Lecture 2. Thoughts toward global nutrient cycling frontiers: Questions, techniques and opportunities

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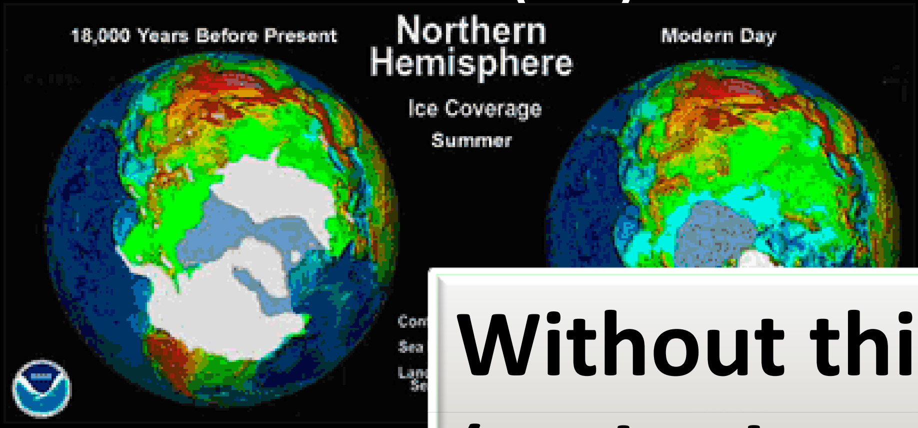
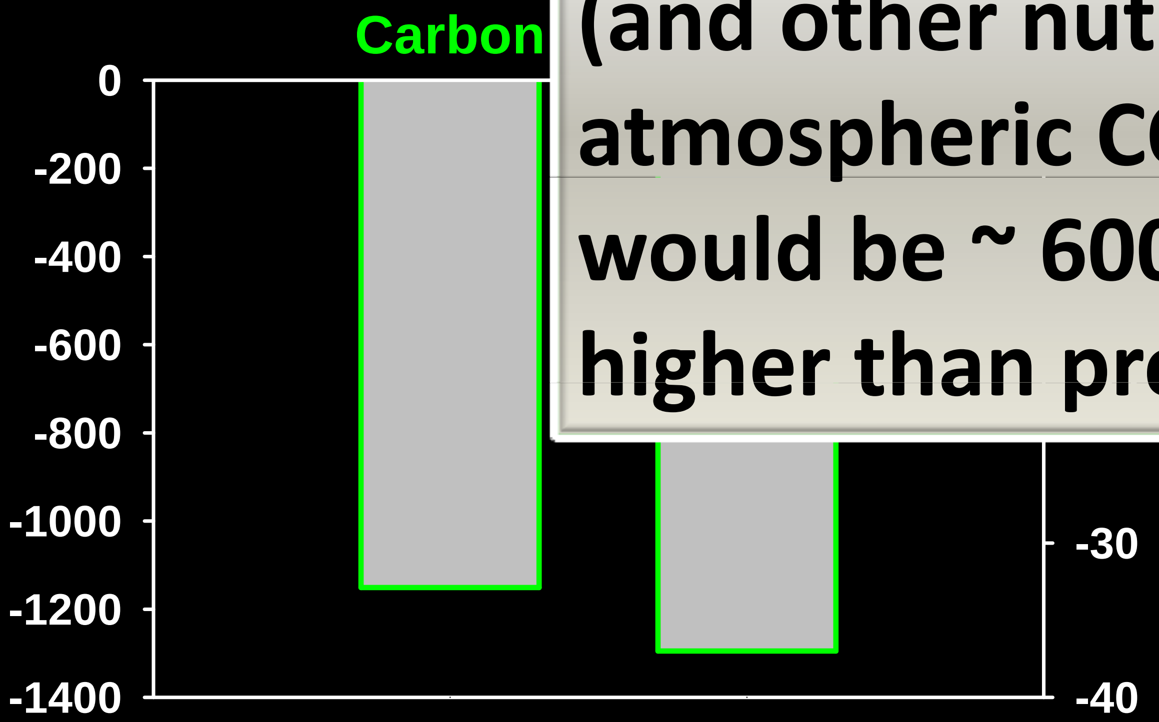
Carbon and nitrogen (and other nutrients) since LGM (Gt)





Without this added N (and other nutrients), atmospheric CO_2 would be ~ 600 ppm higher than present

1. Global hotspots of gaseous N losses in the terrestrial biosphere – missing N sink?
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2. N input via rock weathering – missing N source?
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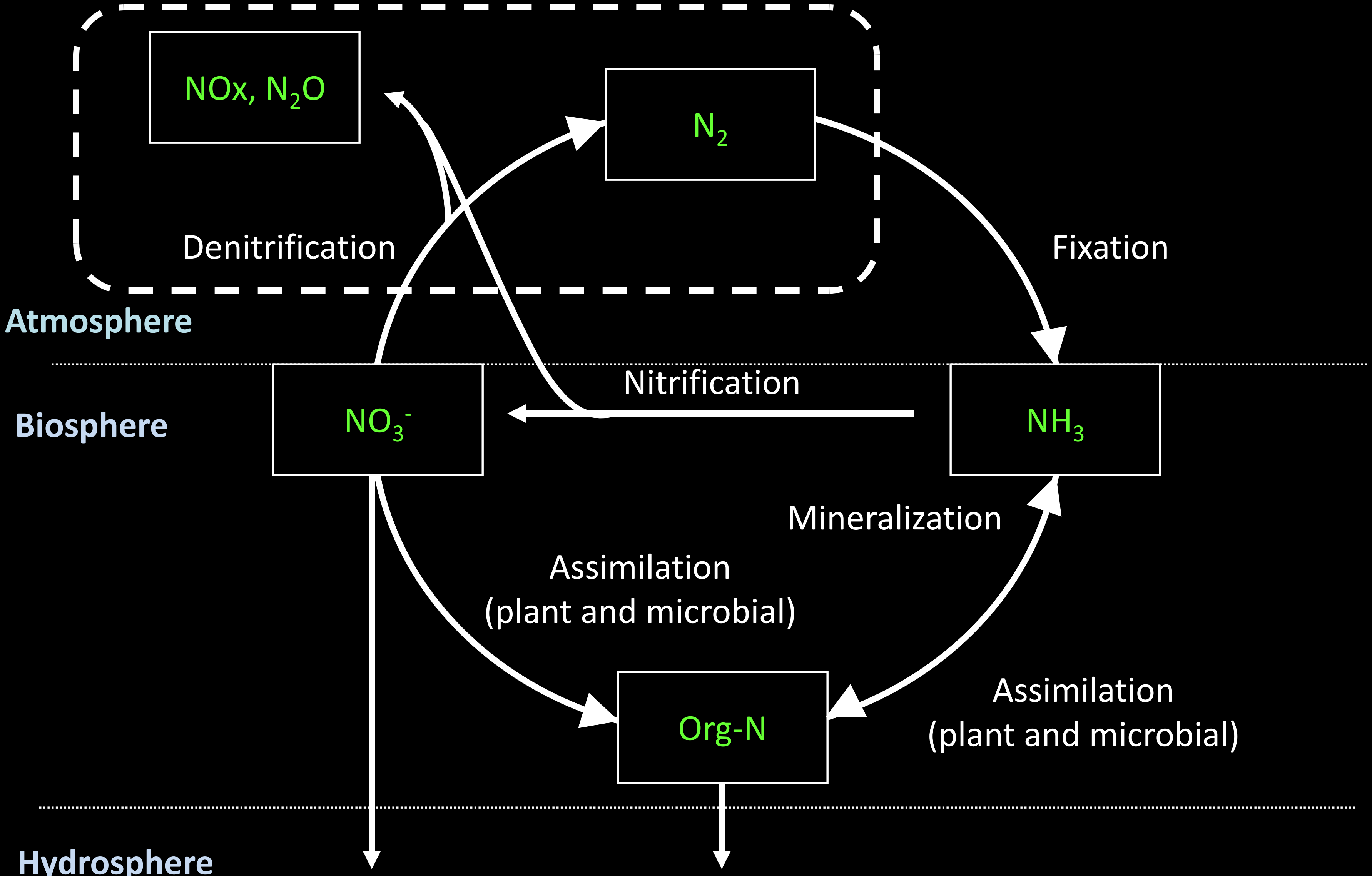
3. Patterns of new production: N, P and satellites

