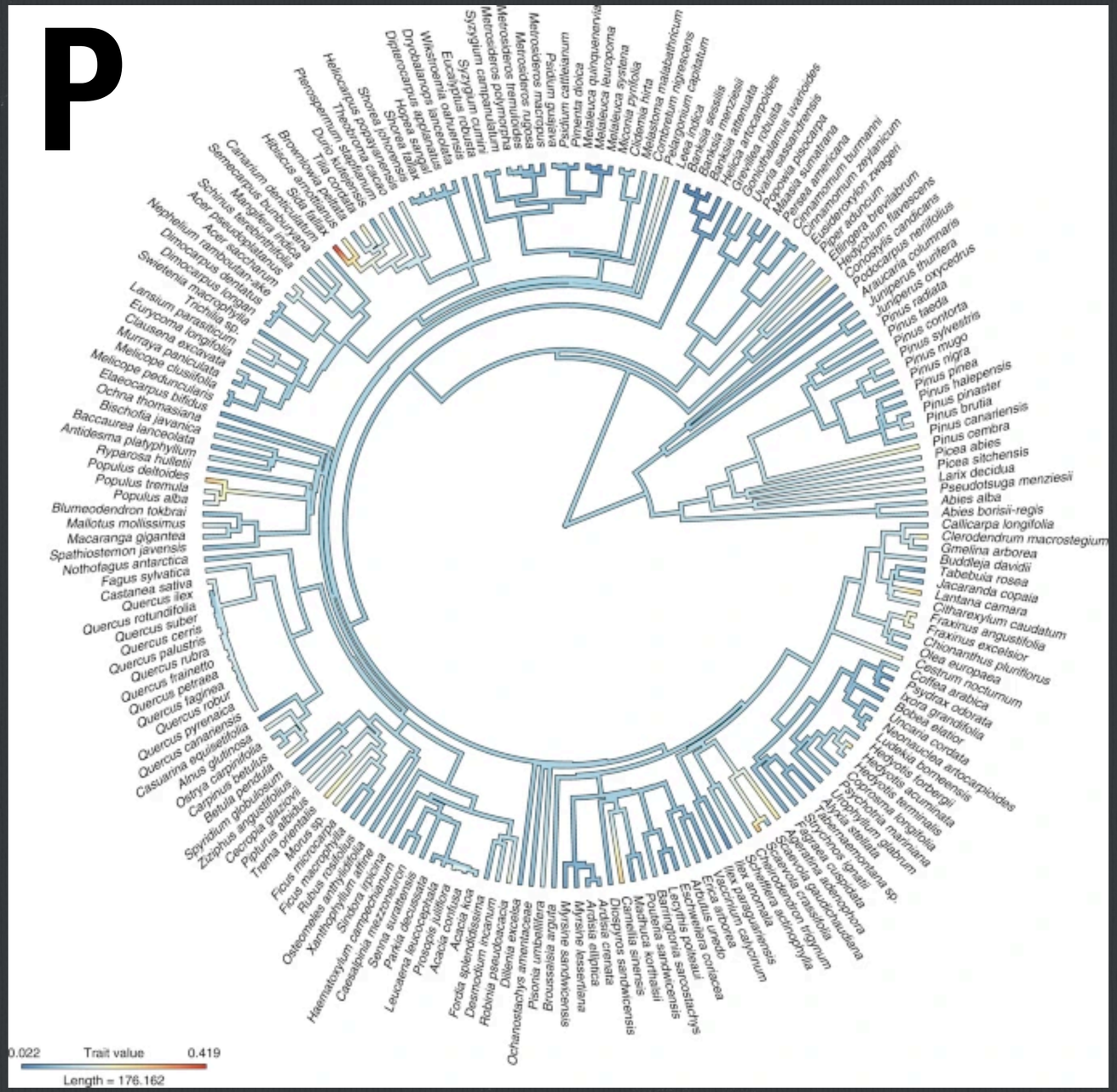


Table 2 Differences in N and P concentrations and N : P mass ratios among plant growth forms in various vegetation types of the world

	[N] mg g^{-1}	[P] mg g^{-1}	N : P ratio
Worldwide[1]			
Evergreen woody	13.7	1.02	13.4
Deciduous woody	22.2	1.60	13.9
Forbs	22.2	1.86	11.9
Graminoids	16.0	0.95	17.8
Mediterranean (Greece)[2]			
Evergreen woody	10.3	0.62	16.6
Deciduous woody	23.0	1.53	15.1
Herbaceous (mainly forbs)	17.5	1.25	14.0
Mediterranean (Australia)[3]			
Woody	9.5	0.7	13.6
Herbaceous	10.6	0.9	11.8
Temperate (Britain)[4]			
Woody (shrubs)	18.0	1.46	12.5
Forbs	32.3	3.14	10.9
Graminoids	21.6	2.23	10.2
Subarctic (Sweden)[5]			
Evergreen woody	na	na	9.1
Deciduous woody	na	na	10.7
Forbs	na	na	11.1
Graminoids	na	na	13.2
European wetlands[6]			
Evergreen woody (shrubs)	13.6	0.73	18.6
Forbs	14.8	1.46	10.3
Graminoids	11.5	0.89	12.9

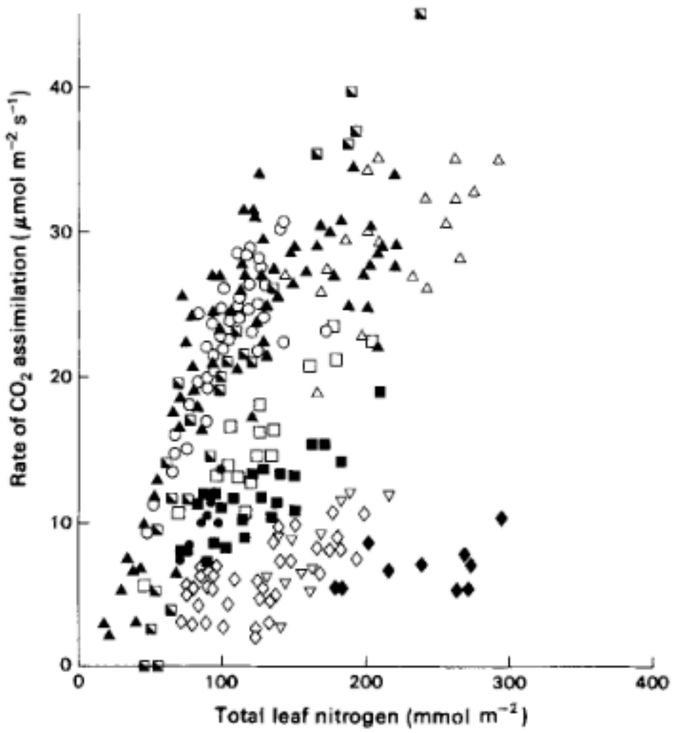
P



C ≈ 50 %
N ≈ 1.5 %
P ≈ 0.15 %

Photosynthesis and nitrogen relationships in leaves of C_3 plants

John R. Evans*
CSIRO, Division of Plant Industry, G.P.O. Box 1600, Canberra, A.C.T. 2601, Australia

