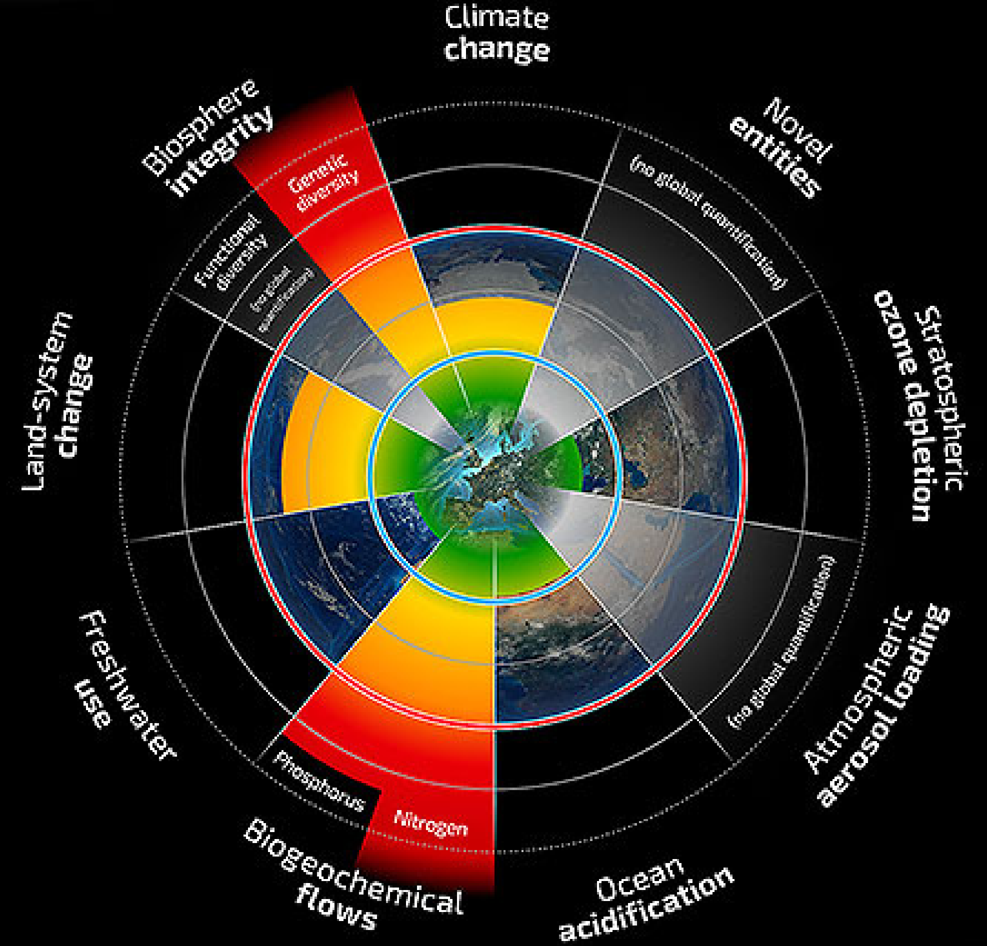
Foodprint:
Understanding the Connections Between Food and the Environment

Session 3

Nitrogen Cycling

Planetary Boundaries: A Safe Operating Space for Humanity

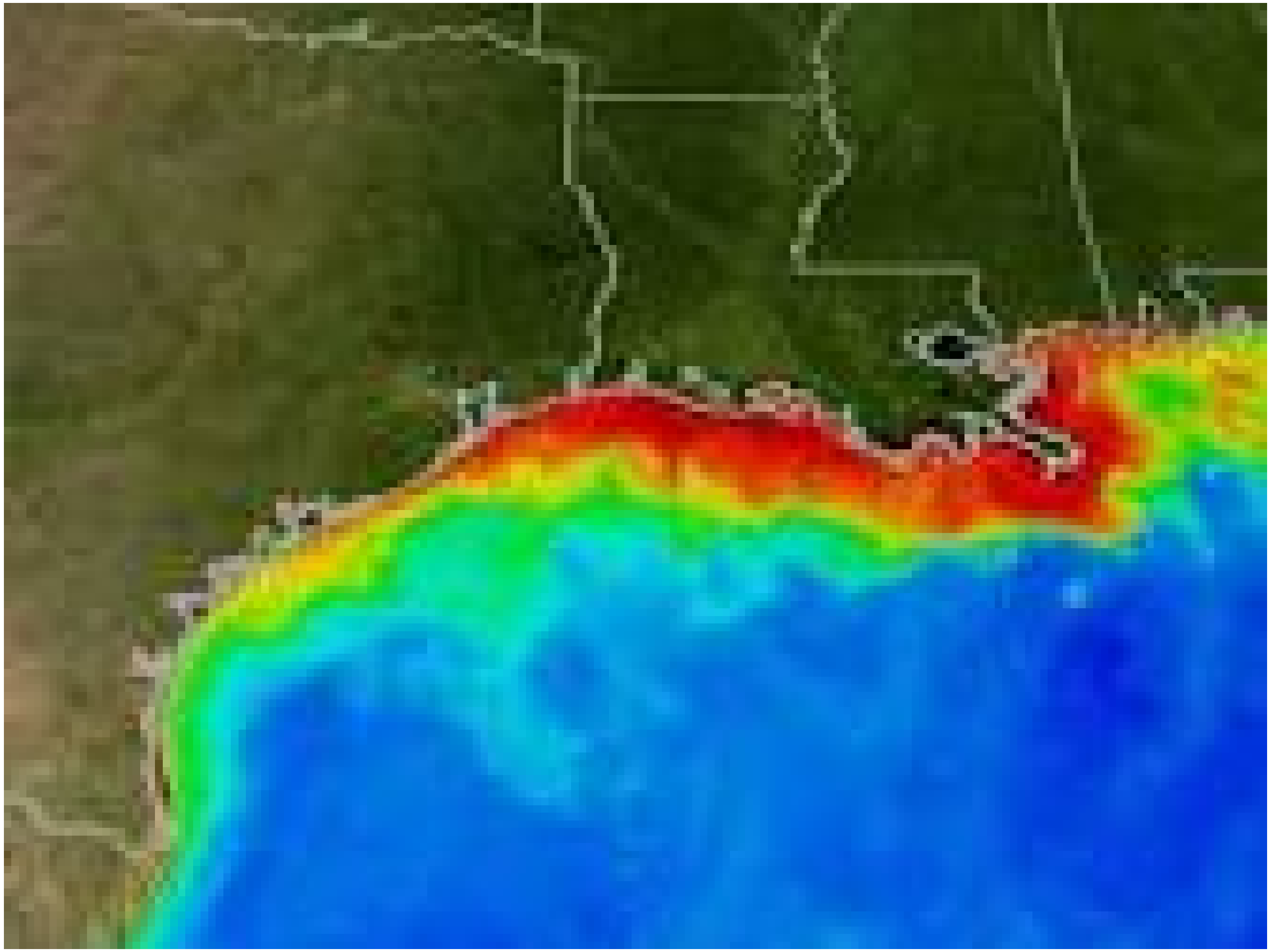


Source: Steffen et aL. 2015

We can track our progress through time and improve the boundaries based on new science.

