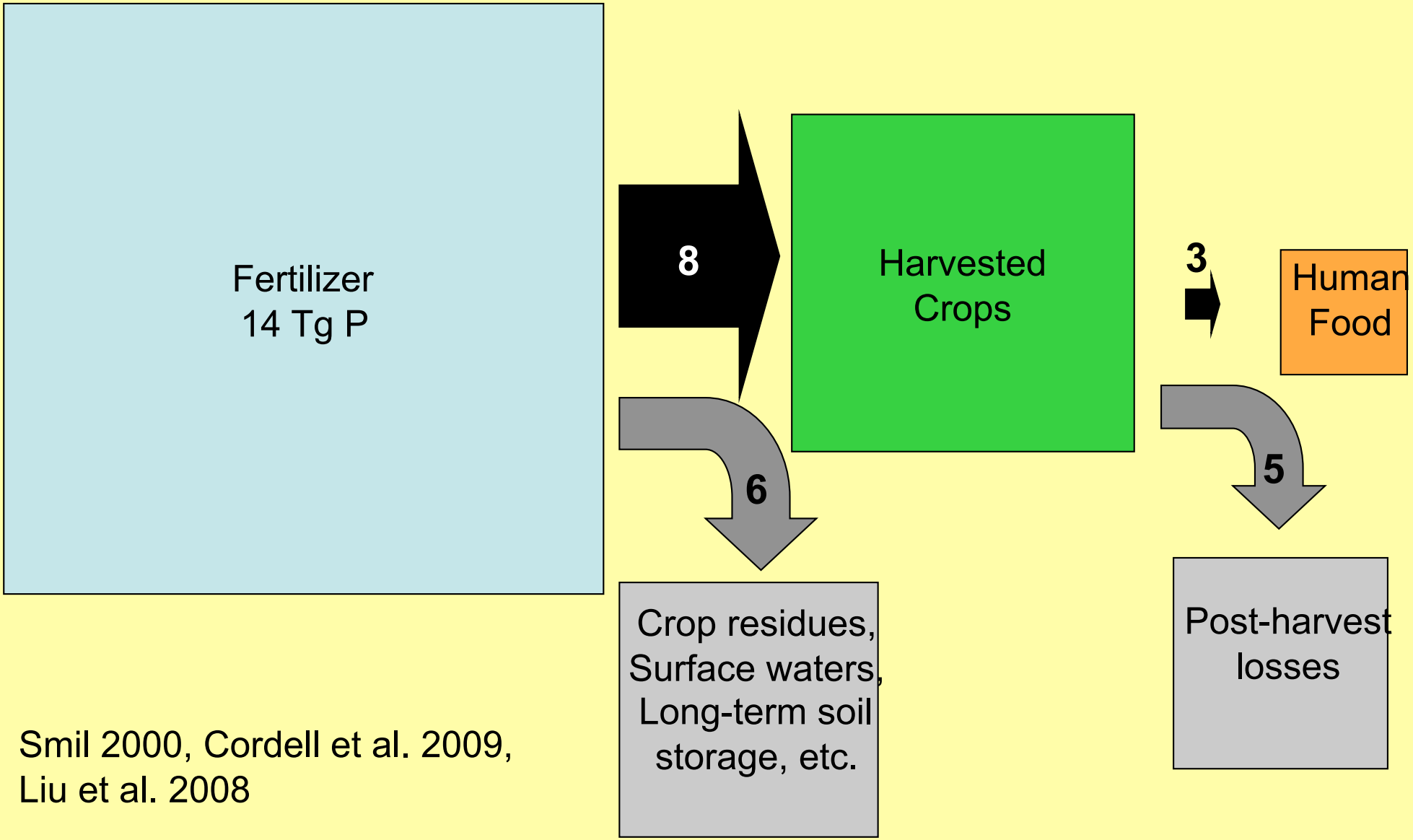
Phosphorus movement in food

From fertilizer to fork

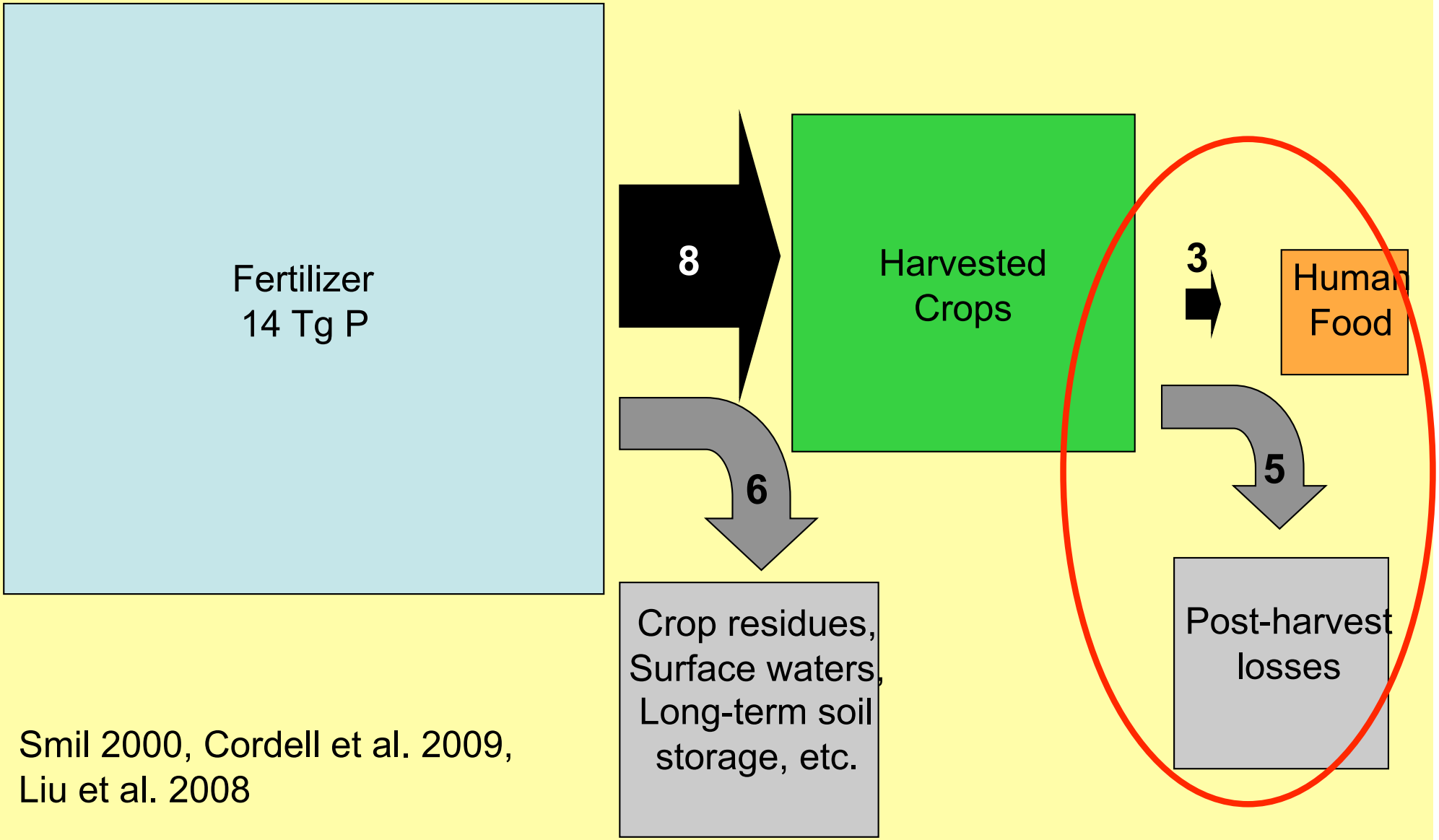
- Global estimates of P flows
  - What don't we know?
- P movement through agricultural trade
  - How much and where?
- P footprint of crop and livestock production
  - U.S. case study
  - Implications of changing diets
- Future questions

