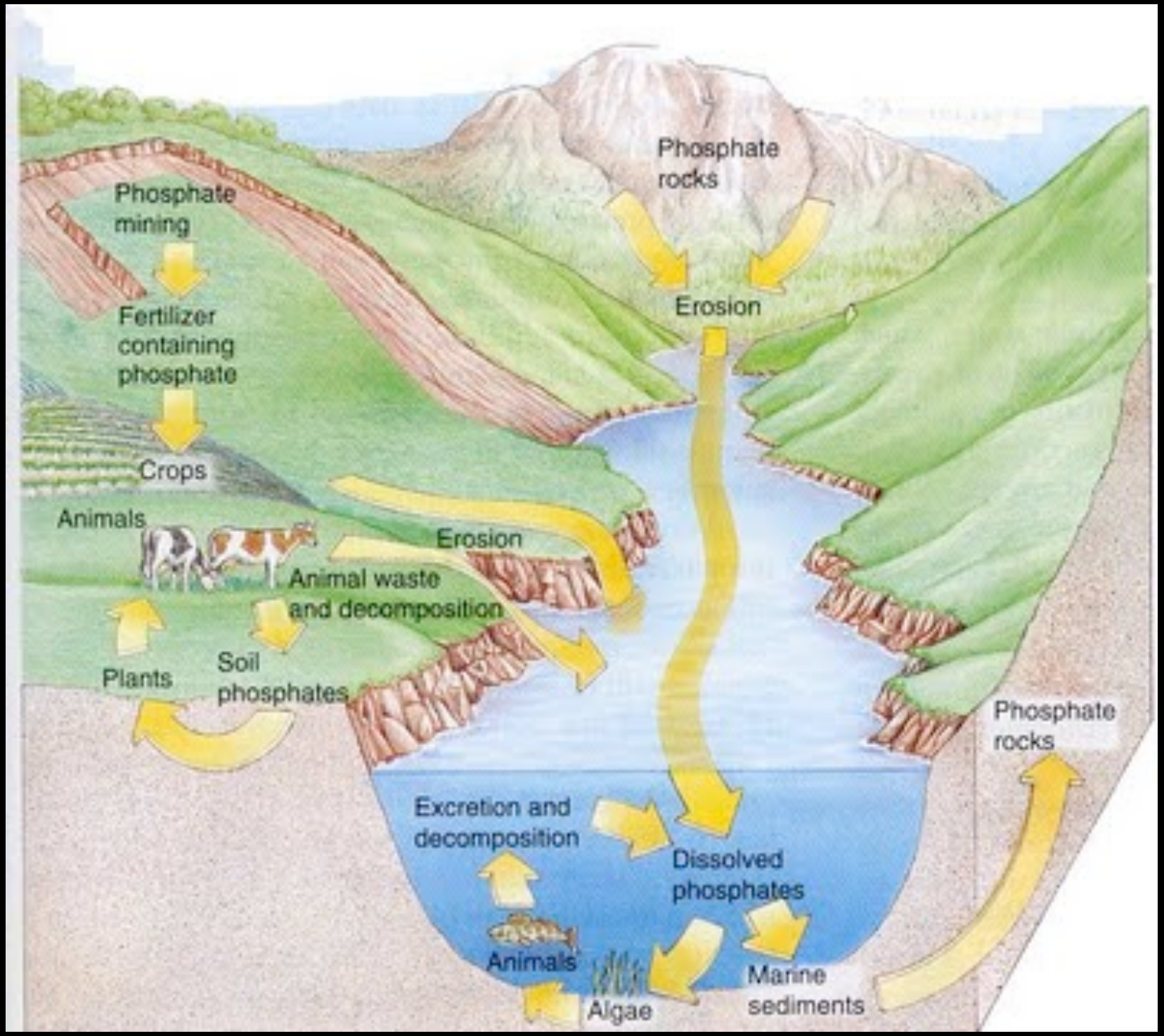
Global phosphorus cycle: Freshwater Realm

Sensitivity of water as compared to terrestrial systems

- 10 ug P/L = 5 kg in a 10-ha lake (avg depth 5m)
  - Runoff from 5-10 ha of intensively fertilized farmland.

- Cornfields receiving 40-65 kg P ha^{-1} yr^{-1} and losing less than 0.2 kg/ha (0.5%) as soluble P are releasing water with concentrations of 0.2 – 0.5 mg P/L, enough to precipitate eutrophication.
  - Even the best agronomic practices may not be able to prevent P losses great enough to produce eutrophication of sensitive waters.

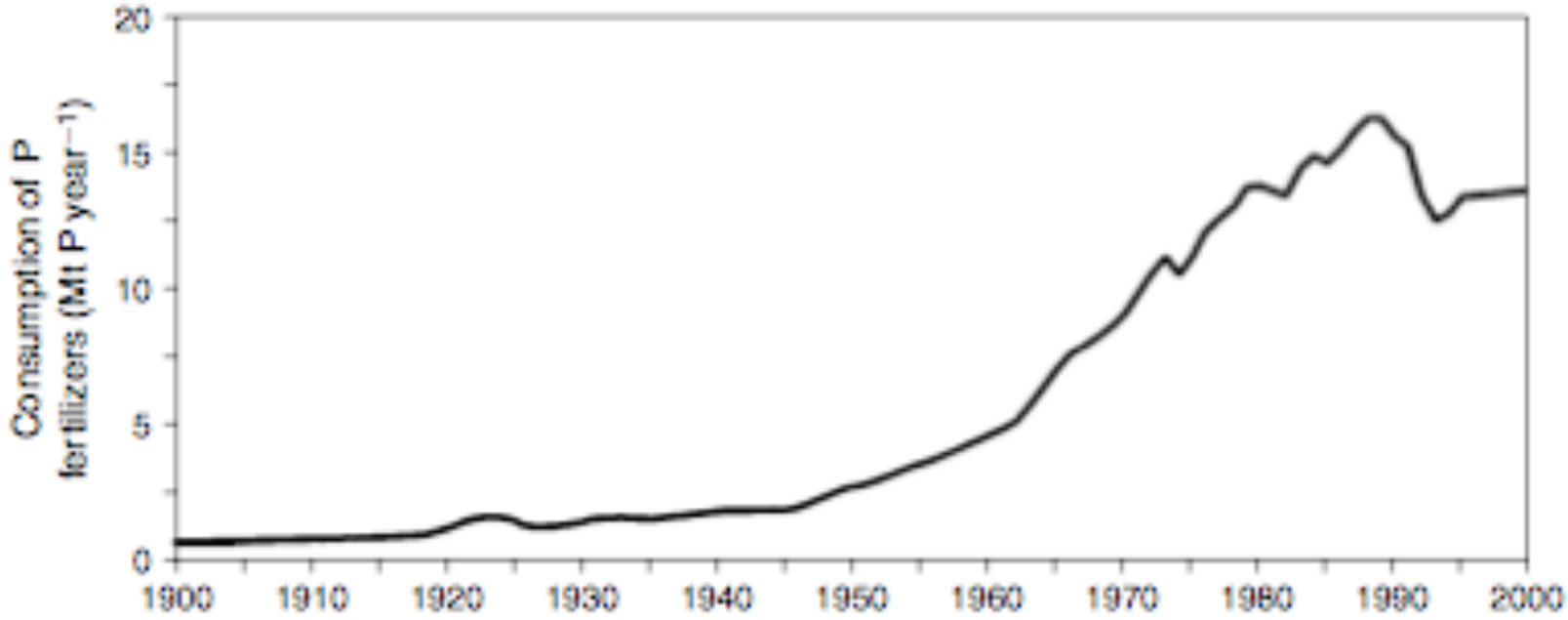
Smil 2000.


Phosphate rocks
Phosphate mining
Erosion
Fertilizer containing phosphate
Crops
Animals
Erosion
Animal waste and decomposition
Plants
Soil phosphates
Phosphate rocks
Excretion and decomposition
Dissolved phosphates
Animals
Algae
Marine sediments