We are now exceeding global sustainability limits for :

- climate change
- nitrogen and phosphorus cycling,
- land use change
- biodiversity loss.

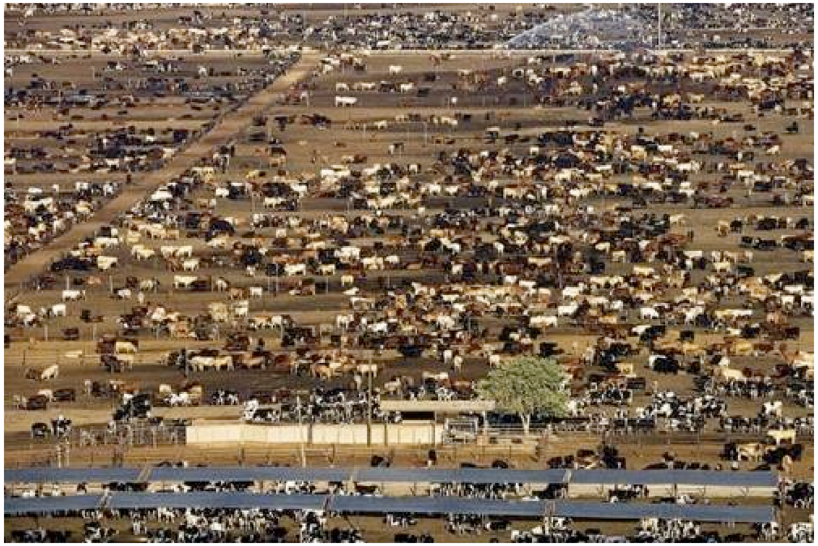


Why is there a dead zone in the Gulf of Mexico?

Farmland runoff containing fertilizers and livestock waste is the main source of the nitrogen and phosphorus that cause the Gulf of Mexico hypoxic zone, which is also known as a dead zone.

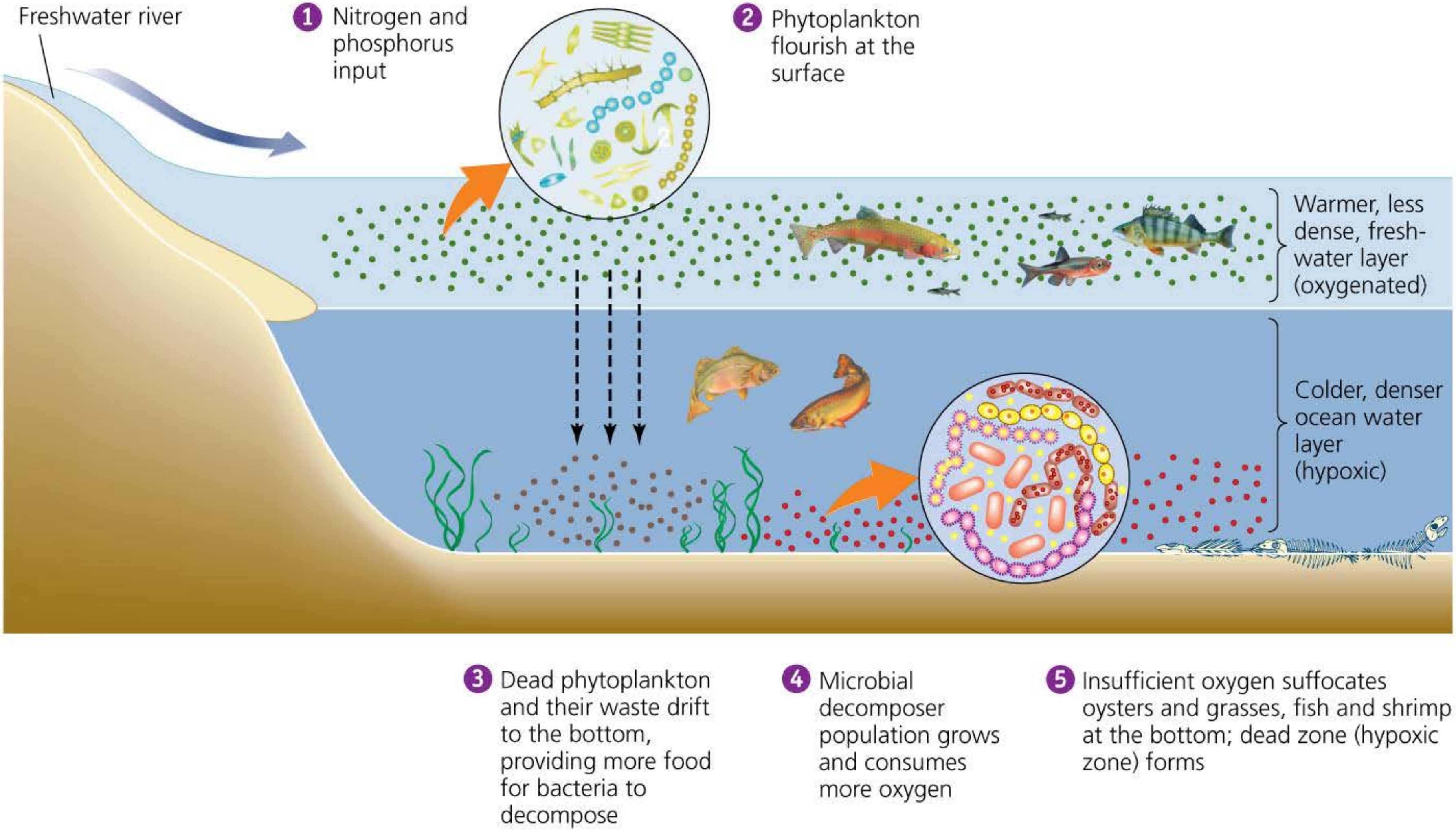
– University of Michigan

In which photo is cow waste assimilated into the ecosystem?

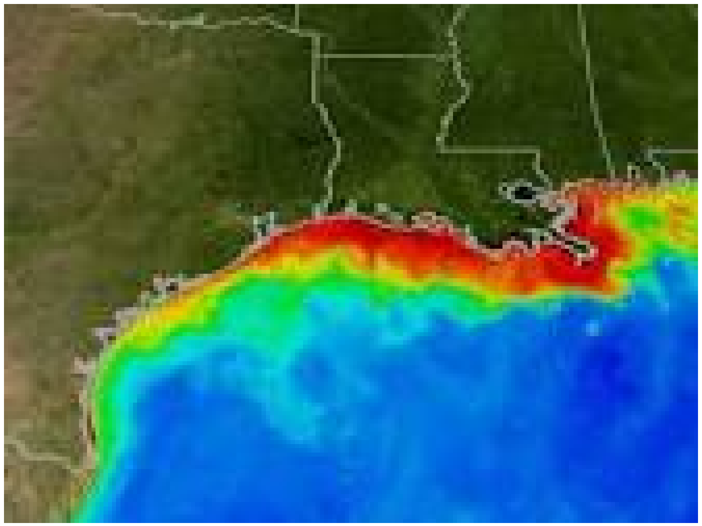



Inside a factory farm
What happens to the waste??
Photo Credit: The HSUS

What is happening in this photo?