P flows from fertilizer to fork



Smil 2000, Cordell et al. 2009,
Liu et al. 2008

P flows from fertilizer to fork



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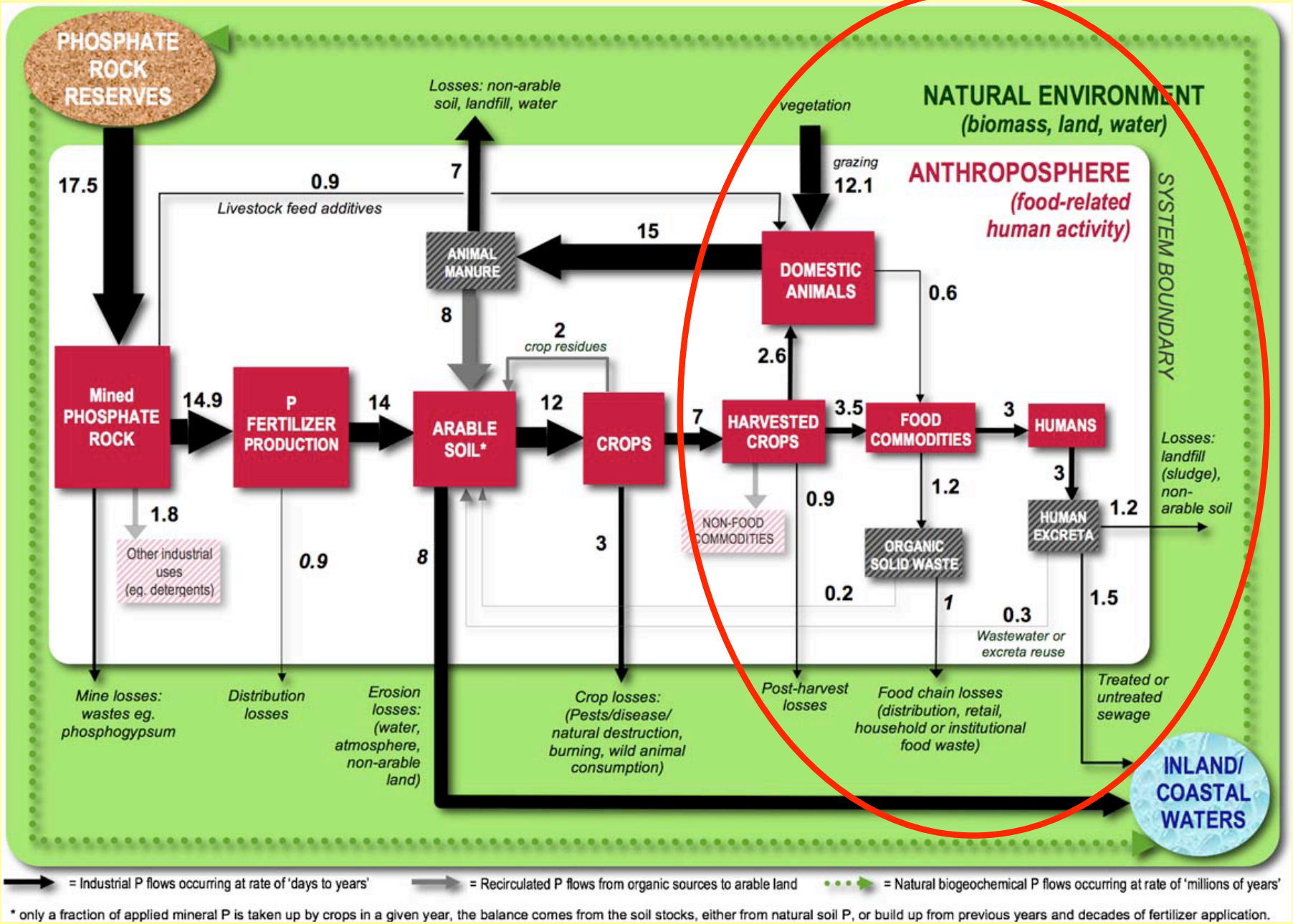
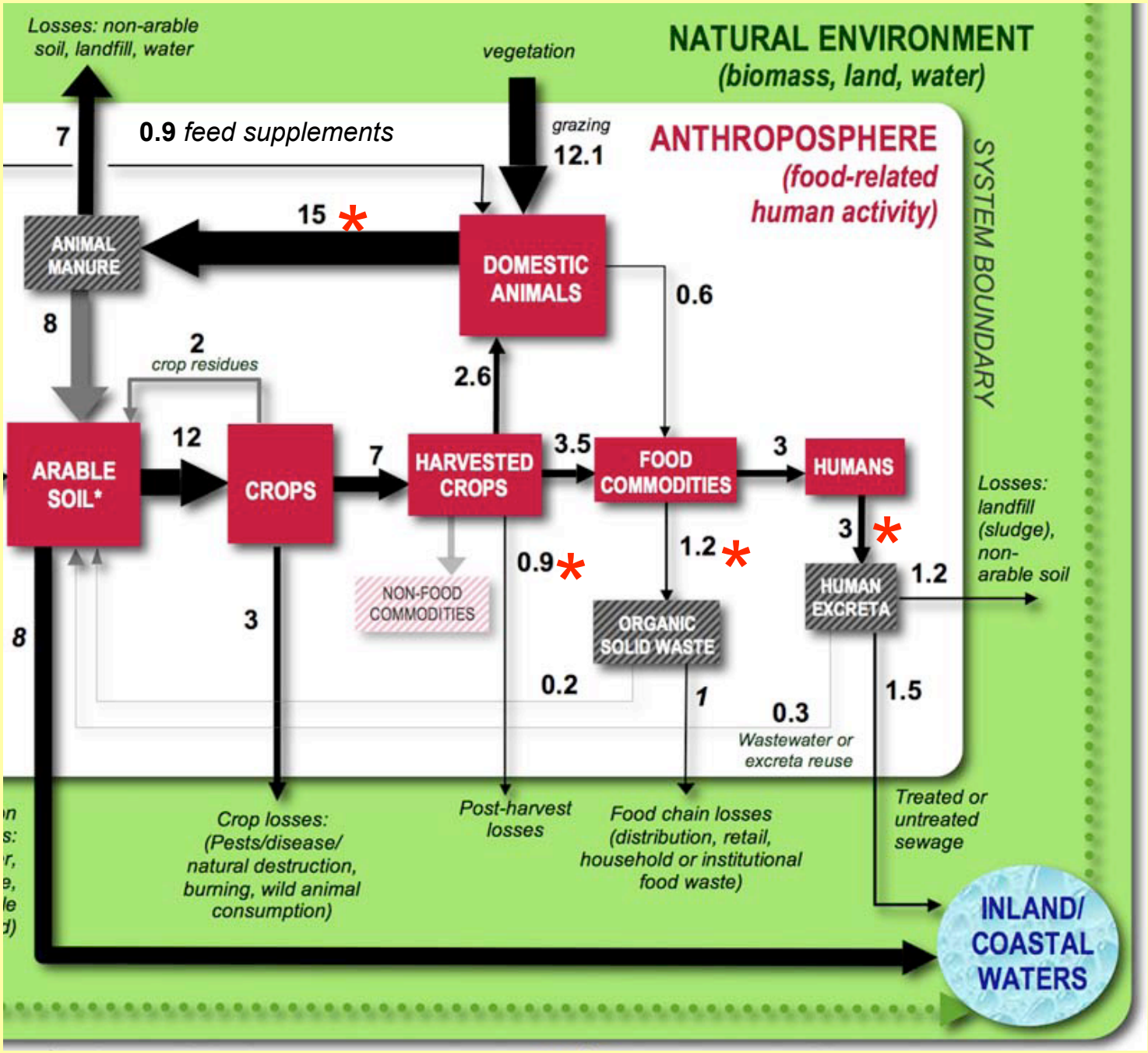


Cordell et al. 2008, based on Smil 2000



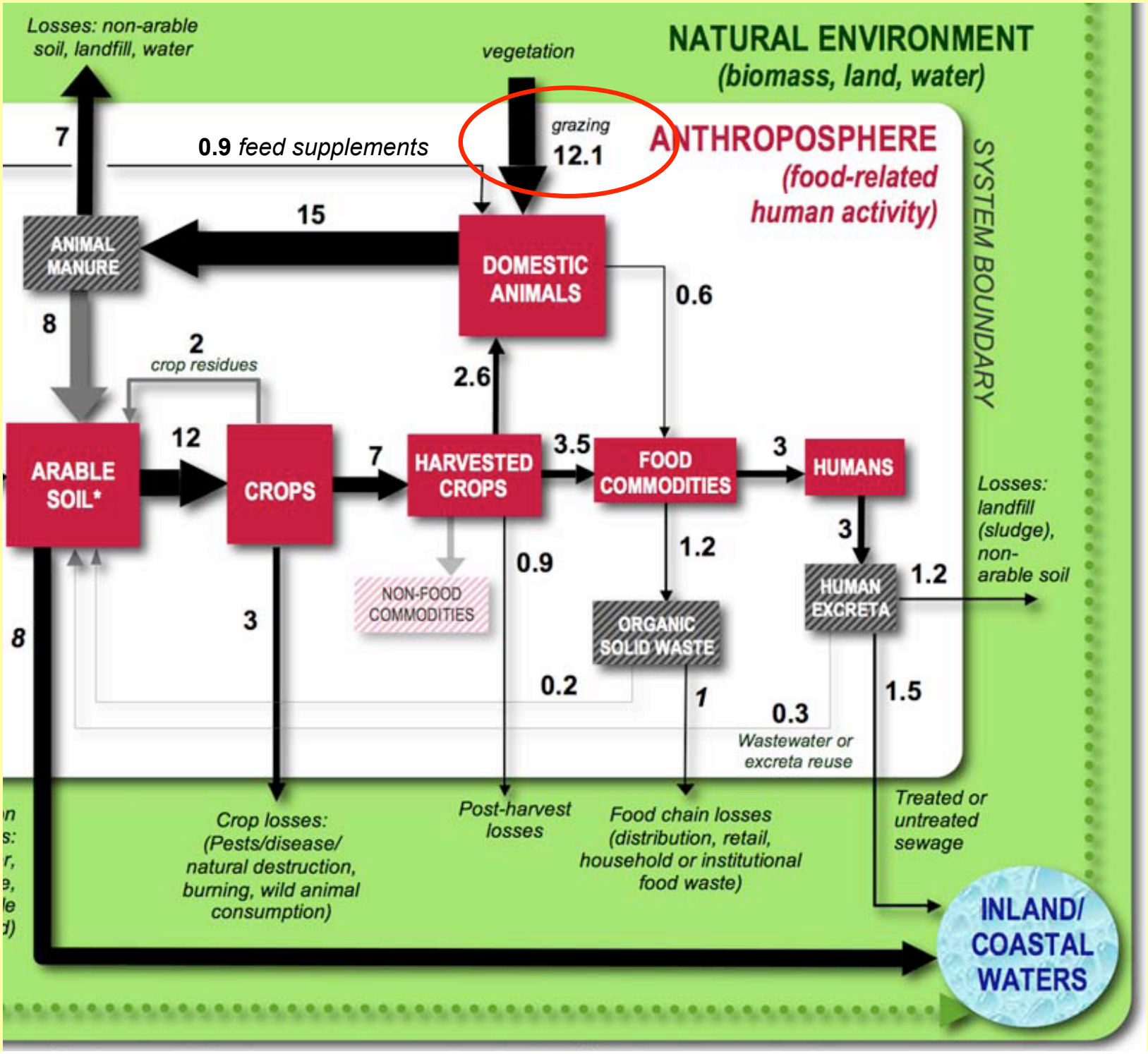
Cordell et al. 2008, based on Smil 2000

P flows through food

- Livestock: in one end, out the other
  - ~ 4-6% of P in fed to livestock is converted to meat
  - ~ 40-50% of P in manure produced in confined production systems and available for recycling to arable land (Kellogg et al. 2000)
  - 2.5–8 of 15-18 Tg P of manure returned to arable land (Liu et al. 2008, Cordell et al. 2009)
- Post-harvest and processing losses
  - 30-50% of P in harvested crops is lost via post-harvest losses and food chain waste (Cordell et al. 2009, Smil 2000, Liu et al. 2008)

Fate of “losses”: point vs. non-point

- Manure: ~ 7-10 Tg P
  - Non-arable land
  - Losses to water through erosion and run-off
- Post-harvest organic wastes: ~2 Tg P
  - Landfills
  - Livestock
- Human sewage and waste: ~3 Tg P
  - ~ 50% of human excreted P lost to surface waters, primarily as DIP
  - Industrial DIP losses are roughly equivalent
  - Human sewage is largest source of DIP to coastal waters (Harrison et al. 2005)