How people change the global P cycle

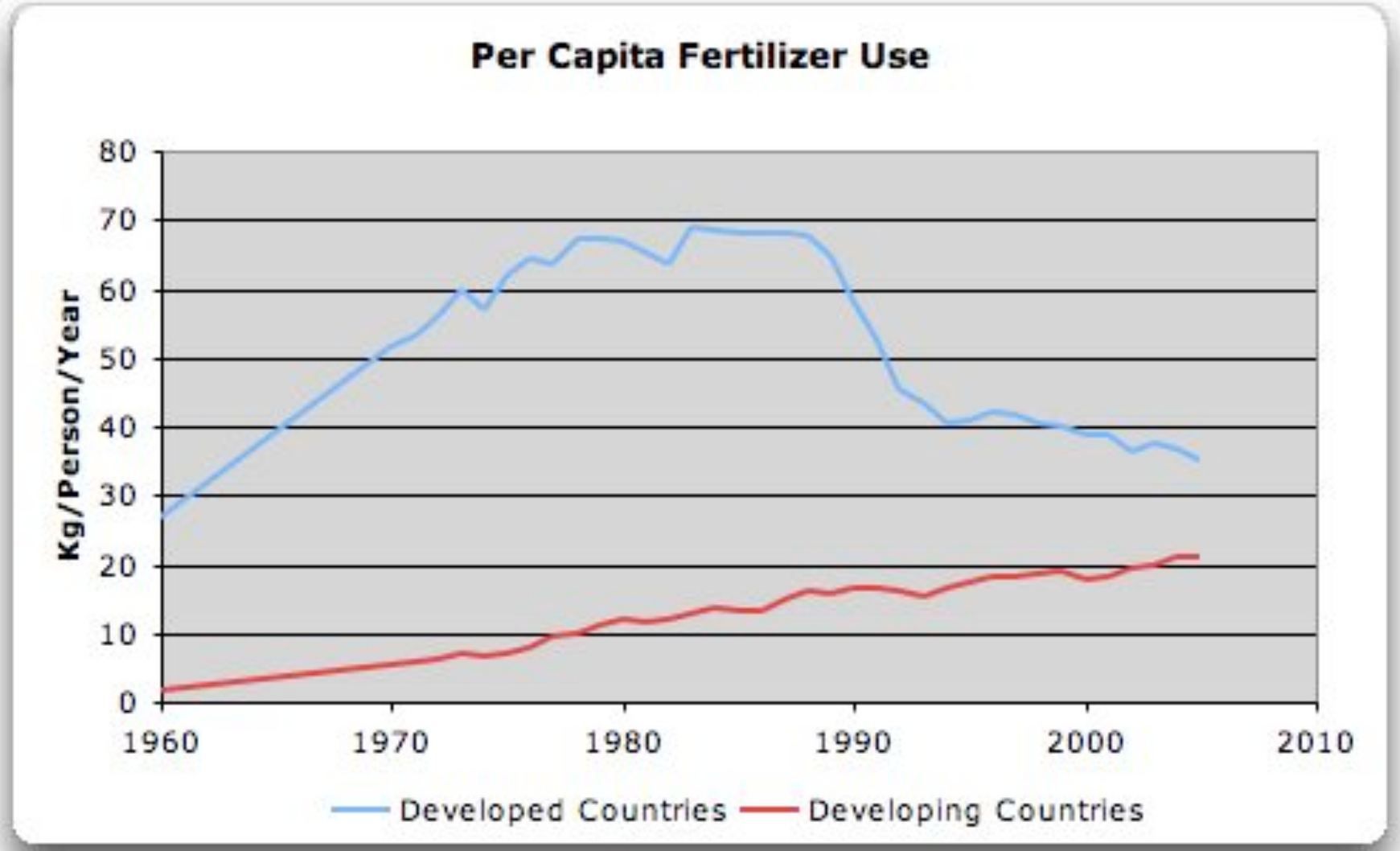
- Mining P for use in fertilizers
- Spreading P in fertilizers them in soils around the world
- Transporting food containing P (grains and meat) around the world and depositing them in urban sewage
- Accelerating erosion and other P transport

Consumption of P fertilizers



V. Smil. 2002.

Consumption of fertilizers in "developed" and "developing" countries



P budget – world's *cropland* (mid-1990s, Mt P)

Smil 2000..

How do humans change the P cycle?

	Natural	Preindustrial	Recent (2000)
Erosion	>10	>15	>30
River transport	>7	>9	>22
particulate P	>6	>8	>20
dissolved P	>1	<2	<2
Crop uptake	--	1	12
Animal wastes	--	>1	>15
Human wastes	--	0.5	3
Organic recycling	--	<0.5	>6
Inorganic fertilizers	--	--	15

Smil 2000.

Pre-human dissolved P cycle (Tg P)

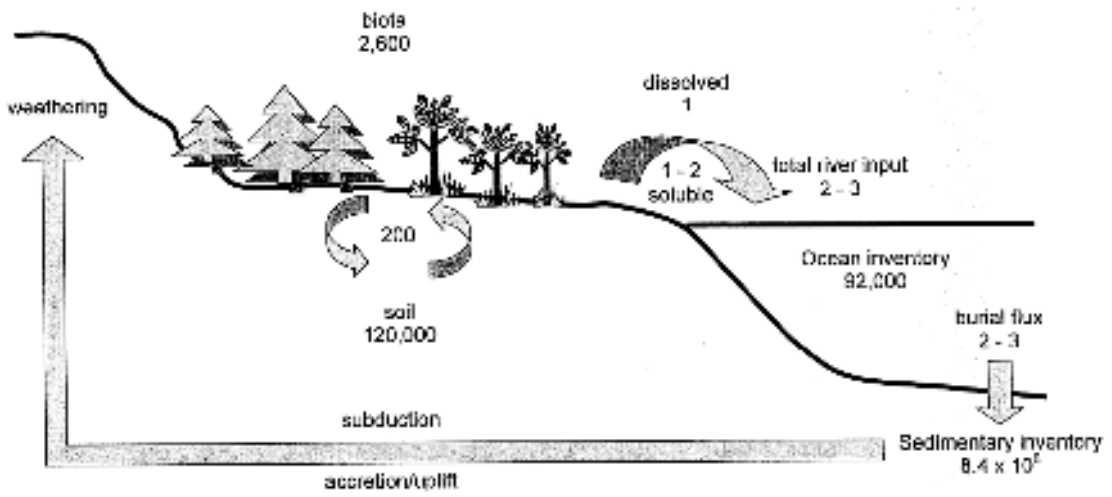


Figure 1. The natural (pre-human) dissolved phosphorus cycle, showing reservoirs (in Tg P) and fluxes (denoted by arrows, in Tg P/yr) in the P mass balance.

Modern dissolved P cycle (Tg P)

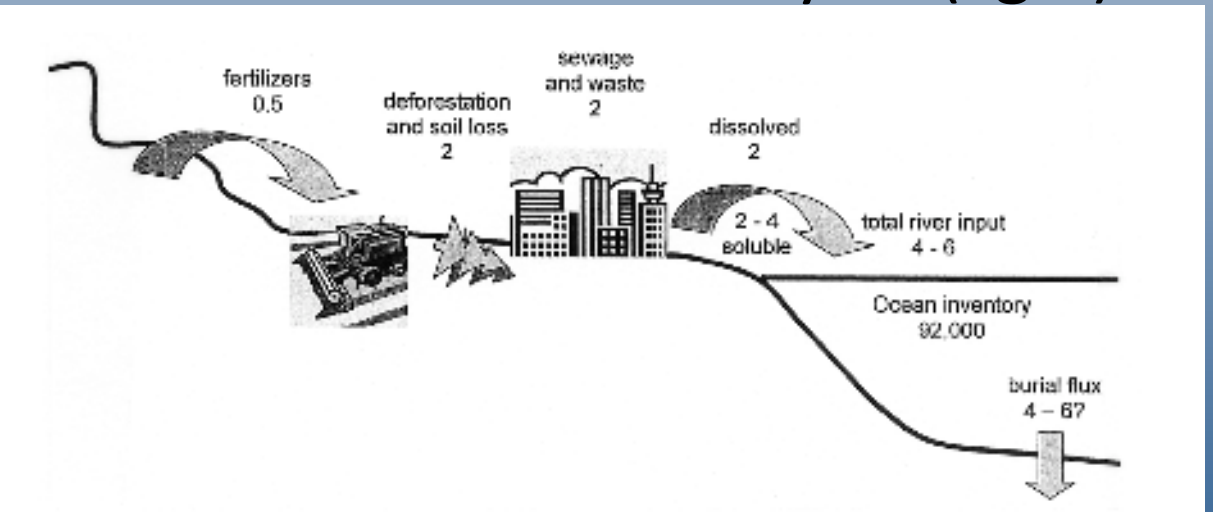
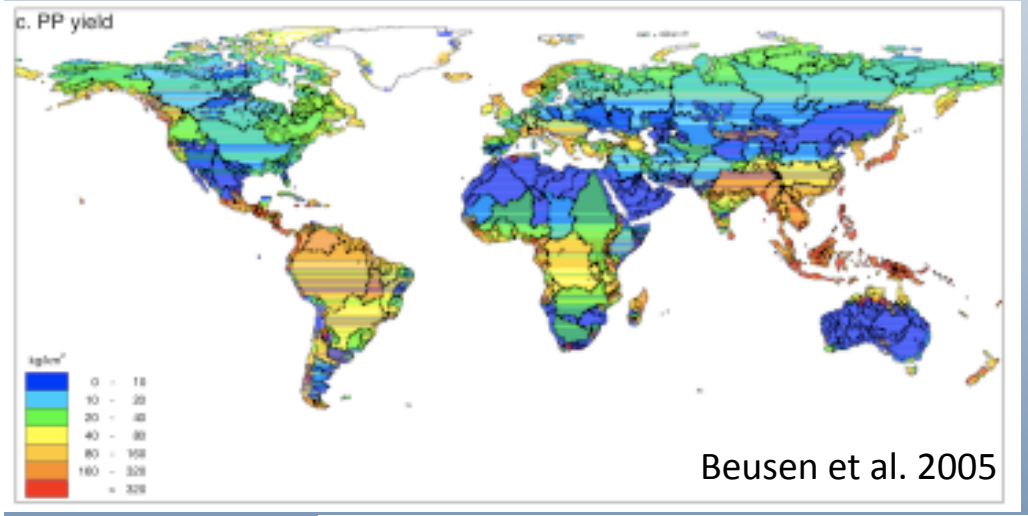


Figure 4. The modern (syn-human) phosphorus cycle, showing reservoirs (in Tg P) and fluxes (denoted by arrows, in Tg P/yr) associated with human activities, which have effectively doubled the natural dissolved P fluxes (cf. Fig. 1).