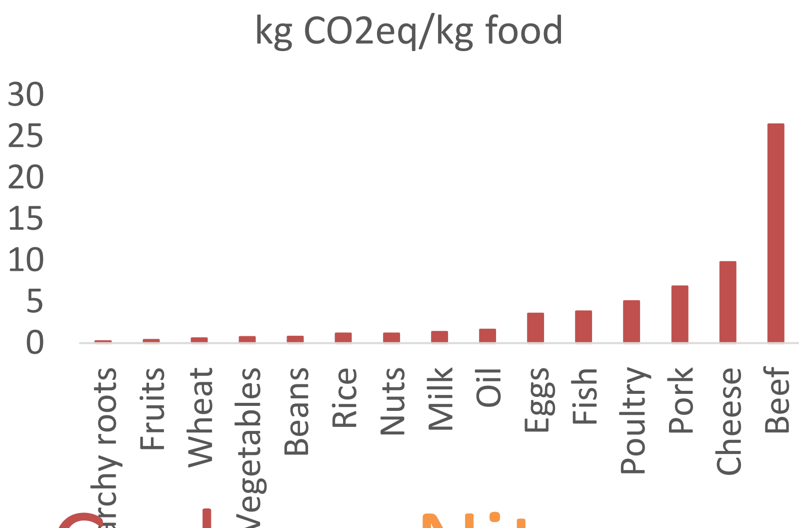

Freshwater river
1 Nitrogen and phosphorus input
2 Phytoplankton flourish at the surface
Warmer, less dense, fresh-water layer (oxygenated)
Colder, denser ocean water layer (hypoxic)
3 Dead phytoplankton and their waste drift to the bottom, providing more food for bacteria to decompose
4 Microbial decomposer population grows and consumes more oxygen
5 Insufficient oxygen suffocates oysters and grasses, fish and shrimp at the bottom; dead zone (hypoxic zone) forms

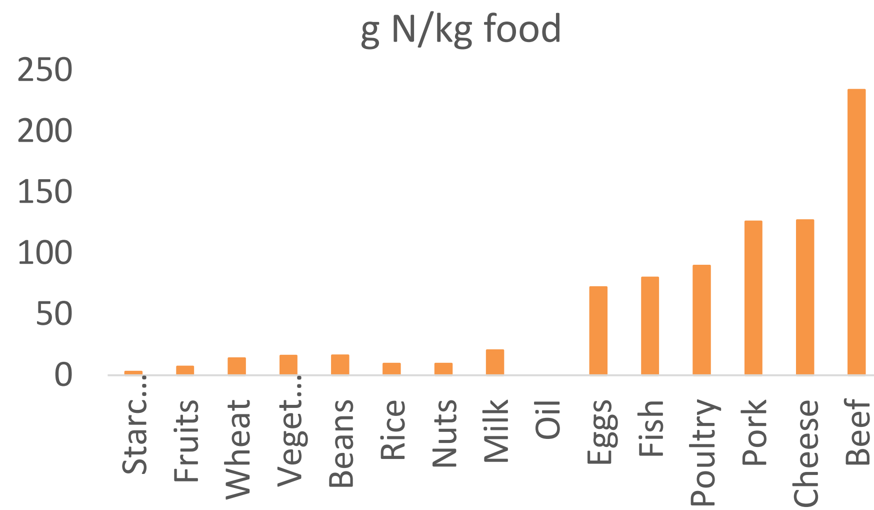
Nutrient pollution from fertilizers and manure causes dead zones and water contamination

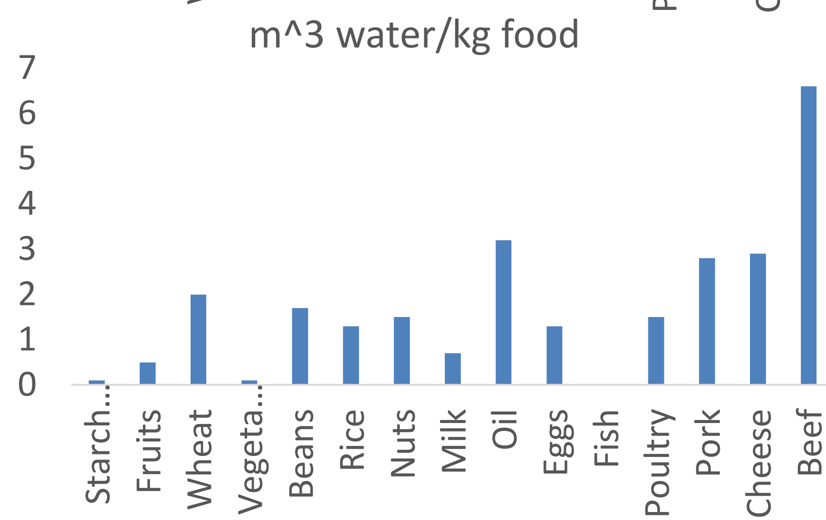


- Over 500 hypoxic dead zones occur globally
- Causes over $2 billion/year in lost harvests