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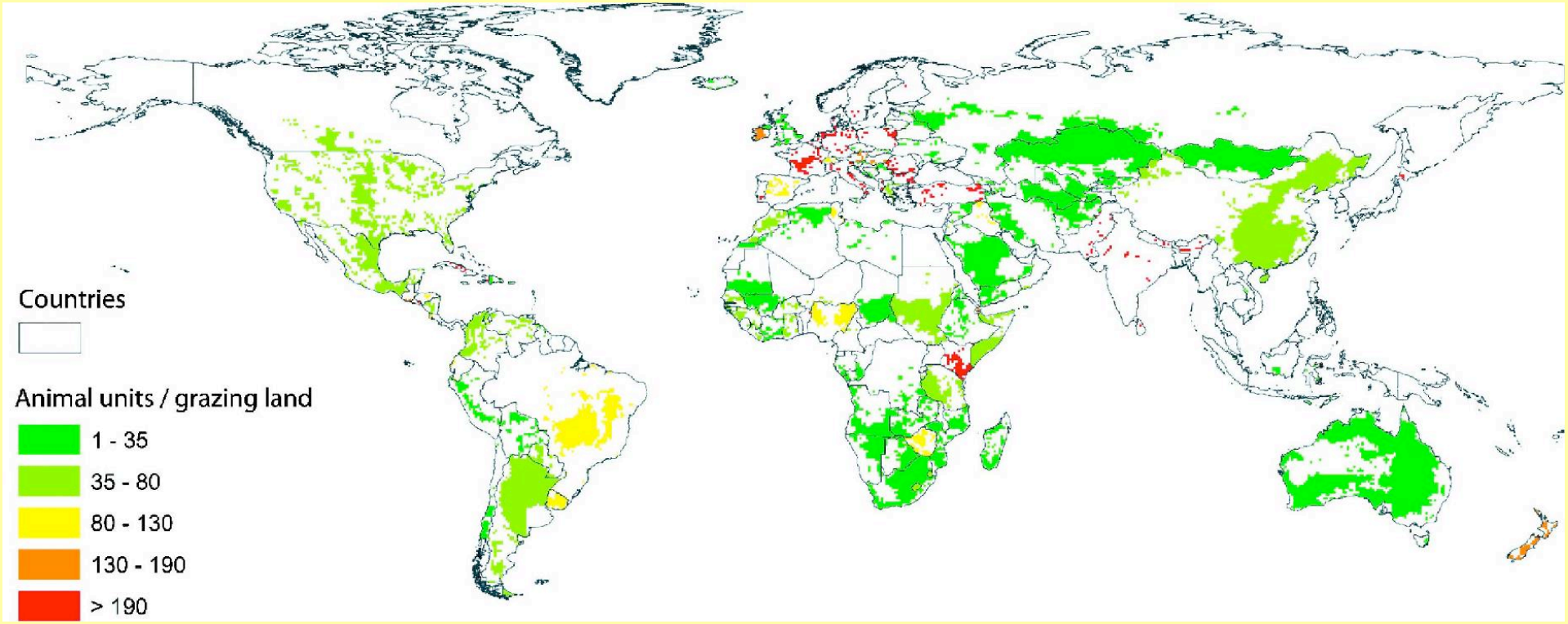
Global grazing estimates



Asner et al. 2004

P movement through trade

Rank	Export commodity	Quantity traded (Tg)	% P	Total P (Gg)
1	Wheat	133	0.23	306
2	Maize	110	0.21	230
3	Soybeans	74	0.66	490
4	Cake of Soybeans	61	0.08	49
5	Pigs	31	0.56	172
6	Sugar Raw Centrifugal	29	0.01	3
7	Rice Milled	27	0.21	58
8	Palm oil	26		
9	Barley	24	0.24	57
10	Sugar Refined	23		
11	Bananas	18	0.02	4
12	Waters,Ice Etc	15		
13	Beverage Non-Alc	15	0.02	3
14	Sheep	15	0.16	23
15	Soybean oil	12		
16	Rapeseed	12	0.60	70
17	Beer of Barley	12	0.01	2
18	Flour of Wheat	11		
19	Food Prep Nes	10		
20	Potatoes	10	0.04	4
	Total P in 2007 global exports (Gg)			**1471**

+ 370 Gg P traded in cotton

FAO 2007; Grote et al. 2005, USDA; Beacon et al. 1995

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- Corn and soybeans account for ~ 50% of global trade in P
- About 50% of U.S. P exports go to confined animal production (MacDonald et al.)
- Similar to flows estimated by SCOPE P report in 1995

FAO 2007; Grote et al. 2005, USDA; Beacon et al. 1995

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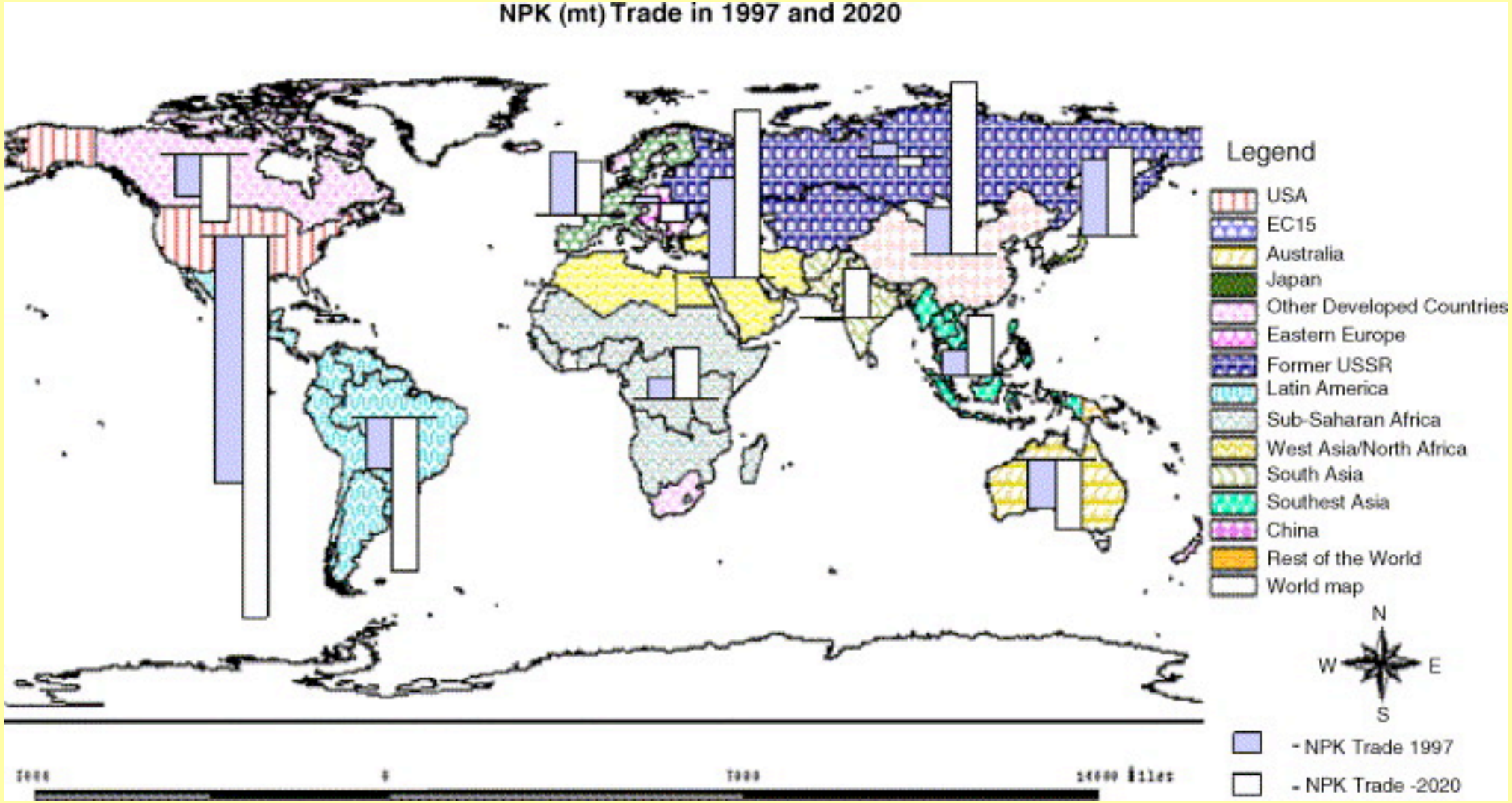
Water trade is primarily between countries in Europe

U.S. largest importer of non-alcoholic beverages (ie, Coca Cola)

