Eutrophication

The nitrogen cascade

Eutrophication

- Eutrophication comes from Greek *eu trophos*, i.e. well nourished
- The process by which an ecosystem, or parts of it, becomes progressively enriched with nutrients.
- Terms often used for lakes and other water bodies
  - Eutrophic
  - Mesotrophic
  - Oligotrophic
- When taken to extremes a system may become “dystrophic” or “hypertrophic”
- Two key nutrients typically implicated
  - Nitrogen
  - Phosphorous
- Both are added to ecosystems naturally, and through human activity

Impacts of phosphates and nitrates

- It was once assumed that phosphorous was the key limiting nutrient in lakes, while nitrogen was the key limit for terrestrial ecosystems
- More recent research shows a more complex picture
- Phosphate enrichment is a very important element of freshwater eutrophication.
- However, nitrogen derived compounds can play a particularly important role in the eutrophication of coastal ecosystems

Inputs of P and N

- Both P and N are used as fertilizers
- N is more mobile than P and moves through run off and ground water
- P tends to bind to sediments
- Sewage and manure contain both at high concentrations
- Phosphates also present in detergents

Algal mat (Poole harbour)

Direct impact of eutrophication

- Algal mats or blooms can have the most visible and damaging impact
- When an algal mat (or algal bloom) decays, oxygen is depleted
- Can lead to fish kills

Toxic blooms

- Tends to be associated with intensified agriculture

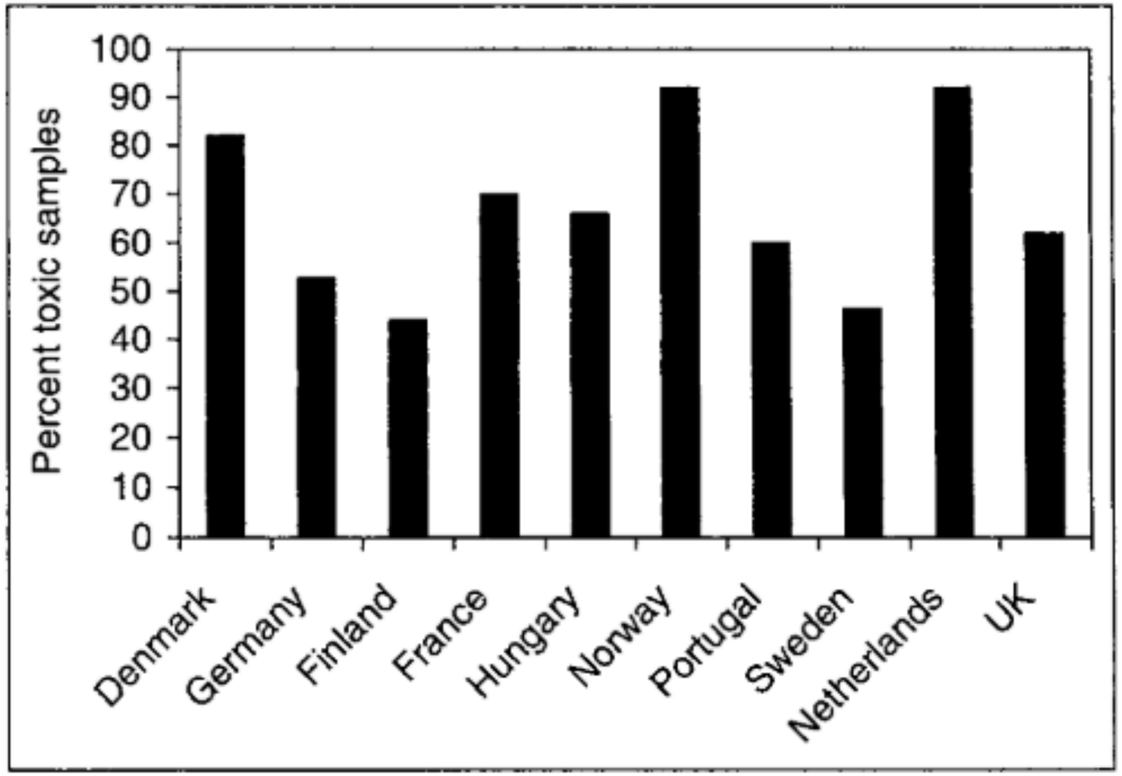


Fig. 1: Frequencies of toxic cyanobacterial blooms in 11 European countries (data from Table 2.2.1 in Sivonen 2000)

Effects on salt marshes

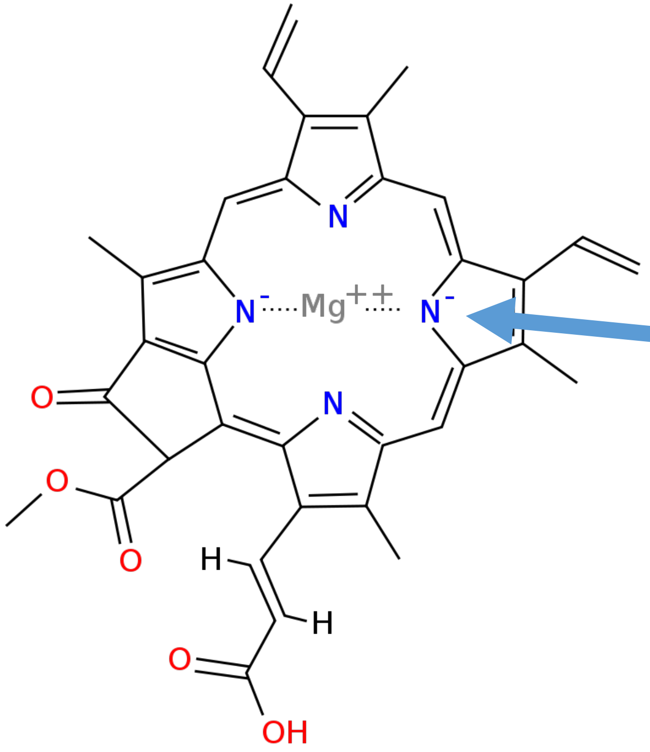
“Improved” grassland

Why focus on nitrogen?