Carbon, Nitrogen, and water foodprints

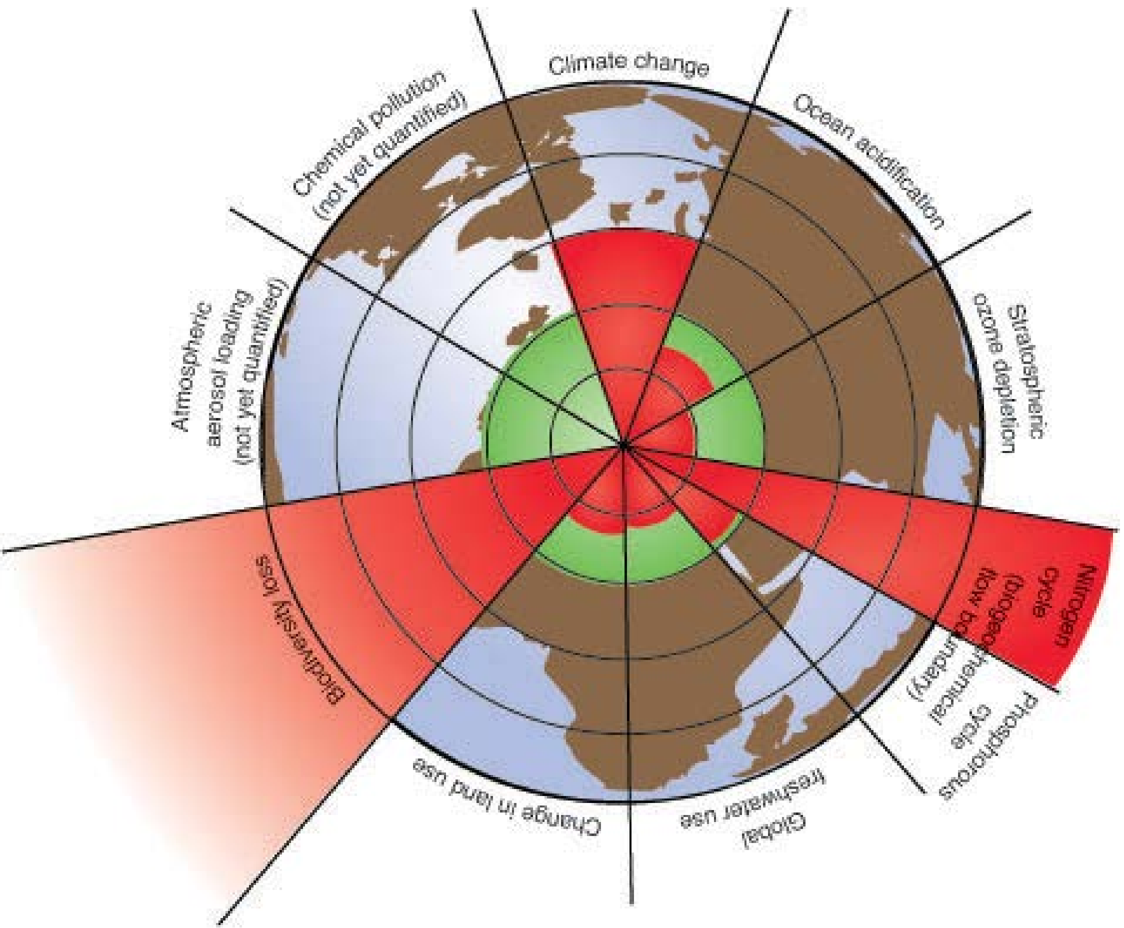






(Leach et al, 2016)

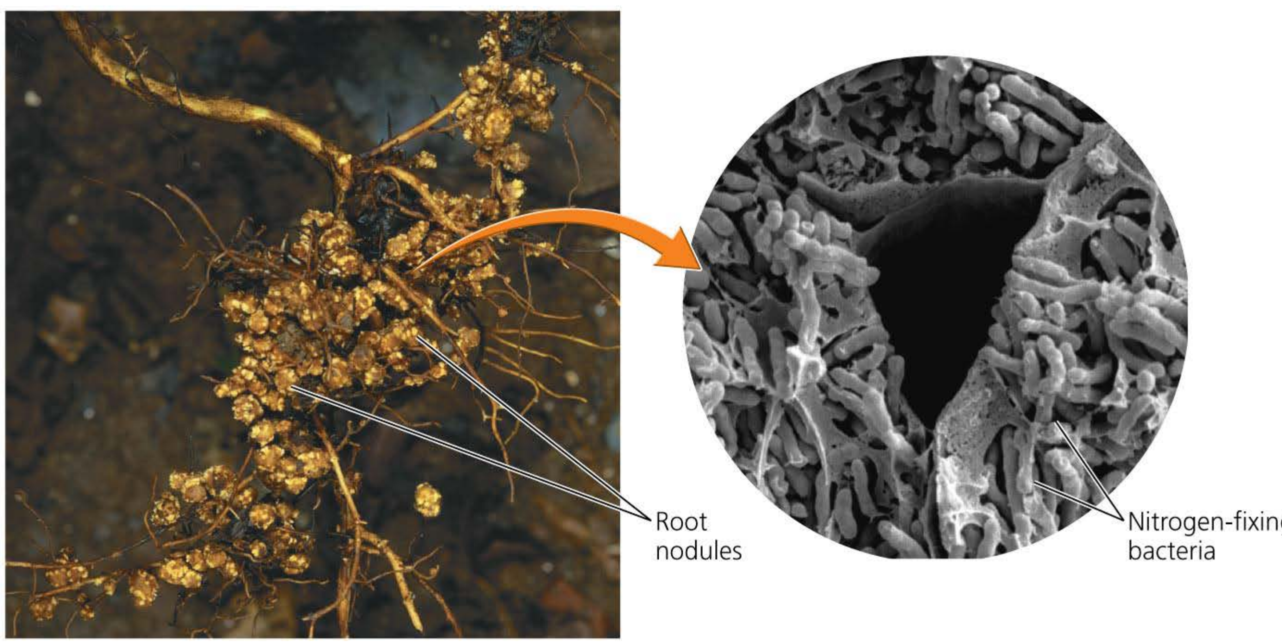
“At the global scale, the addition of various forms of reactive N to the environment acts primarily as a slow variable, ***eroding the resilience of important sub-systems of the Earth System.*** The exception is nitrous oxide, which is one of the most **important greenhouse gases** and thus acts as a systemic driver at the planetary scale. (Rockstrom et al. 2009)



“We suggest that the boundary initially be set at approximately 25% of its current value, or to about 35 Mt N yr-1.“

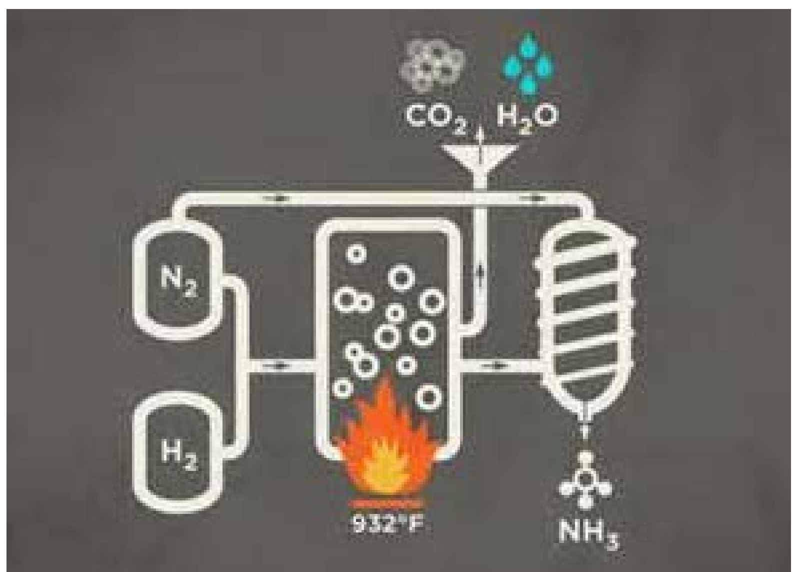
The nitrogen cycle involves specialized bacteria

- Nitrogen comprises 78% of our atmosphere but is unusable to most plants in this form
- **Nitrogen-fixing bacteria** combine, or “fix,” nitrogen with hydrogen to form ammonium, which can be used by plants
- Bacteria living on soybean roots can do this, which is why soy is often rotated with other crops



We have greatly influenced the nitrogen cycle

- Nitrogen fixation was a crop production **bottleneck** = the limiting factor in crop production
- **Haber-Bosch process** = production of fertilizers by combining nitrogen and hydrogen to synthesize ammonia