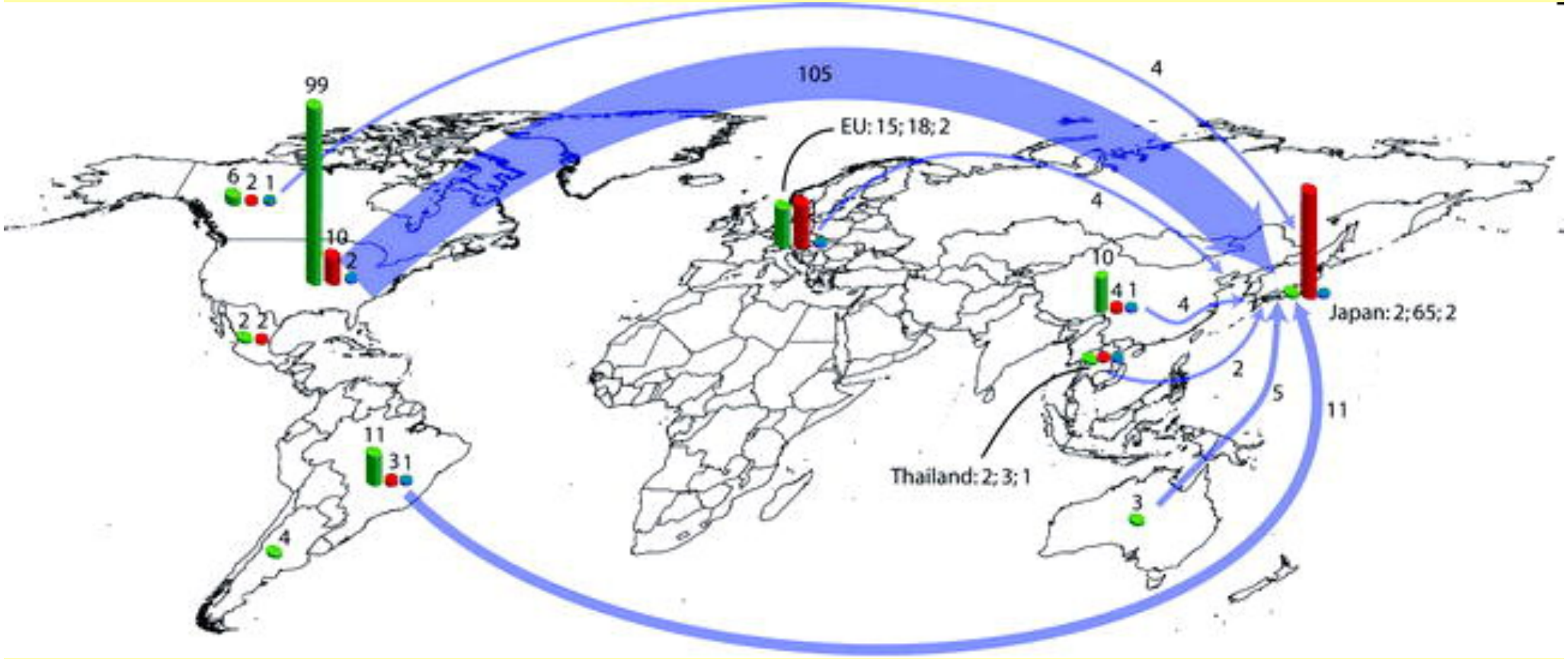
FAO 2007; Grote et al. 2005, USDA; Beacon et al. 1995

Global nutrient trade in agricultural commodities



Grote et al. 2005

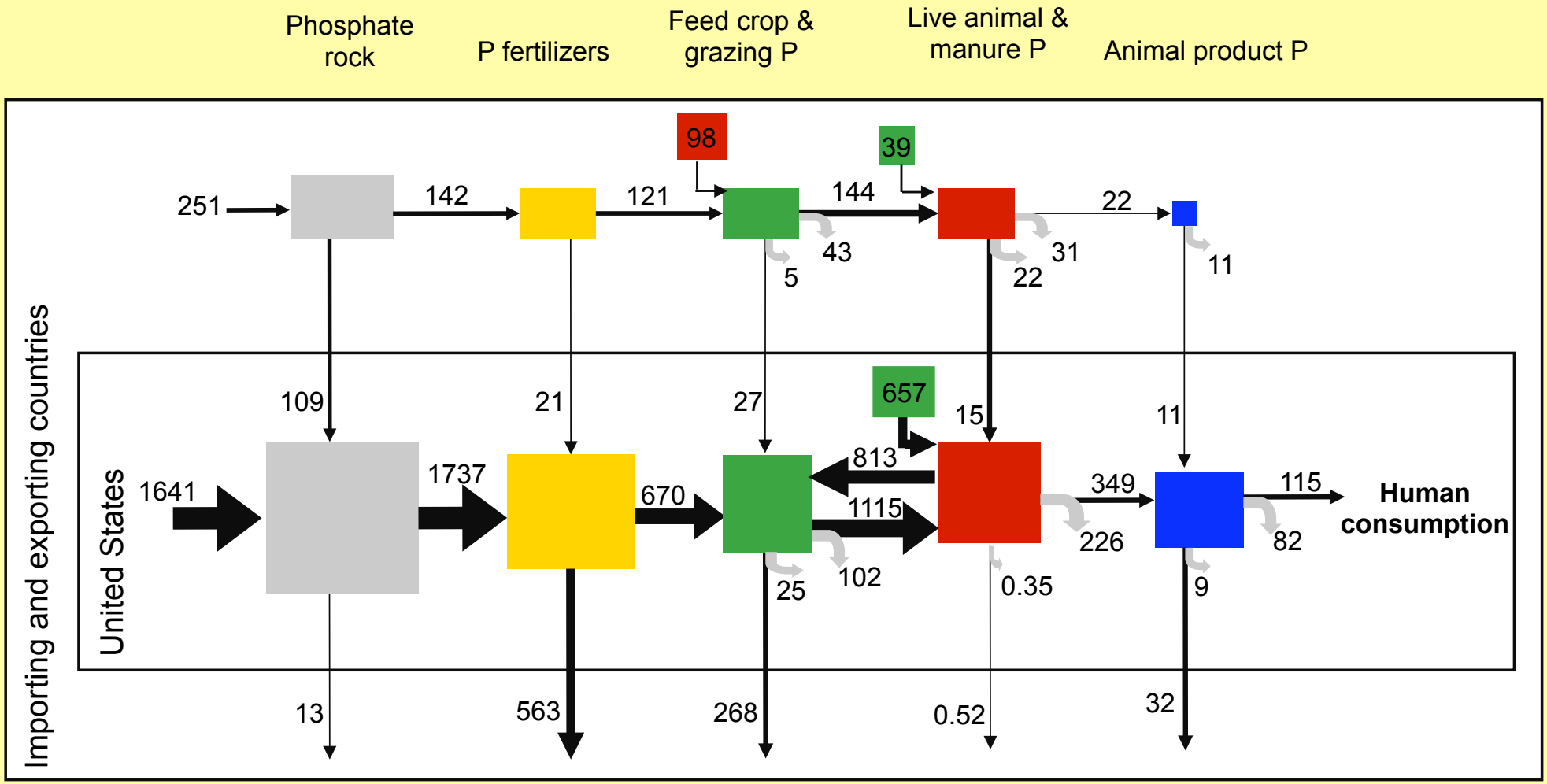
“Virtual” resource use



Nitrogen associated with pig and poultry consumption in Japan (Gg/yr)

Galloway et al. 2007

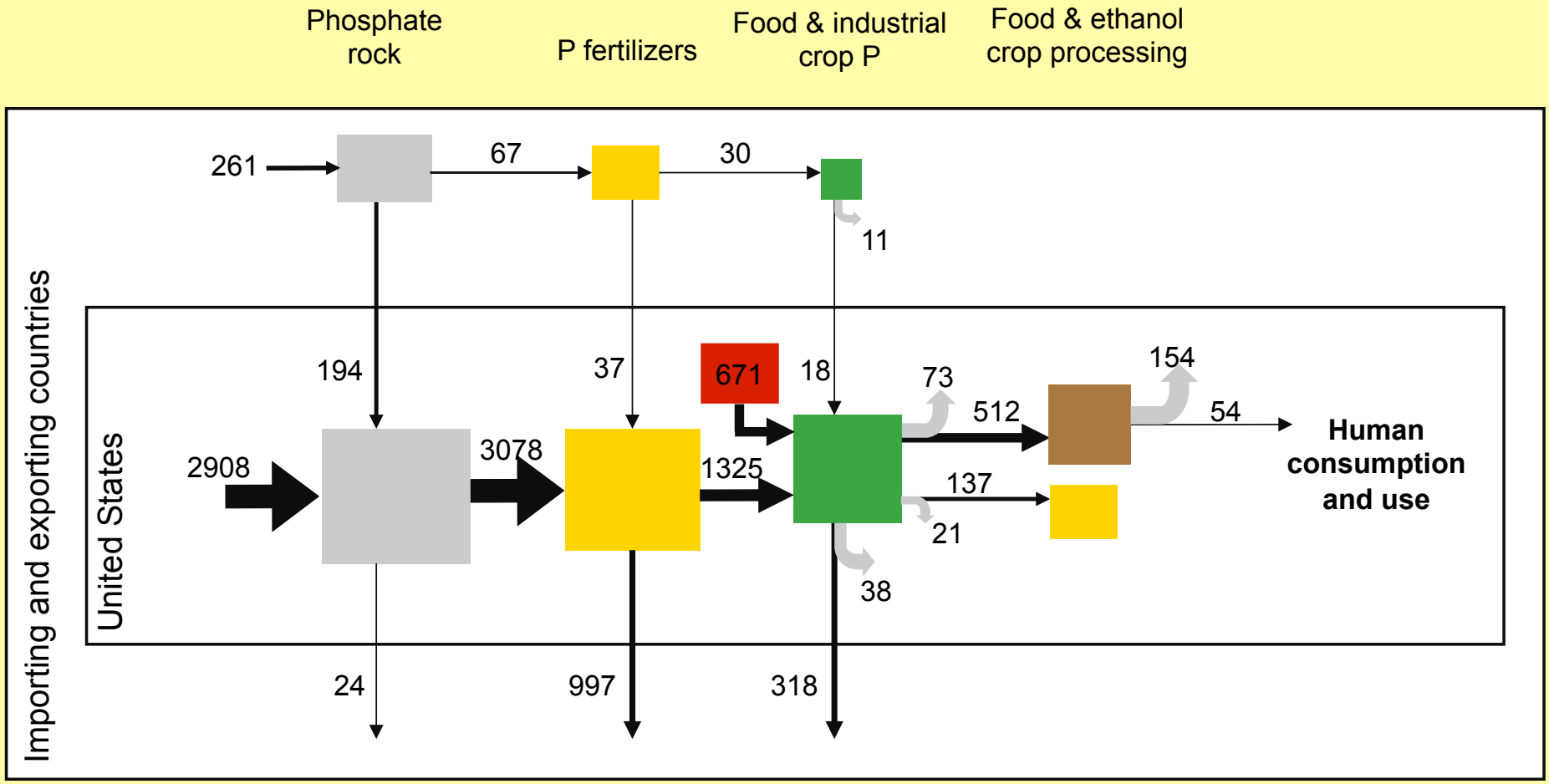
Estimating P footprint of U.S. livestock production



Feed crop and livestock phosphorus flows in 2007 (Gg P yr^{-1})

MacDonald et al., *in prep*

Estimating P footprint of U.S. food and biofuel crop production



Food and industrial (ethanol) crop phosphorus flows 2007 (Gg P yr^{-1})