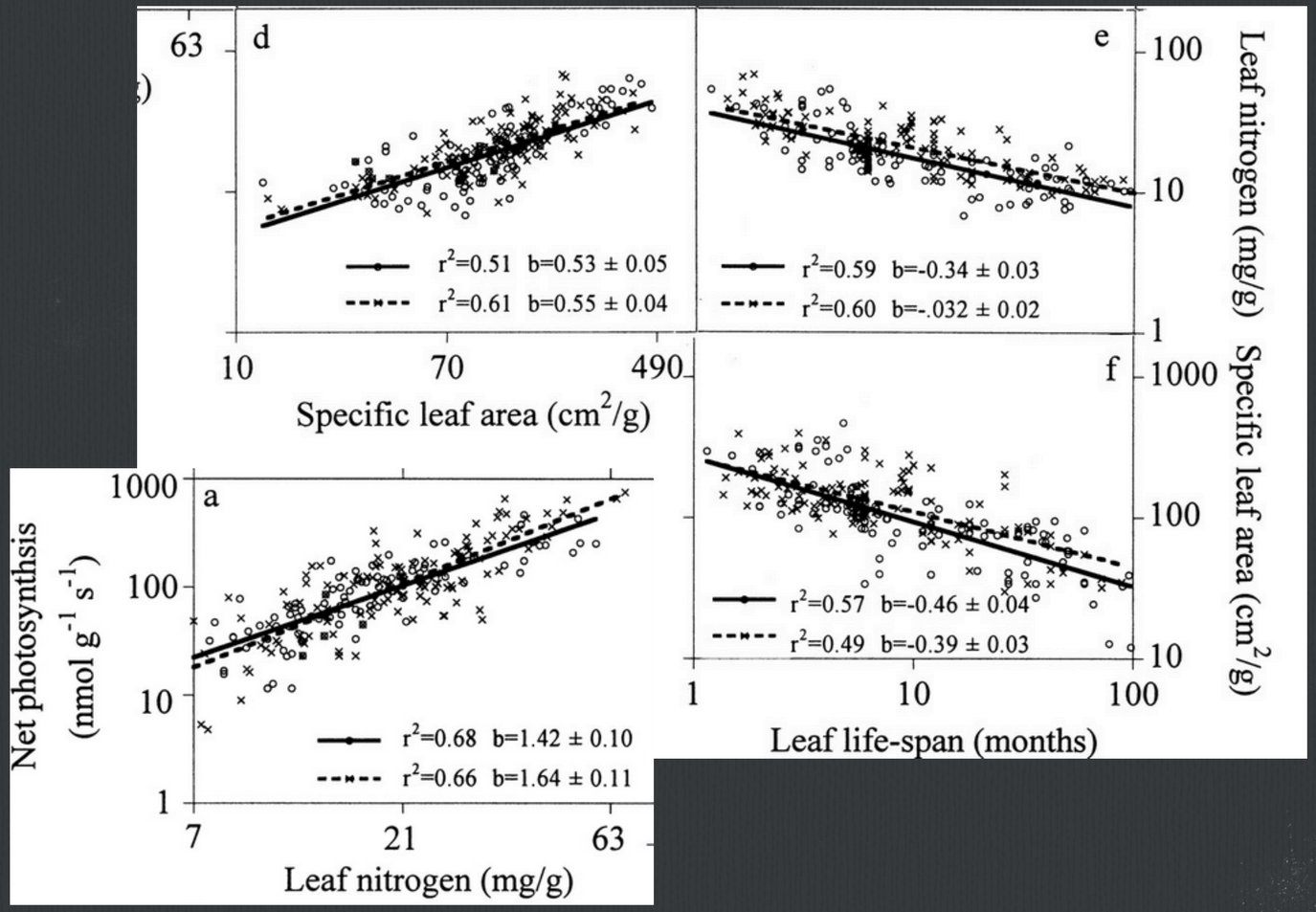


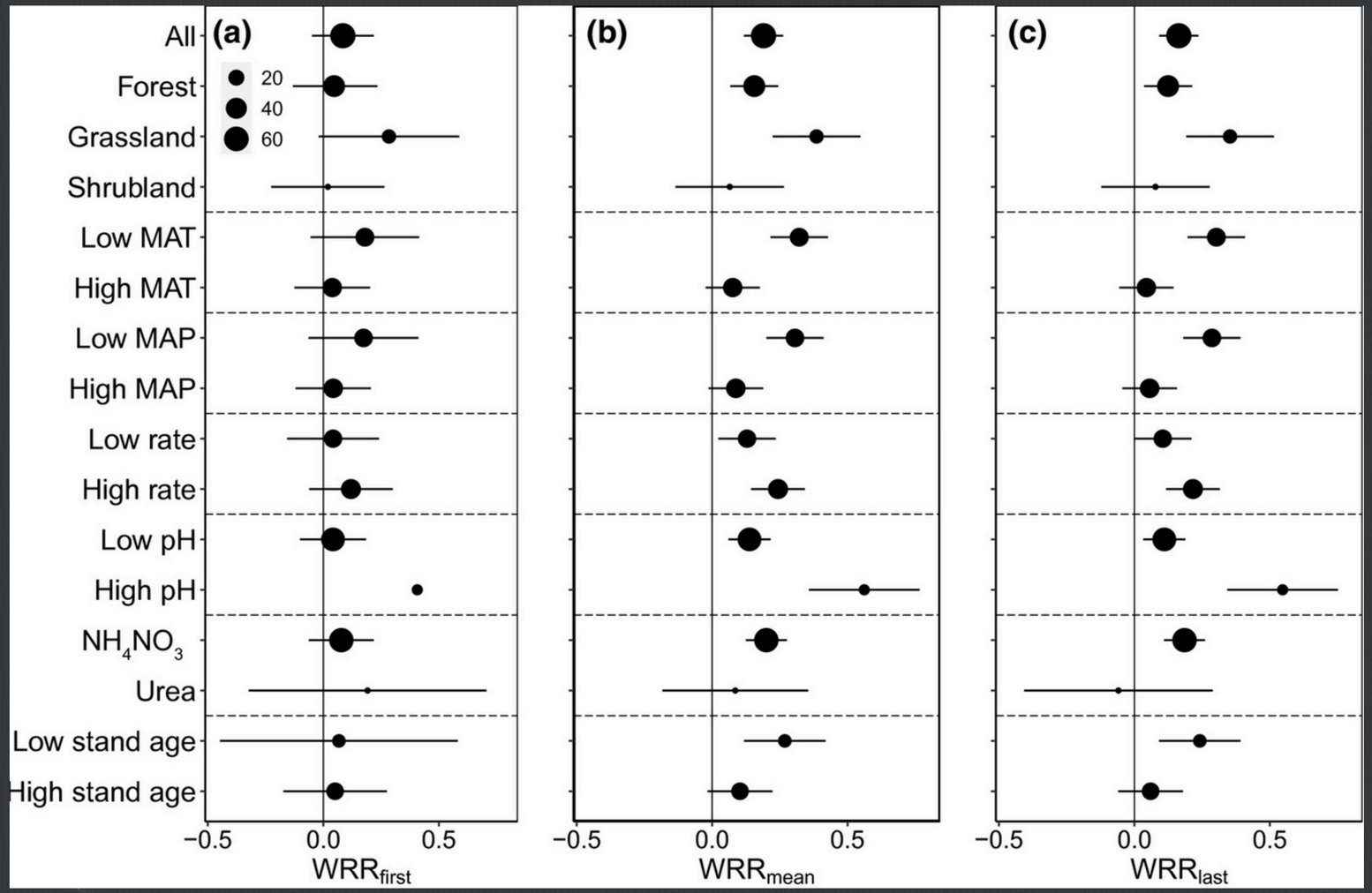
RESEARCH ARTICLE | ECOLOGY

From tropics to tundra: Global convergence in plant functioning

Peter B. Reich, Michael B. Walters, and David S. Ellsworth Authors Info & Affiliations

December 9, 1997 | 94 (25) 13730-13734 | https://doi.org/10.1073/pnas.94.25.13730





Weighted response ratios of plant productivity (WRR) under N addition in studies grouped by biome, climate condition, N fertilization rate, initial soil pH, N fertilizer type and forest age. These weighted response ratios were calculated using: (a) data from only the first year (WRR_{first}); (b) all timepoints (WRR_{mean}); and (c) only the most recent timepoint (WRR_{last}). Values represent effect sizes ±95% confidence intervals. The size of each point is proportional to the sample size. Cut-off values of mean annual temperature (MAT), mean annual precipitation (MAP), N fertilization rate and forest age were their medians (6.3°C, 875 mm, 50 kg N/ha/year and 30 years, respectively). The cut-off value of the initial soil pH (pH) was 7

Table 1 Correlations between N or P concentrations or N : P ratios in the biomass of plant species and (a) maximxal relative growth rate (Grime *et al*. (1988)) or (b) nutrient indicator values (Ellenberg *et al*. (1991))

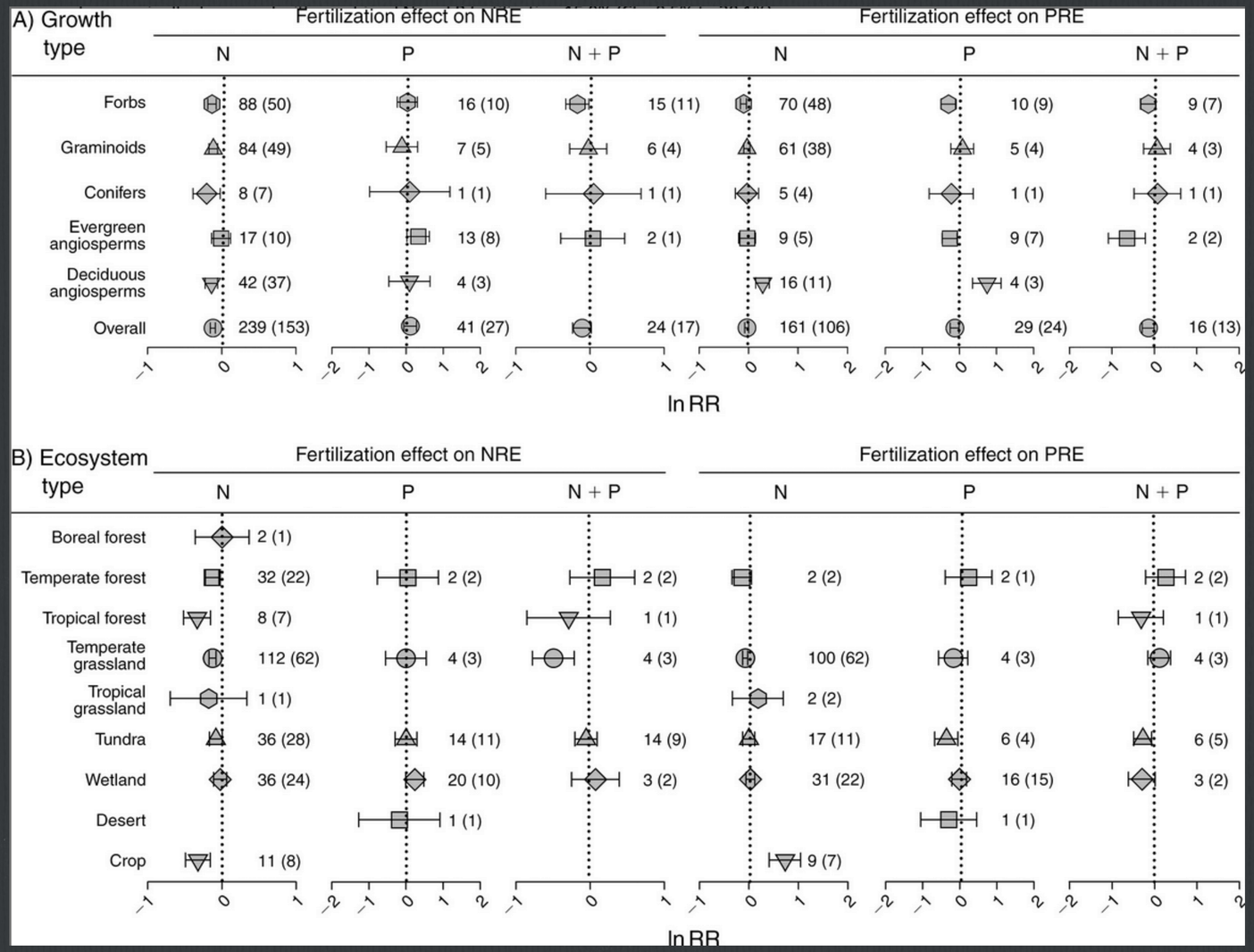
	n	[N]	[P]	N : P ratio
(a) Correlations with RGR				
Forest floor forbs[1]	17	0.69**	0.79***	na
Forest floor graminoids[1]	16	0.48	0.41	na
Herbaceous species[2]	67	0.33*	0.51***	–0.50***
Vascular plants[3]	250	0.62***	0.56***	na
Woody plants[4]	79	0.52***	0.50***	–0.17
(b) Correlations with Ellenberg N-values				
Forest floor forbs[1]	84	0.51***	0.54***	na
Forest floor graminoids[1]	39	0.50*	ns	na
Herbaceous species[2]	67	0.75***	0.75***	–0.29*
Wetland species[5]	71	0.43***	0.58***	–0.41***
– forbs	31	0.41*	0.60***	–0.44*
– graminoids	40	0.33*	0.48**	–0.34*
Wetland species[6]	15	–0.39	0.44	–0.60**

Correlations (Pearson's *r*) were calculated after log-transformation if required to obtain normally distributed variables. Significance levels are given as: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; no symbol, $P > 0.05$. Sources: [1]Meerts (1997); [2]Thompson *et al*. (1997); [3]Nielsen *et al*. (1996); [4]Cornelissen *et al*. (1997); [5]Güsewell & Koerselman (2002); [6]Güsewell *et al*. (2003a).