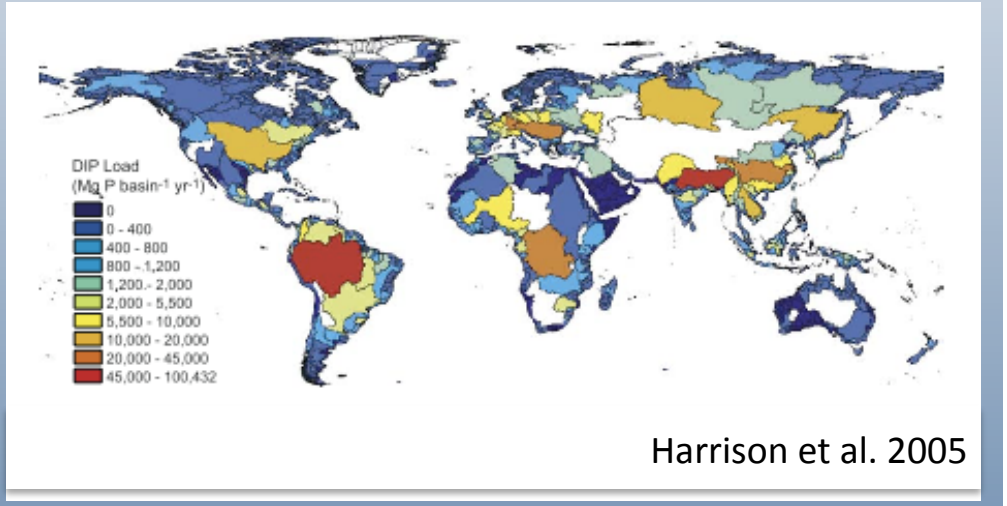
Filippelli 2002.

Global NEWS

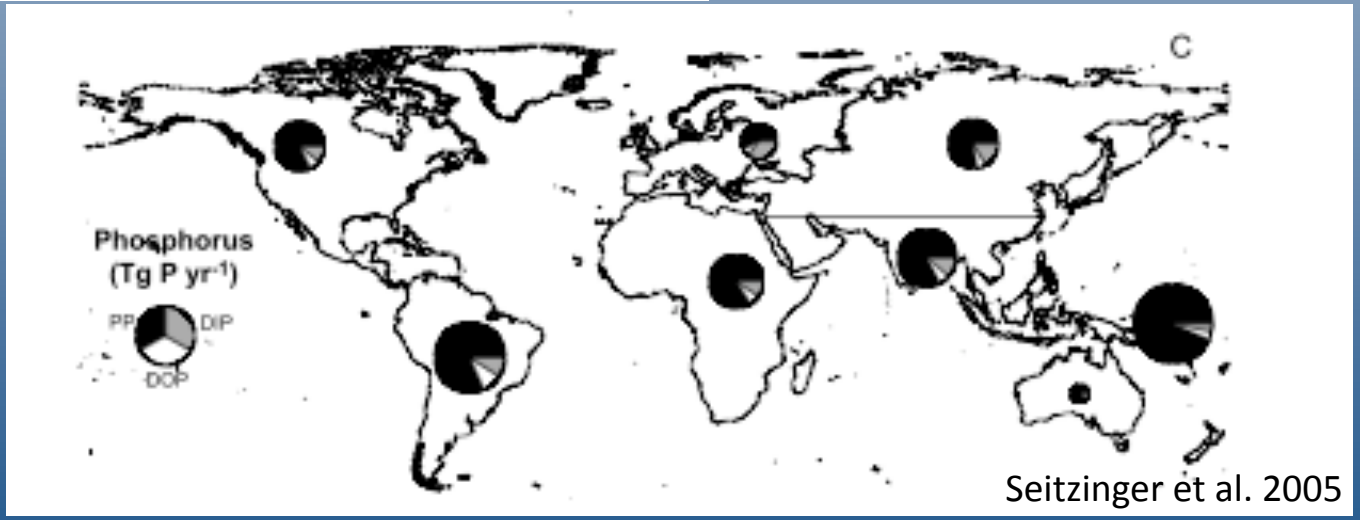
- People have dramatically altered nutrient cycles
- Sources to coastal zones likely to increase in coming decades
- This change will be spatially variable and diverse



Beusen et al. 2005



Harrison et al. 2005

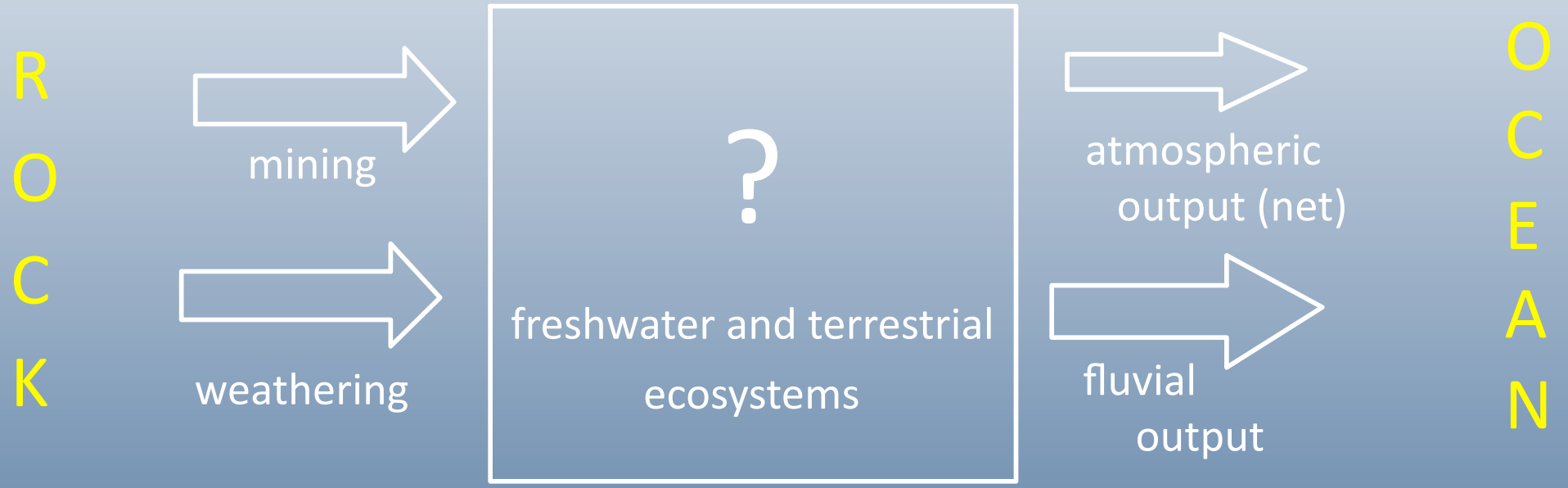


Seitzinger et al. 2005

Global P Cycle: Questions

- Is P accumulating in Earth's surface soil?
- If so, where?
- How do current global P fluxes compare to pre-mining fluxes?

Terrestrial Phosphorus Fluxes



Inputs - Outputs = Change in Storage

Pre-Mining
Global Phosphorus Budget (Tg/yr)