MacDonald et al., *in prep*

P footprints of U.S. livestock and food production

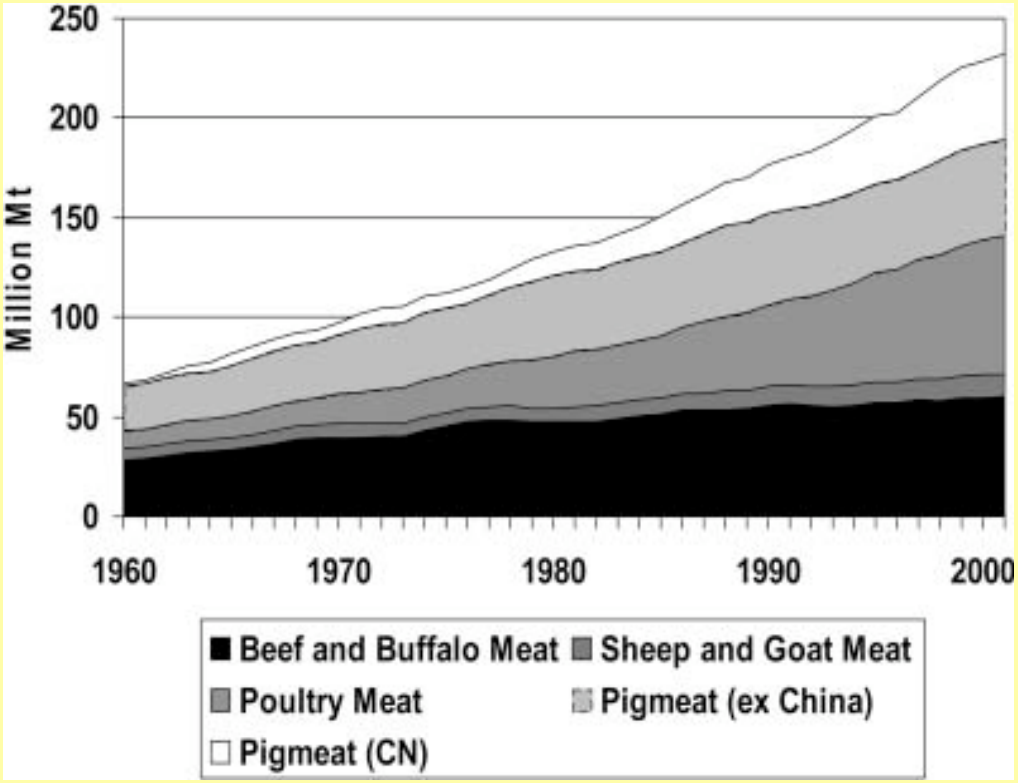
- 410 Gg P lost for 115 Gg P in meat consumed
  - Half is manure P
- 225 Gg P lost for 54 Gg P in non-meat food consumed
  - About 60% in processing losses

- Almost 25% of the total P loss associated with production of export-oriented crop and livestock commodities

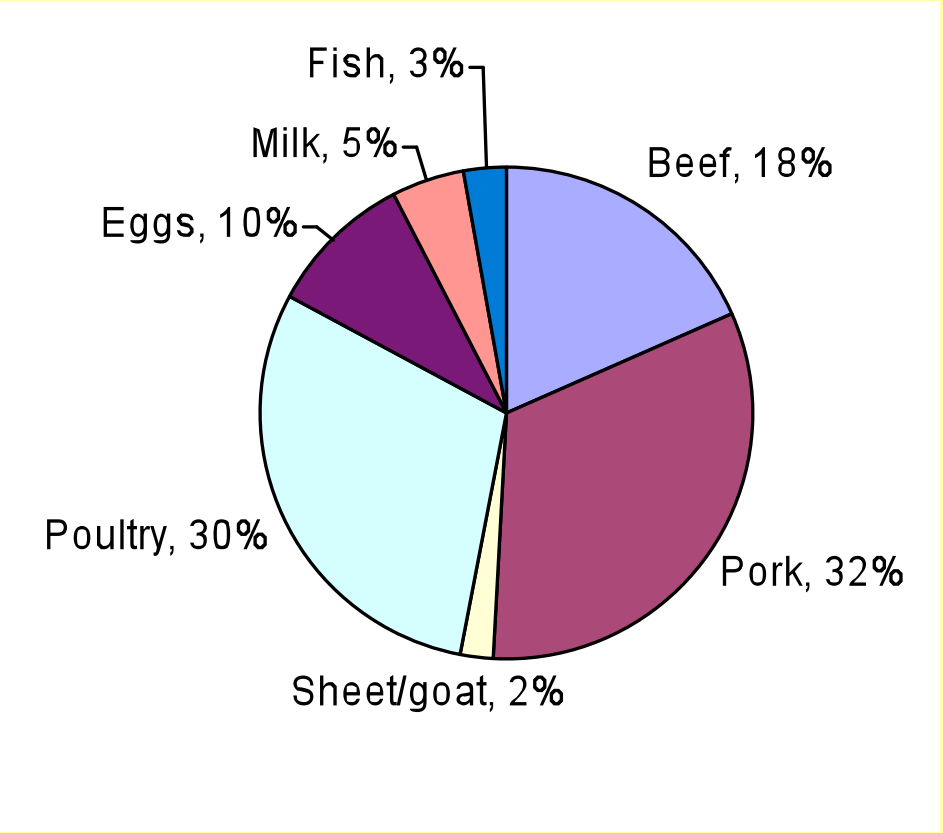
- 50% of crop P exports are in feed crops

Shifts in meat consumption

Total production trends over time

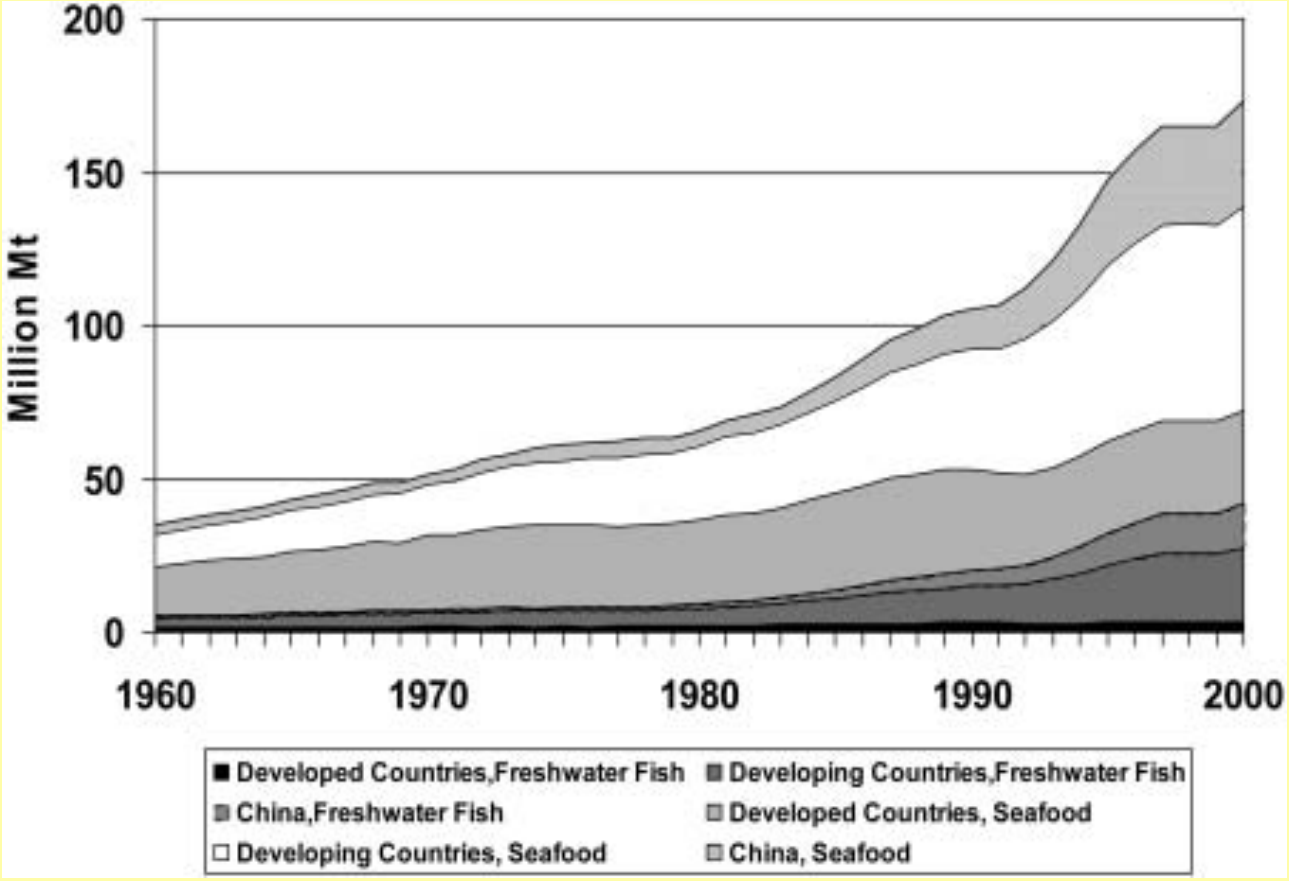


Consumption on P basis (2000)



Sources: Speedy 2003 (FAO), USDA

Fish production



~ 25% of production is freshwater

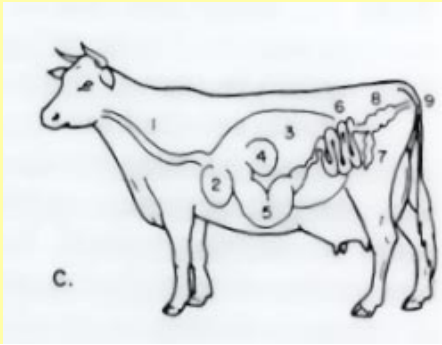
Speedy 2003

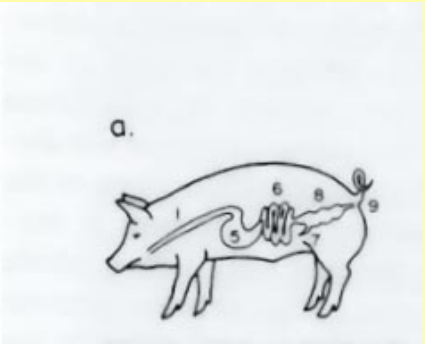
Fish farm P balances

- Estimates range from 10-110 kg P/ ton of fish released as waste from fish farms (Beveridge et al. 1982, Folke et al. 1994)
- Global production of 170 Mt fish contribute 1.7-19 Gg P to surface waters
- Efforts to reduce P pollution from fish farms has resulted in increased N:P of wastes and increases in toxic algal blooms in Baltic (Folke et al. 1994)

Are cows and pigs/chickens created equal?