Limitation

- The addition of nutrient X makes the plant grow faster
- The addition of nutrient X increase the nutrient X concentration in tissue
- In N and P, we can establish the N:P ratio and look at the ratio $14 < N:P < 20$
- Reabsorption rates

Resorption rates



Negative effects of fertilization on plant nutrient resorption

Z. Y. Yuan, Han Y. H. Chen

First published: 01 February 2015 | https://doi.org/10.1890/14-0140.1 | Citations: 171

The law of the minimum

"If one of the essential plant nutrients is deficient, plant growth will be poor even when all other essential nutrients are abundant"

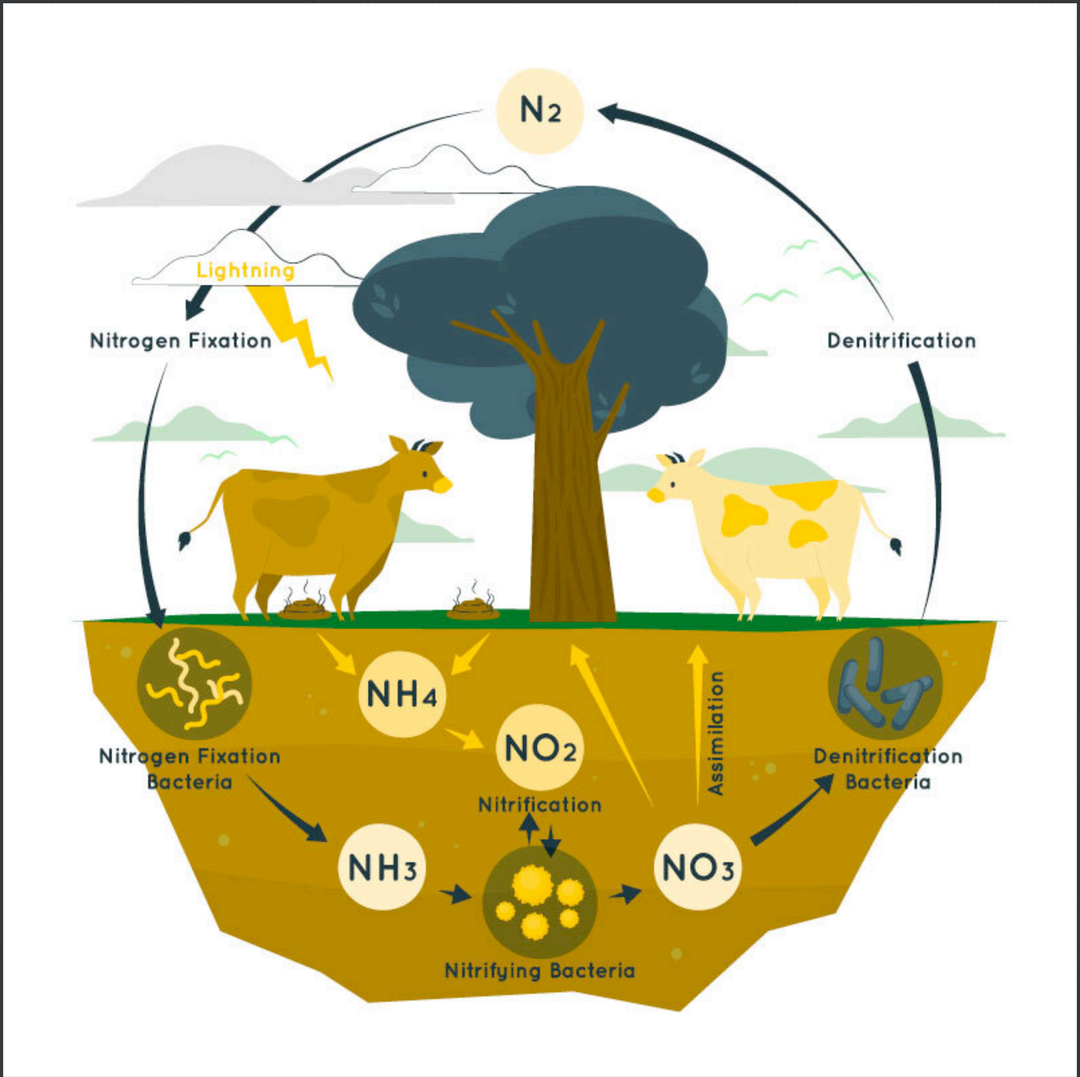
Liebig, 19th century

Key messages

- Abundance of nutrients condition plant biological processes (growth, photosynthesis…)
- The optimal nutrients concentration varies among species, and growth forms
- How we can determine limitation
- The law of the minimum

Global scale patterns

Context in BGQ: N cycle



Context in BGQ: N cycle

Is nitrogen the next carbon?

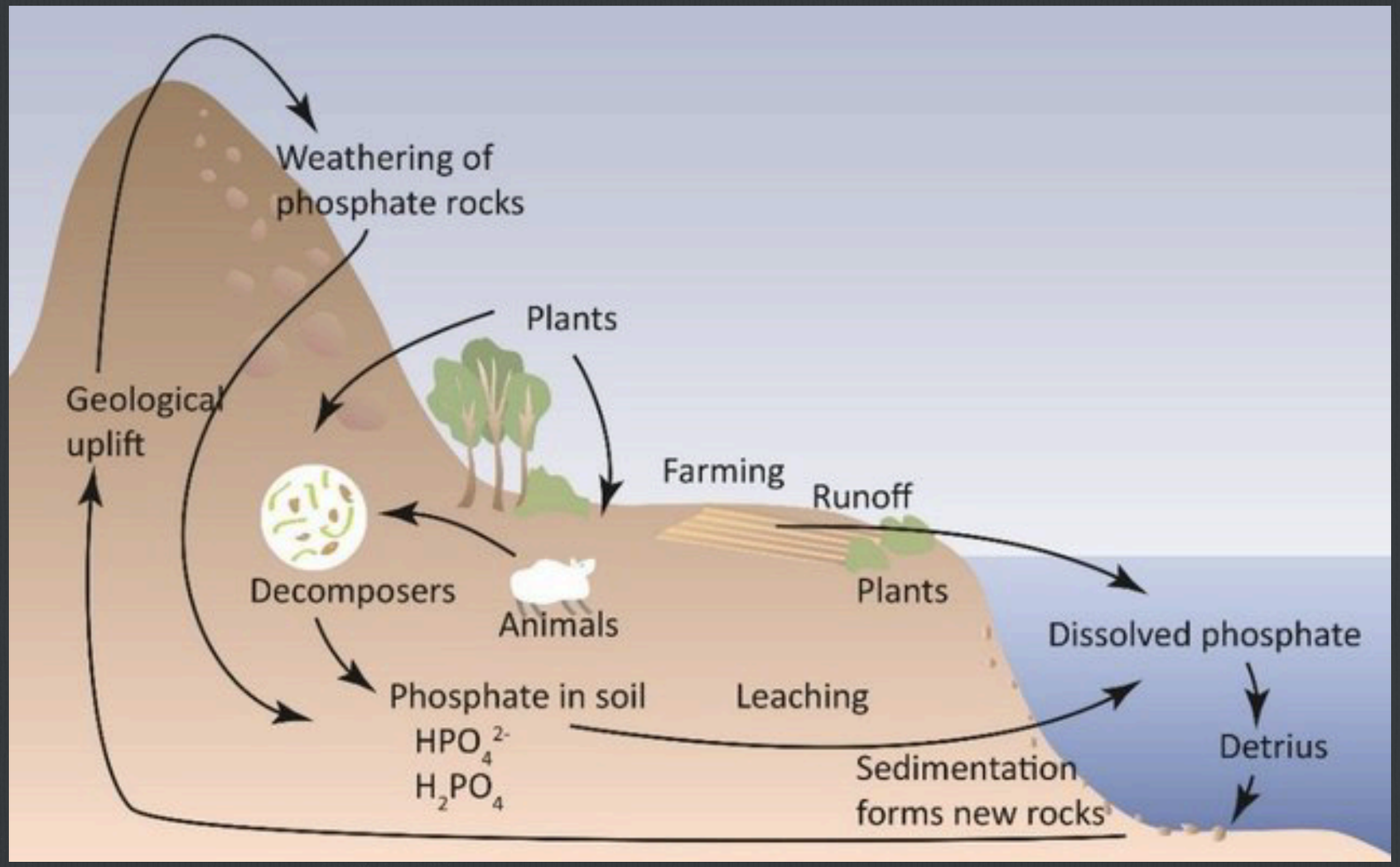
William Battye[1], Viney P. Aneja[1], and William H. Schlesinger[2]

[1]Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina, USA,
[2]Nicholas School of the Environment, Duke University, Durham, North Carolina, USA