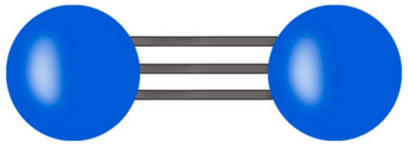
- The elements nitrogen (N), carbon (C), phosphorus (P), oxygen (O), and sulphur (S) are all necessary for life, and so are present in all ecosystems
- Total amount of N in the atmosphere, soils, and waters of Earth is approximately 4×10^{21} grams (g)
- More than the total mass of C + P + O + S !
- But … > 99% of N unavailable for use
- N_2 held together by triple bond

Chlorophyl

$C_{55}H_{72}O_5N_4Mg$



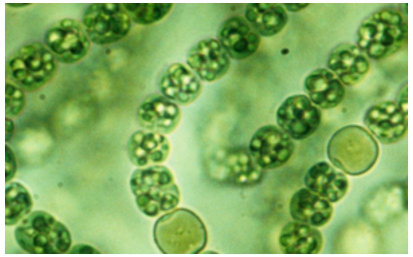
How does it from this to that?



Biological nitrogen fixation

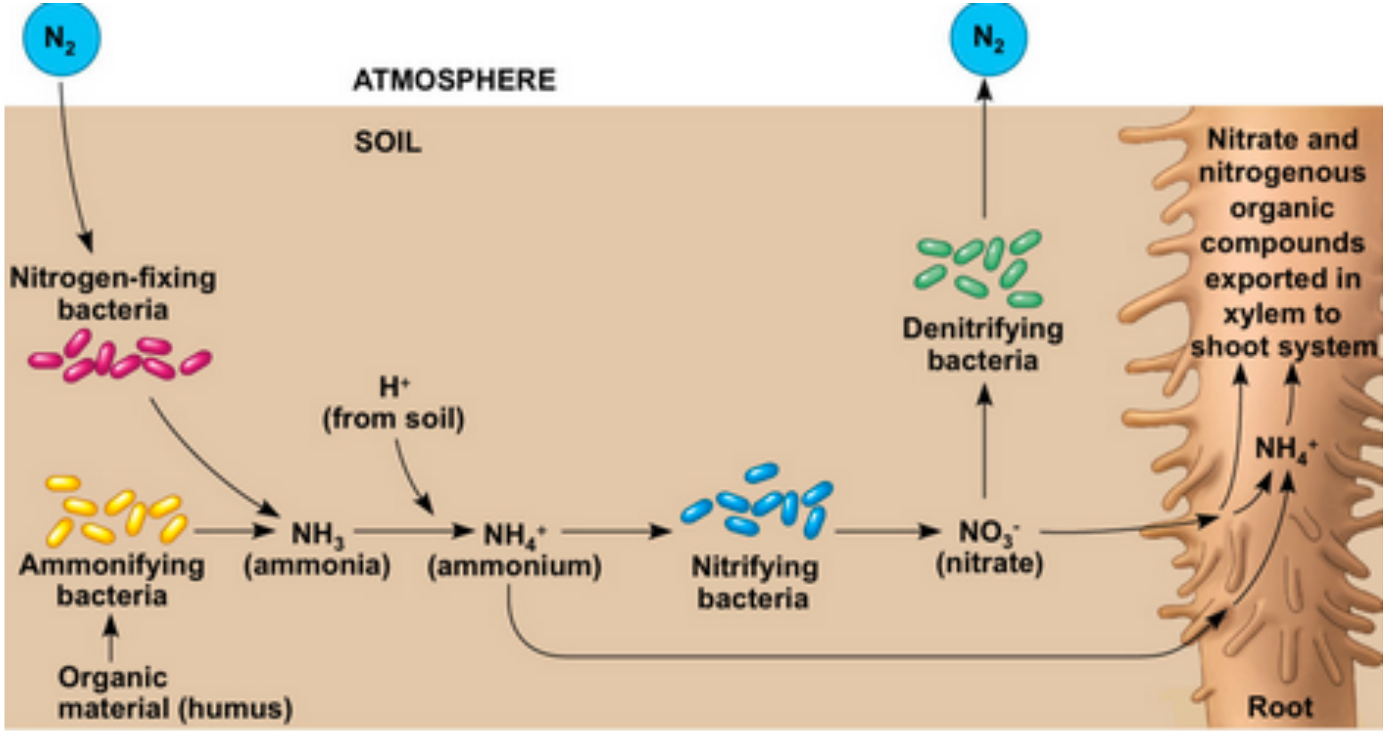
- Nitrogen fixation occurs naturally in soils through a range of microbes known as diazatrophs.
  - Bacteria,e.g. Azobacter
  - Archea (“blue green algae”)
- Symbiotic relationships with some plants, particularly legumes.
- Looser relationship with other plants, e.g. rice