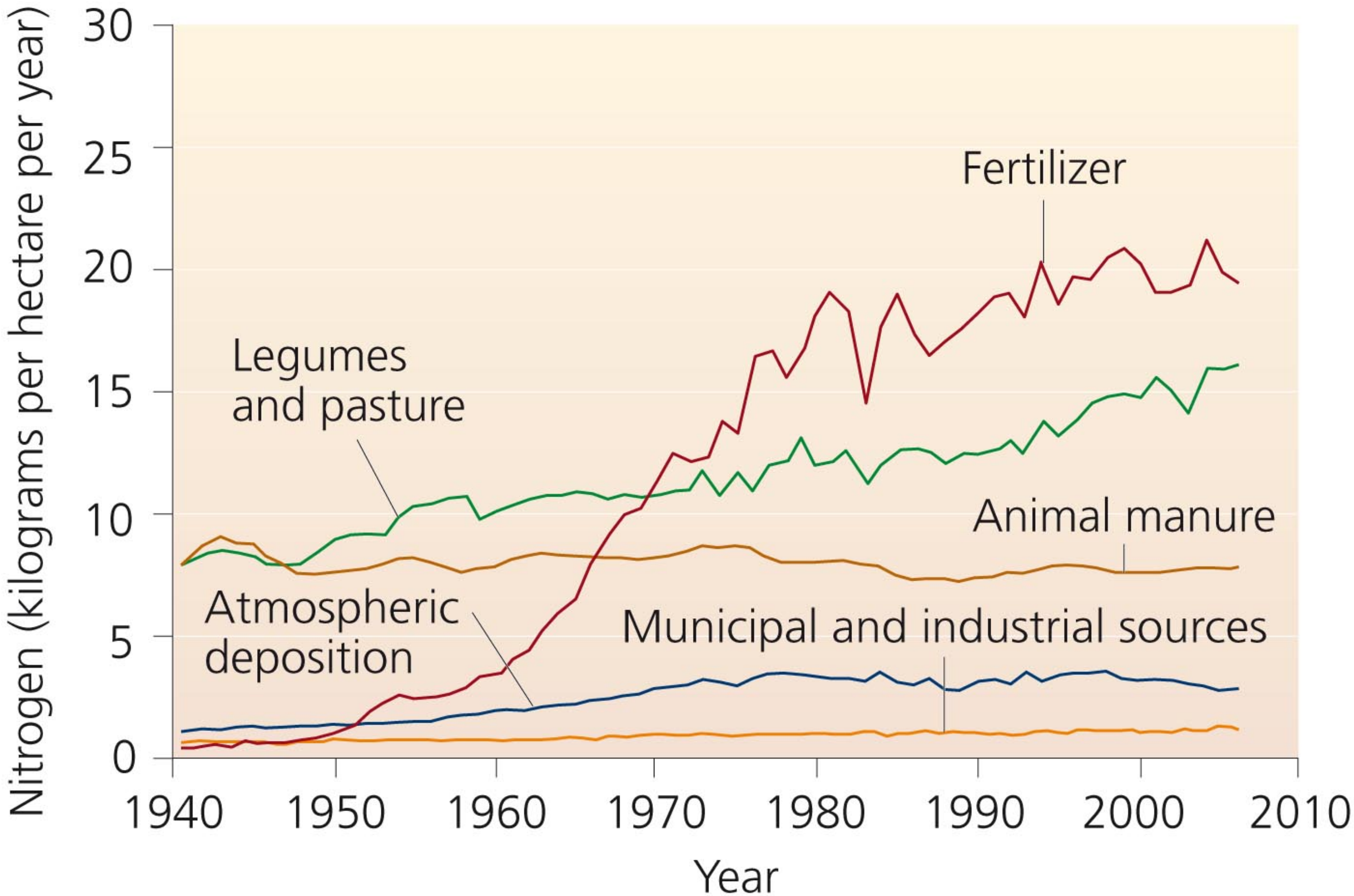


We have greatly influenced the nitrogen cycle

- Overuse of fertilizers has negative side effects:
  - Causes eutrophication
  - Washes essential nutrients out of the soil
- Burning fossil fuels adds nitrogen compounds to the atmosphere that contribute to acid precipitation

Human-driven N conversion occurs primarily through four processes:

- Industrial fixation of atmospheric N_2 to ammonia (~80 Mt N yr^{-1})
- Agricultural fixation of atmospheric N_2 via cultivation of leguminous crops (~40 Mt N yr^{-1})
- fossil-fuel combustion (~20 Mt N yr^{-1})
- biomass burning (~10 Mt N yr^{-1}).



Human activity has doubled the amount of nitrogen entering the environment, overwhelming nature's denitrification abilities

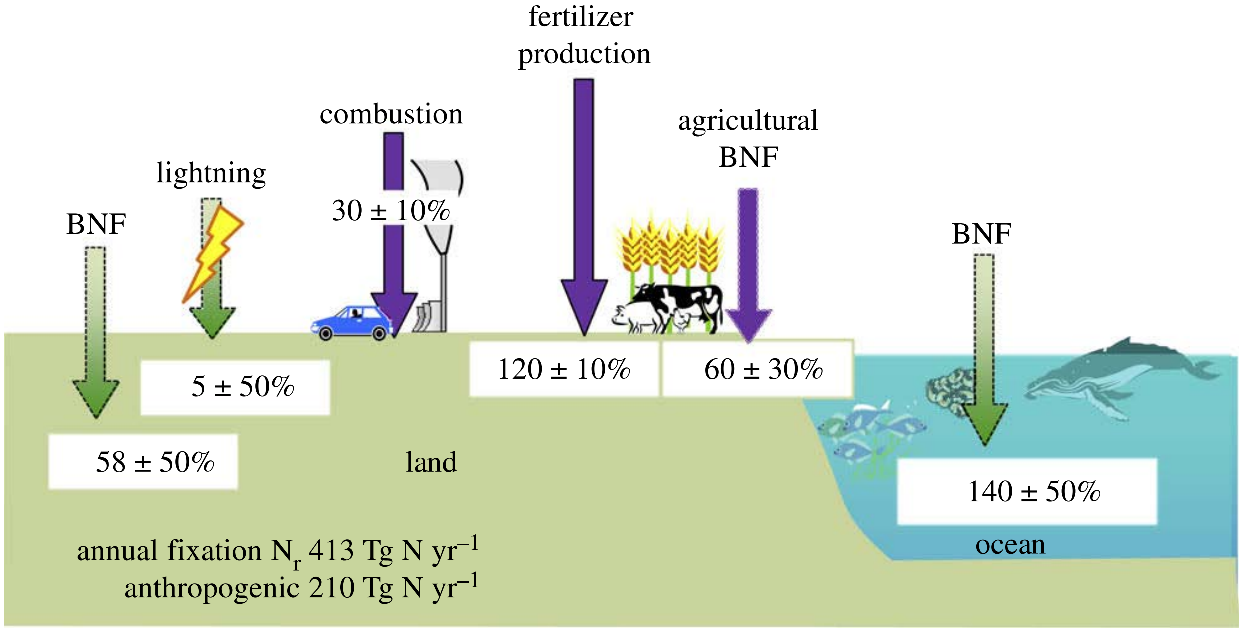


Figure 1. Global nitrogen fixation, natural and anthropogenic in both oxidized and reduced forms through combustion, biological fixation, lightning and fertilizer and industrial production through the Haber–Bosch process for 2010. The arrows indicate a transfer from the atmospheric N_2 reservoir to terrestrial and marine ecosystems, regardless of the subsequent fate of the N_r. Green arrows represent natural sources, purple arrows represent anthropogenic sources.