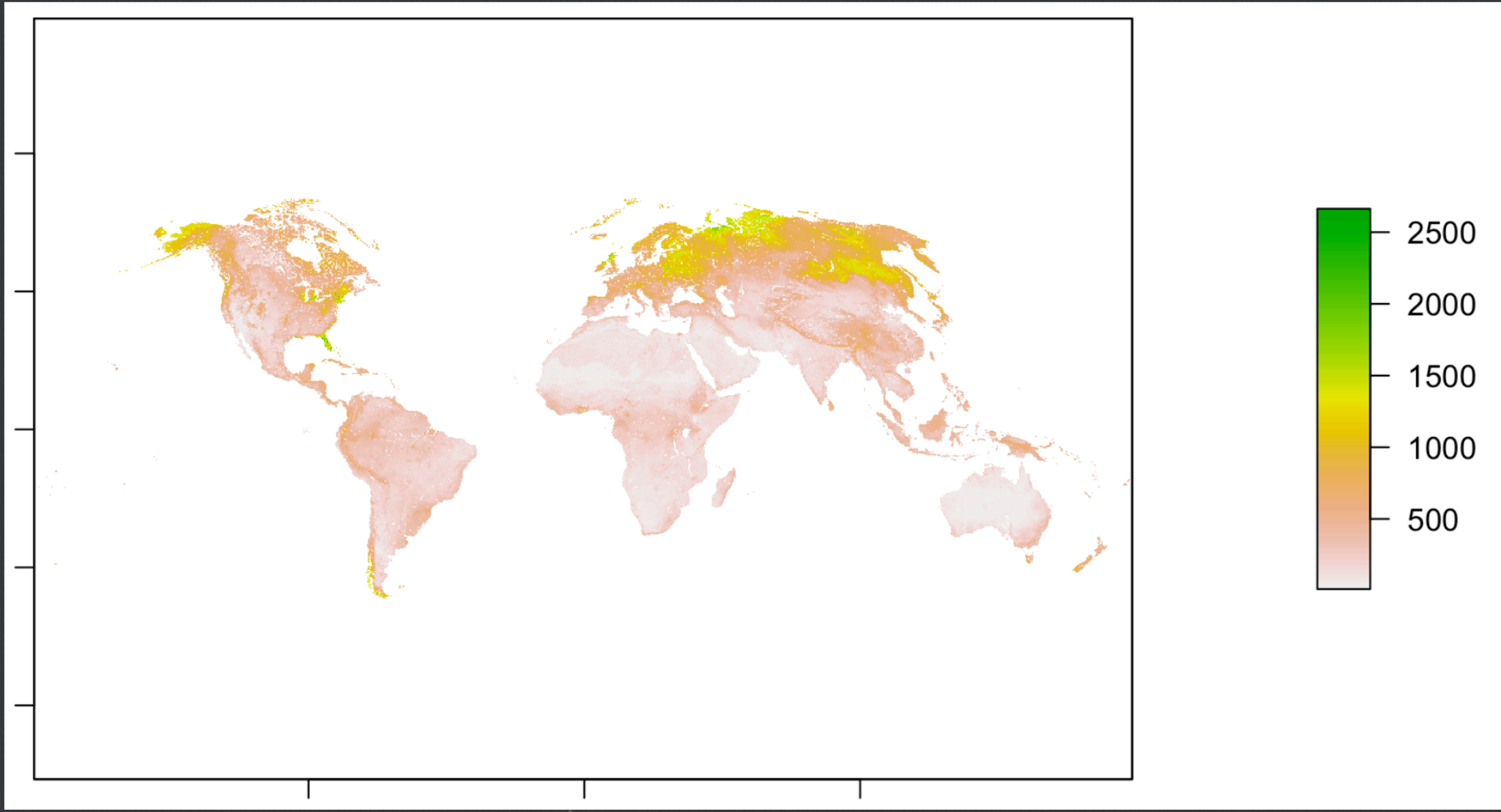
Table 1. Fluxes of Reactive Nitrogen

	Sources (Tg N y^{-1})			Range (for	
	1910	1960	Present	Present Values)	References
Sources					
Anthropogenic					
Synthetic or mined fertilizers	1	12	110		*Cushman* (2013), *IFA* (2016), *Smil* (2001)
N-fixing crops					
Soybeans	0.4	1.5	25		*Shurtleff and Aoyagi* (2004), *FAO* (2015), *Herridge et al*. (2008)
Other beans and legumes		2.9	7.5		*FAO* (2015), *Herridge et al*. (2008)
Other		7.4	10		*FAO* (2015), *Herridge et al*. (2008)
Total N-fixation		12	43	30–51	
NO_X from combustion	2.5	15	38		*UN* (2010)
Total anthropogenic	~4	39	190	160–210	
Natural					
Terrestrial N-fixation			84	40–127	*Galloway et al*. (2004), *Vitousek et al*. (2013), *Cleveland et al*. (2013)
Lightning			5.4		*Galloway et al*. (2004)
Marine N-fixation			150	121–177	*Galloway et al*. (2004), *Groβkopf et al*. (2012)
Total natural sources			240	166–310	
Total sources			430		
Sinks					
Denitrification					
Agricultural soils				22–87	*Hofstra and Bouwman* (2005)
Total terrestrial			130	58–175	*Seitzinger et al*. (2006), *Eugster and Gruber* (2012)
Freshwater and groundwater			120	39–216	*Eugster and Gruber* (2012)
Marine			150	107–331	*Seitzinger et al*. (2006), *Eugster and Gruber* (2012), *DeVries et al*. (2013a)
Total denitrification			400	210–720	
Other sinks					
Terrestrial biomass change			9	9	*Schlesinger* (2009)
Marine sediments			13	10–16	*Galloway et al*. (2004), *Schlesinger and Bernhardt* (2013)
Total sinks			420	220–745	

Context in BGQ: P cycle



Soil grids. Total soil N

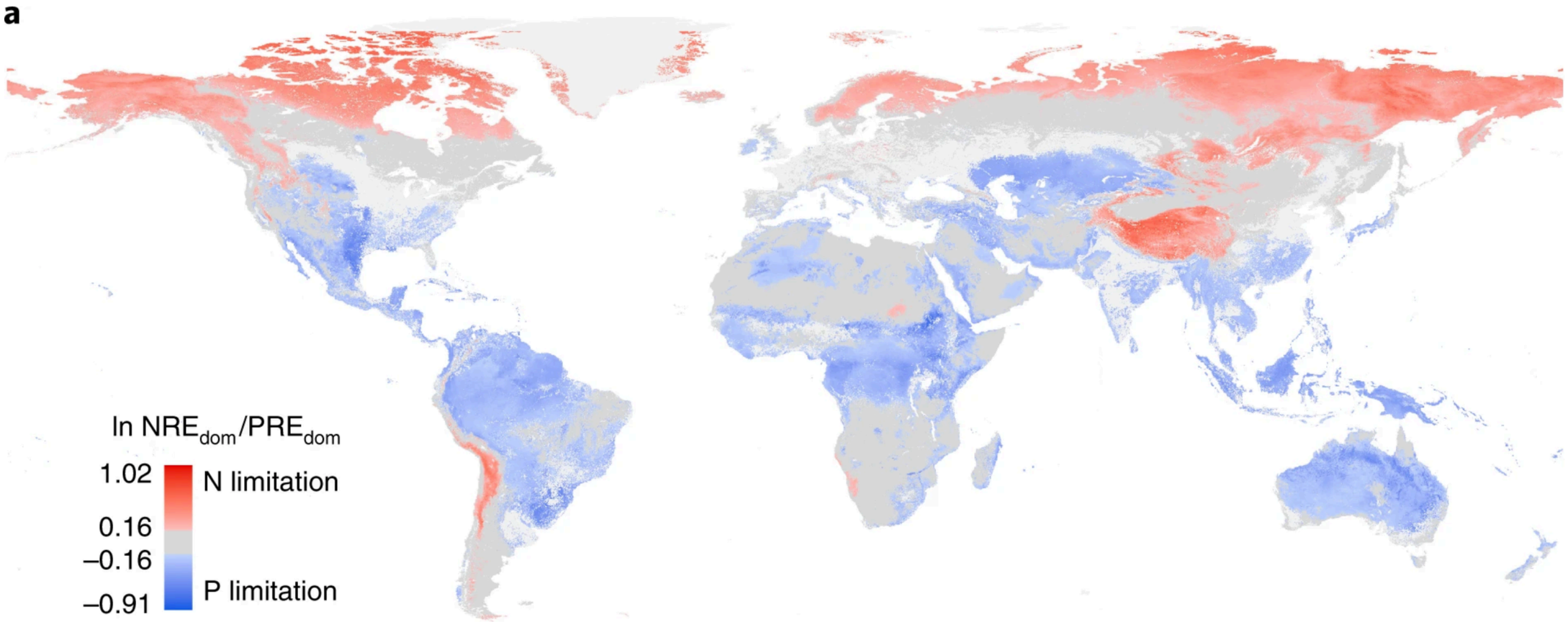


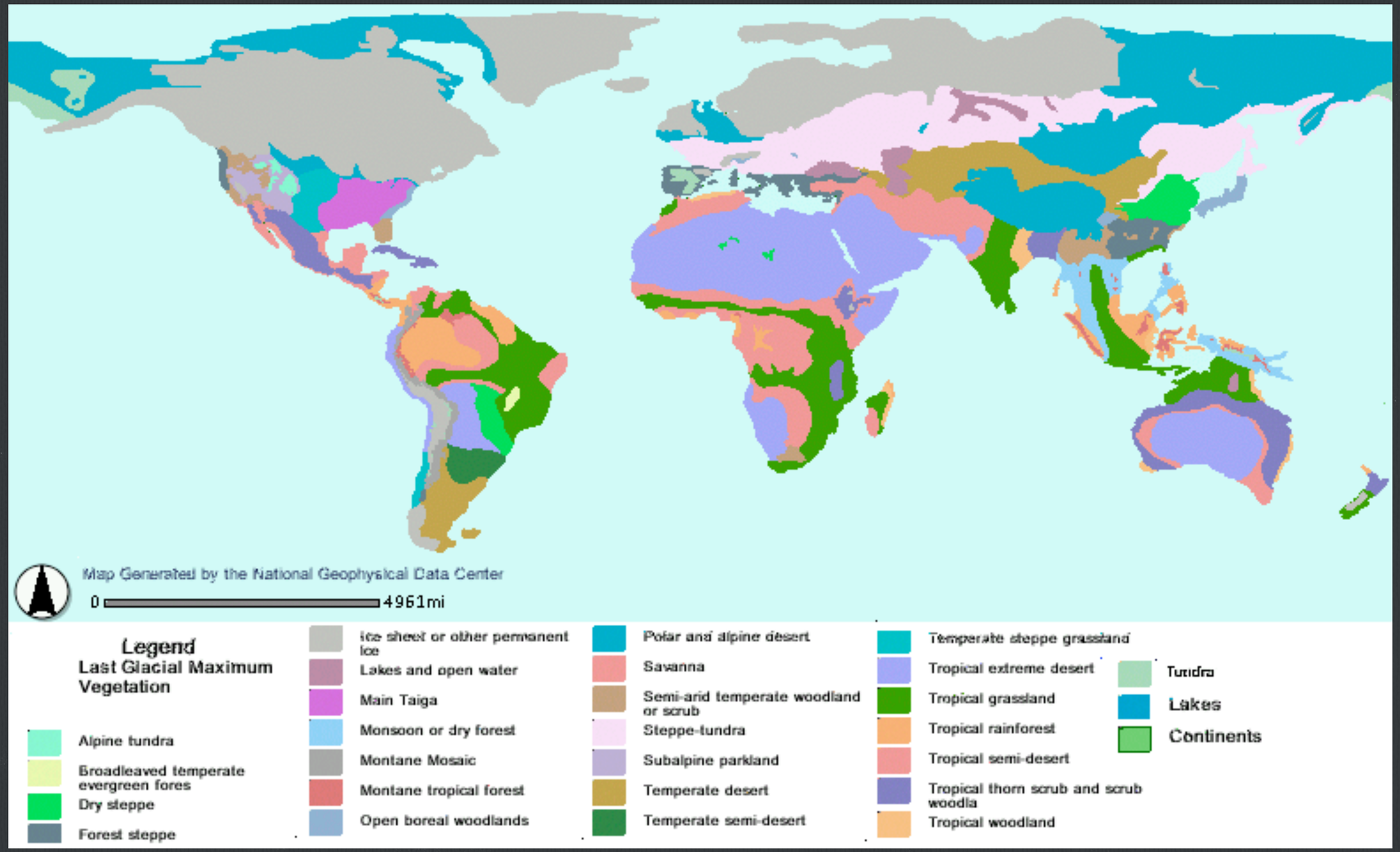
Du et al., 2020. Global patterns of terrestrial nitrogen and phosphorus limitation. *Nature geoscience*

Fig. 3: Global mapping of N and P limitation.