Biological nitrogen fixation

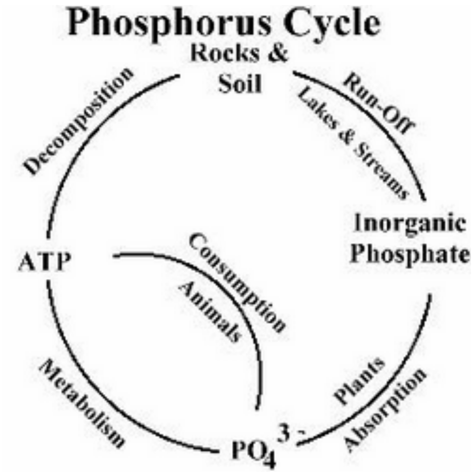





Biological nitrogen fixation



Compare with



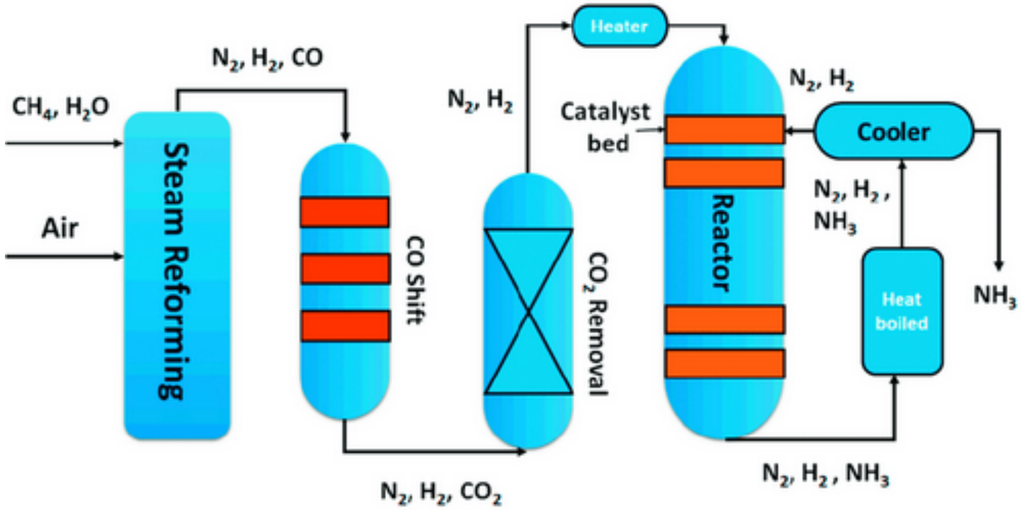
Sources of fixed nitrogen

- Prehuman world: creation of N_r from N_2
  - lightning
  - biological nitrogen fixation (BNF).
- Prior to human influence active N did not accumulate rapidly in environmental reservoirs: Microbial N fixation and denitrification processes were probably approximately equal

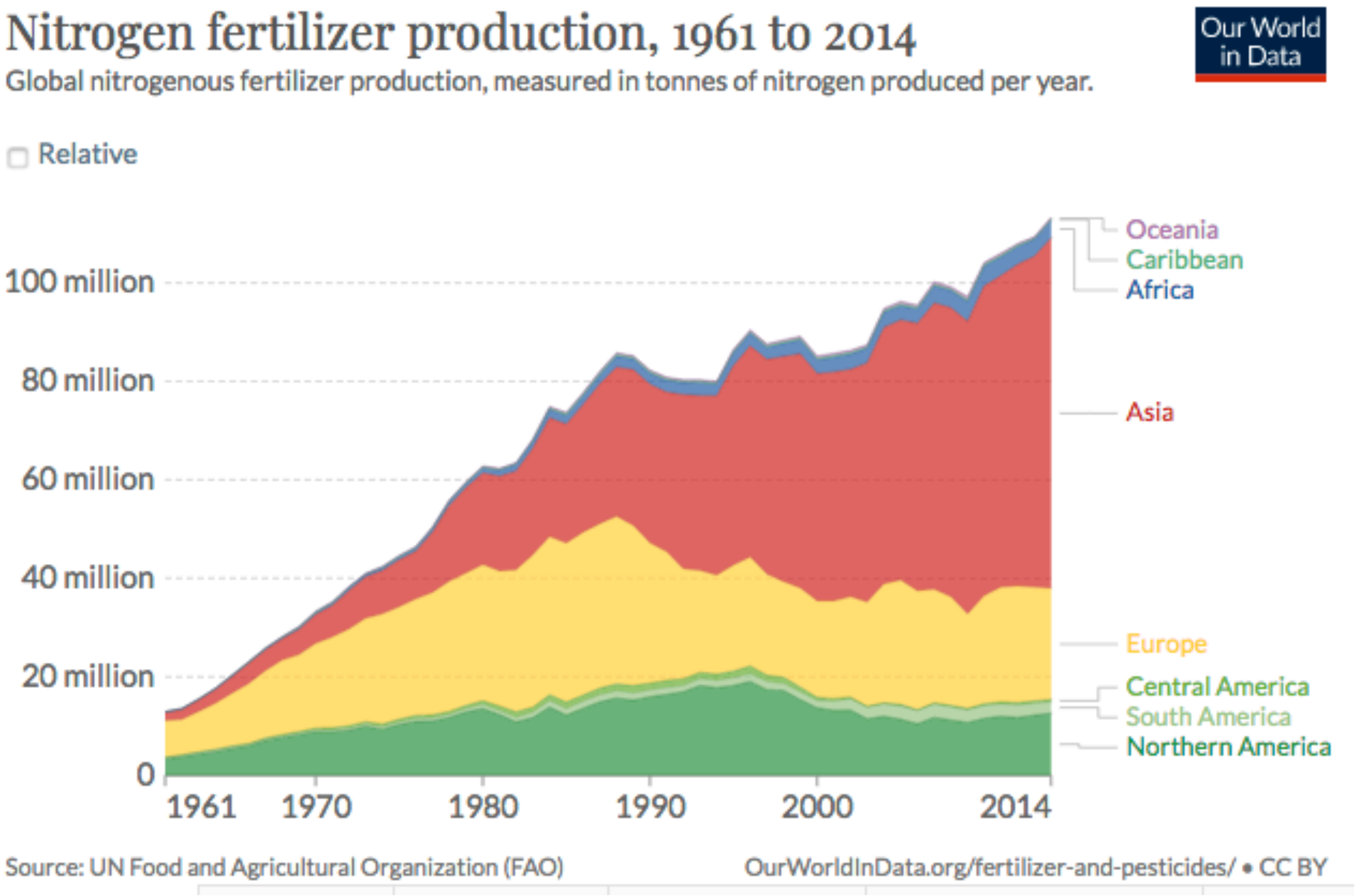
Sources of fixed nitrogen

- Production of Nr by humans now much greater than production from all natural terrestrial systems.
- Global increase in Nr production has three main causes:
  - Cultivation of legumes, rice, and other crops that promote conversion of N2 to organic N through biological nitrogen fixation
  - Combustion of fossil fuels, which converts both atmospheric N2 and fossil N to reactive NOx;
  - The **Haber-Bosch** process, which converts nonreactive N2 to reactive NH3 to sustain food production and some industrial activities.