$$10 - (8 + 1) = 1$$

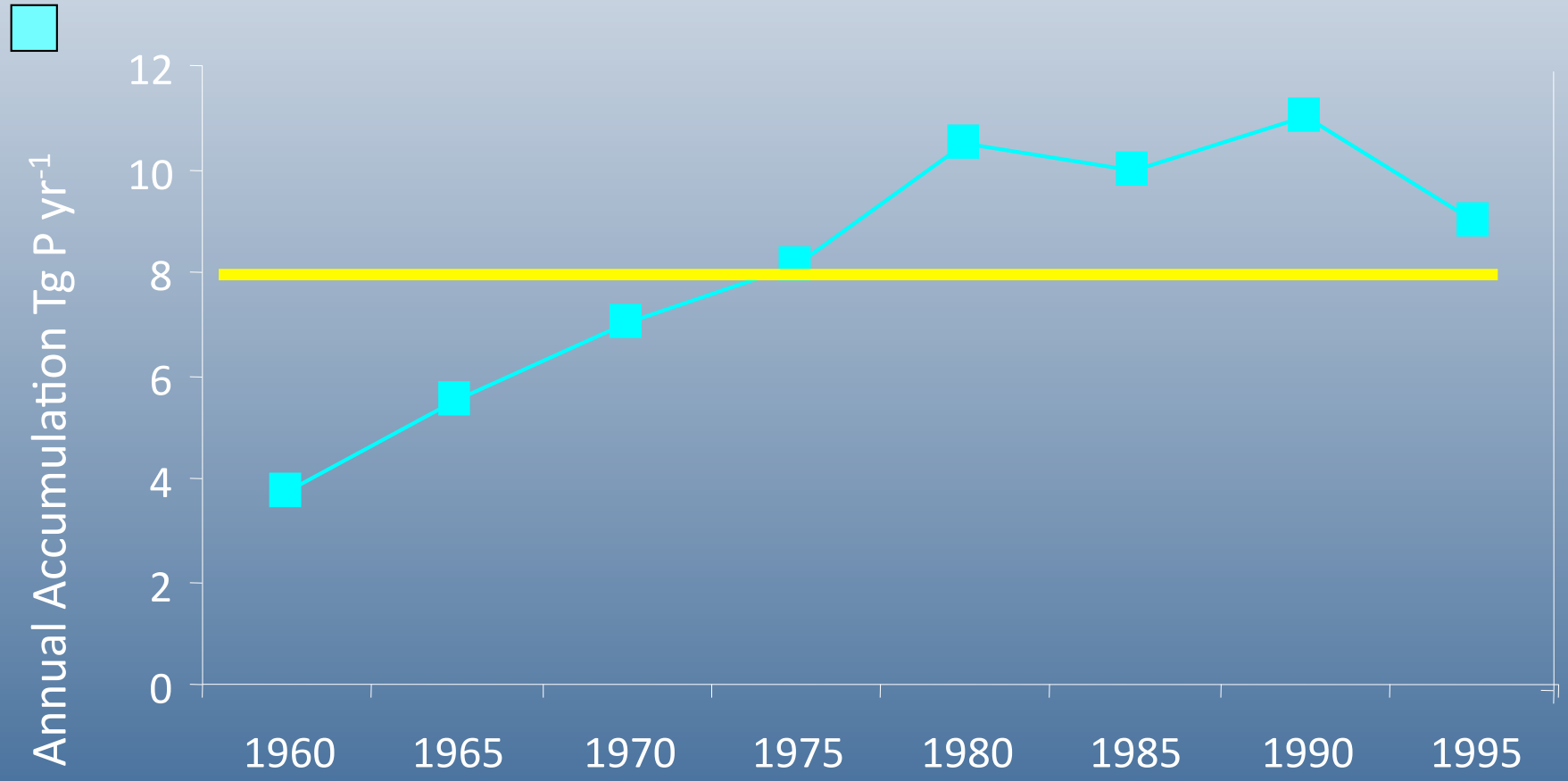
Bennett et al. 2001

Global Phosphorus Budget (Tg/yr)

$$(18.5 + 20) - (22 + 1) = 15.5$$

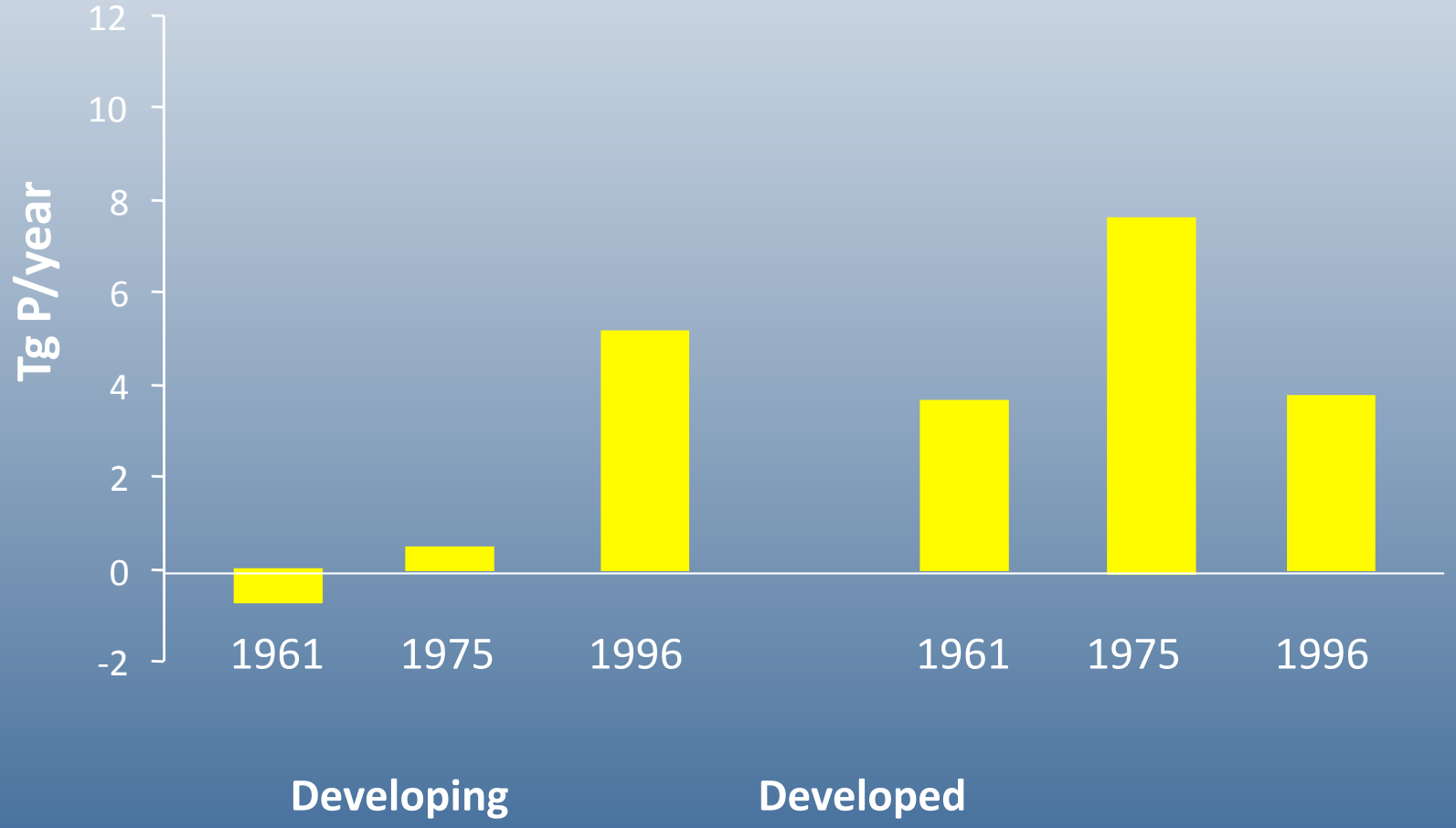
Bennett et al. 2001

Annual Global P accumulation: Agricultural Areas



Bennett et al. 2001

Change-in-storage: P in agricultural areas



Bennett et al. 2001

Global balances probably hide many important details

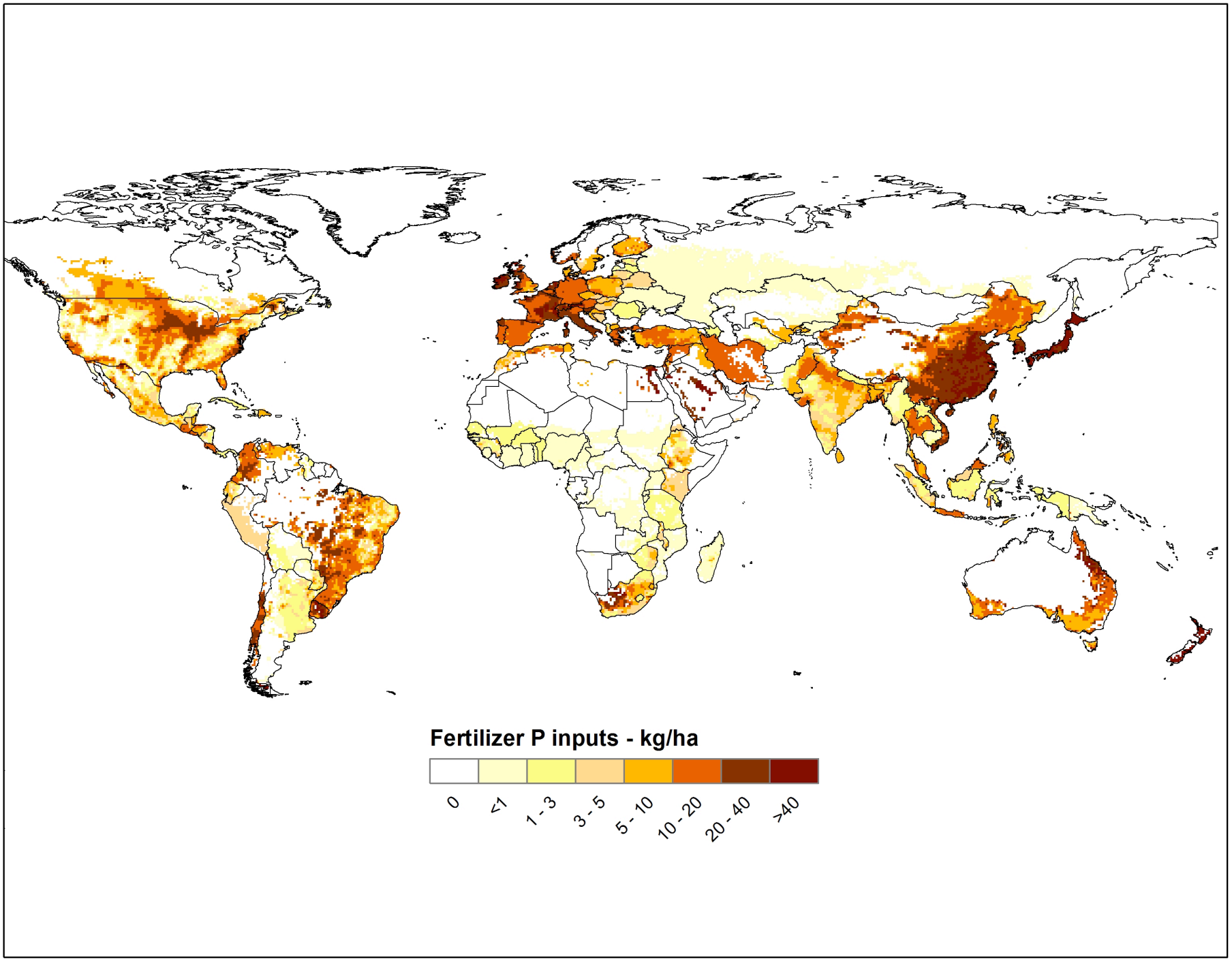
Can we calculate a spatially-explicit global P budget?