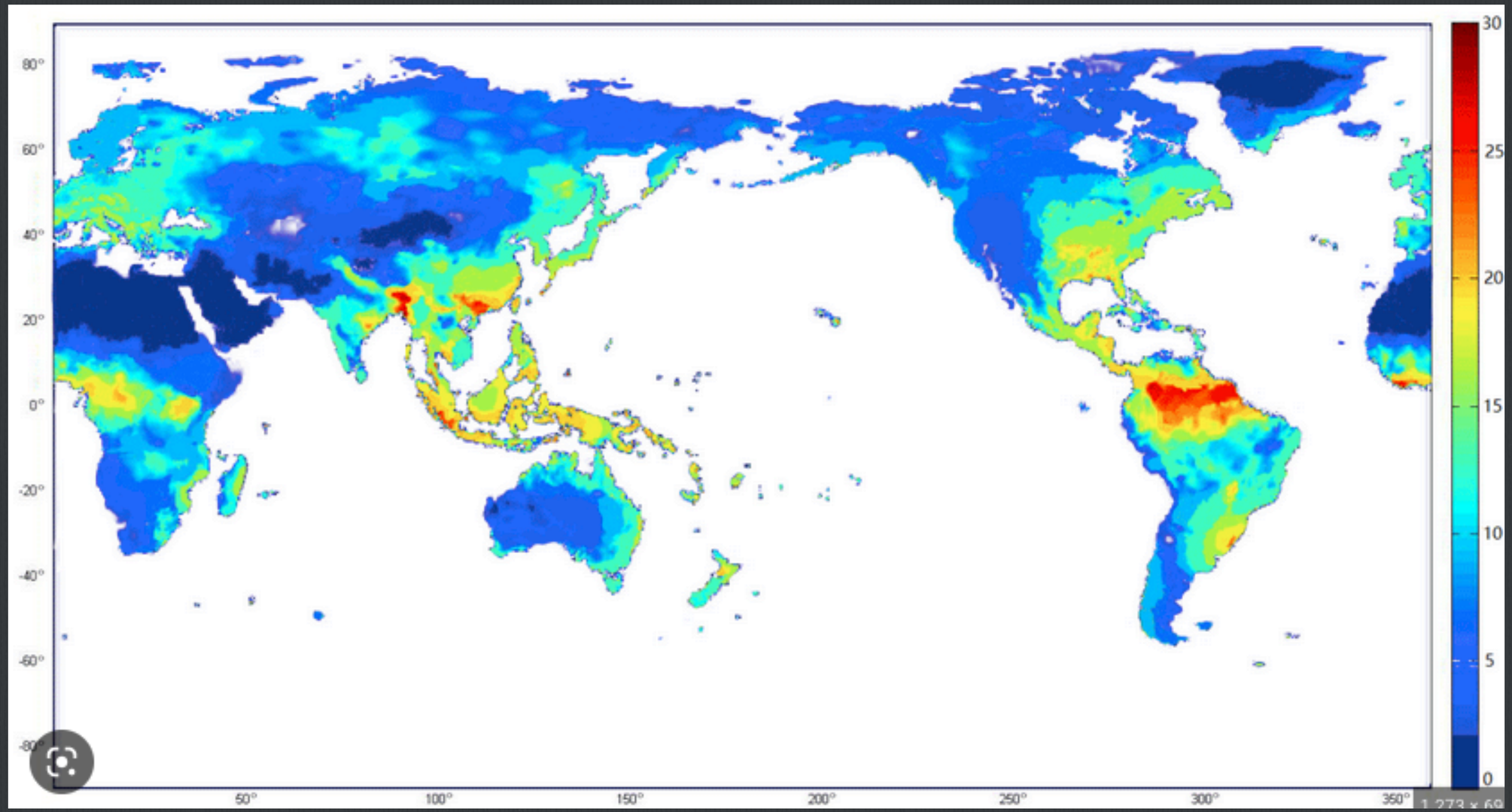
From: Global patterns of terrestrial nitrogen and phosphorus limitation

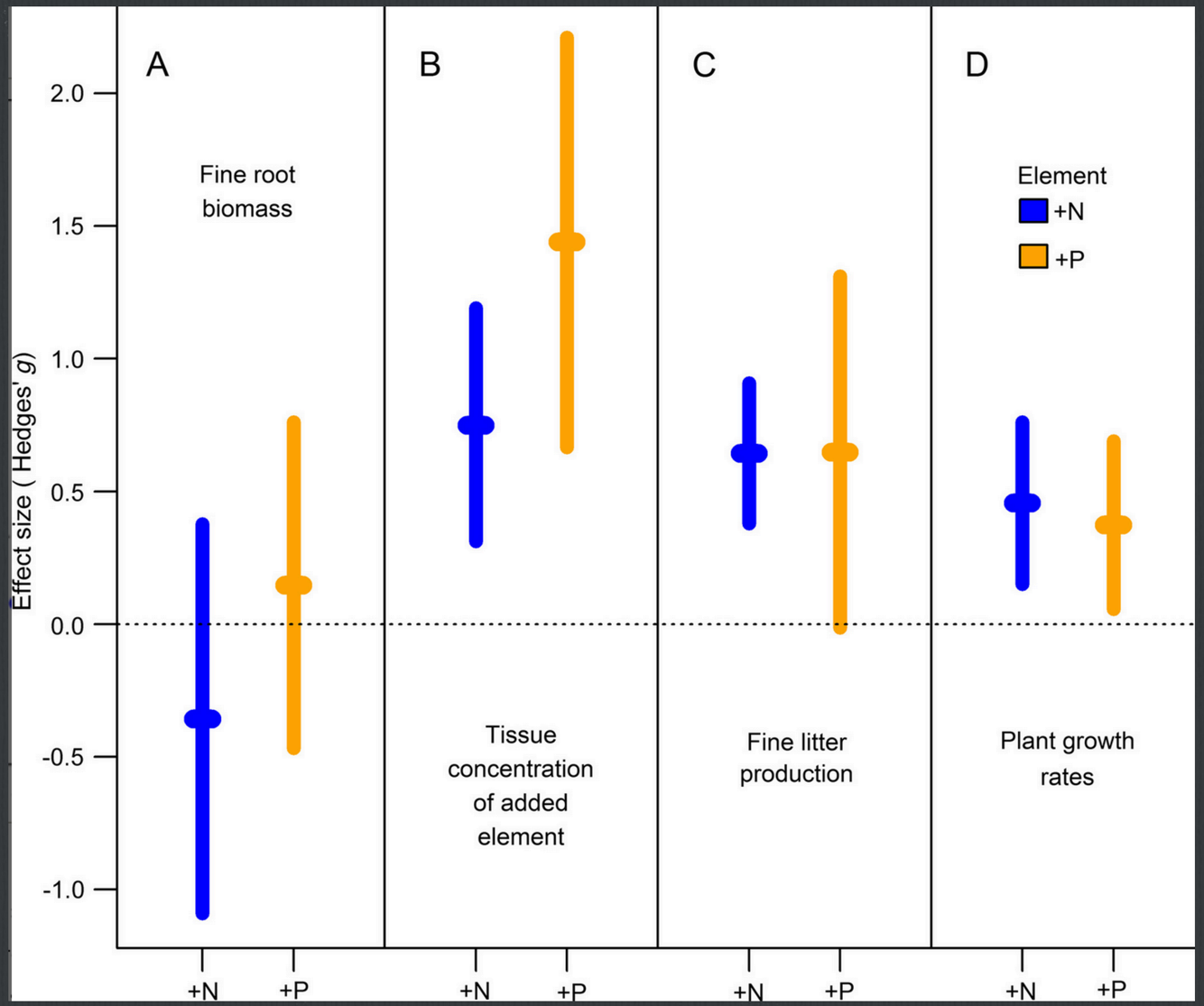
Soil age hypothesis




Map Generated by the National Geophysical Data Center
0
4961mi
Legend
Last Glacial Maximum Vegetation
Alpine tundra
Broadleaved temperate evergreen fores
Dry steppe
Forest steppe
Ice sheet or other permanent ice
Lakes and open water
Main Taiga
Monsoon or dry forest
Montane Mosaic
Montane tropical forest
Open boreal woodlands
Polar and alpine desert
Savanna
Semi-arid temperate woodland or scrub
Steppe-tundra
Subalpine parkland
Temperate desert
Temperate semi-desert
Temperate steppe grassland
Tropical extreme desert
Tropical grassland
Tropical rainforest
Tropical semi-desert
Tropical thorn scrub and scrub woodla
Tropical woodland
Tundra
Lakes
Continents

N availability strongly linked to biological fixation





Plant responses to nutrient addition experiments conducted in tropical forests

S. Joseph Wright

First published: 08 June 2019 | https://doi.org/10.1002/ecm.1382 | Citations: 58

Article | Published: 04 July 2022

Increasing calcium scarcity along Afrotropical forest succession

Marijn Bauters, Ivan A. Janssens, Daniel Wasner, Sebastian Doetterl, Pieter Vermeir, Marco Griepentrog, Travis W. Drake, Johan Six, Matti Barthel, Simon Baumgartner, Kristof Van Oost, Isaac A. Makelele, Corneille Ewango, Kris Verheyen & Pascal Boeckx