Problem: N_2 production < 10^{-7} of atmospheric N_2 reservoir



NOx, N_2O

N_2

Denitrification

Fixation

Atmosphere

Biosphere

NO_3^-

Nitrification

NH_3

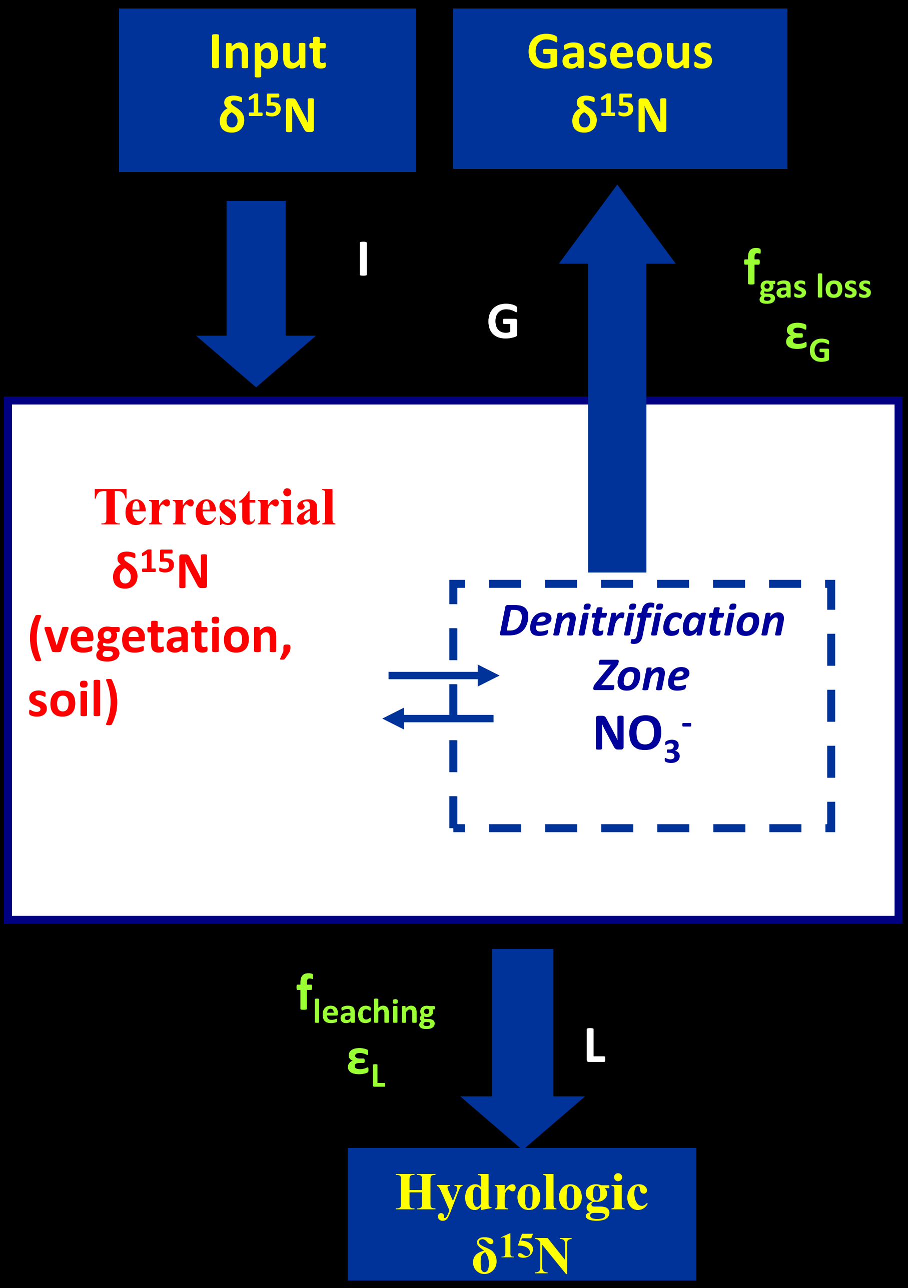
Mineralization

Assimilation
(plant and microbial)

Org-N

Assimilation
(plant and microbial)

Hydrosphere



Input $\delta^{15}N$

Gaseous $\delta^{15}N$

I

G

$f_{gas\ loss}$

ε_G

Terrestrial $\delta^{15}N$ (vegetation, soil)

Denitrification Zone NO_3^-

$f_{leaching}$

ε_L

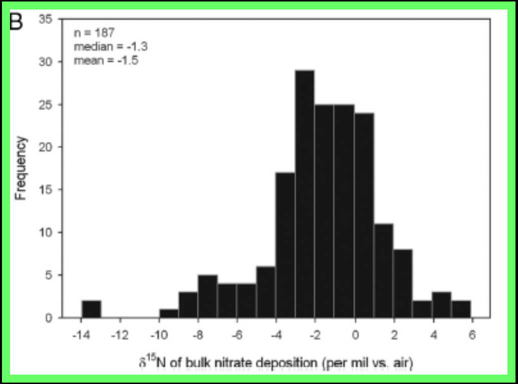
L

Hydrologic $\delta^{15}N$

$$f_{gas} = \frac{\delta^{15}N_{TB} - \delta^{15}N_I + \varepsilon_L}{\varepsilon_L - \varepsilon_G}$$

(Houlton et al., *PNAS*, 2006;
Houlton et al., PNAS, 2007;
Houlton and Bai, *PNAS*, 2009
Bai and Houlton, *GBC*, 2009;
Bai et al. Biogeosciences, 2012)

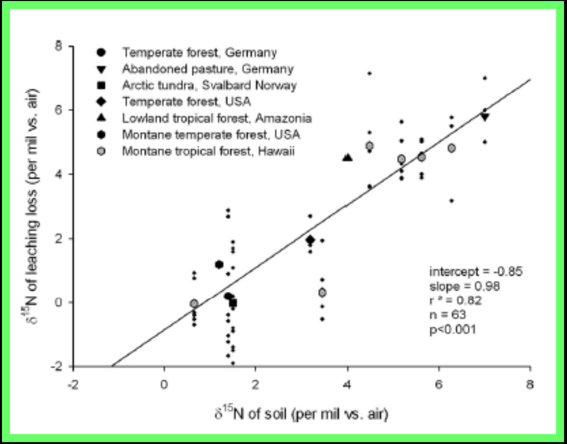
Global data



Observation and modeling

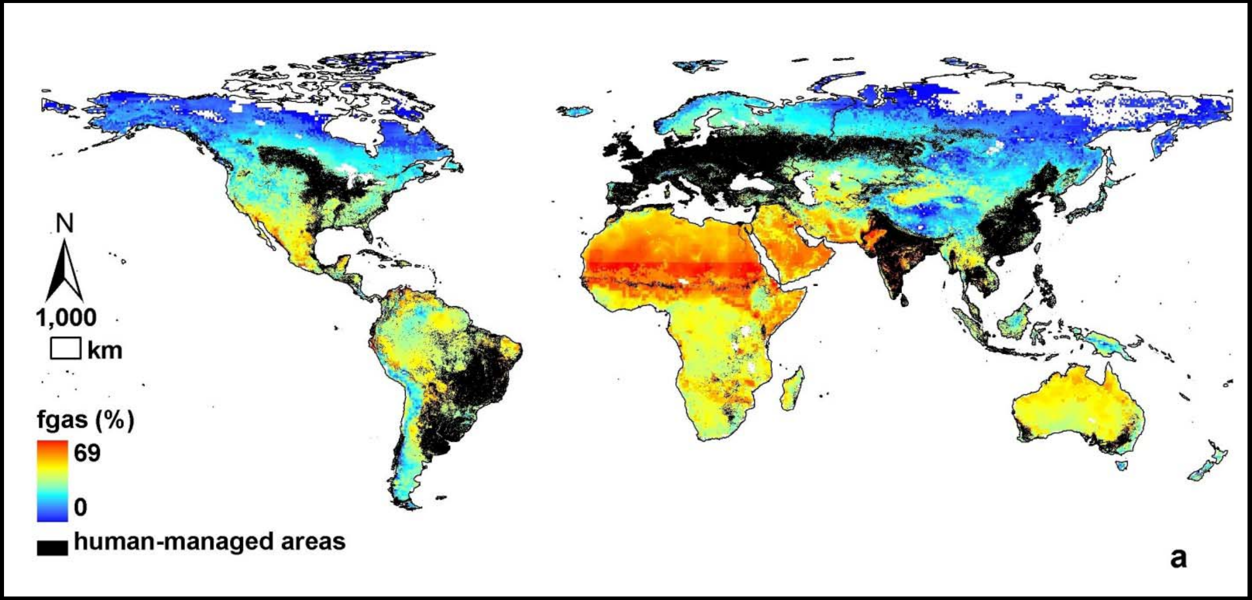
$$f_{gas} = \frac{\delta^{15}N_{soil} - \delta^{15}N_{I} - (\varepsilon_{NH3} - \varepsilon_{L}) \times f_{NH3} - \varepsilon_{L}}{\varepsilon_{G} - \varepsilon_{L}}$$