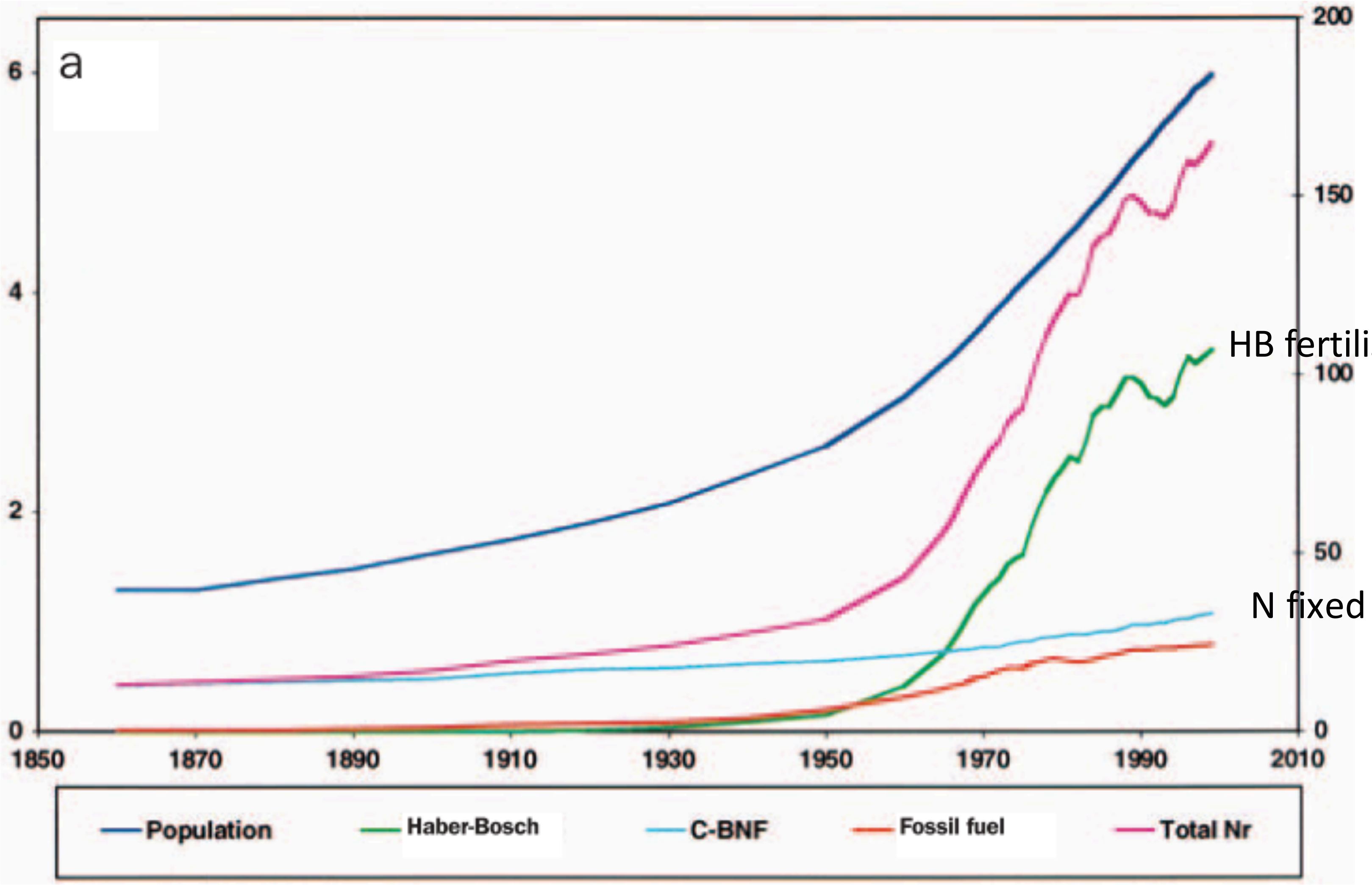
Haber Bosch process



Nitrogen fertiliser production



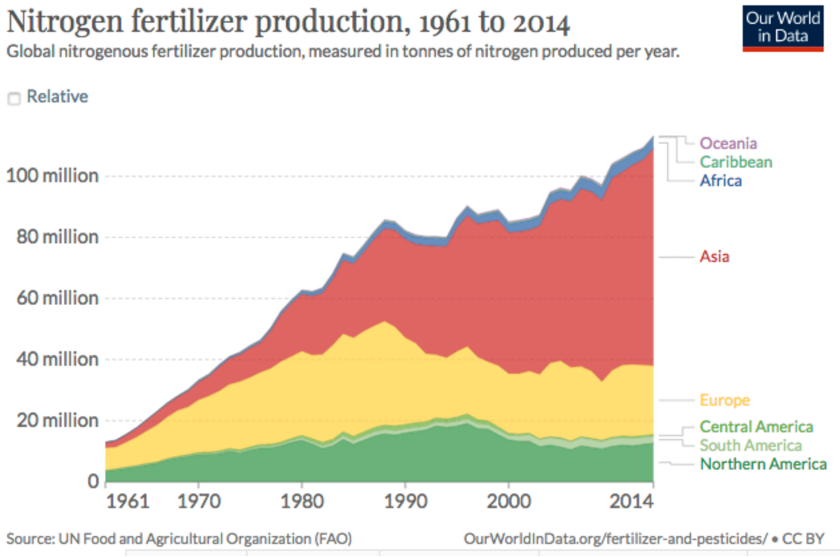
Haber Bosch nitrogen fixation

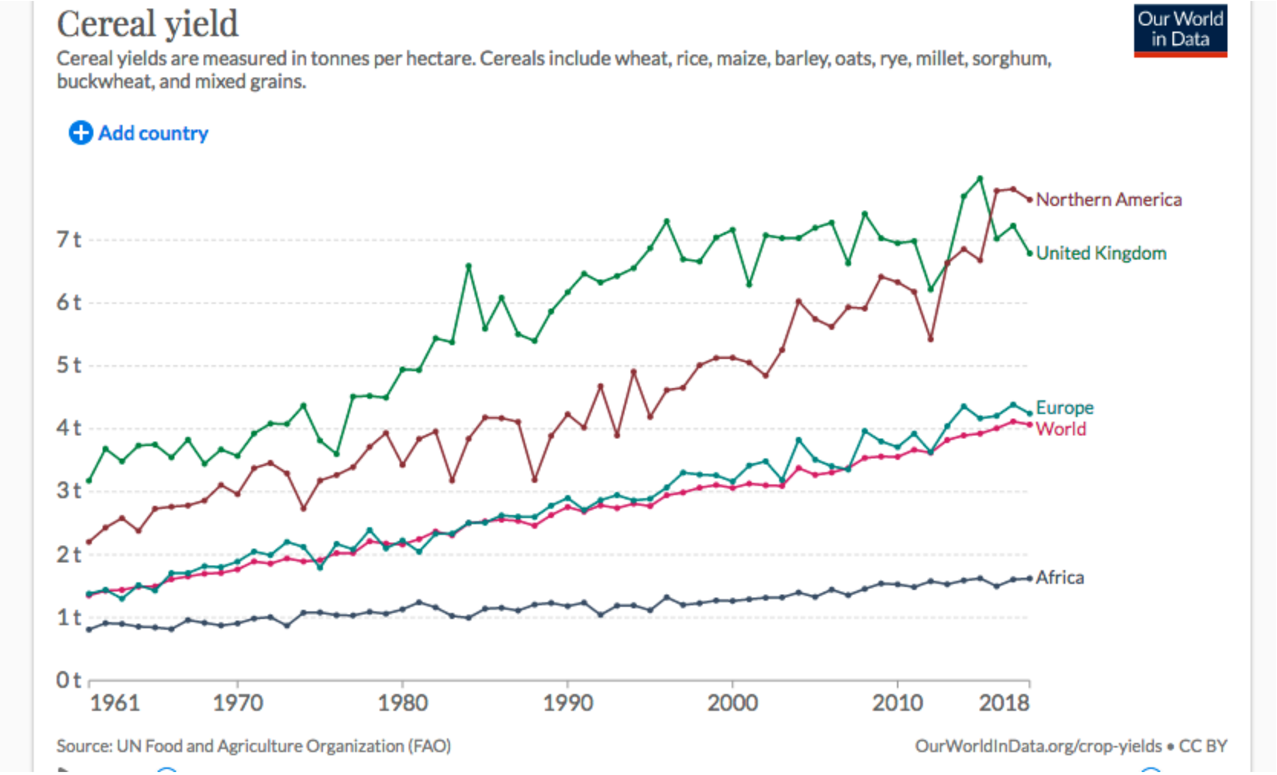


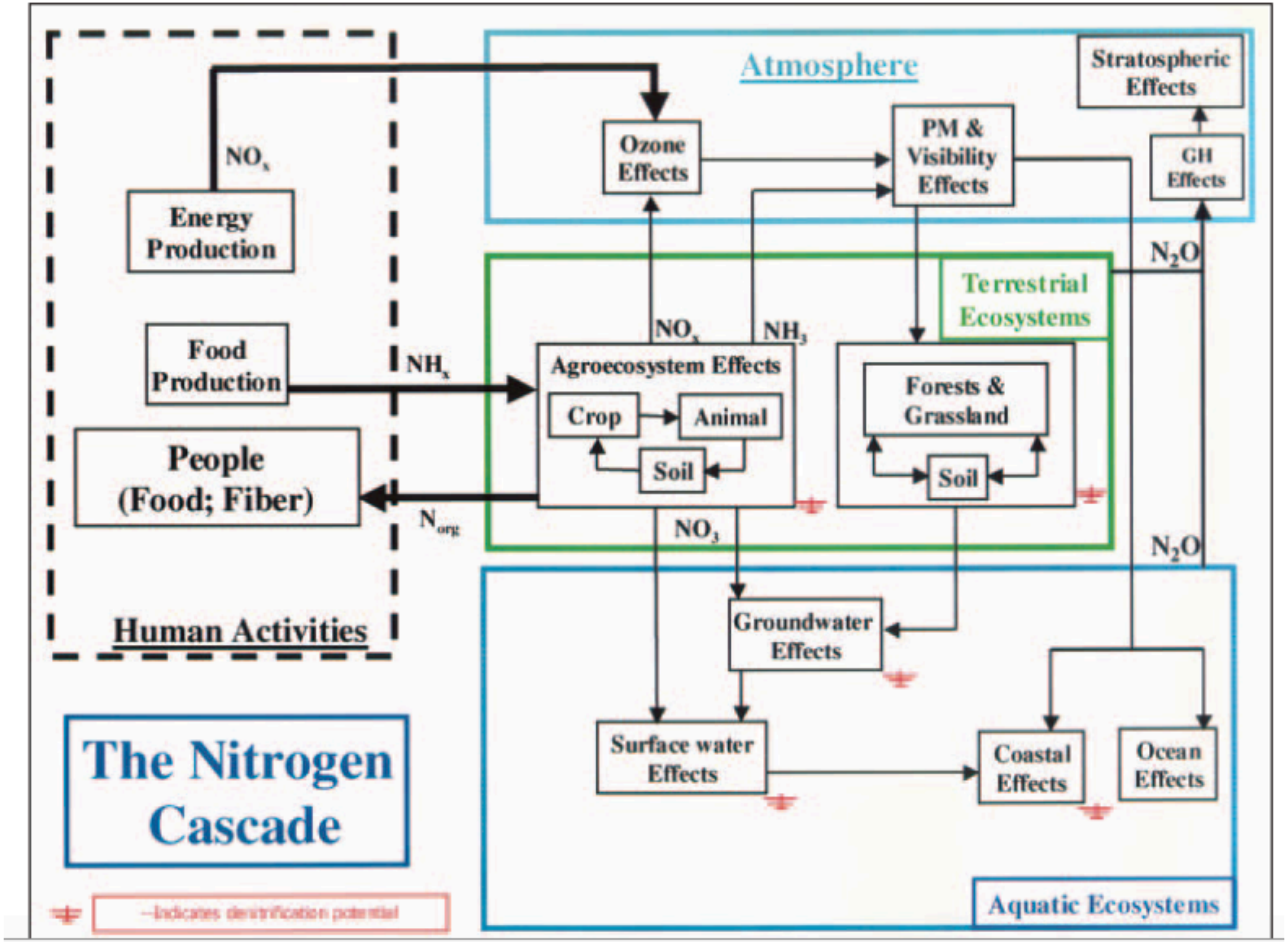
HB fertiliser

N fixed by legumes etc

Impact on crop yields







Human Activities
Energy Production
NO_x
Food Production
NH_x
People (Food; Fiber)
N_{org}
Atmosphere
Ozone Effects
PM & Visibility Effects
Stratospheric Effects
GH Effects
N_2O
Terrestrial Ecosystems
NO_x
NH_3
Agroecosystem Effects
Crop
Animal
Soil
Forests & Grassland
Soil
NO_3
Groundwater Effects
Surface water Effects
Coastal Effects
Ocean Effects
N_2O
Aquatic Ecosystems
The Nitrogen Cascade
–Indicates denitrification potential

Table 1. Characteristics of different systems relevant for the nitrogen cascade.