Nature Ecology & Evolution **6**, 1122–1131 (2022) | Cite this article

1390 Accesses | **2** Citations | **60** Altmetric | Metrics

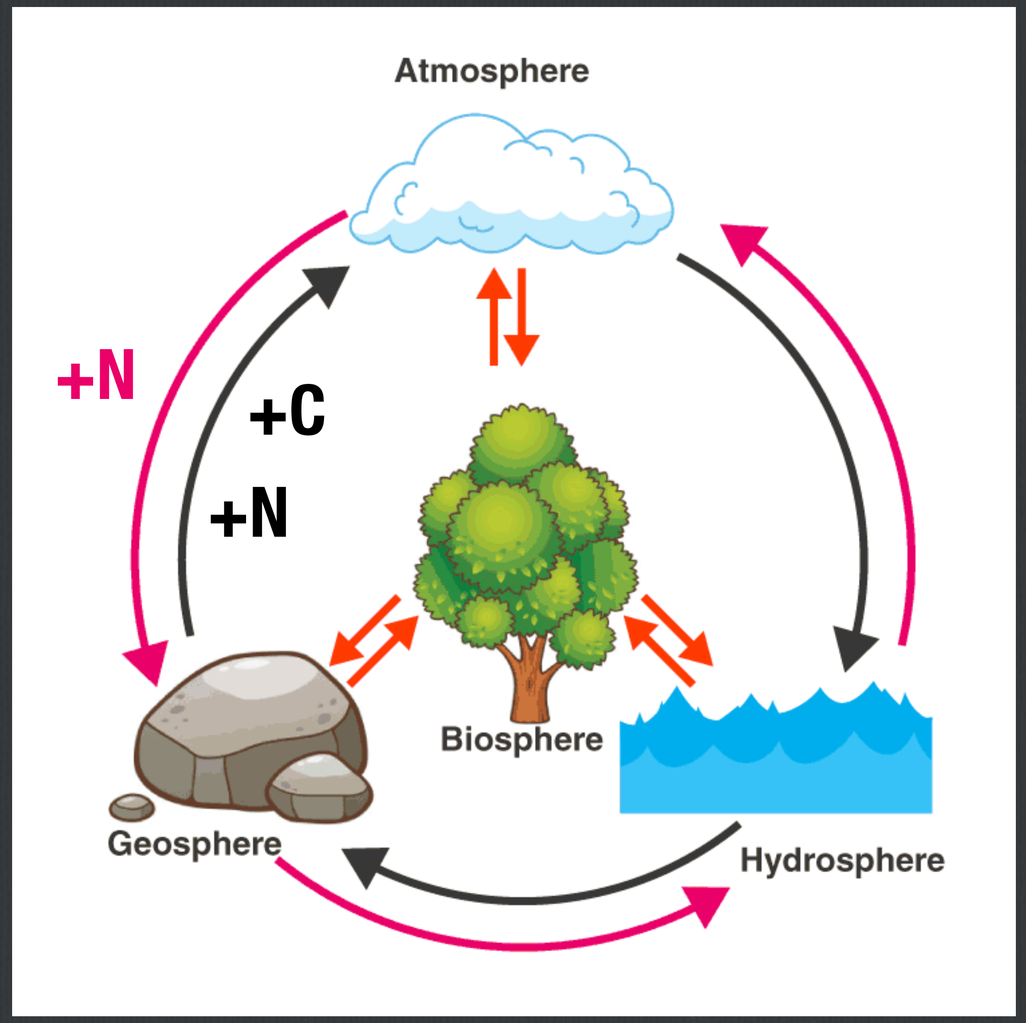
Fig. 1: Calcium and phosphorus dynamics along an Afrotropical forest succession.

Key messages

- N depends on biological processes
- P is strongly parental material dependent
- Soil age hypothesis
- N limitation in the tropics?!

Biogeochemical disruption in the antropocene

Humans and biogeochemical cycles



Fossil fuel burning (C,N)

Agriculture intensification (+N +P) & Haber-Bosch

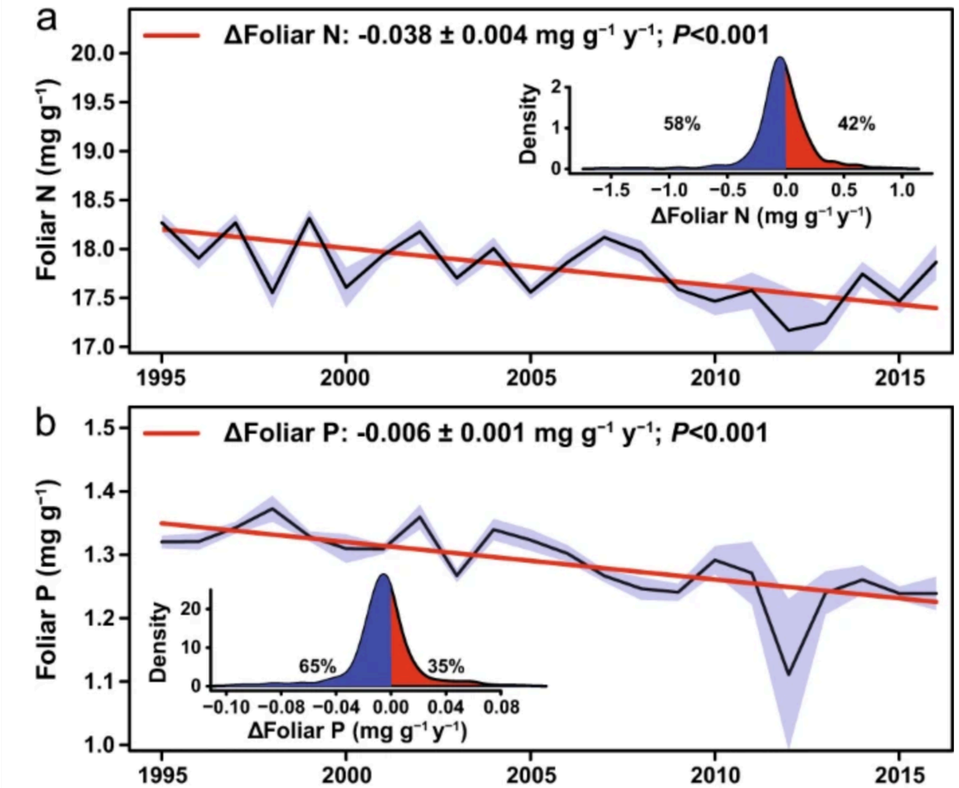
Industrial revolution

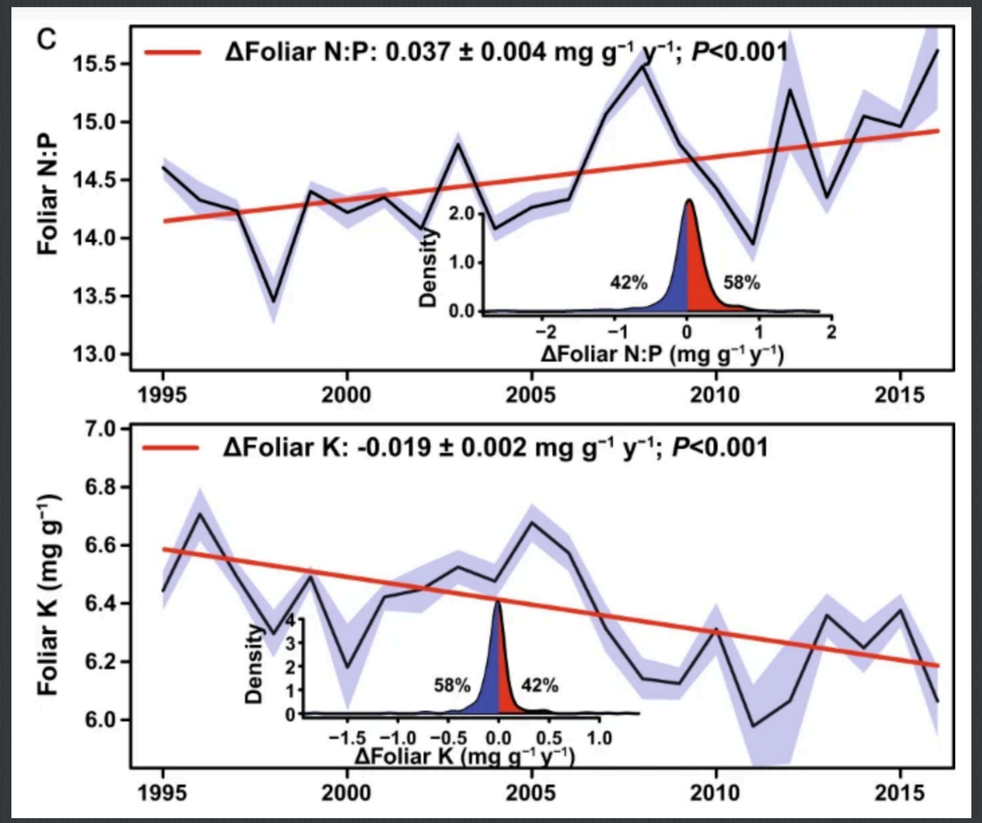
Biogeochemical cycle disruption

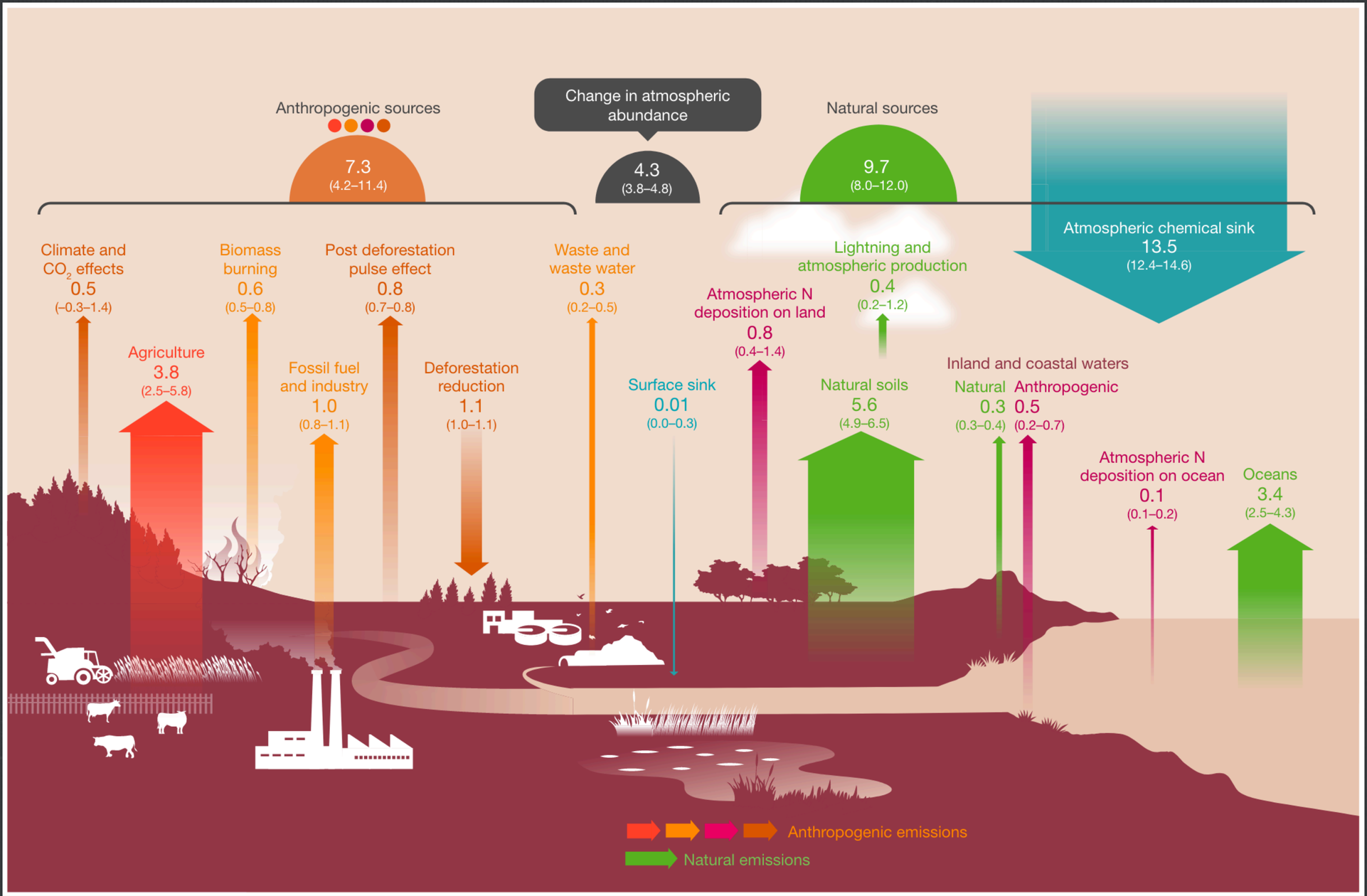
Dilution effect

Peñuelas et al., 2020. Increasing atmospheric CO_2 concentrations correlate with declining nutritional status of European forests. *Communications Biology*.