	Ruminants	Non-Ruminants
Conversion efficiency[1]		
Total feed to meat	5%	26%
Arable feed to meat	33%	29%
P metabolism	phytase	no phytase
Fate of excess P[2]	Most in manure	In urine & manure
Manure quality	high C:P	low C:P
Fate of manure P[3]	responsive to soil P status; sorption-desorption	independent of soil P status; Ca, Mg mineral complexes





[1] weight basis, Galloway et al. 2007
[2] Valk et al. 2000
[3] Cooperband et al. 2002

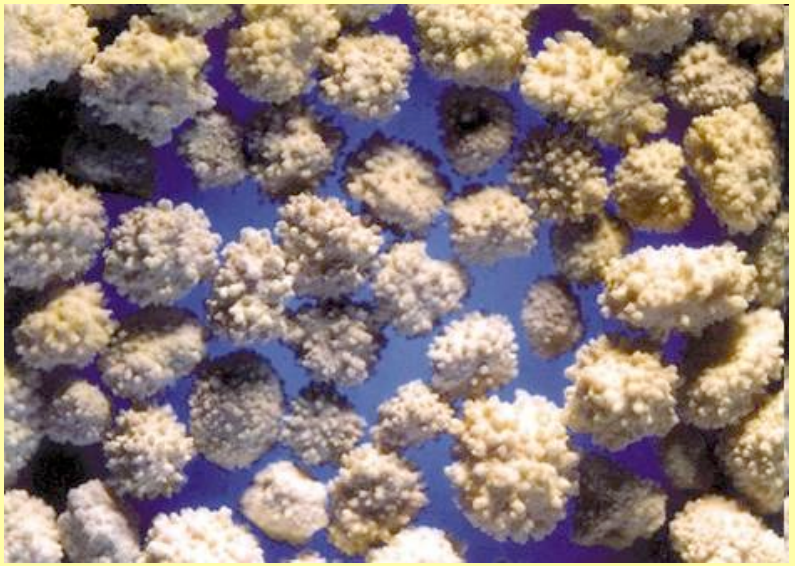
Trade and livestock production

- Decoupling crop-livestock production reduces opportunities for P recycling

- Increases in global nutrient trading influenced by
  - Energy-intensive production systems
  - Crop subsidies
  - Increasing demand for livestock products
  - Regional resource availability

Opportunities for recycling

- Human waste
  - Does increased meat consumption, linked to increasing wealth, parallel increase in sewage treatment systems?
- Manure
  - Composting
  - Re-coupling
  - Sewage treatment?
- Organic wastes



http://www.phosphorus-recovery.tu-darmstadt.de

Questions

What don't we know about the fate of P through food production channels?

- Largest uncertainties: grazing, manure recycling, crop residue recycling, fate of post-harvest wastes
- How much P is exported from rangelands and can we estimate "sustainable" removal rates?
- Relative influence of fish production on water quality
- Has cereal grain P concentration changed over time?

Questions

- How will increase in consumption of livestock products affect global distribution of P?
  - Regional analysis
  - Are there functionally important differences between livestock sources?
- How are we shifting surface water stoichiometry through food production systems and trade?
- Analysis of the relative contribution of agricultural trade on nutrient pollution and water quality
  - What is the appropriate scale of analysis?

Questions

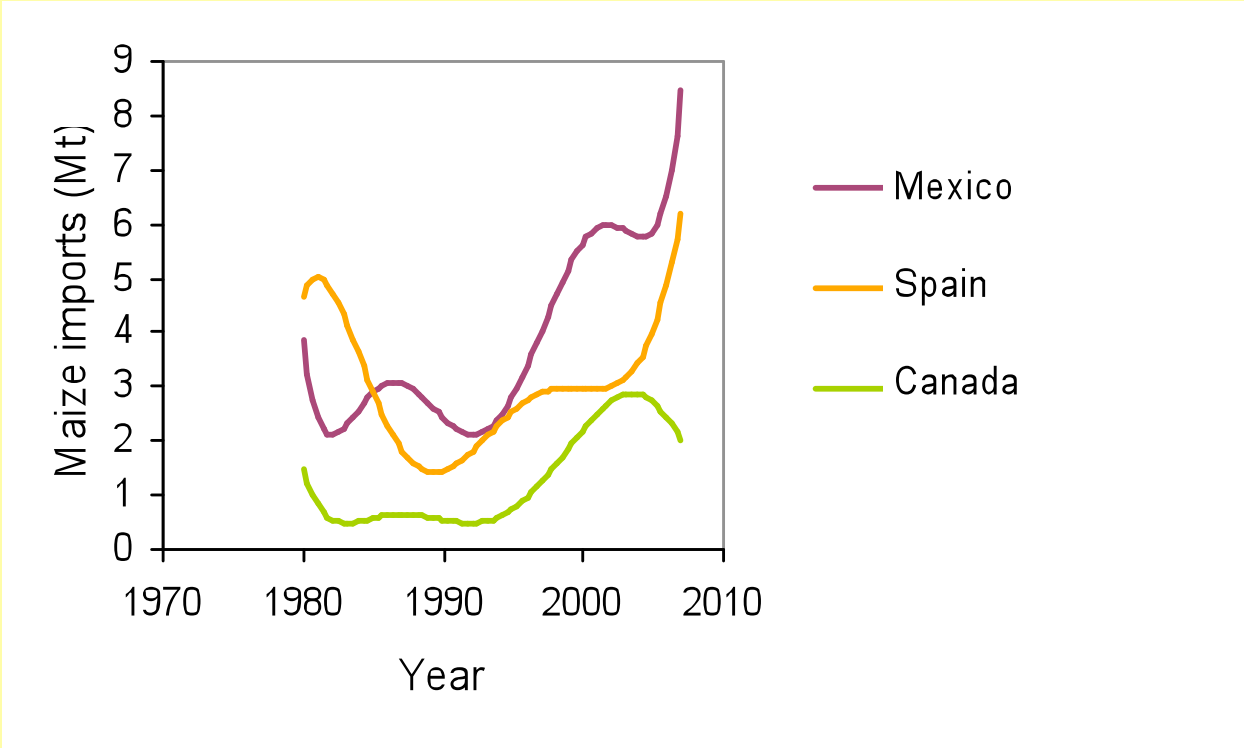
- Where are opportunities to increase P use efficiency and recycling? Questions of carrying capacity and footprints
  - Human waste recycling
  - Manure handling and movement
    - If manure can only economically be moved <15 km from source
  - Moving from counting calories to complete diet analysis
    - Analysis of regionally-adapted diets (Peters et al. 2006)

- Policy arena
  - Cross-disciplinary analysis of the institutional arrangements that influence global trade and its effect on nutrient pollution
    - Role of U.S. grain subsidies as a driver of crop-livestock decoupling
    - The difference between point and non-point source pollution

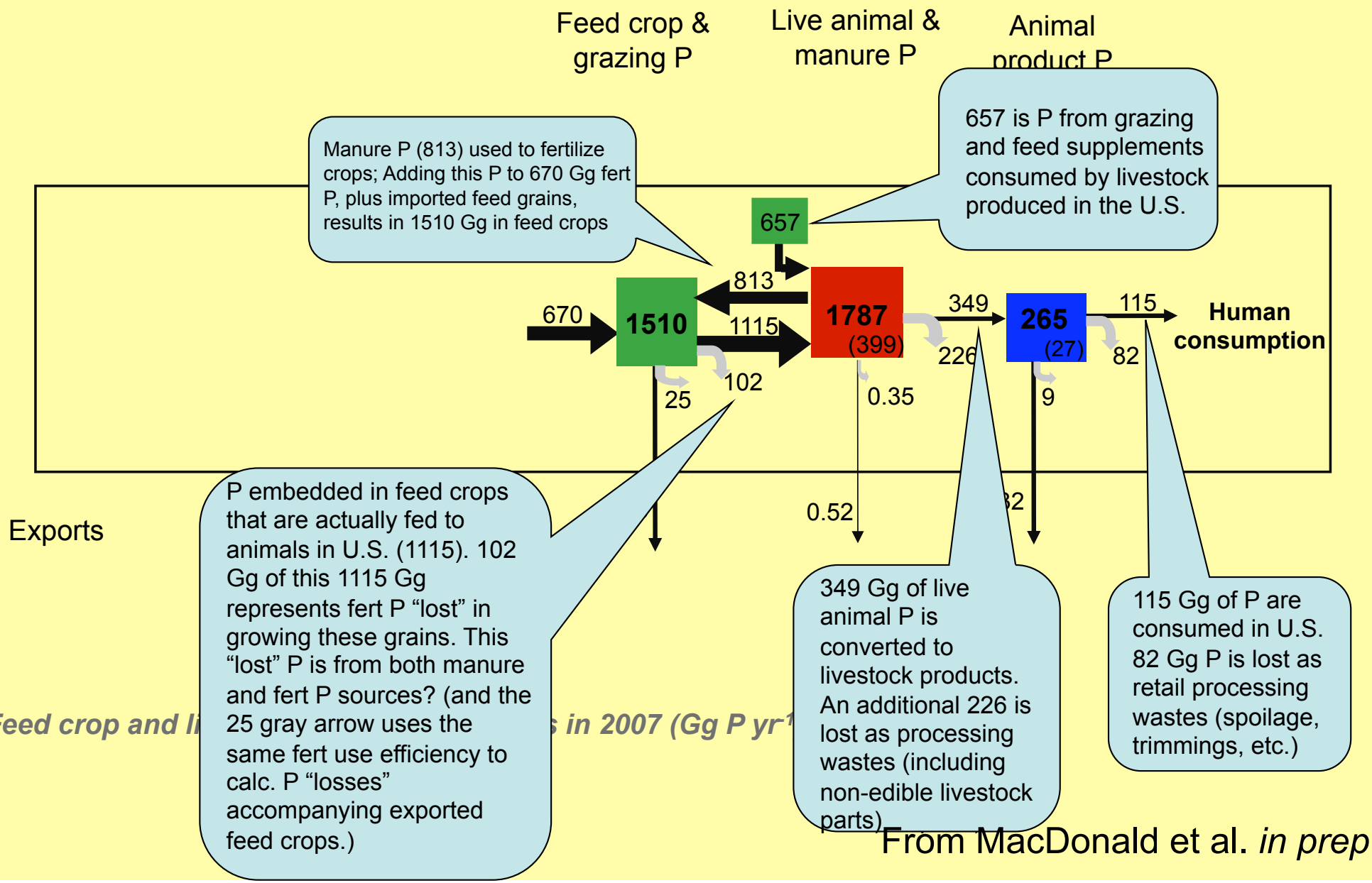
Regional complete diet analysis

- What is the most “efficient” diet for a region based on resource availability (land, nutrients, water)?