Fowler et al., Global N Cycle. Phil Trans. Royal Soc. 2013

Erisman et al., 2013, Consequences of human modification of the global nitrogen cycle. Phil Trans of the Royal Soc.

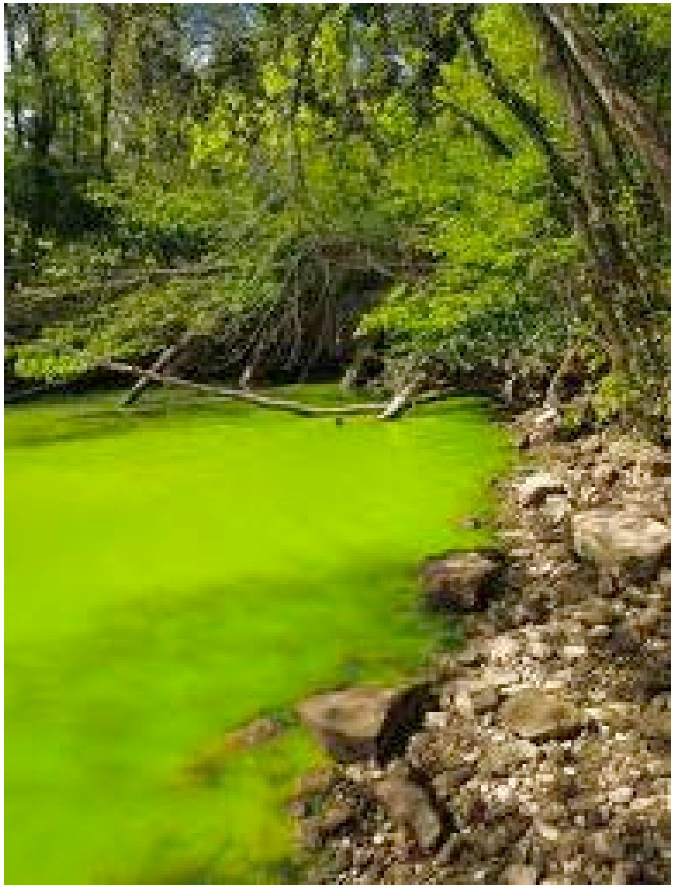
Human Health

- NO_x in lower atmosphere leads to increased tropospheric ozone, smog, particulate matter
- Increase ozone leads to increased asthma and premature death
- Nitrate pollution of drinking water is a major problem

Erisman et al., 2013, Consequences of human modification of the global nitrogen cycle. Phil Trans of the Royal Soc.

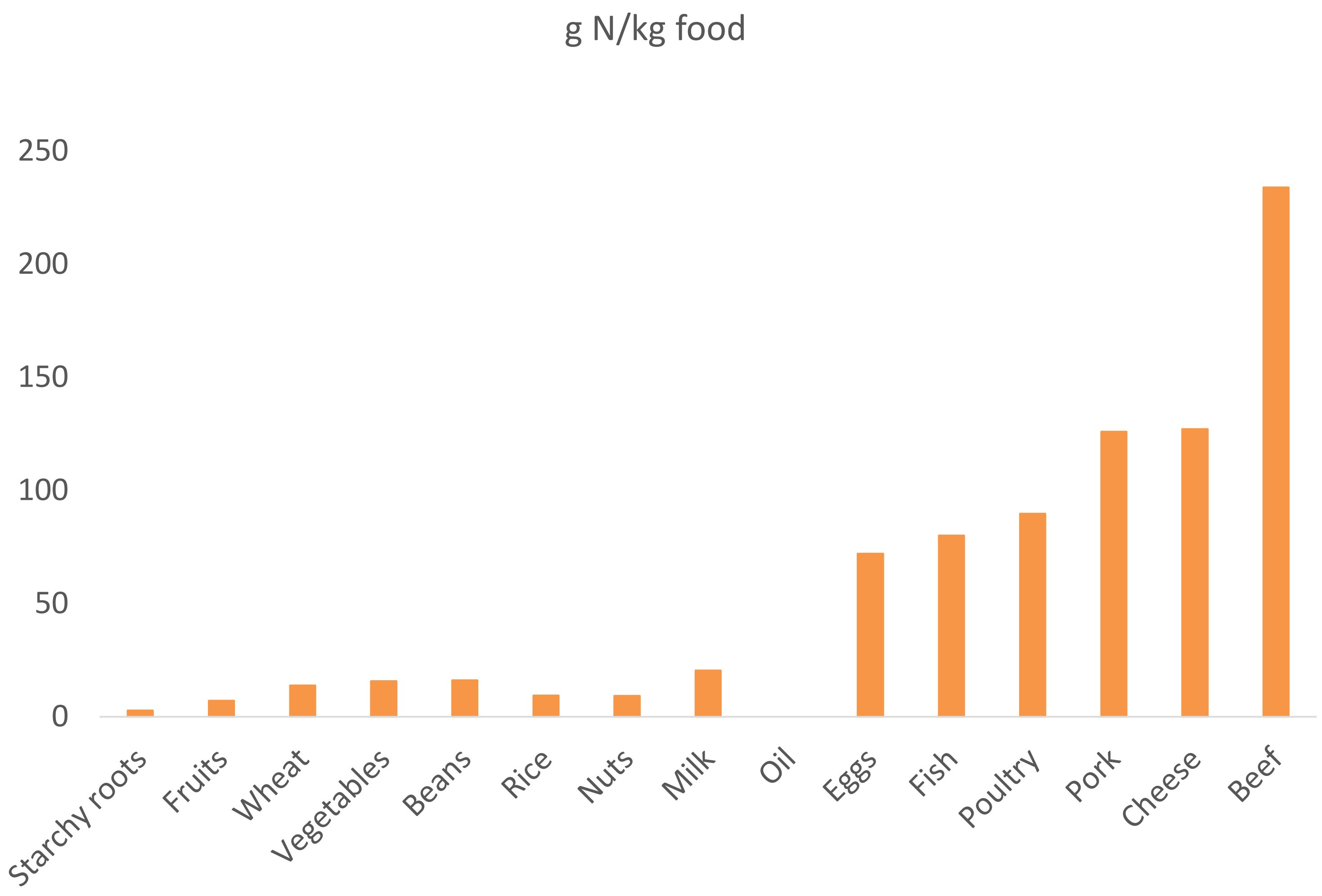
<u>Aquatic systems</u>

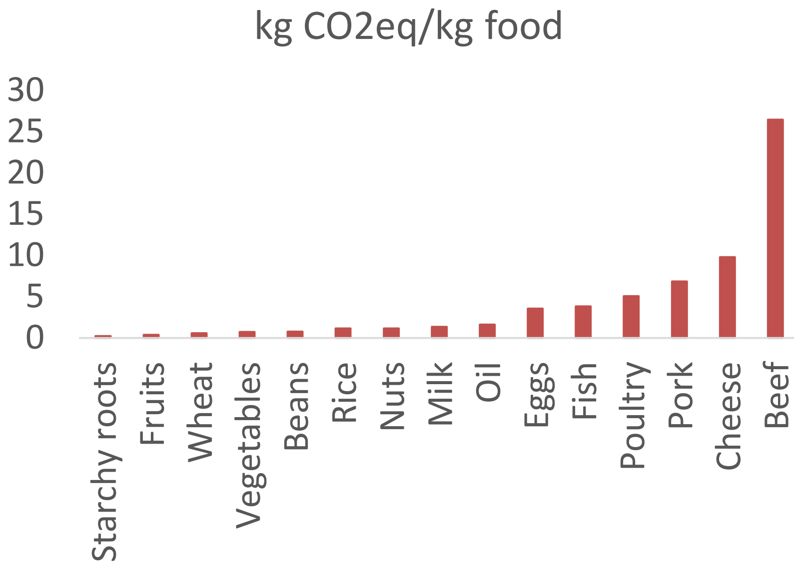
- Acidification of water bodies. Early life stages sensitive
- Increased eutrophication