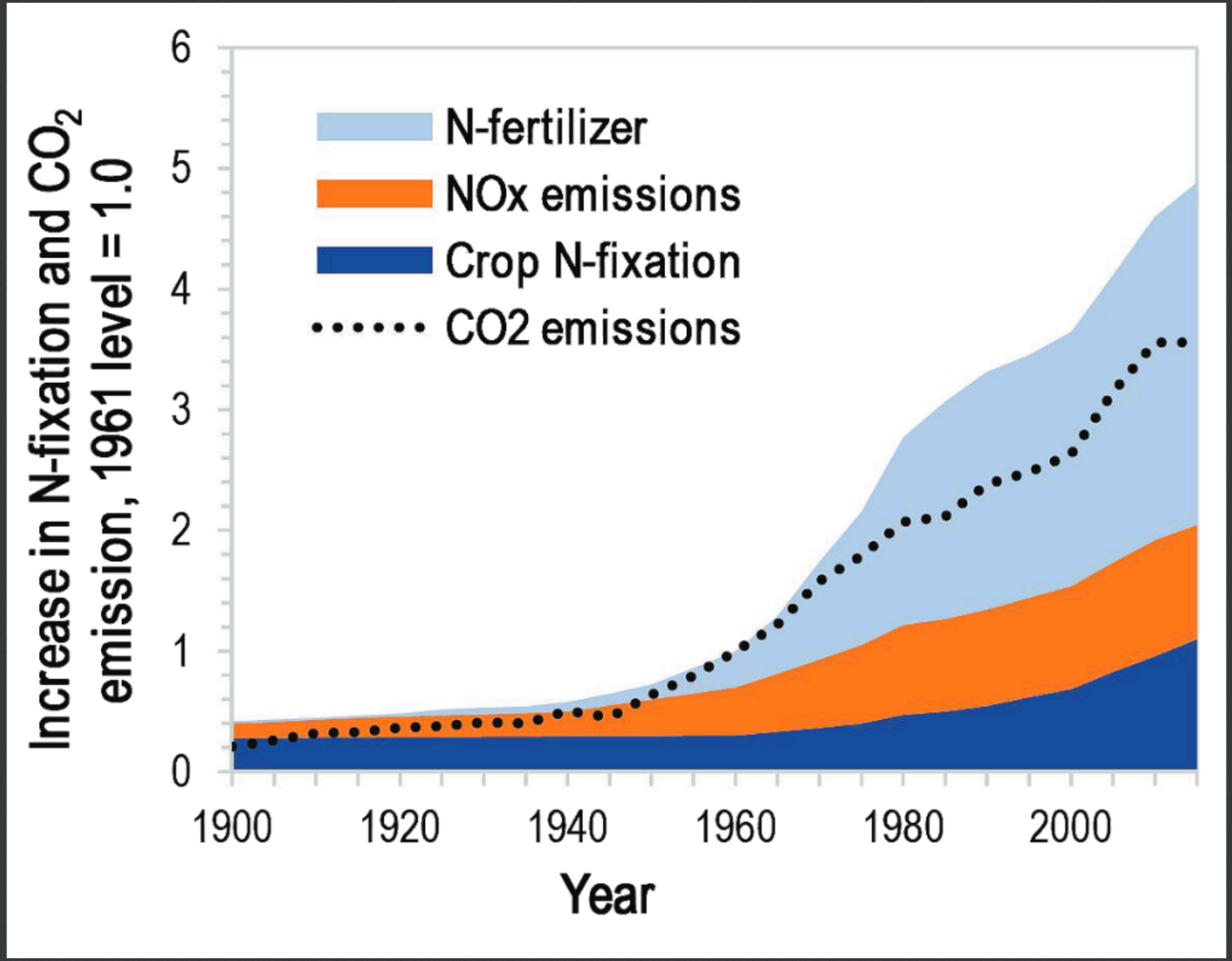
Fig. 1: Decreasing tree foliar N, P and K concentrations and increasing N:P ratio.



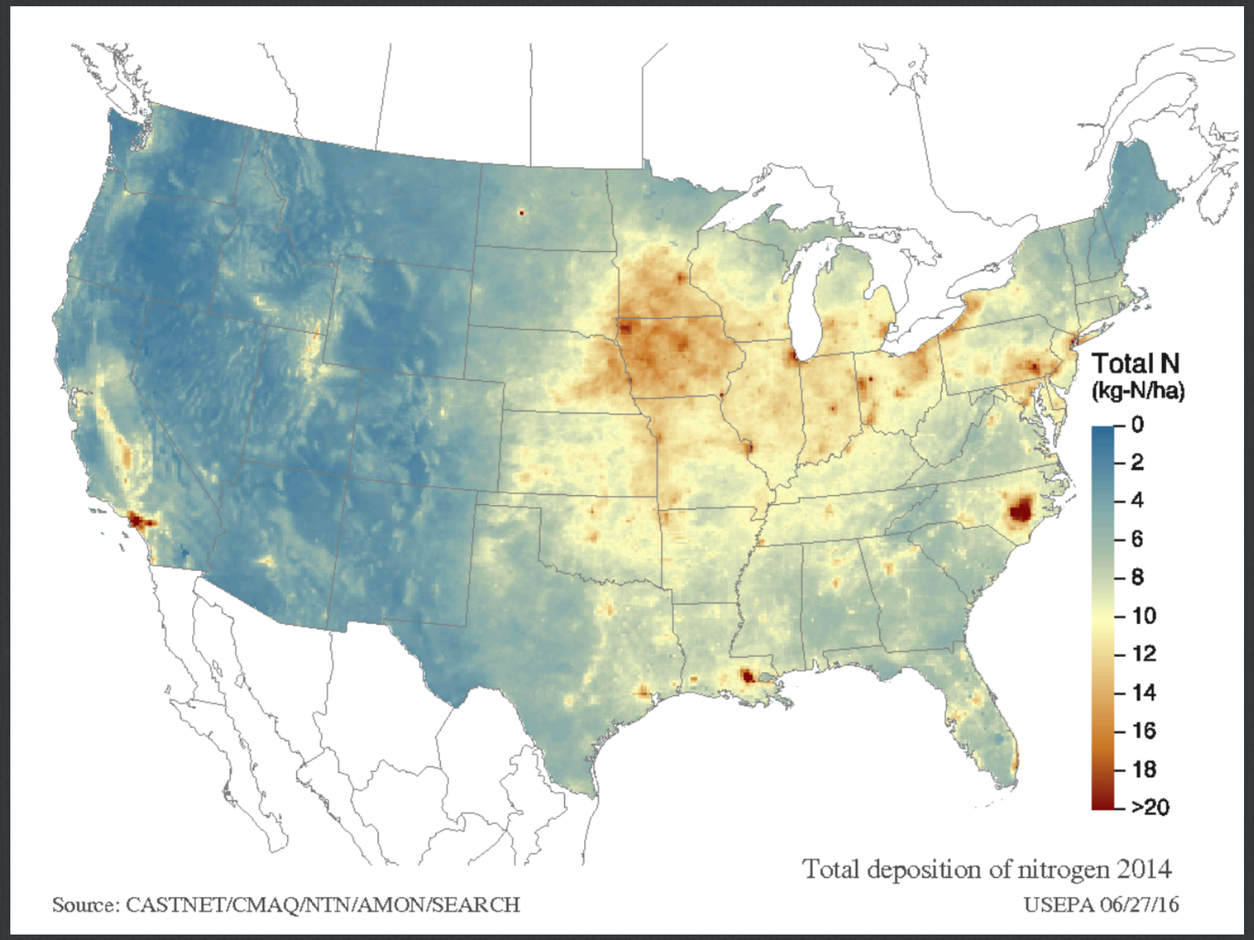



Anthropogenic sources
7.3
(4.2–11.4)
Change in atmospheric abundance
4.3
(3.8–4.8)
Natural sources
9.7
(8.0–12.0)
Atmospheric chemical sink
13.5
(12.4–14.6)
Climate and CO_2 effects
0.5
(–0.3–1.4)
Biomass burning
0.6
(0.5–0.8)
Post deforestation pulse effect
0.8
(0.7–0.8)
Waste and waste water
0.3
(0.2–0.5)
Lightning and atmospheric production
0.4
(0.2–1.2)
Atmospheric N deposition on land
0.8
(0.4–1.4)
Agriculture
3.8
(2.5–5.8)
Fossil fuel and industry
1.0
(0.8–1.1)
Deforestation reduction
1.1
(1.0–1.1)
Surface sink
0.01
(0.0–0.3)
Natural soils
5.6
(4.9–6.5)
Inland and coastal waters
Natural 0.3 (0.3–0.4)
Anthropogenic 0.5 (0.2–0.7)
Atmospheric N deposition on ocean
0.1
(0.1–0.2)
Oceans
3.4
(2.5–4.3)
Anthropogenic emissions
Natural emissions

N_2O


Increase in N-fixation and CO_2 emission, 1961 level = 1.0
6
5
4
3
2
1
0
N-fertilizer
NOx emissions
Crop N-fixation
CO2 emissions
1900
1920
1940
1960
1980
2000
Year

Humans and biogeochemical cycles



Schwede, D., & Lear, G.C. (2014). A novel hybrid approach for estimating total deposition in the United States. Atmospheric Environment, 92, 207-220.