Lab and field experiments



Houlton and Bai, *PNAS*, 2009

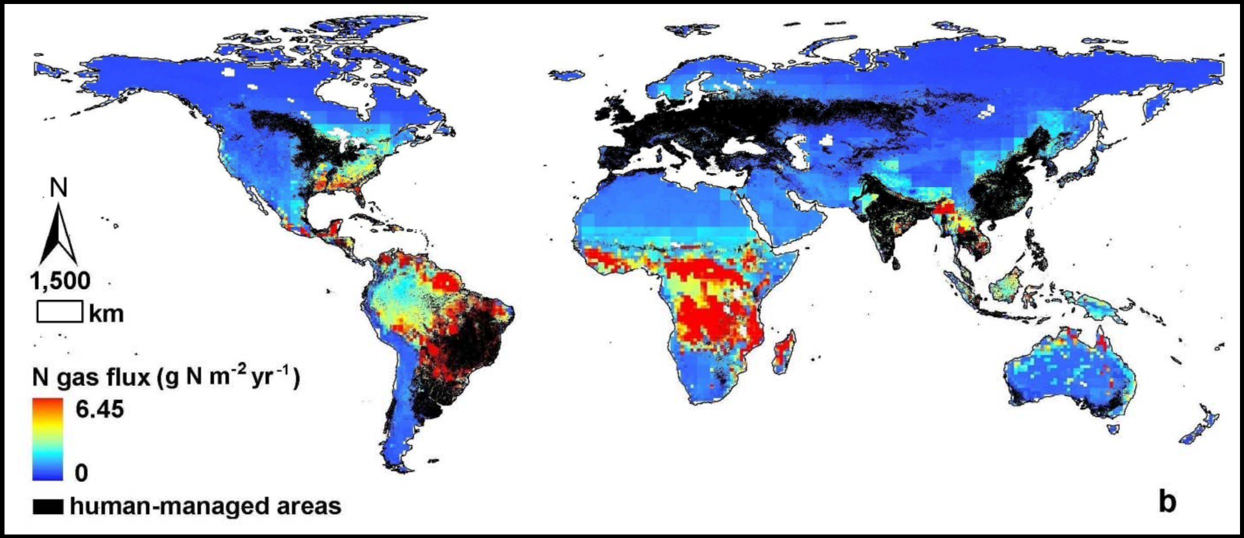
Denitrification gas loss fractions



$$f_{gas} = \frac{\delta^{15}N_{soil} - \delta^{15}N_{I} - (\varepsilon_{NH3} - \varepsilon_{L}) \times f_{NH3} - \varepsilon_{L}}{\varepsilon_{G} - \varepsilon_{L}}$$

Bai, Houlton and Wang, *Biogeosciences*, 2012

Denitrification fluxes



$$f_{gas} = \frac{\delta^{15}N_{soil} - \delta^{15}N_{I} - (\varepsilon_{NH3} - \varepsilon_{L}) \times f_{NH3} - \varepsilon_{L}}{\varepsilon_{G} - \varepsilon_{L}}$$

+

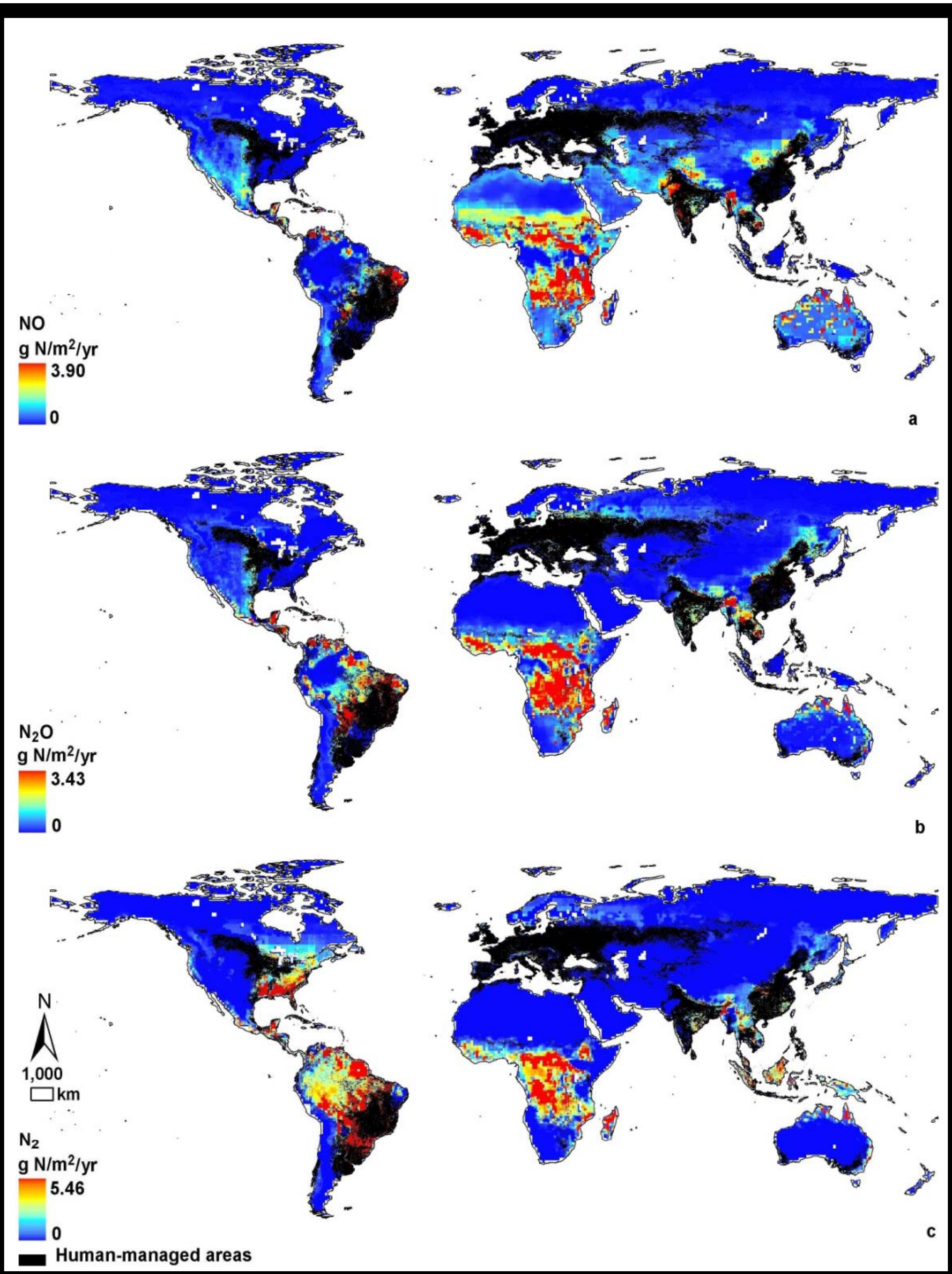
N deposition (Lelieveld and Dentener, *JGR*, 2000)
N fixation (Houlton et al., *Nature*, 2008)

Bai, Houlton and Wang, *Biogeosciences*, 2012

No_x^*
11 – 20 Tg
*(cut in half with canopy)