Phosphorus balances by region (kg $ha^{-1}yr^{-1}$)			
	Western Kenya	N. China	Midwest USA
Fertilizer inputs	8	92	14
Total removal (harvest)	7	39	23
Inputs - Removals	1	53	-9

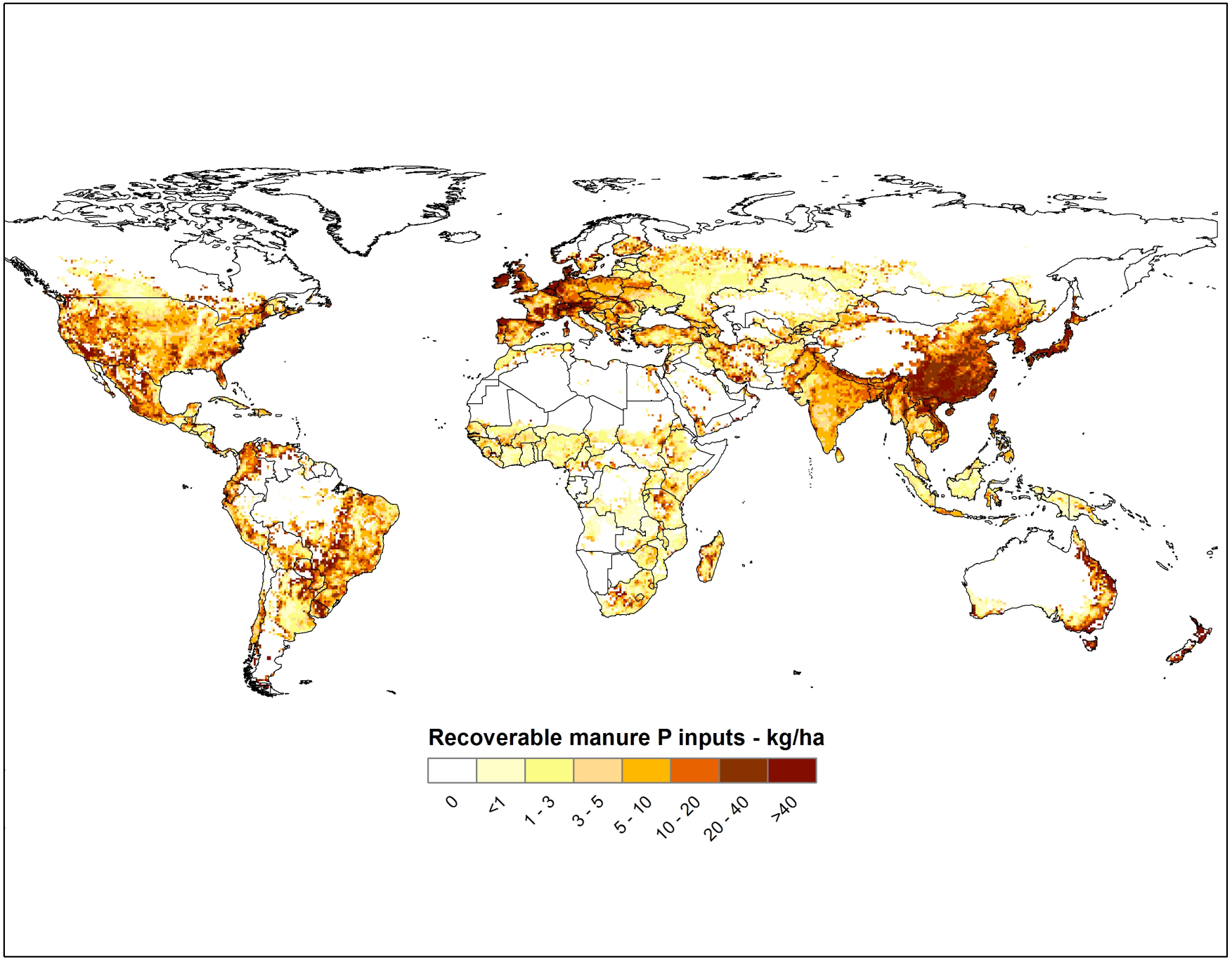
Vitousek et al. 2009. *Science*

Methods

- Location of 175 crops, 0.5°resolution (Monfreda et al. 2008)
- National-level fertilizer application rates for these crops (IFA/FAO/IFDC 2002)
- Livestock distribution, 5 km^2 resolution (FAO 2007)
- Nutrient content of manure (OECD 2008)