Effects of trade policies on nutrient flows



P footprint: U.S. case study

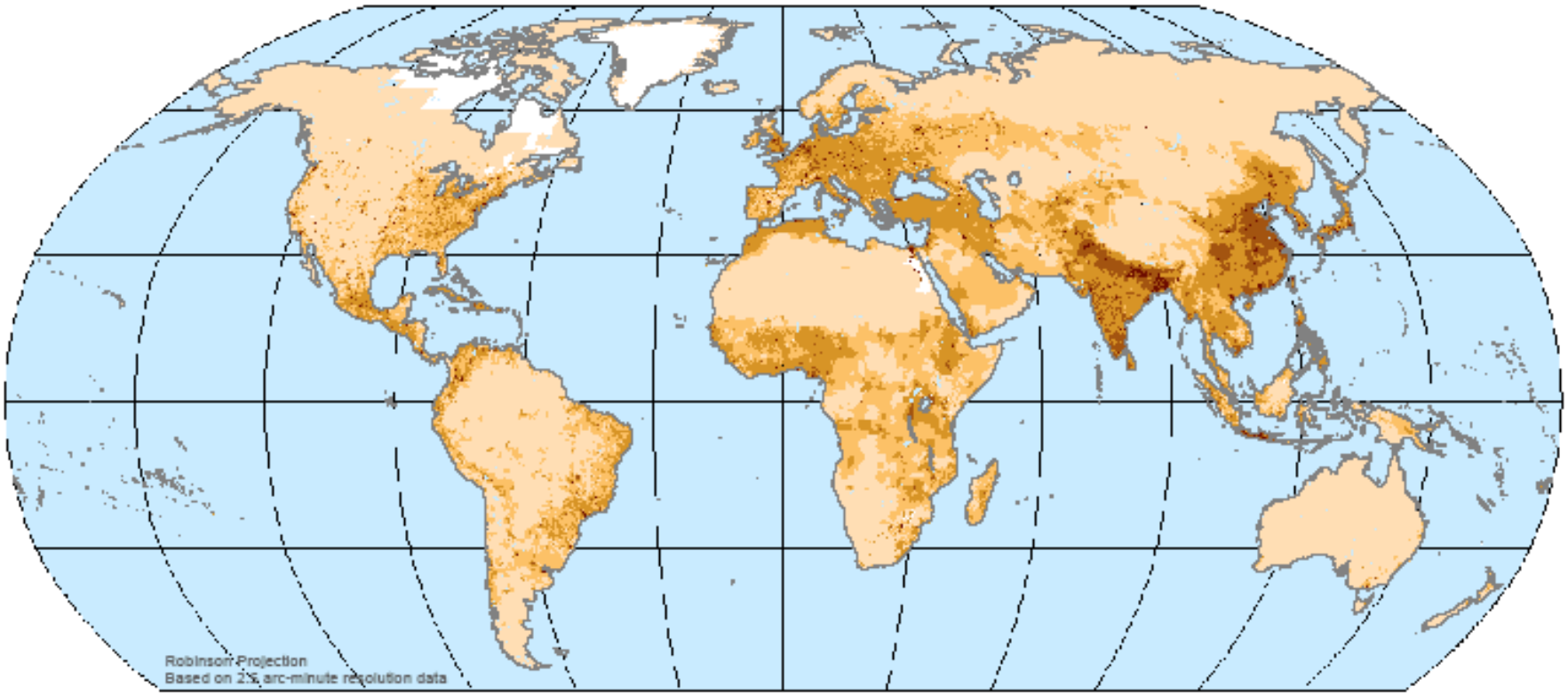


Feed crop and li s in 2007 (Gg P yr

From MacDonald et al. *in prep*

The World: Population Density, 2000

GPW [v3]