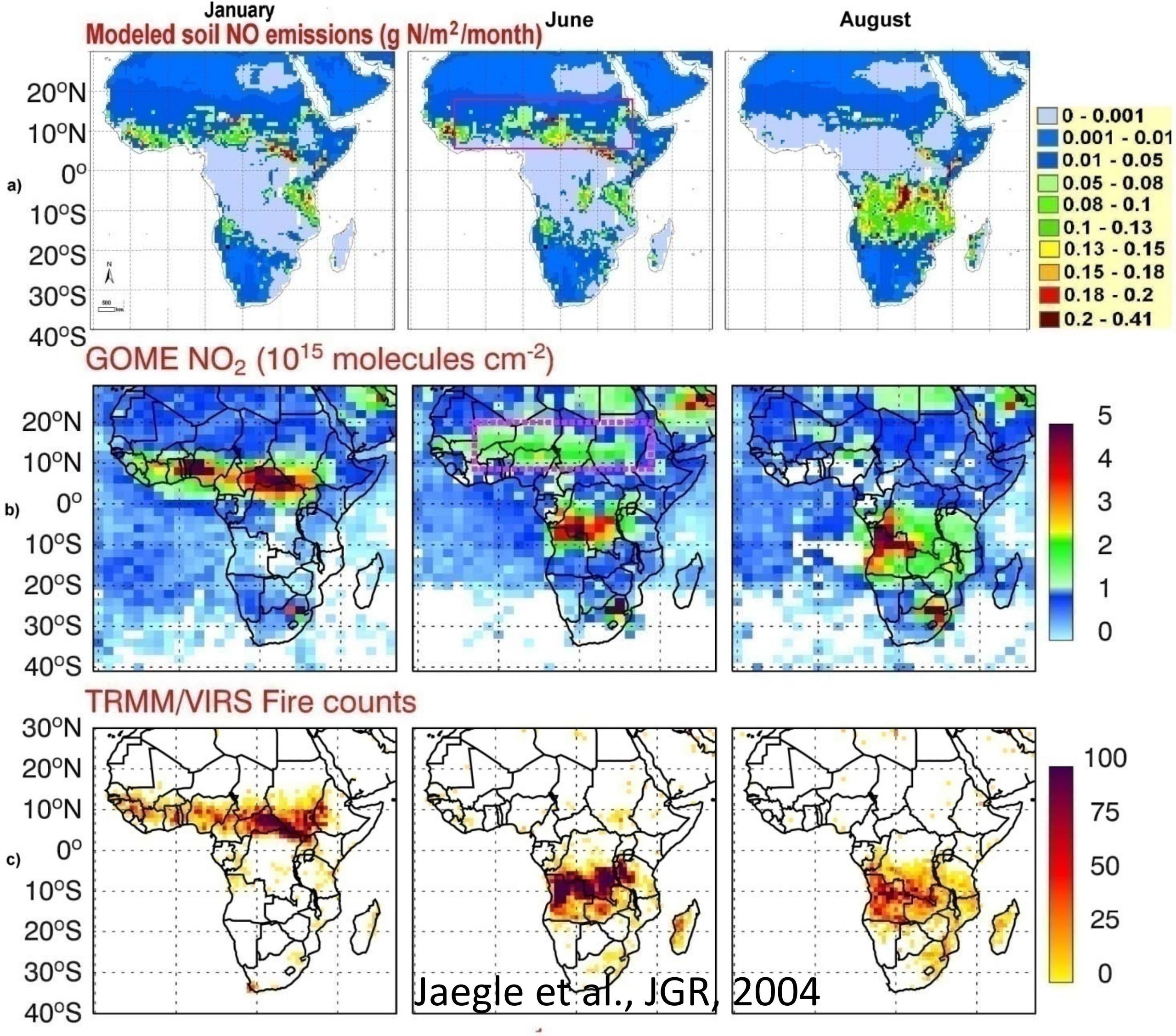
N_2O
7 – 13 Tg
(Ag. ~3)

N_2
15 – 27 Tg



Bai, Houlton and Wang, *Biogeosciences, 2012*

Example: isotopic modeling and satellites



Jaegle et al., JGR, 2004

Bai, Houlton and Wang, *Biogeosciences*, 2012

1. Global hotspots of gaseous N losses in the terrestrial biosphere – missing N sink?
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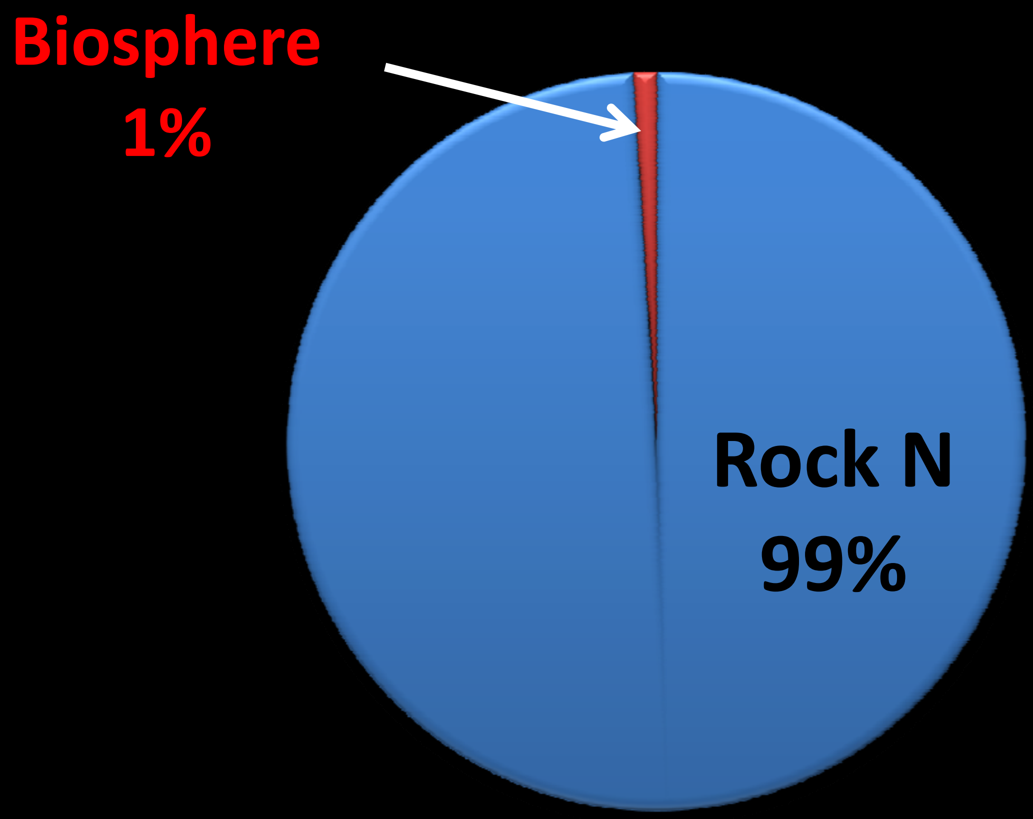
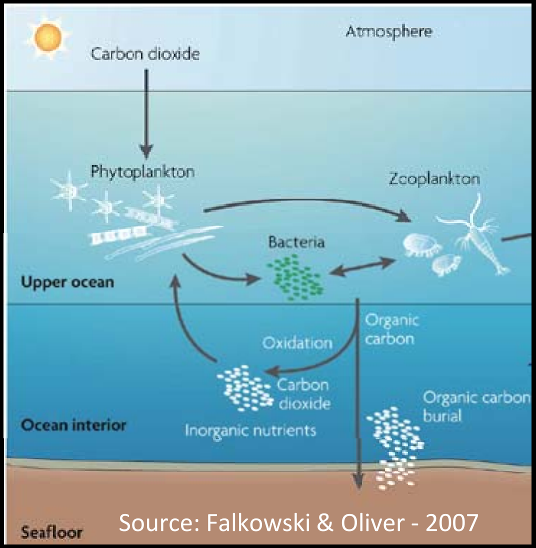
3. Patterns of new production: N, P and satellites