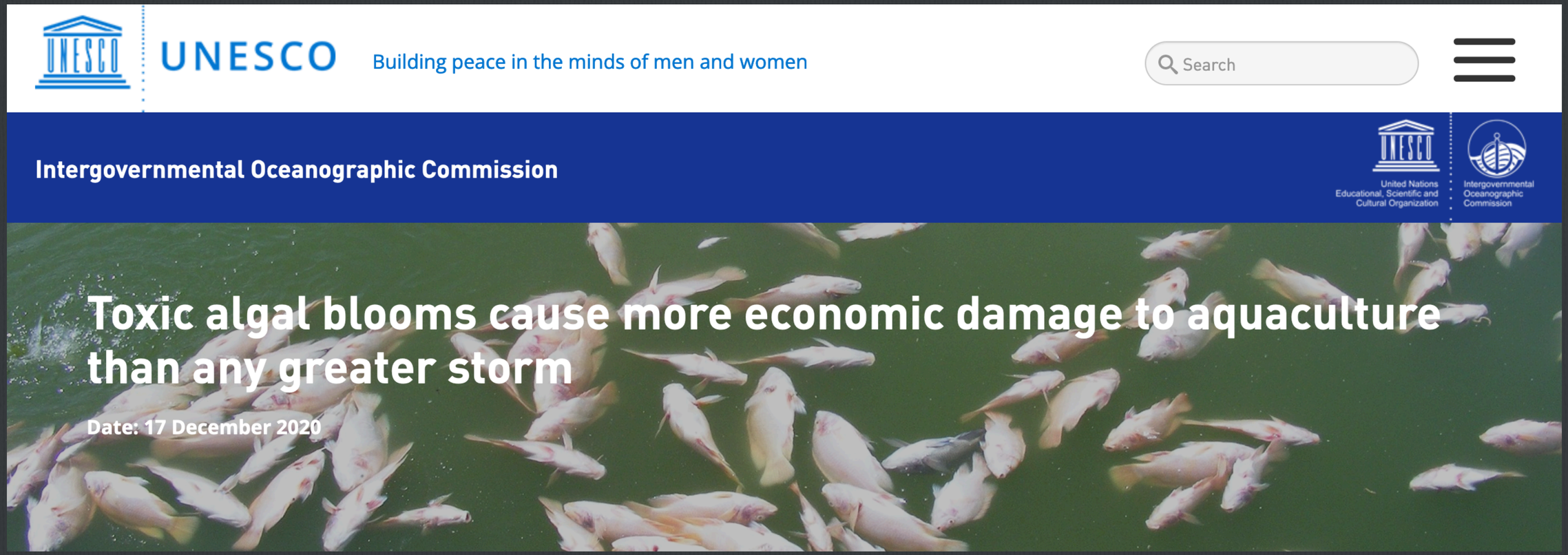
The resulting **changes in competitive relationships within plant communities** lead to **long-term changes in species community composition**, which could culminate in the extinction of endemic species and reduce overall levels of species diversity.

Vallicrosa et al., 2021

Global perspective of biogeochemical cycles

Atmospheric	Biospheric	Geospheric
↑↑↑ C	↑↑↑ N	↑ P
Homogeneous	Heterogeneous	Heterogeneous

Humans and biogeochemical cycles



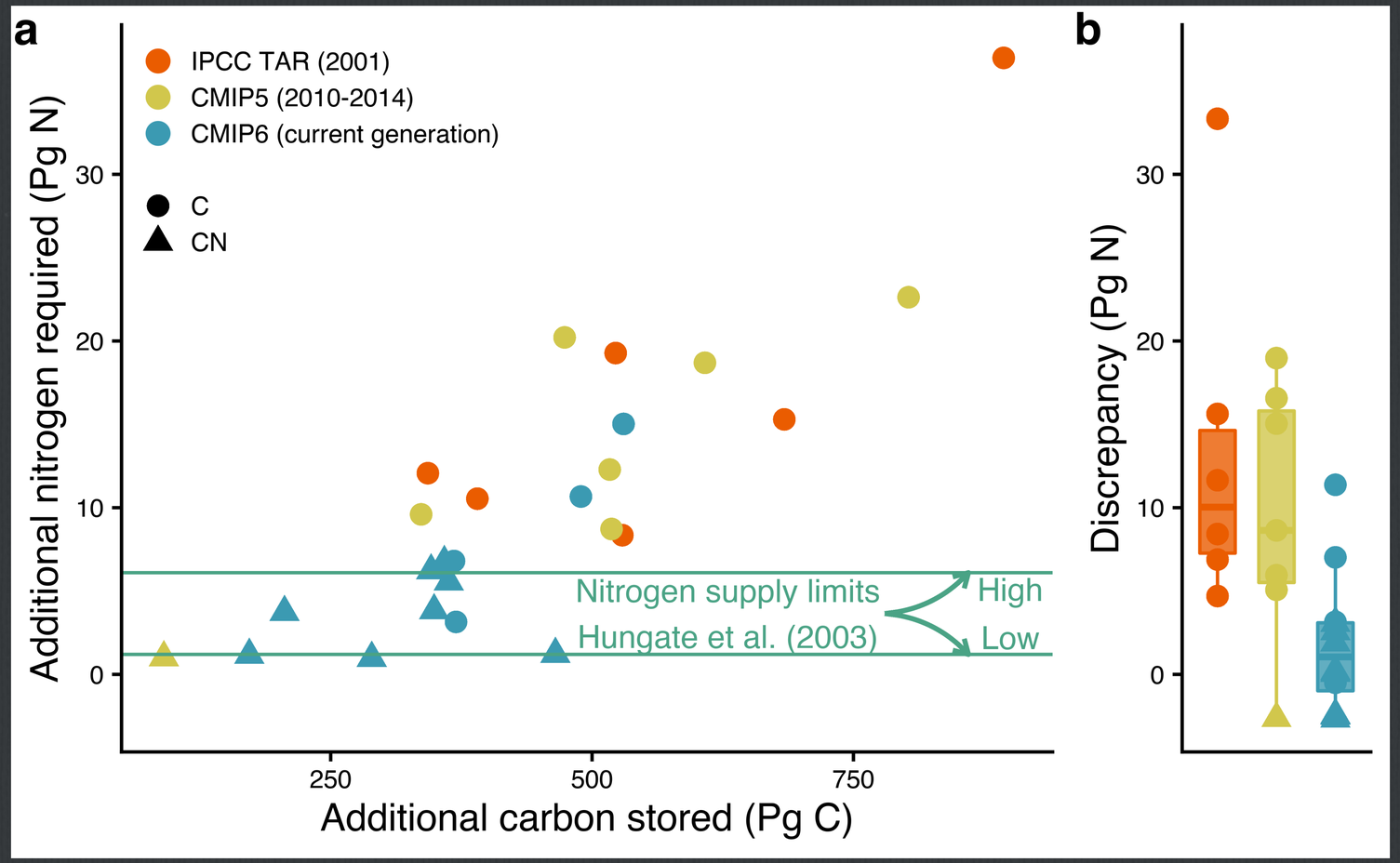
Global perspective of biogeochemical cycles

C: Greening effect → Limitation → Dilution

N: Plant N increase → Alterations in biotic relationships

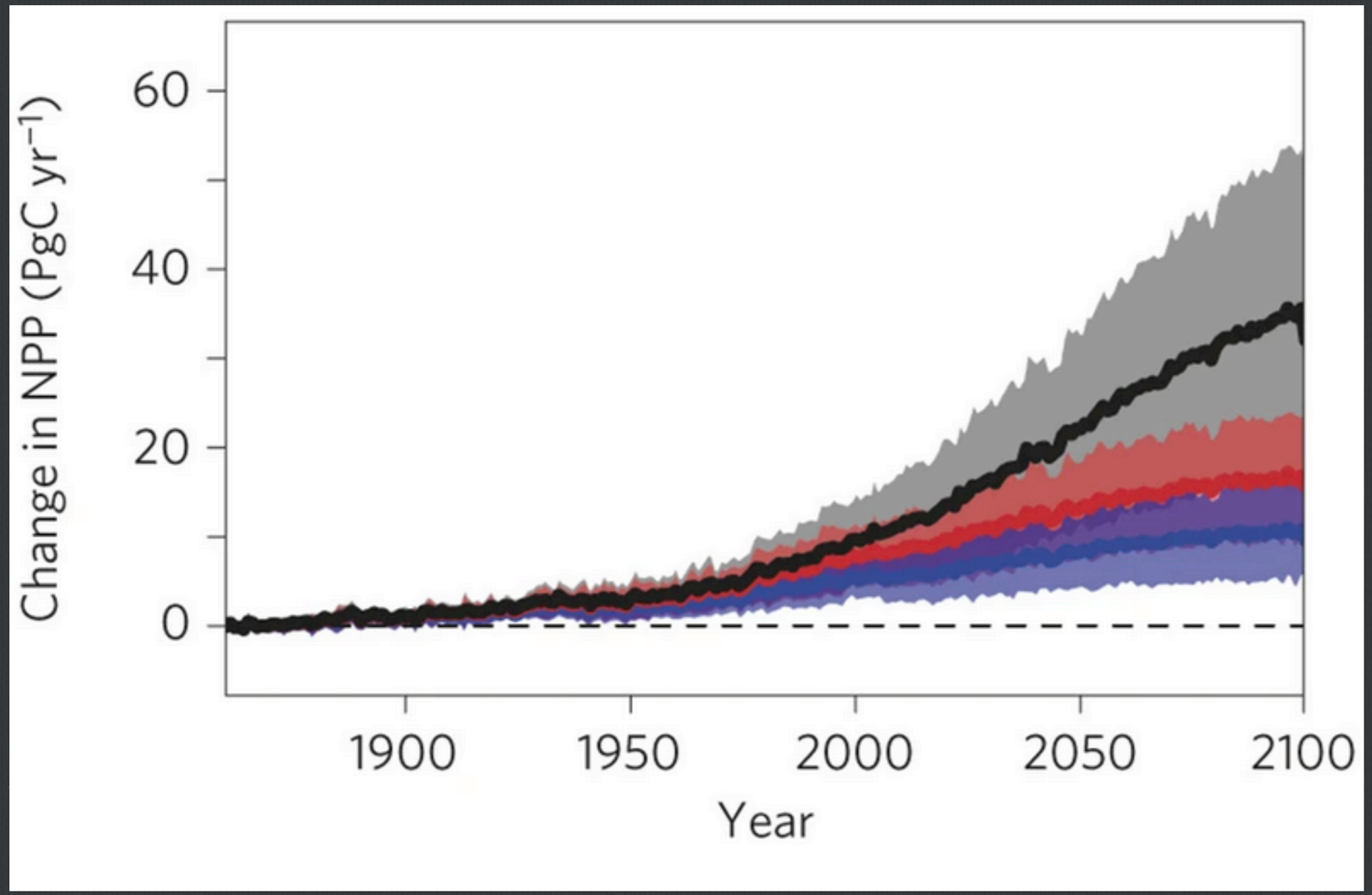
General nutrients imbalances

Land sink may be limited by nutrients



Adapted from Hungate et al., 2003. Nitrogen and Climate change. *Science*

Coupling N and P in C-cycles



CMIP5

N constrain

N and P constrain

Wieder et al., 2015. Nat Geo

Key messages

- Human activities are disrupting biogeochemical cycles
- It affects terrestrial and marine ecosystems
- The inclusion of nutrients in global C models improve its performance

Let's consider nutrients as important C sink cofactors