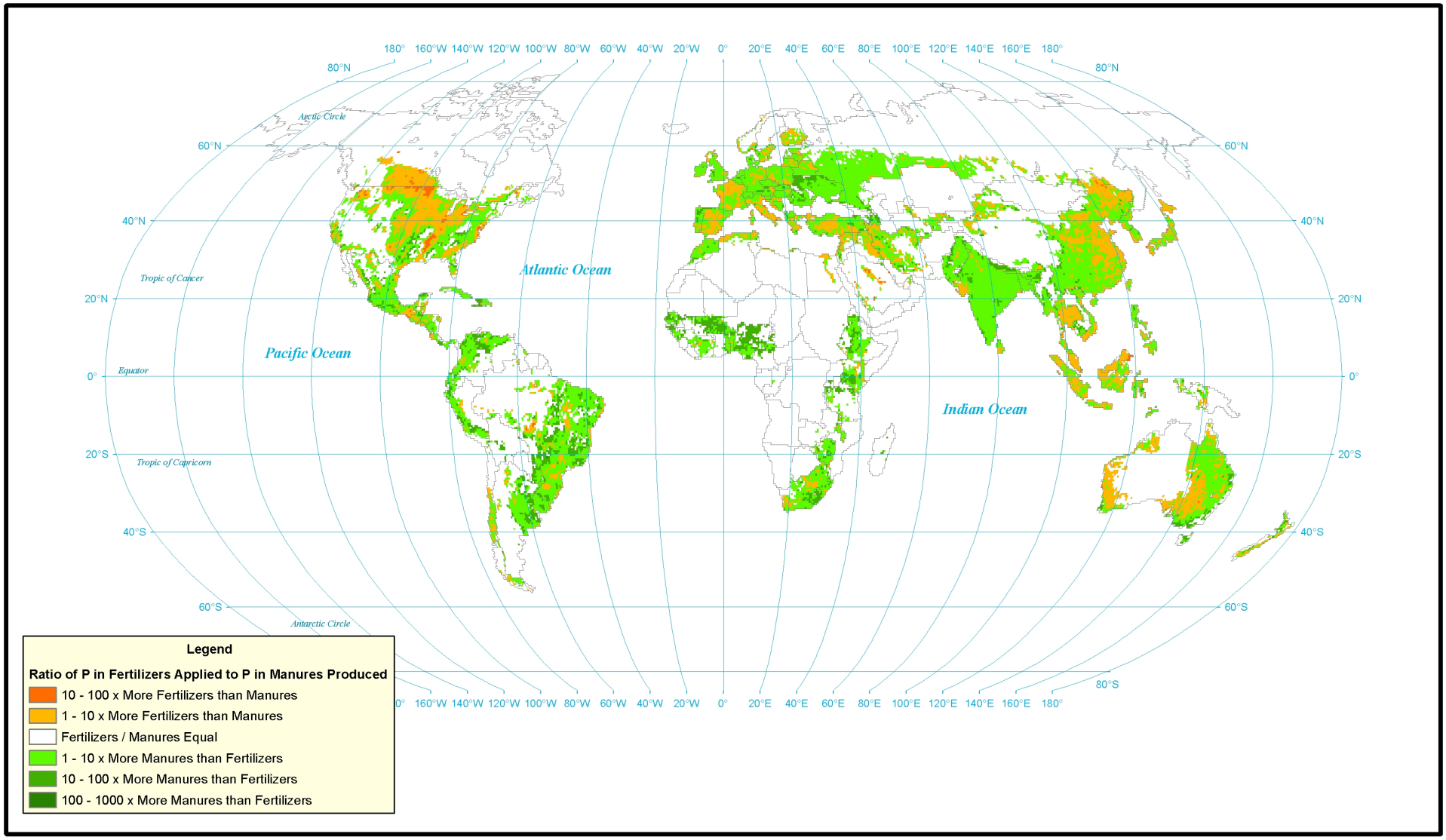
Potter et al. Submitted



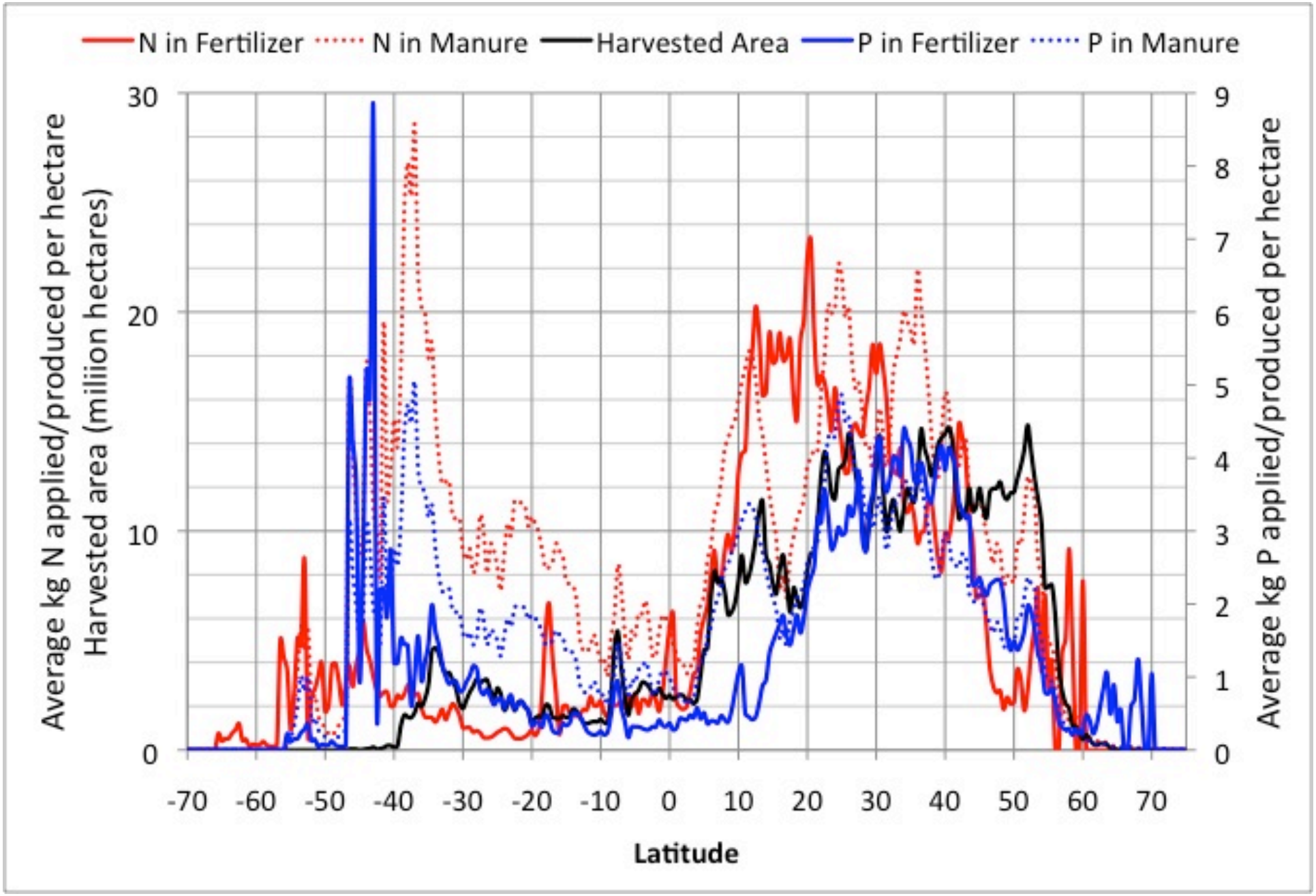
MacDonald et al. In prep.

	Nutrients introduced through manures (Tg)		Nutrients introduced as fertilizers (Tg)		Year for which estimates are relevant	
	N	P	N	P	Manures	Fertilizers
van der Hoek et al. [1999]	102.4	--	73.6	--	1994	1994
Siebert [2005]	107.7	--	72.3	--	1995	1995
Sheldrick et al. [2002]	-- [1]	-- [1]	78.2	12.7	--	1996
Sheldrick et al. [2003]	93.6	21.1	--	--	1996	--
Smil [2000]	--	> 15	--	15	2000	2000
Study Results	128.3	24.3	70.2	14.3	2007	2000 [2]