Global distribution of **“fixed” N**

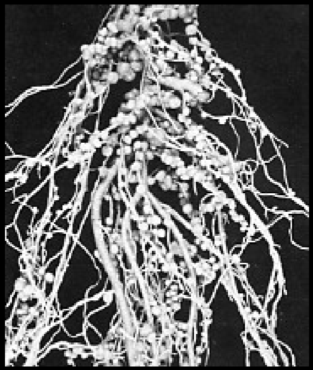


Origin and Genesis of Geologic N

N fixation in the past → Diagenesis → Low-grade metamorphism



Source: Falkowski & Oliver - 2007

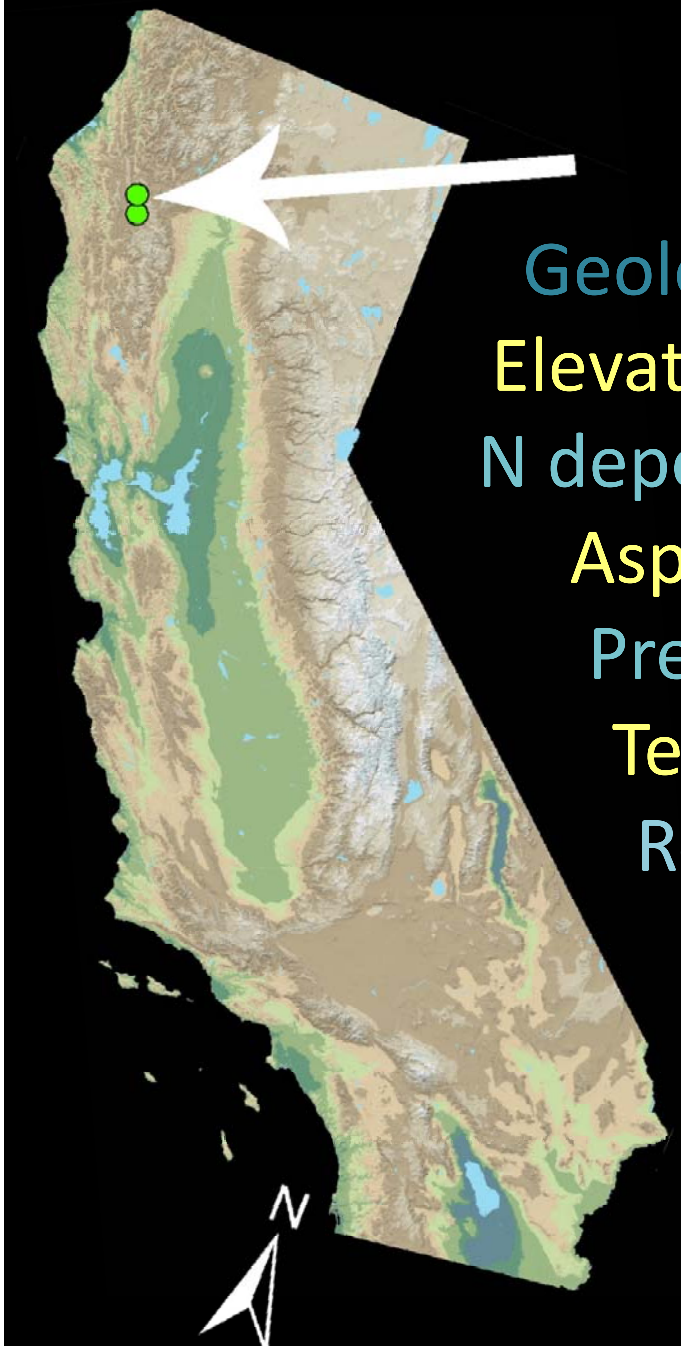


Organic N in shale and mudstones

Fixed NH_4^+ in silicate rocks

Have we been working with the right N cycle?

Study Sites

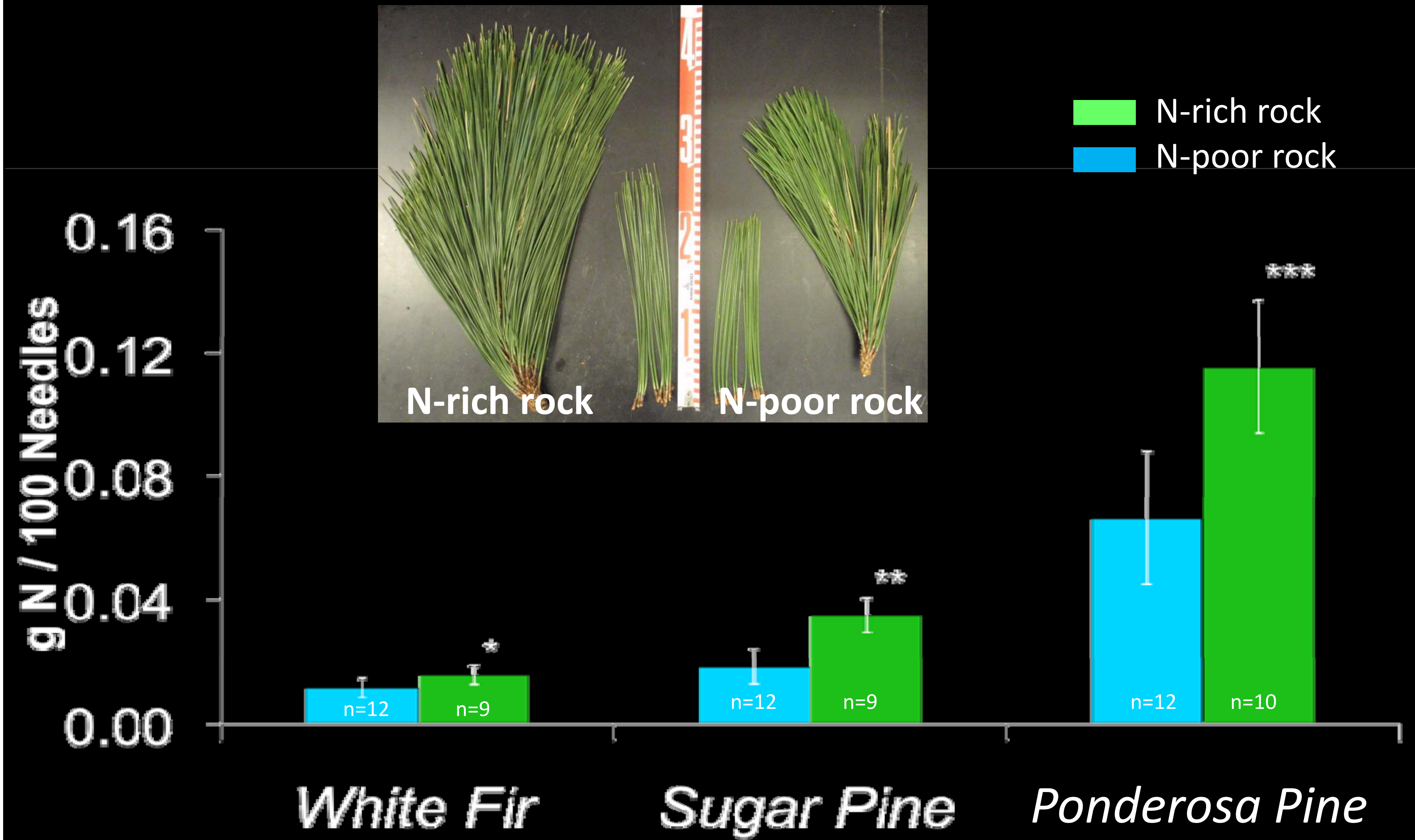


	N-rich rock	**N-poor rock**
Geology:	Mica Schist	Diorite
Elevation:	1750 m	1500 m
N deposit:	< 1kg ha^{-1}	< 1kg ha^{-1}
Aspect:	NE & N	N
Precip:	1520 mm	1400 mm
Temp:	9° c	10.5° c
Rock:	682 ppm	55 ppm

Species sampled:

Abies concolor (White Fir)
Pinus lambertiana (Sugar Pine)
Pinus ponderosa (Ponderosa Pine)
Calocedrus decurrens (Incense Cedar)