System	Accumulation potential	Transfer potential	N_2 production potential	Links to systems down the cascade	Effects potential
Atmosphere	Low	Very high	None	All but groundwater	Human and ecosystem health, climate change
Agroecosystems	Low to moderate	Very high	Low to moderate	All	Human and ecosystem health, climate change
Forests	High	Moderate, high in places	Low	All	Biodiversity, net primary productivity, mortality, groundwater
Grasslands	High	Moderate, high in places	Low	All	Biodiversity, net primary productivity, groundwater
Groundwater	Moderate	Moderate	Moderate	Surface water, atmosphere	Human and ecosystem health, climate change
Wetlands, streams, lakes, rivers	Low	Very high	Moderate to high	Atmosphere, marine coastal systems	Biodiversity, ecological structure, fish
Marine coastal regions	Low to moderate	Moderate	High	Atmosphere	Biodiversity, ecological structure, fish, harmful algal blooms

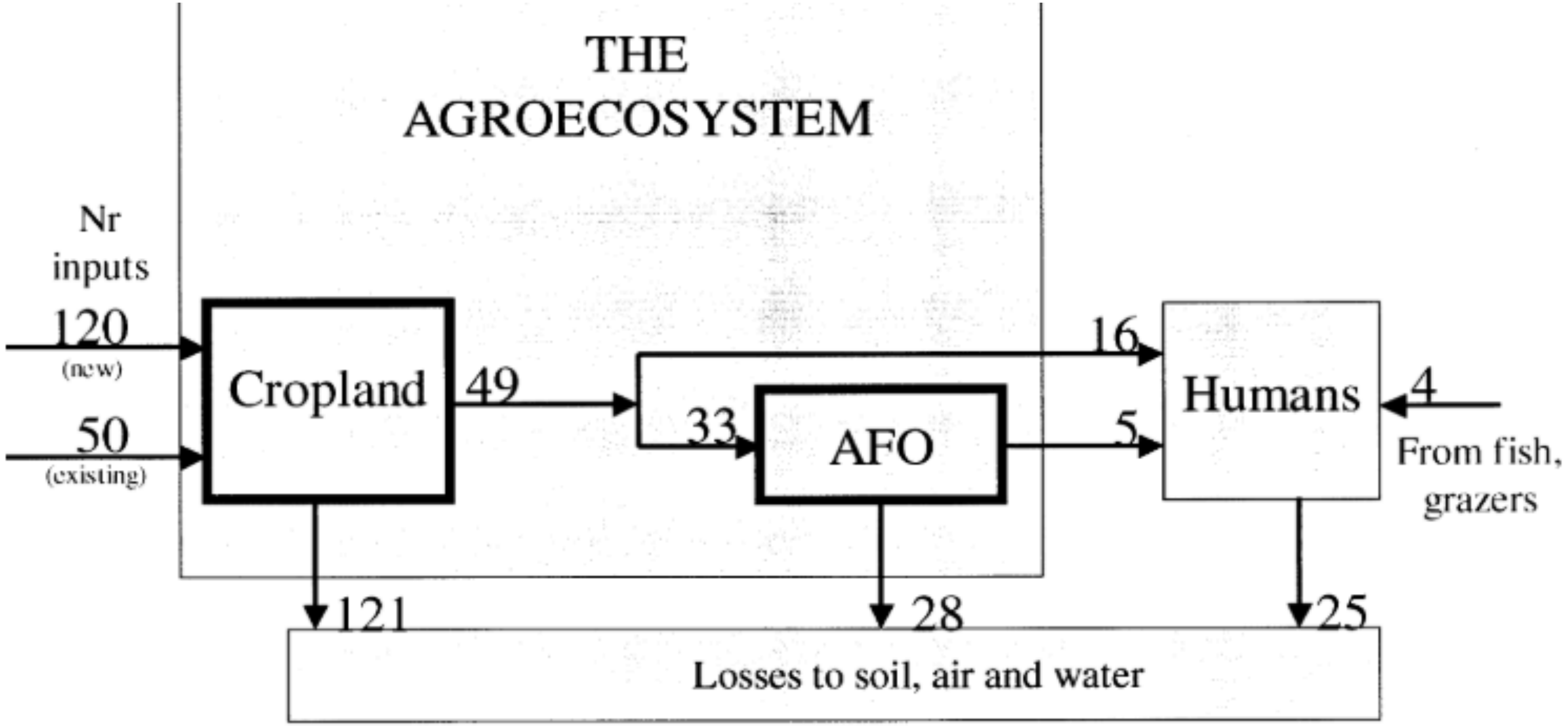


Figure 3. Major reactive nitrogen (Nr) flows in crop production and animal production components of the global agroecosystem. Croplands create vegetable protein through primary production; animal production utilizes secondary production to create animal protein. Reactive nitrogen inputs represent new Nr, created through the Haber-Bosch process and through cultivation-induced biological nitrogen fixation, and existing Nr that is reintroduced in the form of crop residues, manure, atmospheric deposition, irrigation water, and seeds. Portions of the Nr losses to soil, air, and water are reintroduced into the cropland component of the agroecosystem (Smil 2001, 2002). Numbers represent teragrams of nitrogen per year; AFO, animal feeding operations.