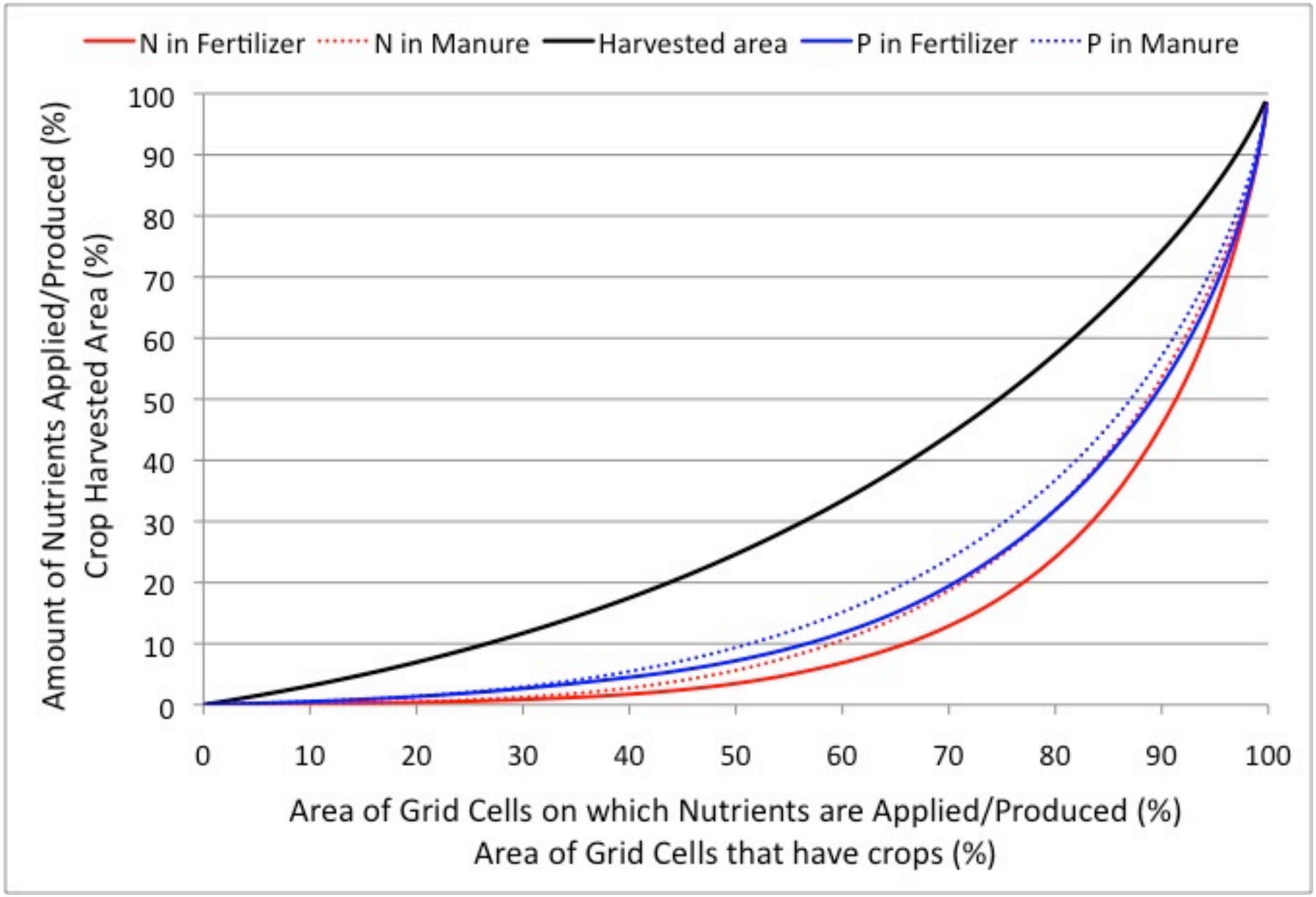
Potter et al. Submitted



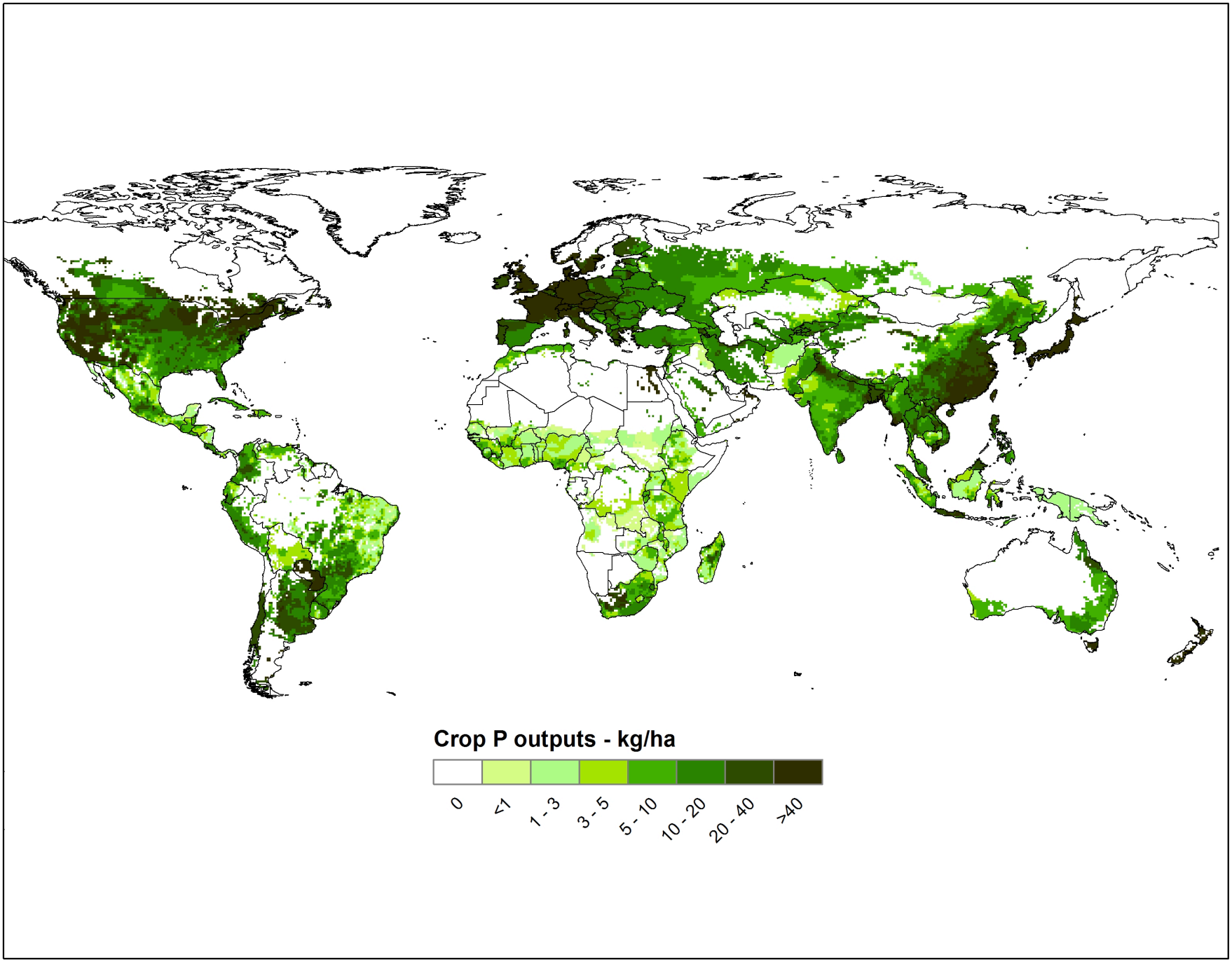
Potter et al. Submitted



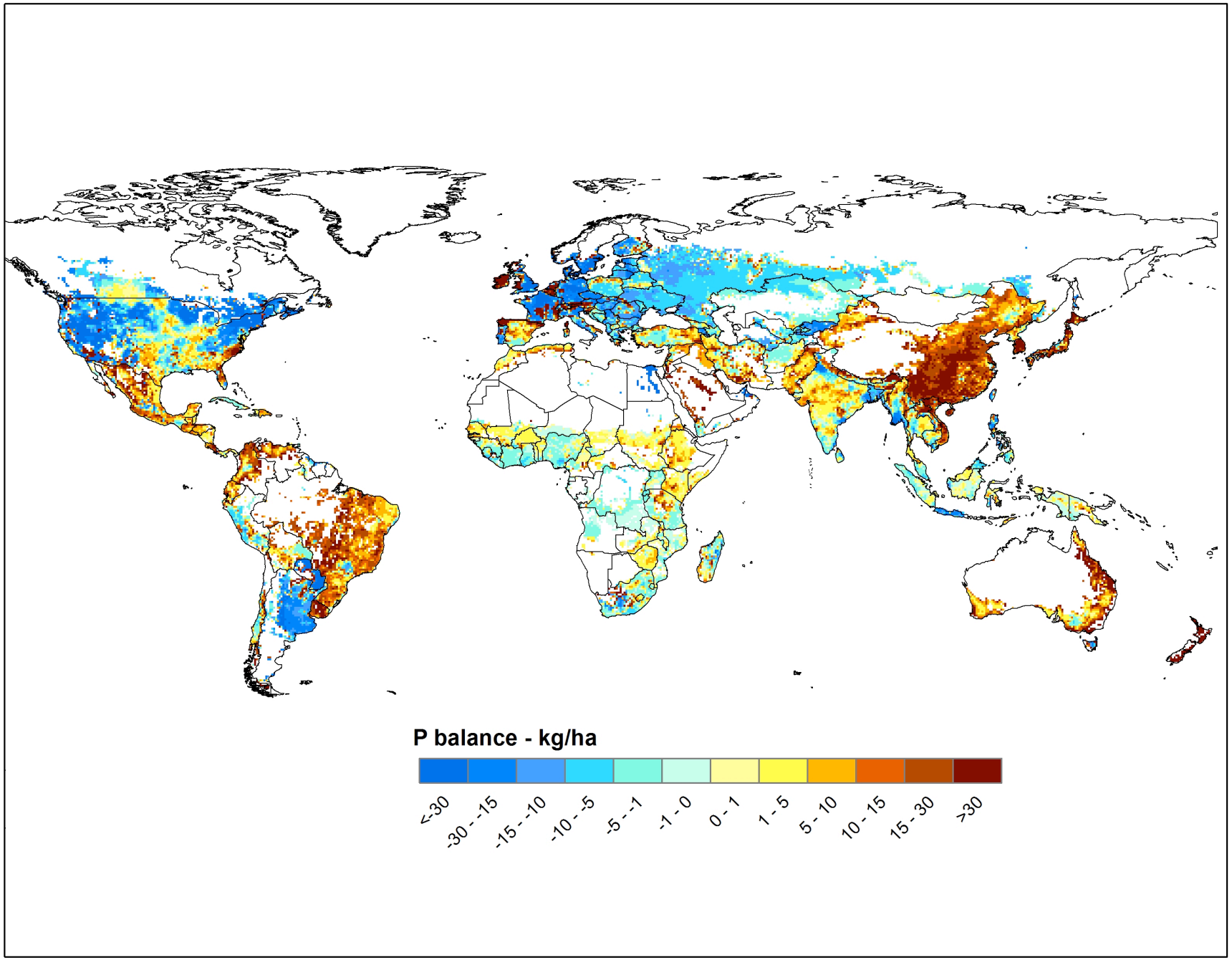
Potter et al. Submitted



Potter et al. Submitted



MacDonald et al. In prep.



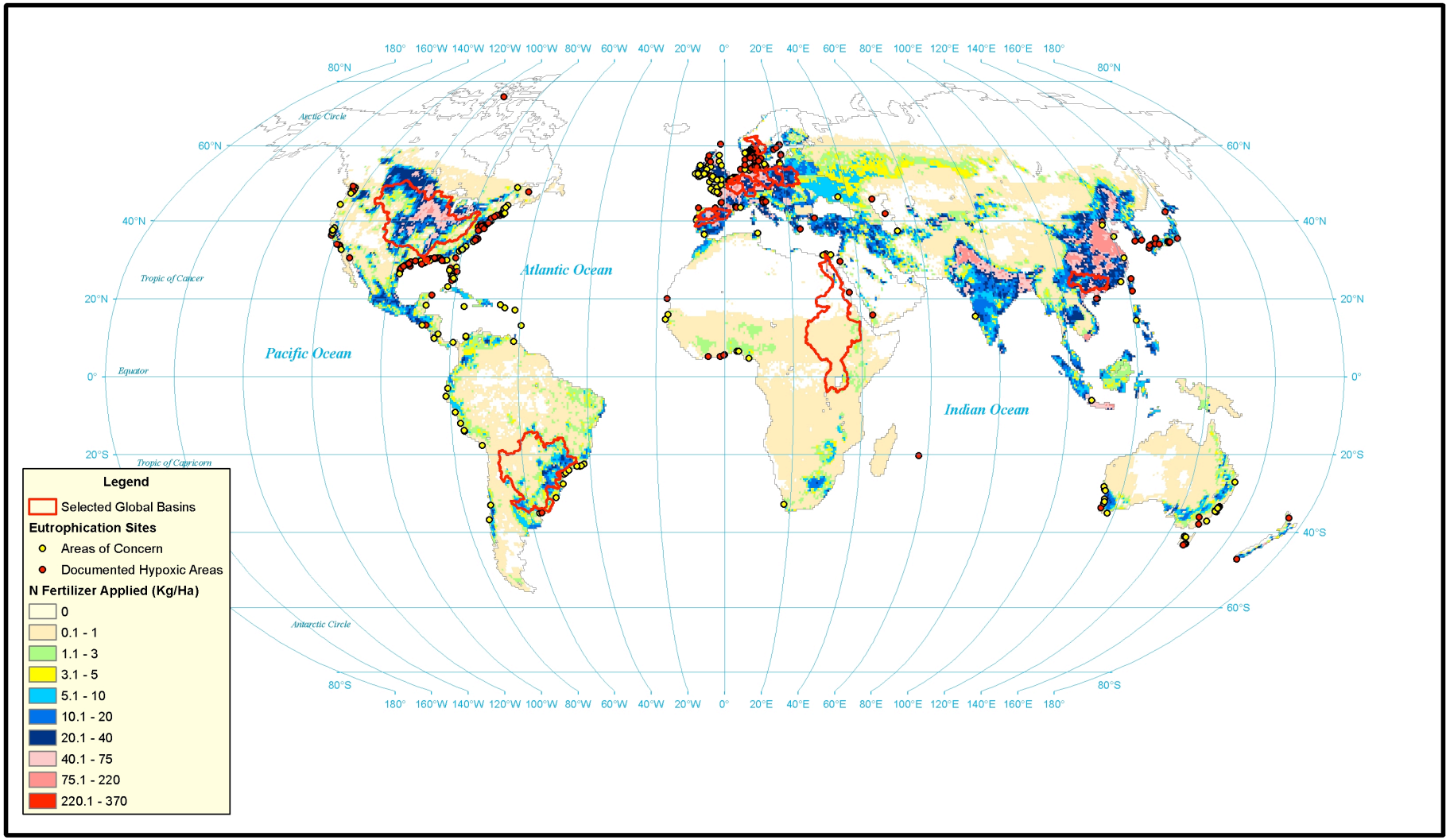
MacDonald et al. In prep.