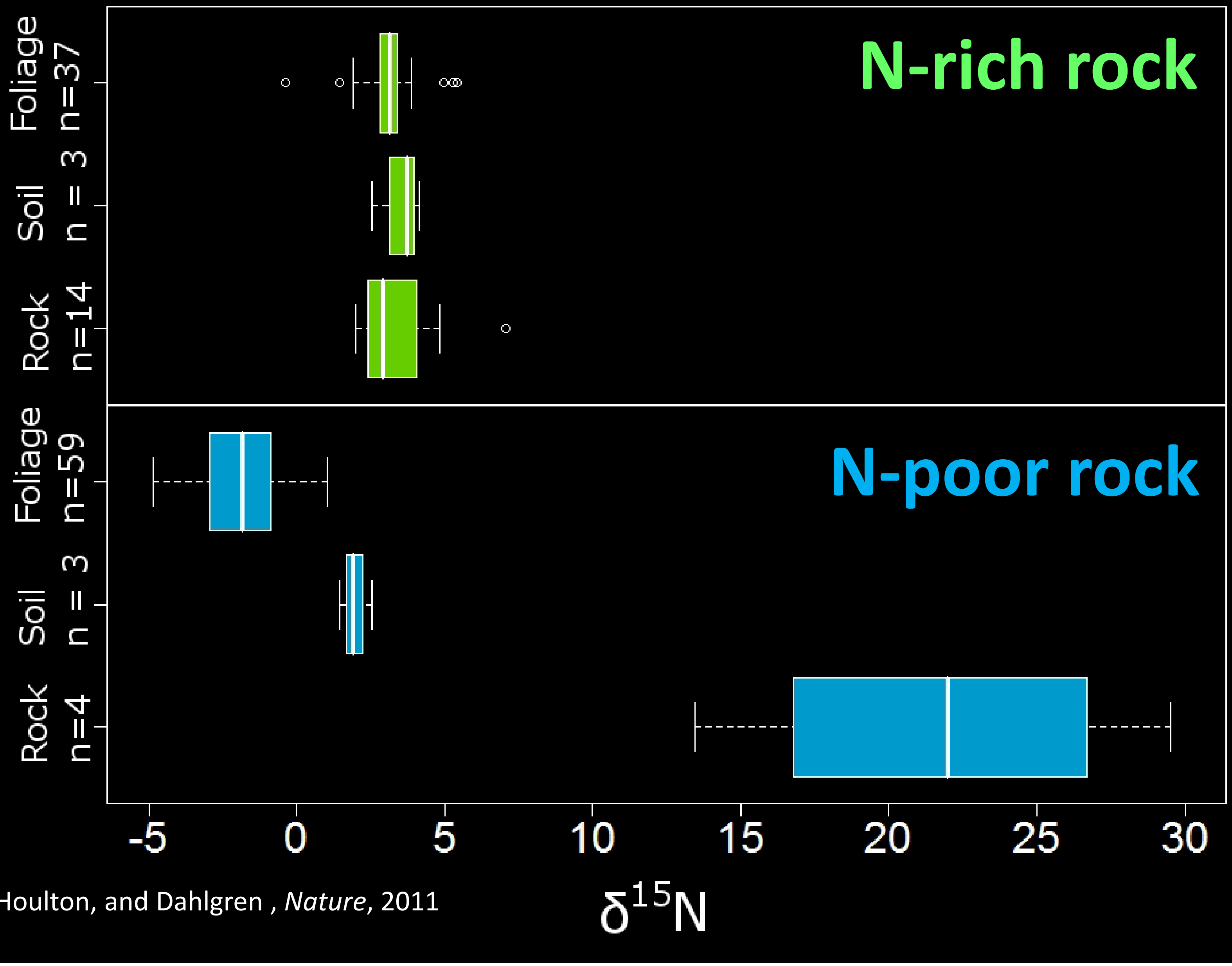
Total N in Plant Foliage



* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Morford, Houlton, and Dahlgren , *Nature*, 2011

$\delta^{15}N$ of Plant – Soil – Rock System



Morford, Houlton, and Dahlgren , *Nature*, 2011

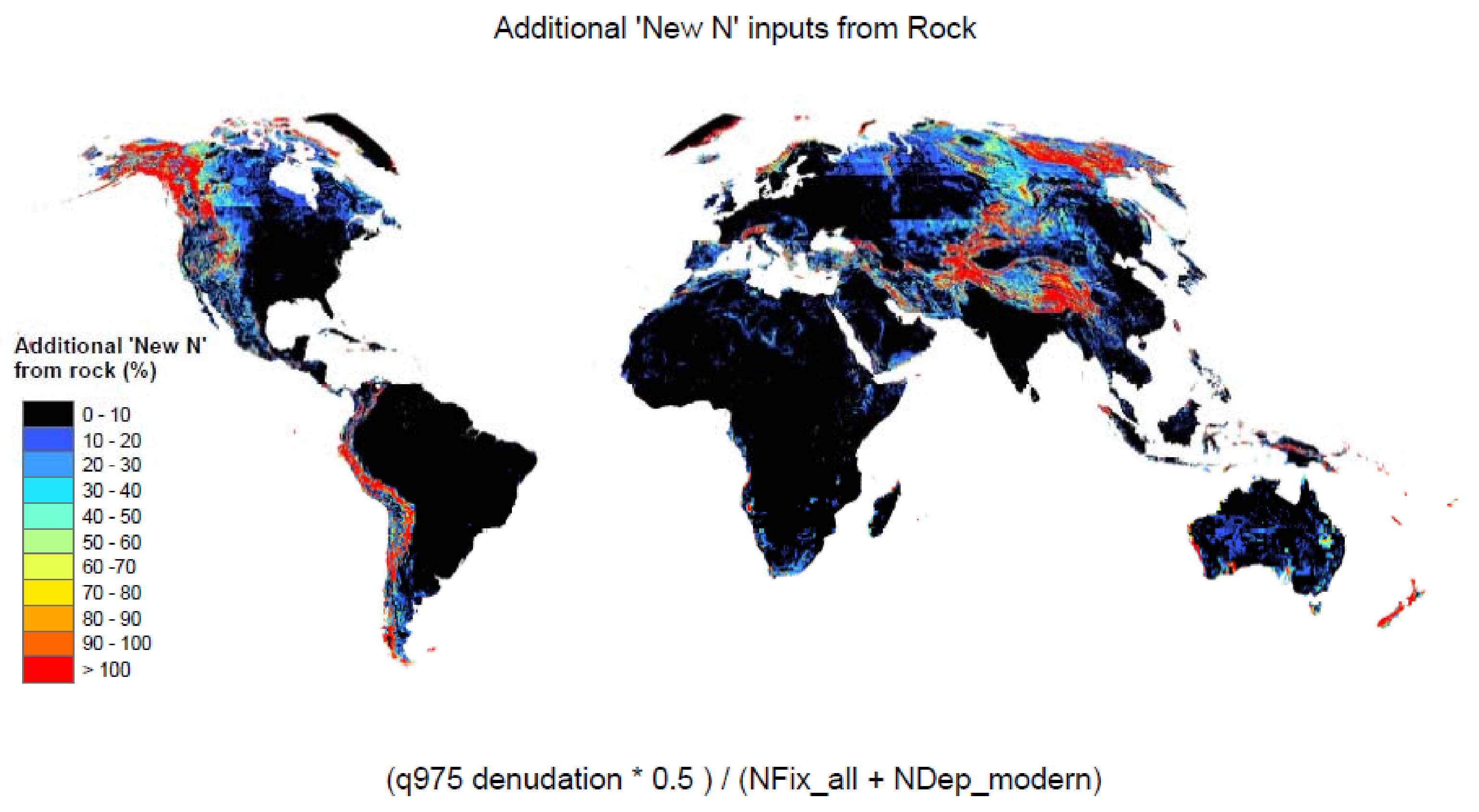
Estimated N Inputs

	Isotope balance	Isotope balance with fractionations	Uplift	Lab weathering
Fraction of total N inputs via rock weathering	**1.22**	**0.30**	**0.47**	**0.64**

3 to 10 Kg N/ha/yr, or ~ doubling of N inputs

Morford, Houlton, and Dahlgren , Nature, 2011

Global implications



~ 24 Tg N at the global Scale, cf. ~120 for natural N fixation, 5 for lightening

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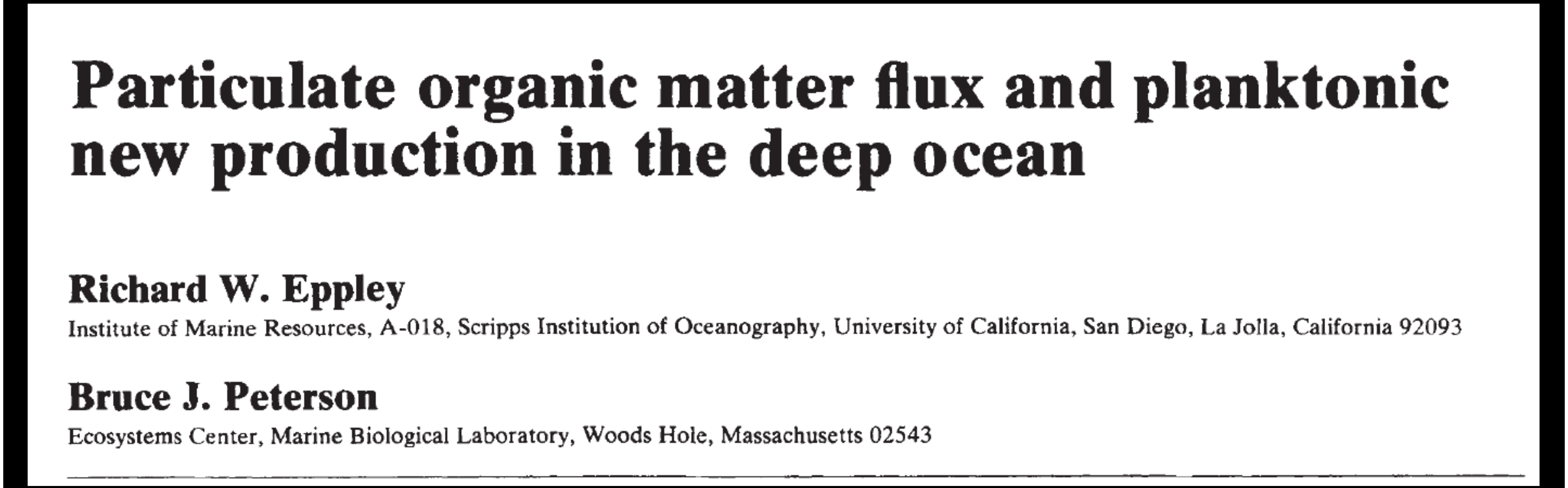