Points to note

- Most fixed N added to croplands is “lost” to soil air and water
  - Losses can end up somewhere else if not denitrified
- Around 66% of the N in crops passes through livestock production, and 34% directly consumed by humans
- Human consumption of N is around 25% animal product derived and 75% directly from crops (highly variable between countries)
- All fixed nitrogen passing through humans ends up in soil, air and water

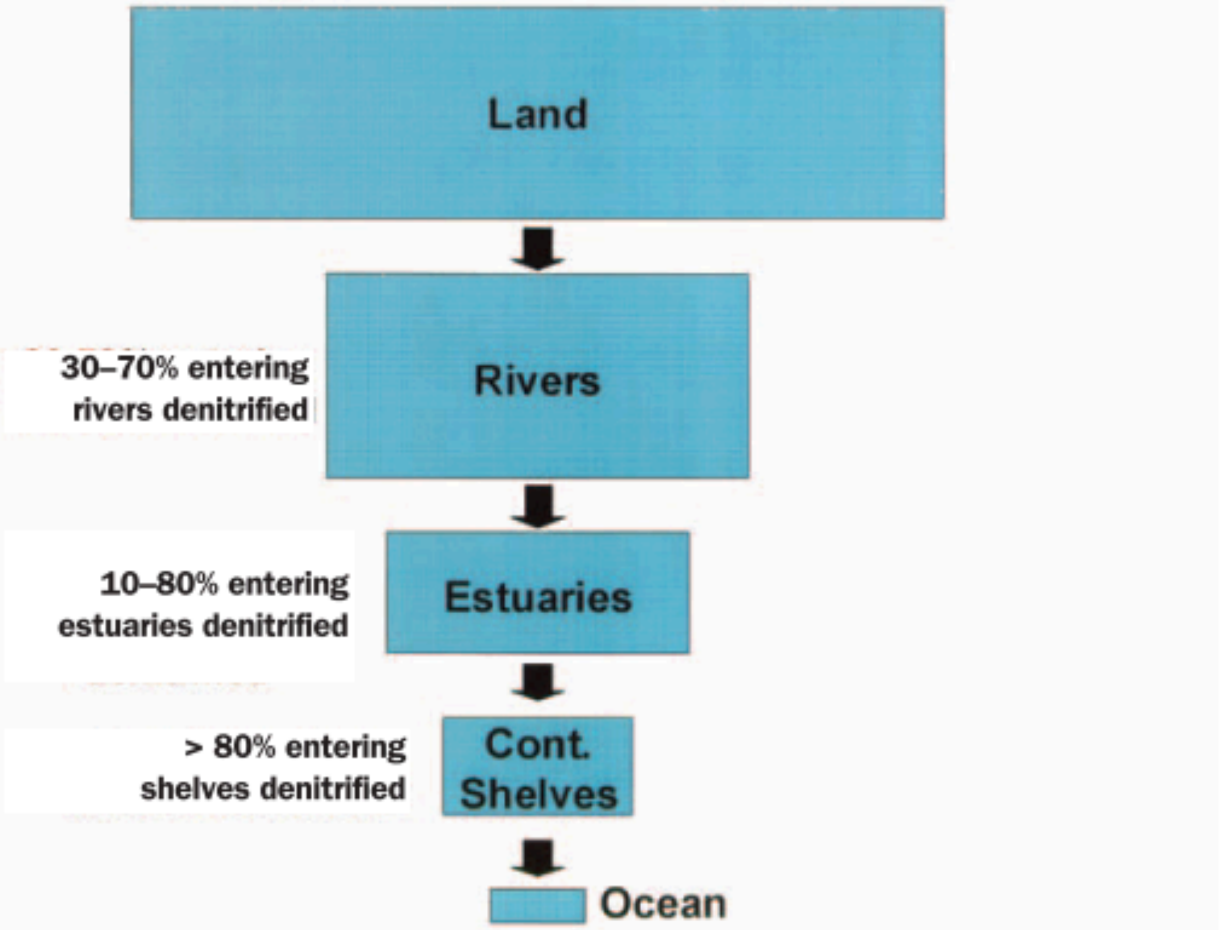
Improving nitrogen use efficiency

- Loss of fertilizer N results from gaseous plant emission, soil denitrification, surface runoff, volatilization, and leaching.
- Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33%.
- The unaccounted 67% represented a $15.9 billion annual loss of N fertilizer (assuming fertilizer-soil equilibrium in 1999).
- Increased cereal NUE requires
  - Application of prescribed rates consistent with in-field variability
  - Low N rates applied at flowering, and forage production systems.
  - **Adjusting the fertilizer rate by soil mineral N before N application**

Nitrogen losses

- Denitrification occurs in all ecosystems
- Only a fraction of fixed nitrogen reaches the sea
- Coastal ecosystems at greatest risk of nitrogen enhanced eutrophication if sources are close by

Denitrification reduces the downstream transport of N



Return to neverland?

- Do ecosystems recover from eutrophication?
- In some cases recovery is rapid (short sharp shocks)
- In others it is very gradual and may not take the expected trajectory
- Return to “neverland” baseline may not be achievable
- Hysteresis and non linear trajectories of change