Gridded Population of the World

Persons per km^2

- 0
- 1 - 4
- 5 - 24
- 25 - 249
- 250 - 999
- 1,000 +

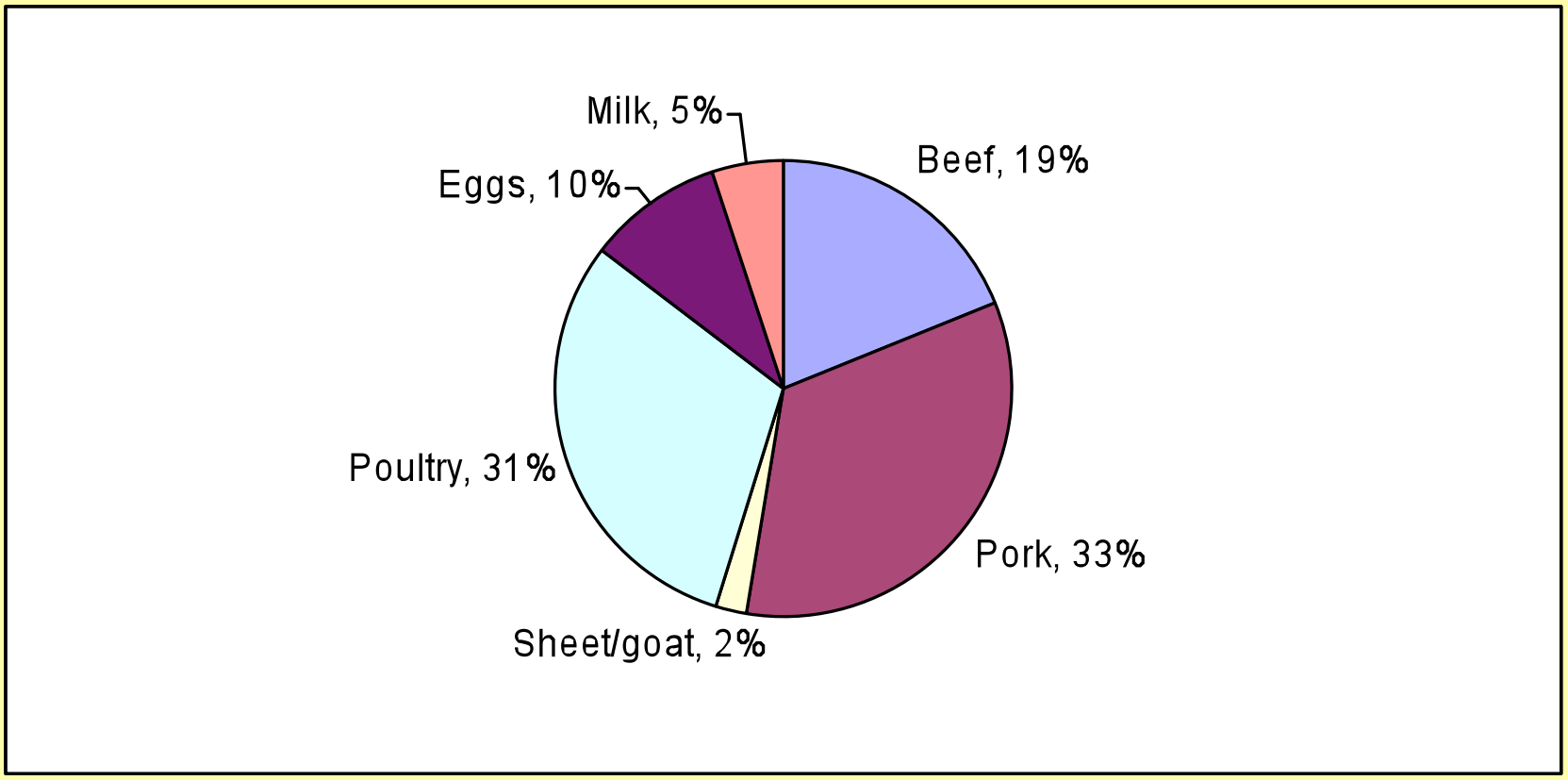
SEDAC

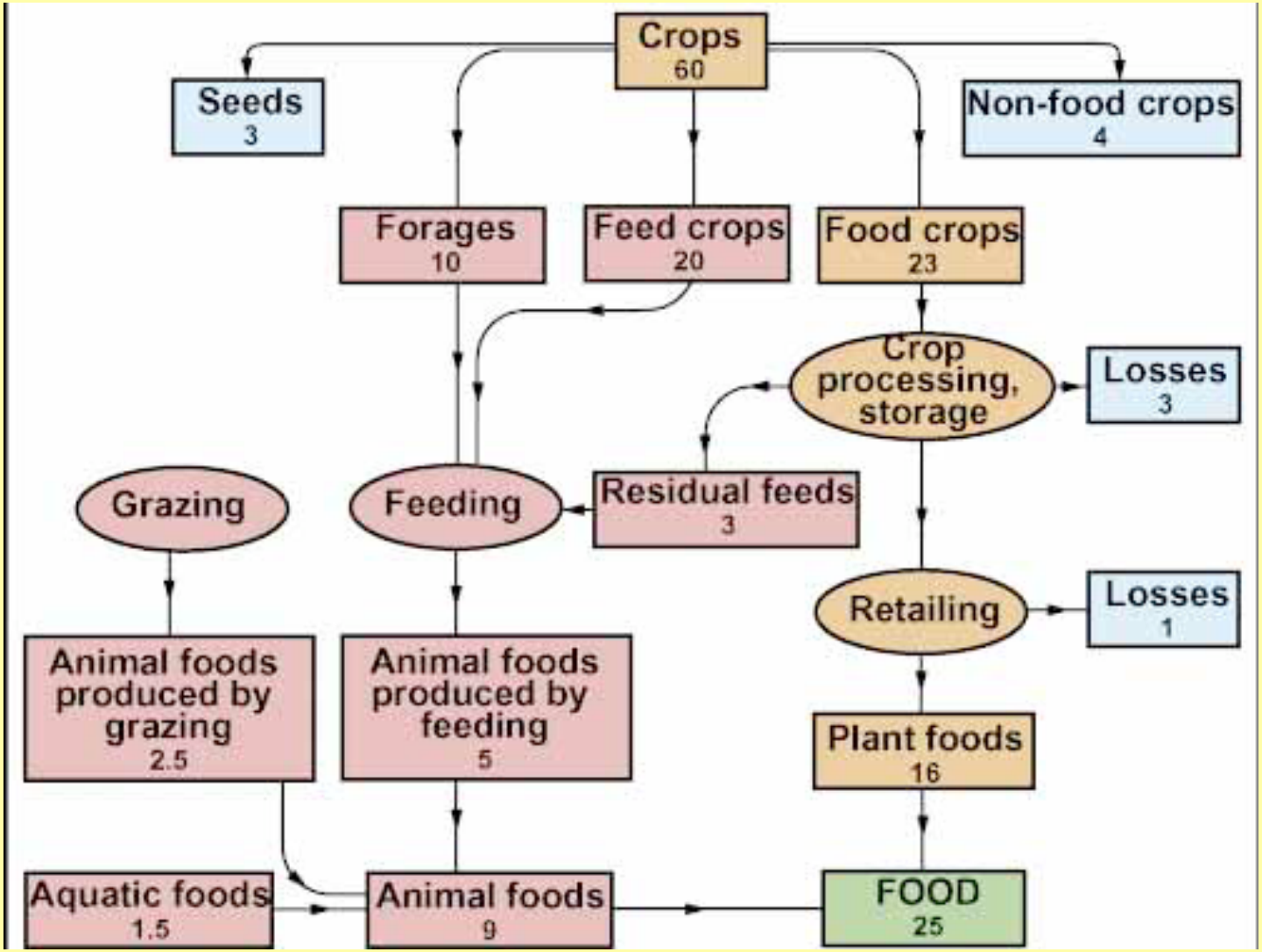
CIESIN
Columbia University

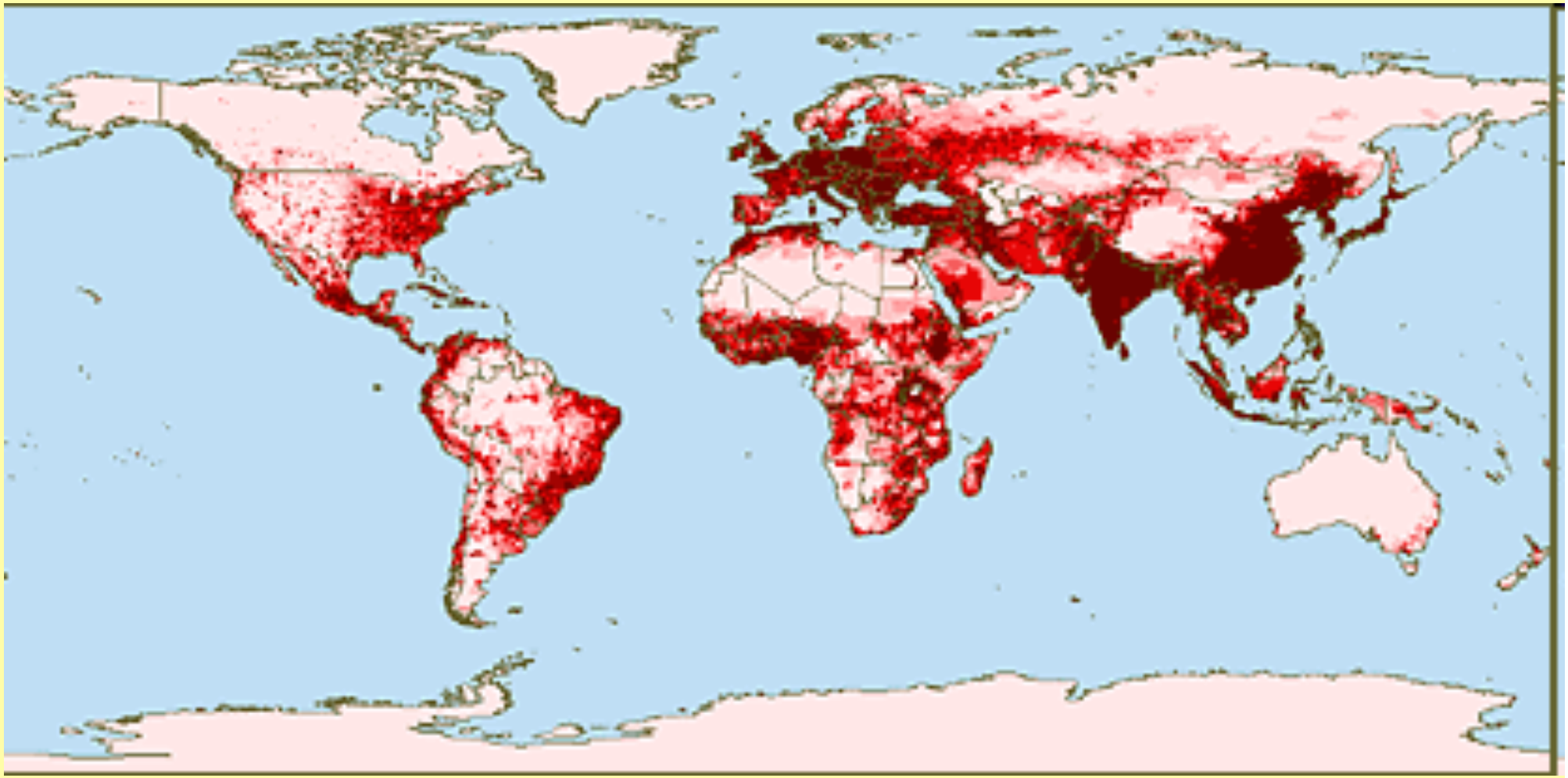
Source: Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). Gridded Population of the World (GPW), Version 3. Palisades, NY: CIESIN, Columbia University. Available at: http://sedac.ciesin.columbia.edu/gpw.

Effects of trade on P in livestock systems

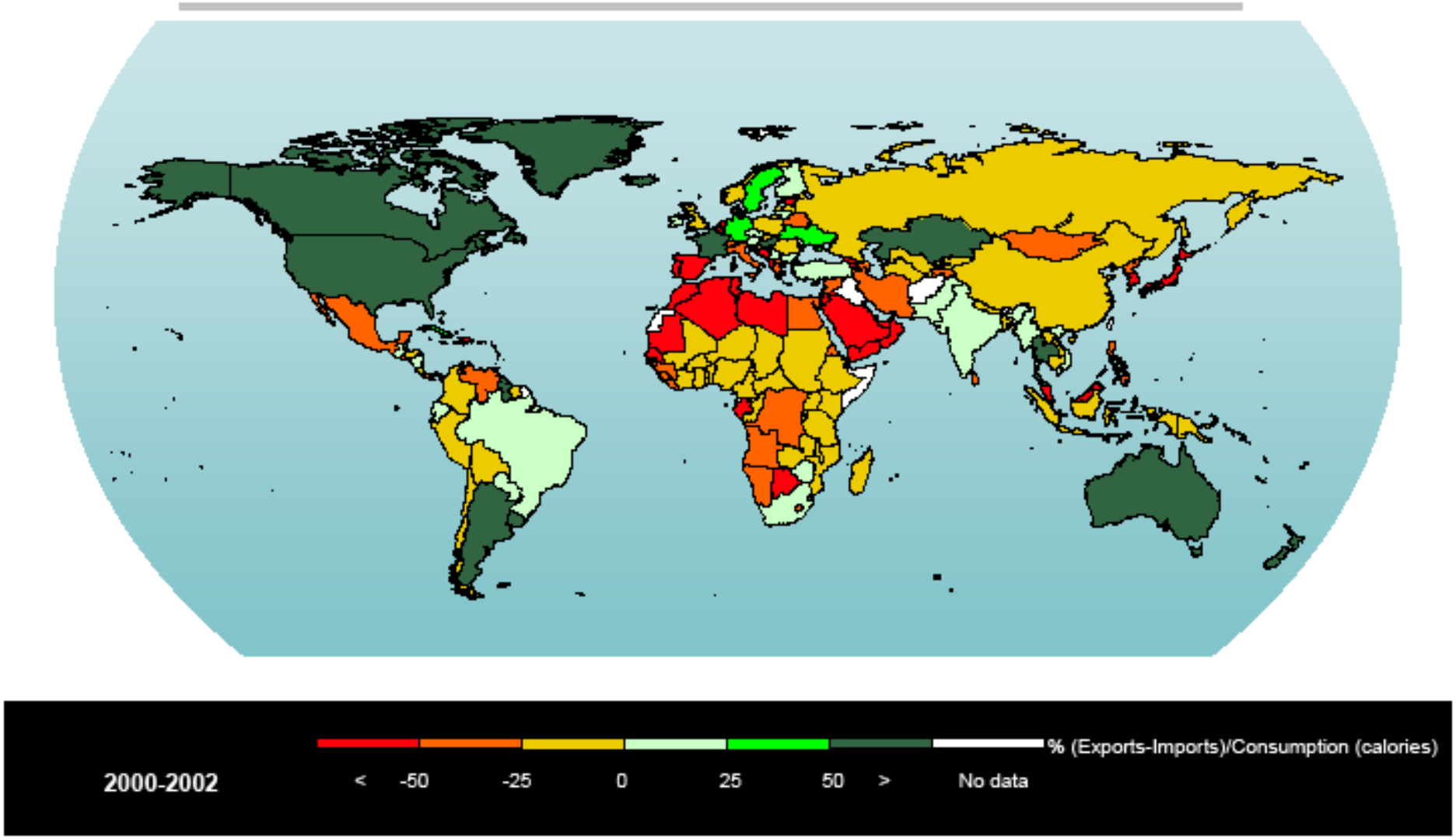
P in global animal products




Crops
60
Seeds
3
Non-food crops
4
Forages
10
Feed crops
20
Food crops
23
Crop processing, storage
Losses
3
Grazing
Feeding
Residual feeds
3
Retailing
Losses
1
Animal foods produced by grazing
2.5
Animal foods produced by feeding
5
Plant foods
16
Aquatic foods
1.5
Animal foods
9
FOOD
25



Global net trade in food



FAO