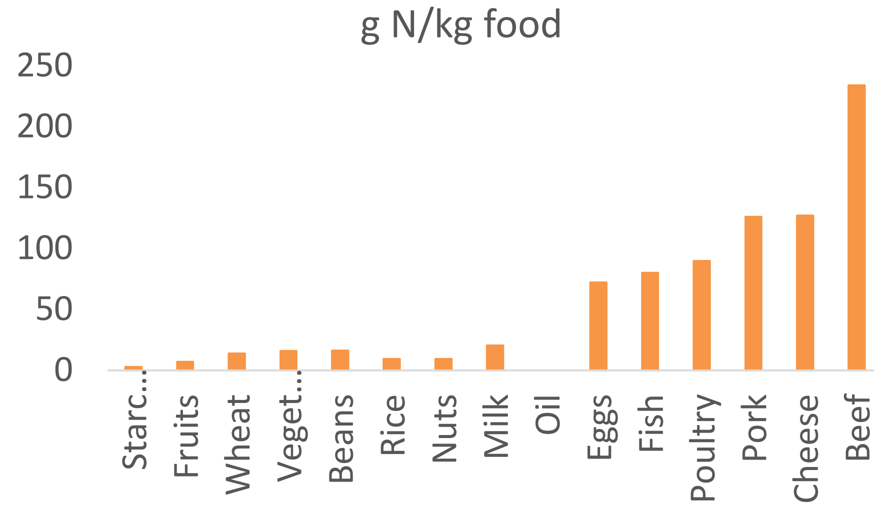


<u>Terrestrial systems</u>

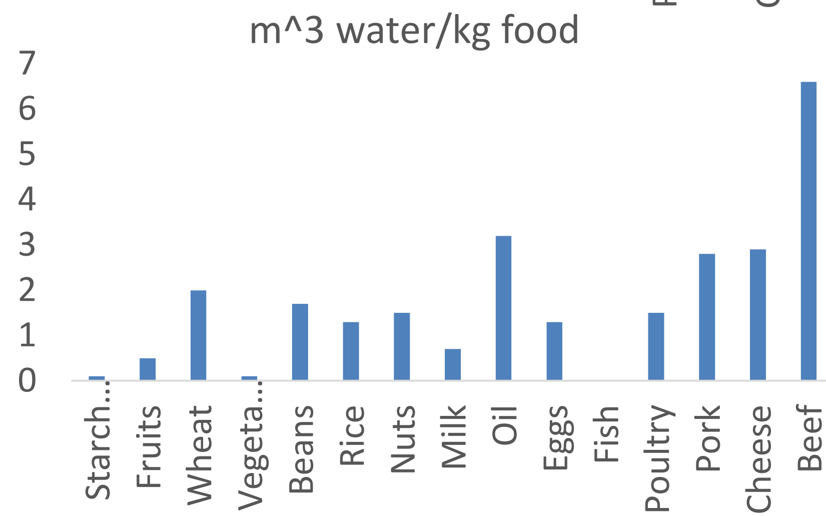
- Foliar damage
- Increased susceptibility to stress
- Decreased species richness


g N/kg food
250
200
150
100
50
0
Starchy roots
Fruits
Wheat
Vegetables
Beans
Rice
Nuts
Milk
Oil
Eggs
Fish
Poultry
Pork
Cheese
Beef



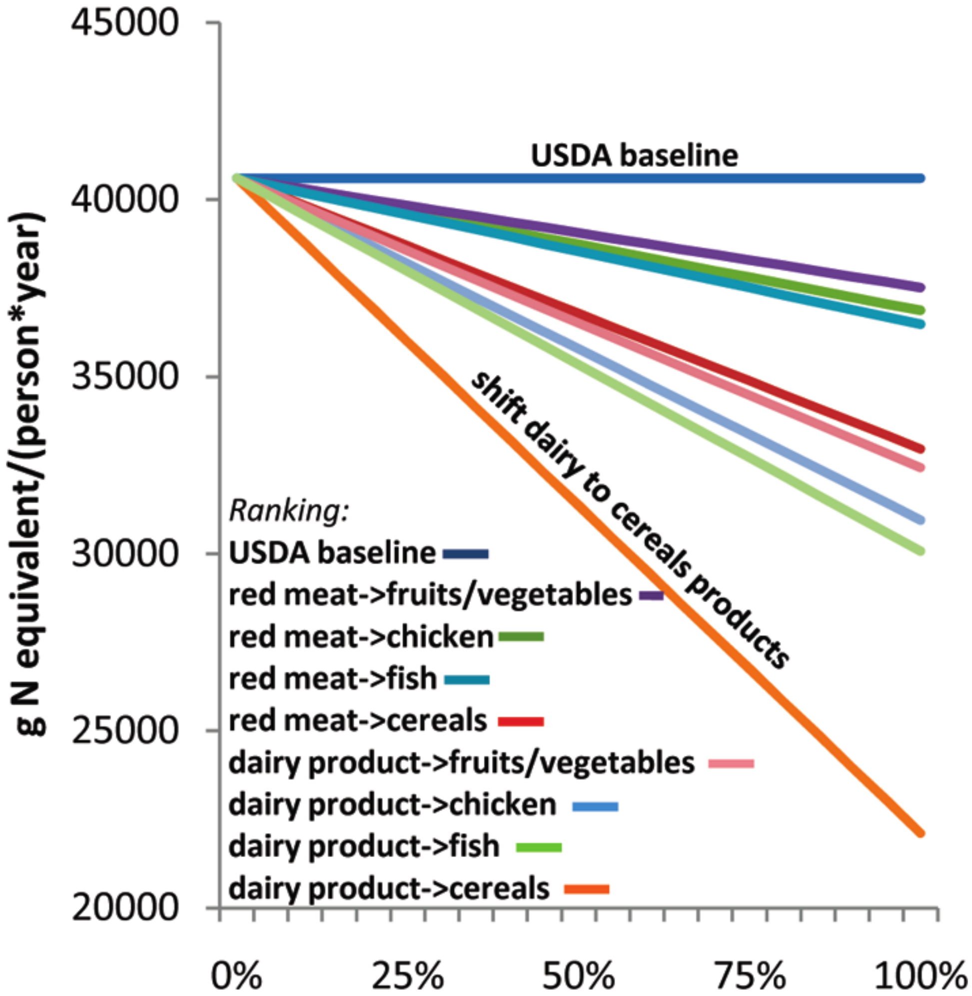


Carbon, nitrogen, and water foodprints



(Leach et al, 2016)