Particulate organic matter flux and planktonic new production in the deep ocean

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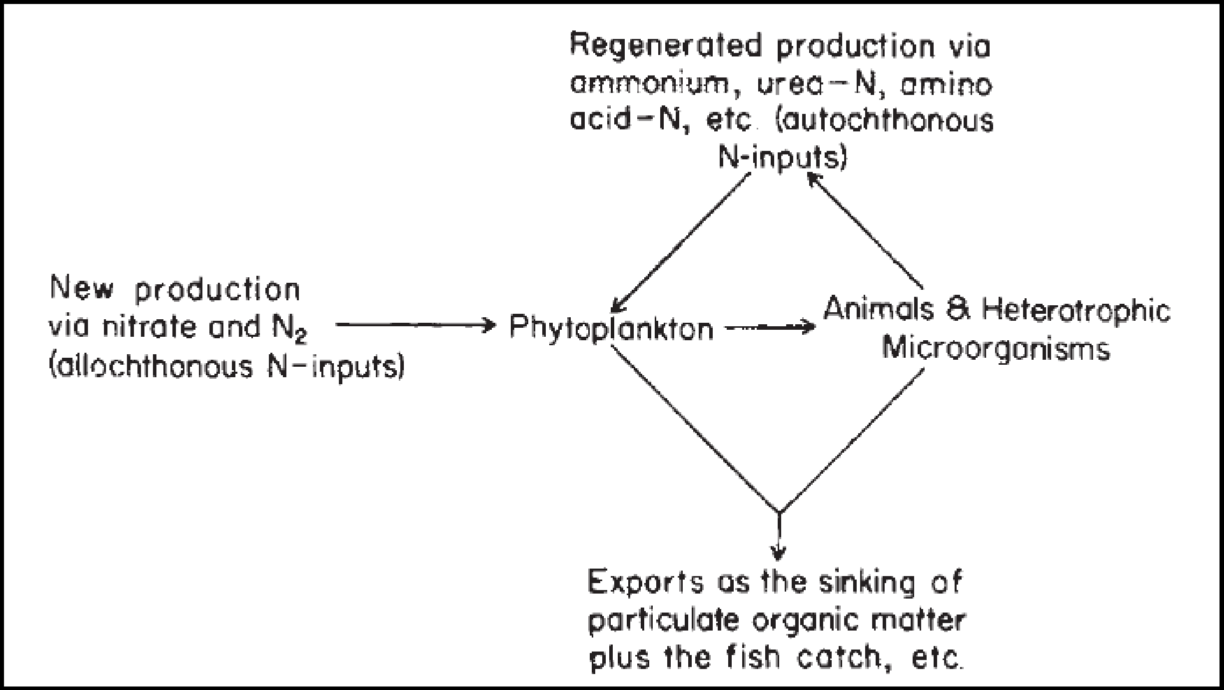
Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts 02543