What's missing from our budgets?

- P loss to large rivers (and ultimately oceans).
  - Dissolved v. particulate and their interactions?
- Spatially-explicit erosion and loss rates that take agricultural practices into account
- How much P is in the soils to begin with?
  - (And how much of this is biologically available?)

Questions - 1

- Can we quantify spatially - explicit maps of total P loss to oceans?
- Where are eutrophic lakes around the world and how does this compare to P budgets?
- How are people moving P not only in fertilizers, but also in traded products (animals, animal products, food products)?



Potter et al. Submitted

Questions - 2

- Will we run out of P?
  - Flip side -- how to recycle better?
- What will P balances be like in the future? Where will P be increasing? Where declining? What will be the sources of P to freshwater systems?
- Because of sensitivity of water (as compared to croplands), should we simply relegate some areas to agricultural production and eutrophication and protect others?

The future?

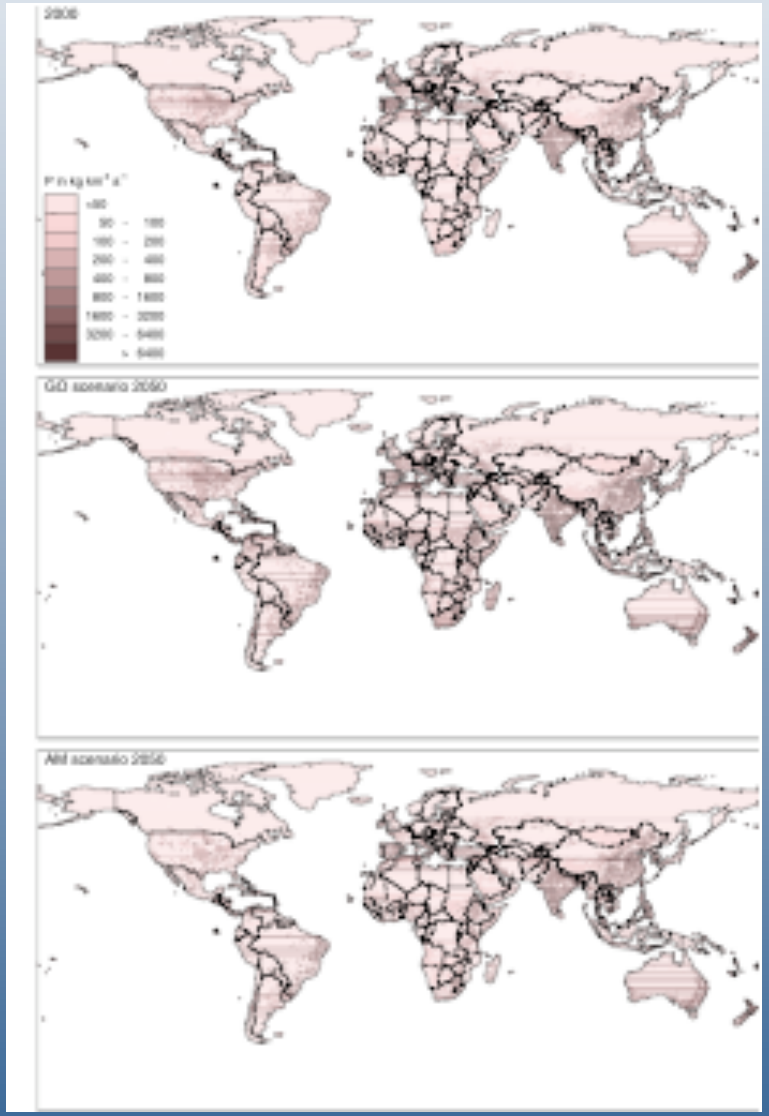
- Agricultural production must double over the next 50 years to meet the demands of a growing and changing human population [*Tilman et al., 2001].*
  - *Some expansion of cultivated area*
  - *Most of need met by intensification of areas already under production*

Modeled Global P Balances in 2050

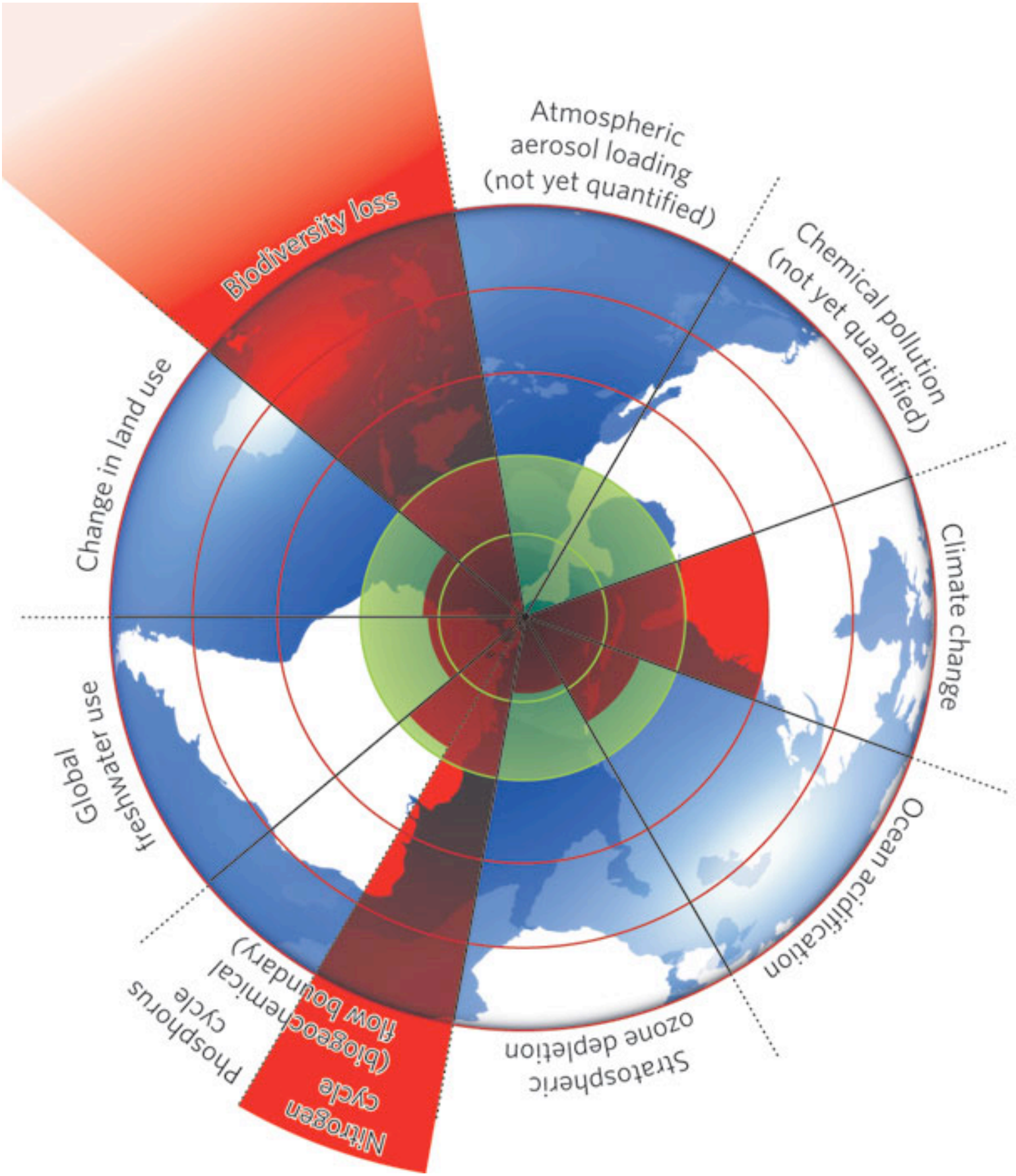
Year 2000

Global Orchestration

Adapting Mosaic



Bowman et al. 2009


Biodiversity loss
Atmospheric aerosol loading (not yet quantified)
Chemical pollution (not yet quantified)
Climate change
Ocean acidification
Stratospheric ozone depletion
Nitrogen cycle
Phosphorus cycle
(biogeochemical flow boundary)
Global freshwater use
Change in land use

P balance inputs/outputs	Tg P yr^{-1}
Inputs	**24.9**
Fertilizer P	14.4
Recoverable manure P	10.5
Outputs	**14.7**
Crops	10.6
Residues (*50% removal*)	4.1
Agronomic Balance	**10.2**