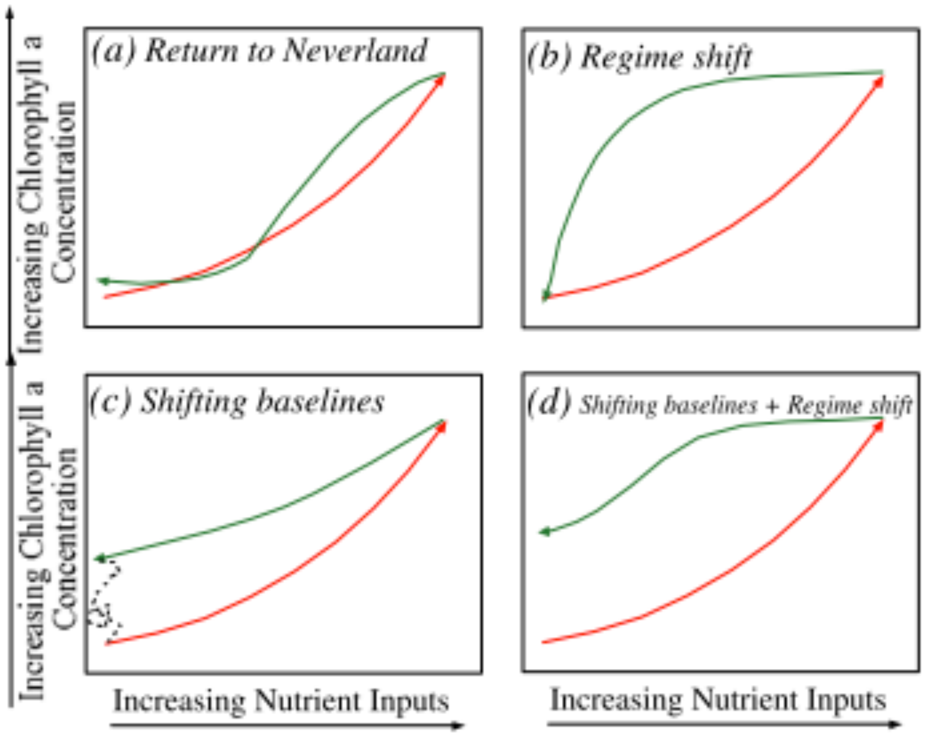
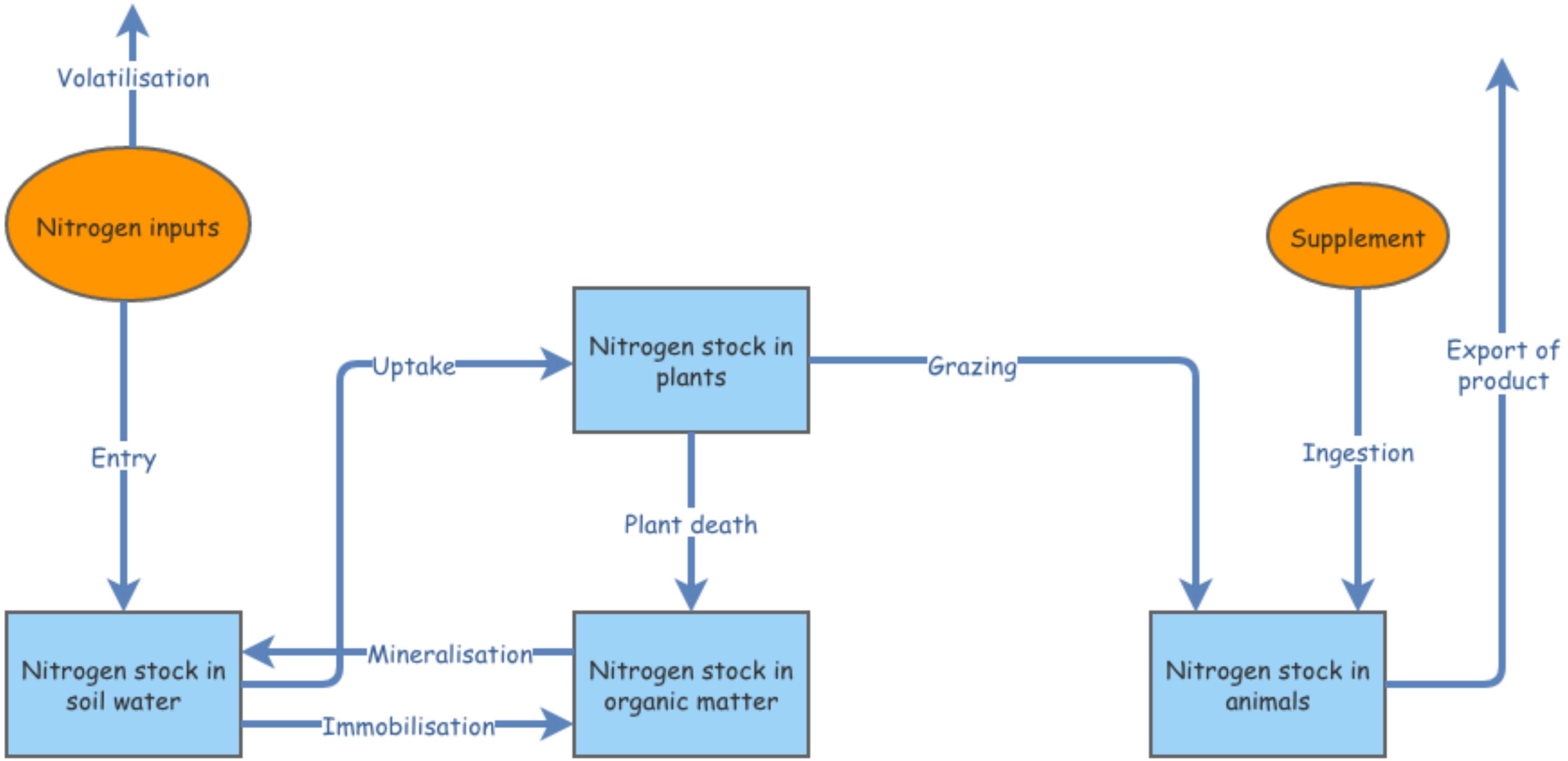


Fig. 1 Idealized trajectories of chlorophyll a concentrations, as an indicator of ecosystem status, and nutrient inputs to coastal ecosystems under increasing (*red line*) and decreasing (*green line*) nutrient inputs under different response scenarios: **a** "Return to Neverland" scenario implying a direct reversible relationship between chlorophyll a concentrations and nutrient inputs; **b** a trajectory resulting from a "Regime Shift" in ecosystem status in response to nutrient inputs. This trajectory results in an apparent time lag, or hysteresis effect, in the response to reducing nutrient inputs; **c** "Shifting Baselines" scenario, where changes in forcing factors other than nutrients (e.g., climate, food web structure) forces a trajectory for the ecosystem independent of that forced by nutrients, depicted by the *dotted line*, preventing the ecosystem to return to the "reference condition" after reducing nutrient inputs; and **d** a trajectory displaying "Regime Shift and Shifting Baselines" combined

Ecosystem model

https://insightmaker.com/insight/172673/Clone-of-Story-of-nitrogen-dynamics-in-a-shallow-lake



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