f = new production/total = ~18 % for new nitrogen

Defining new vs. recycled production for the terrestrial biosphere

$$NPP_{total}(N,P) = NPP_{new}(N,P) + NPP_{recycle}(N,P)$$

$$f_{new}(N,P) = \frac{NPP_{new}(N,P)}{NPP_{total}}$$

$$f_{recycle}(N,P) = \frac{NPP_{recycle}(N,P)}{NPP_{total}}$$

$$NPP_{new}(N,P) = NPP_{total}(N,P) \times f_{new}(N,P)$$

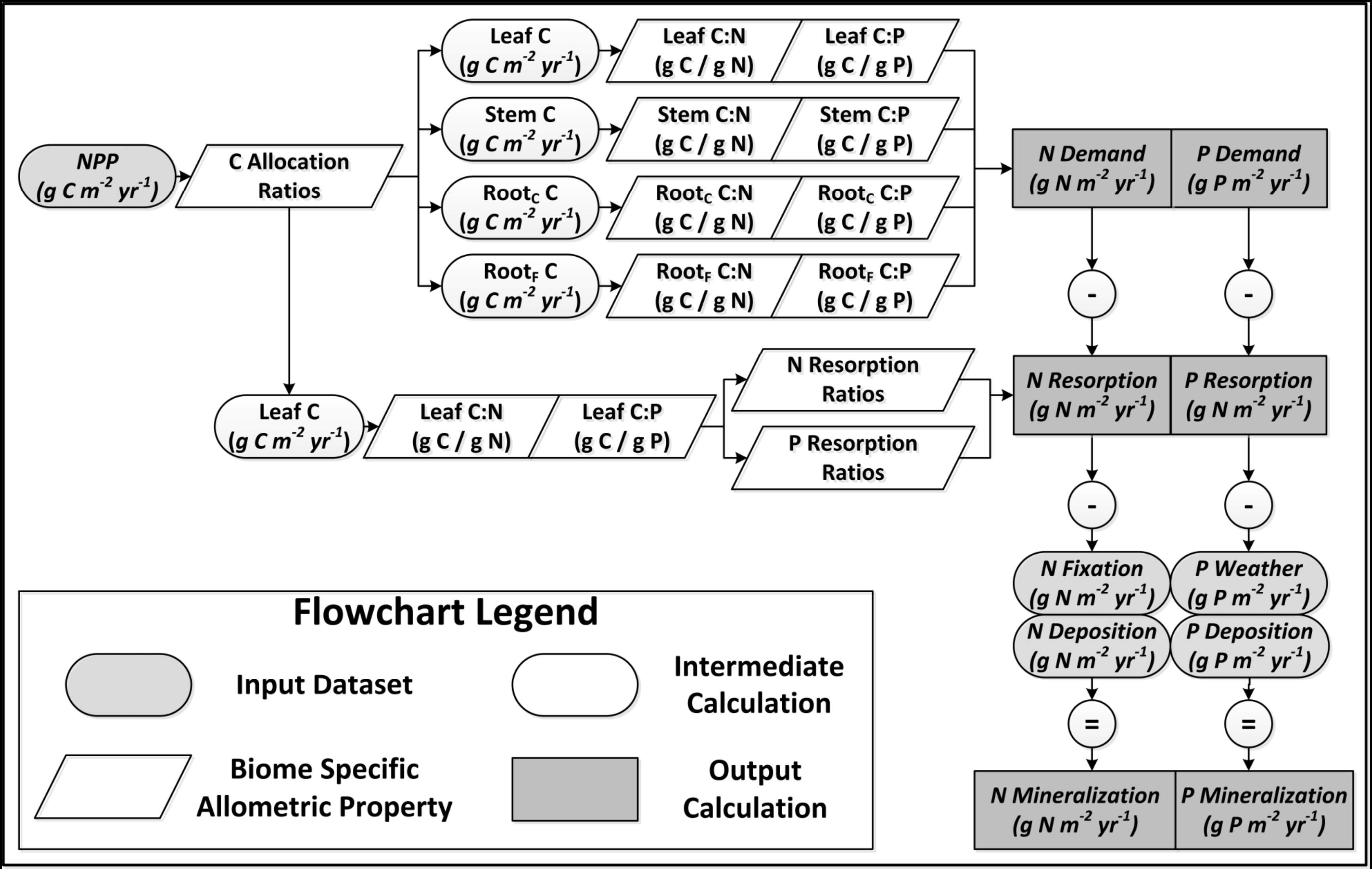
New production vs. recycled production

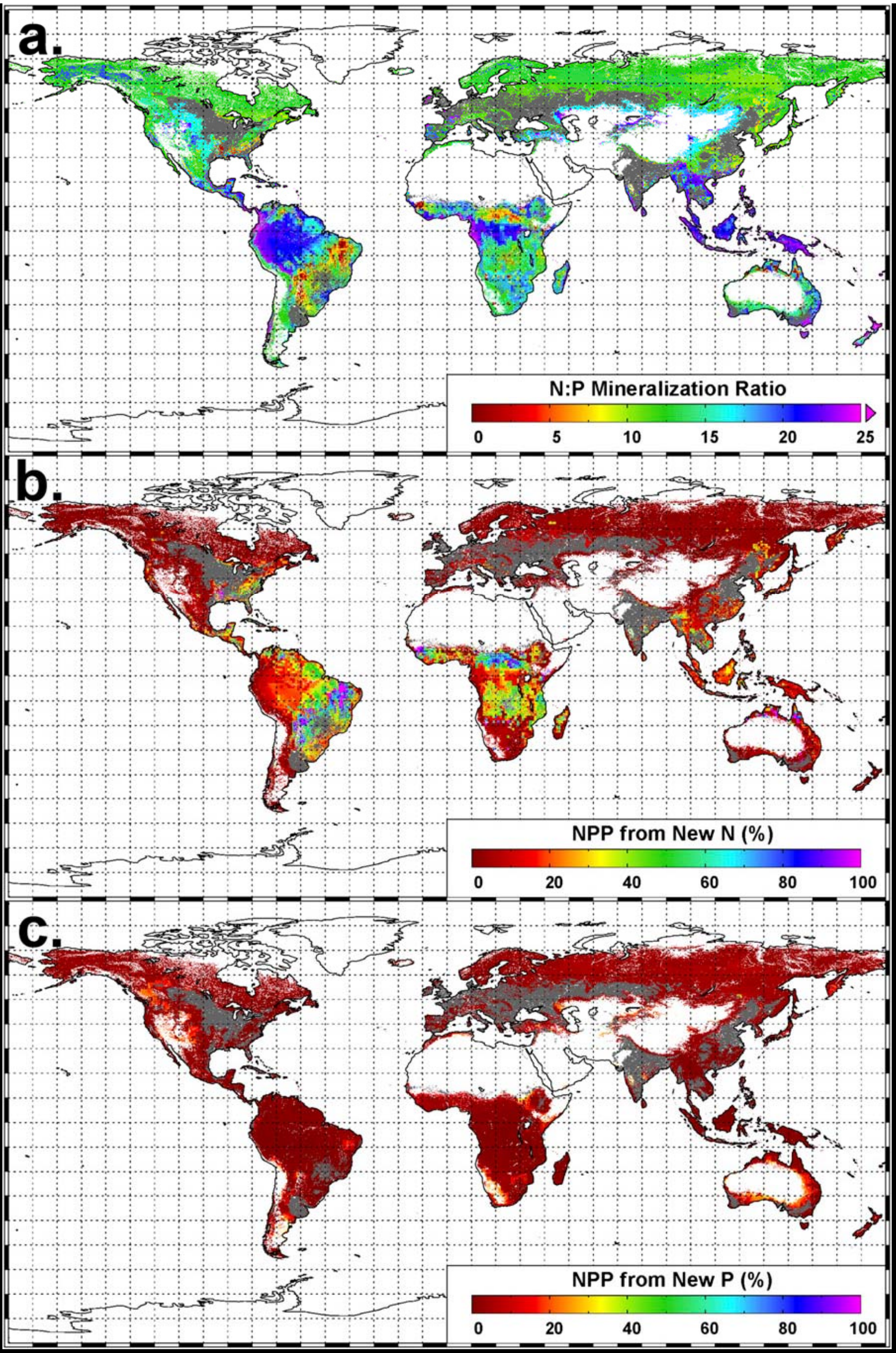
Total plant N demand = N Resorption + Net N Mineralization + N Fixation (f plant) + N Deposition (f plant)

Total plant P demand = P Resorption + Net P Mineralization + P Dust (f plant) + P Weathering (f plant)

$$\text{New N Production} = \frac{\text{N Fixation (f plant) + N Deposition (f plant)}}{\text{N Resorption + Net N Mineralization}}$$

$$\text{New P Production} = \frac{\text{P Dust (f plant) + P Weathering (f plant)}}{\text{P Resorption + Net P Mineralization}}$$


NPP (g C m-2 yr-1)
C Allocation Ratios
Leaf C (g C m-2 yr-1)
Stem C (g C m-2 yr-1)
RootC C (g C m-2 yr-1)
RootF C (g C m-2 yr-1)
Leaf C:N (g C / g N)
Leaf C:P (g C / g P)
Stem C:N (g C / g N)
Stem C:P (g C / g P)
RootC C:N (g C / g N)
RootC C:P (g C / g P)
RootF C:N (g C / g N)
RootF C:P (g C / g P)
N Demand (g N m-2 yr-1)
P Demand (g P m-2 yr-1)
-
-
Leaf C (g C m-2 yr-1)
Leaf C:N (g C / g N)
Leaf C:P (g C / g P)
N Resorption Ratios
P Resorption Ratios
N Resorption (g N m-2 yr-1)
P Resorption (g N m-2 yr-1)
-
-
N Fixation (g N m-2 yr-1)
P Weather (g P m-2 yr-1)
N Deposition (g N m-2 yr-1)
P Deposition (g P m-2 yr-1)
=
=
N Mineralization (g N m-2 yr-1)
P Mineralization (g P m-2 yr-1)
Flowchart Legend
Input Dataset
Intermediate Calculation
Biome Specific Allometric Property
Output Calculation

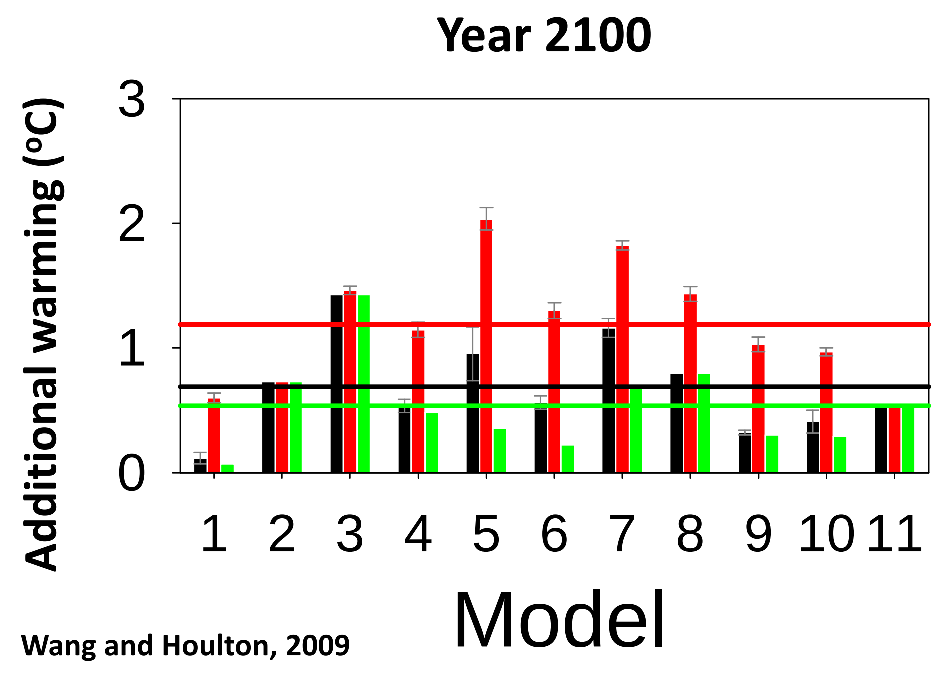

a.
N:P Mineralization Ratio
0
5
10
15
20
25
b.
NPP from New N (%)
0
20
40
60
80
100
c.
NPP from New P (%)
0
20
40
60
80
100

Global Implications of terrestrial f

- Terrestrial new production is 16% for nitrogen; <2 % for phosphorus
- Natural nitrogen fixation accounts for more 10% of new nitrogen production; nitrogen deposition makes minor contribution (<1%)
- Tropical systems – particularly tropical forests – display highest capacity for new nitrogen production, perhaps C uptake in general (~18% vs. ~3% for extra-tropical systems)

Closing thoughts

We have much to learn about global nutrient balances…with significant implications



Wang and Houlton, 2009

Green: C^4MIP results (CO_2-climate; no N limitation)

Black: N limitation (high N fixation)

Red: N limitation (low N fixation)

2100-1900: 0.54°C (C^4MIP); 0.69 to 1.19°C (N limiting)

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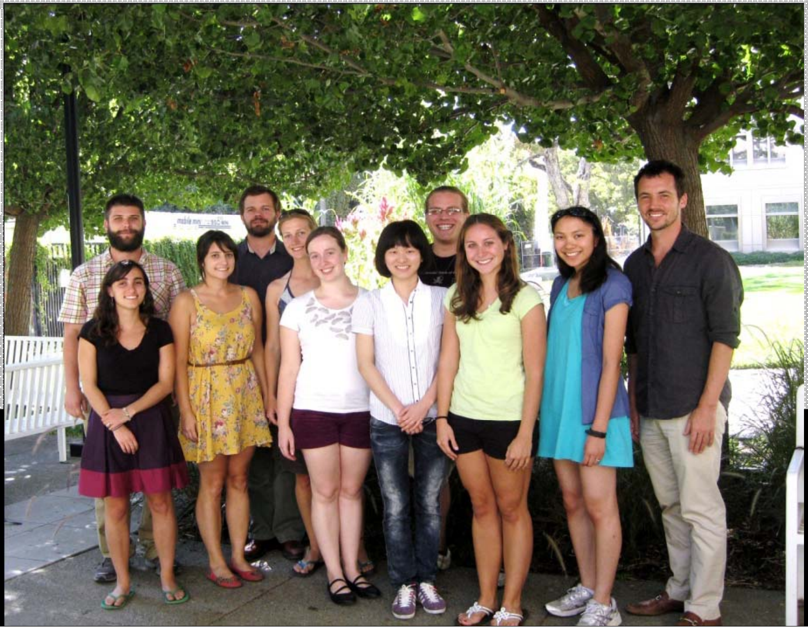
- **National Science Foundation – NSF CAREER**



Questions?