Xue and Landis (2010) Eutrophication potential of food consumption patterns. ES&T



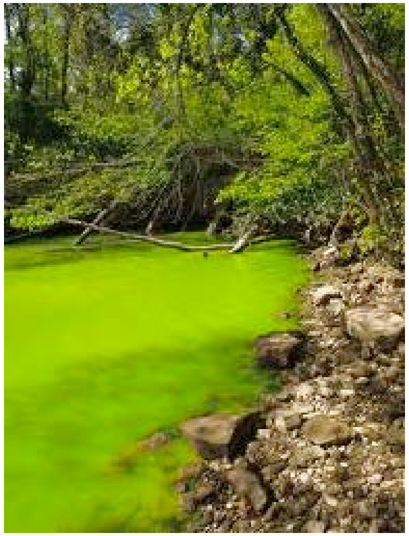
C, N, and water footprints (Leach et al, 2016)

	Carbon		Nitrogen		Water	
	kg CO_2-eq/kg product[a]	kg CO_2-eq/ 1000 kcal[*]	g N lost/kg product[b]	g N lost/ 1000 kcal[*]	m^3/kg product[c]	m^3/ 1000 kcal[*]
Vegetable products						
Wheat	0.58	0.1	13.9	3.7	2.0	0.5
Rice	1.14	0.8	9.4	2.6	1.3	0.4
Fruits	0.36	0.7	7.1	12.4	0.5	0.9
Pulses	0.78	0.1	16.1	4.4	1.7	0.5
Starchy roots	0.21	0.2	2.8	3.7	0.1	0.2
Vegetables	0.73	5.8	15.8	44.1	0.1	0.2
Nuts	1.17	0.4	9.3	1.8	1.5	0.3
Oil	1.63	0.6	0.0	0.0	3.2	0.4
Animal products						
Poultry	5.05	1.2	89.8	74.8	1.5	1.2
Pork	6.87	2.1	126.0	94.0	2.8	2.1
Beef	26.45	11.4	234.0	160.1	6.6	4.5
Milk	1.34	2.6	20.4	40.9	0.7	1.4
Cheese	9.78	2.3	127.1	36.7	2.9	0.8
Eggs	3.54	1.4	72.1	49.7	1.3	0.9
Fish	3.83	1.9	80.1	72.0	X[**]	X[**]

Remember: kg CO_2/kg food is the same as g CO_2/g food, and m^3/kg is the same as L/g

Tackling nutrient enrichment requires diverse approaches

- We rely on synthetic fertilizers and fossil fuels
  - Nutrient enrichment will be an issue we must address
- There are a number of ways to control nutrient pollution
  - Reduce fertilizer use on farms and lawns
  - Apply fertilizer at times that minimize runoff
  - Plant vegetation “buffers” around streams
  - Restore wetlands and create artificial ones
  - Improve sewage treatment technologies
  - Reduce fossil fuel combustion
  - Raise different crops
  - Efficient food systems
- These approaches have varying costs



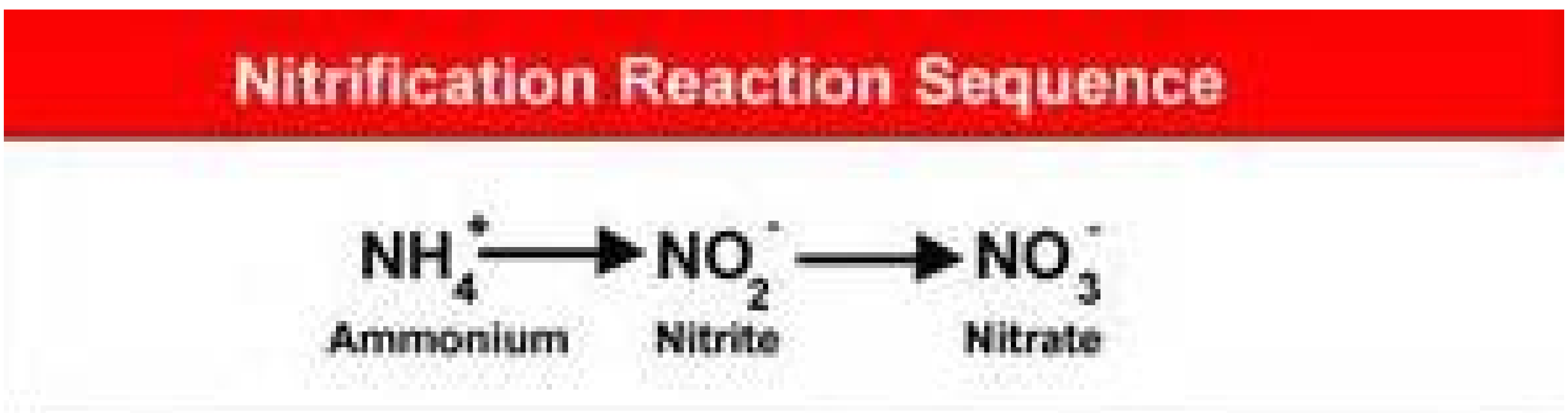
N Footprint Exercises

1) Look up the make up of the current US diet using National Geographic's tool called "What the World Eats." Calculate the N footprint for the 1950 diet and the current diet for a country of your choice
2) Compare the diets of two countries in "What the World Eats" with respect to N footprint.
3) Create pie charts of the N footprint for various sandwiches from the C footprint exercise.

Extra slides

Nitrification and denitrification

- **Nitrification** = process by which bacteria convert ammonium ions, first into nitrite ions, then into nitrate ions
  - Plants can take up nitrate most easily



Nitrification and denitrification

- **Denitrifying bacteria** = bacteria that convert nitrates in soil or water to gaseous nitrogen, releasing it back into the atmosphere and completing the nitrogen cycle

Hallstrom et al. 2017

Table 1 Intake levels of foods in SAD and HADs

Food	g capita^{-1} day^{-1}[a]			
	SAD[b]	HAD-1	HAD-2	HAD-3
Total red[c] and processed meat	92	51	25	0
Unprocessed red meat	58	41	25	0
Processed meat[d]	34	10	0	0
Total fruits and vegetables	335	672	707	741
Fruits	74	299	299	299
Fruit juices	60	75	75	75
Vegetables without beans and peas	194	283	283	283
Beans and peas	7	15	50	84
Total grains	167	131	131	131
Whole grains	17	79	79	79
Refined grains	150	52	52	52

[a] Intake levels of meat, and beans and peas are given in cooked weight, while grains, fruits, and vegetables in uncooked weight. Basis for RR calculations

[b] SAD based on loss-adjusted food availability (USDA ERS 2014)

[c] Red meat refers to beef and pork

[d] Processed meat refers to meat preserved by smoking, curing or salting, or addition of chemical preservatives