Anthropogenic Effects on the Global Nitrogen Cycle

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Senior Seminar on Environmental Studies

Nitrogen: Unreactive vs. Reactive

- **Unreactive** N is N_2 (78% of Earth's atmosphere)
- **Reactive** N (Nr) includes all biologically, chemically and physically active N compounds in the atmosphere and biosphere of the Earth (TABLE)
- N controls productivity of most natural ecosystems:
  - Net Primary Productivity
  - Species composition (biodiversity)

  $\Big\}$ **ECOSYSTEM HEALTH**
- N_2 is converted to Nr by biological nitrogen fixation (BNF)
  - Also converted by lightning (insignificant contribution)
- N_2 is converted to Nr by humans $\rightarrow$ fossil fuel combustion, the Haber-Bosch process, and cultivation of N-fixing crops, as well as mobilization of long-term biological storage pools.

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  - **Humans create more Nr than do natural processes.**
  - **Nr is accumulating in the environment.**
  - **Nr accumulation contributes to many present environmental problems.**
  - **Challenge is to reduce anthropogenic Nr creation.**

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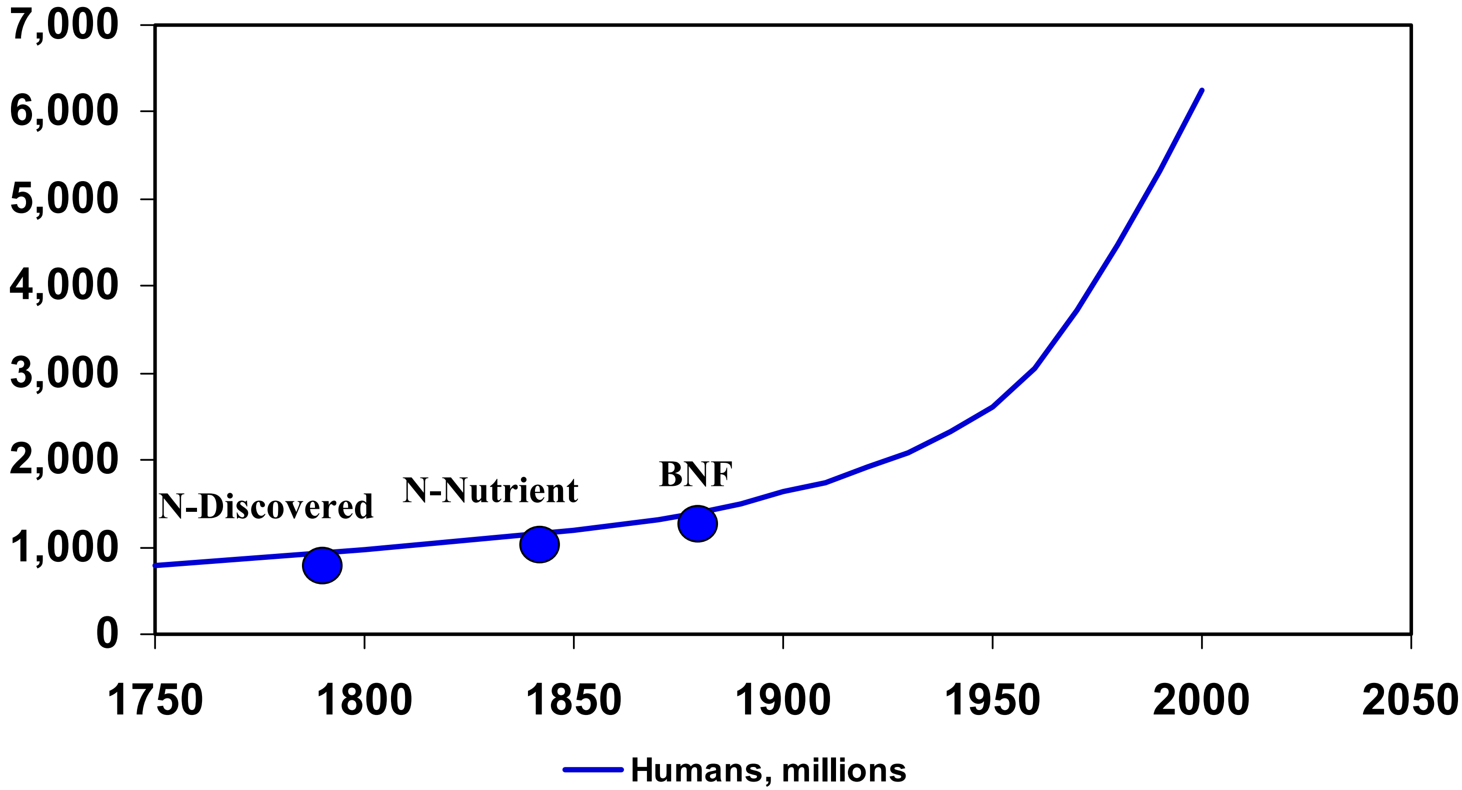
  - Nr is accumulating in the environment.
  - Nr accumulation contributes to many present environmental problems.
  - Challenge is to reduce anthropogenic Nr creation.
- **<u>Complication</u>: Nr creation sustains most of the world's food needs.**
  - **The real challenge is how can we provide food and energy while also reducing Nr creation rates?**

Overview

- **Historical perspective**
  - *Human discovery*
  - *N cycle in 1890 and 1990 (present)*
- **Consequences**
  - *Nitrogen enhances productivity*
  - *Nitrogen cascades*
- **Effects on the Global Environment**
  - *Effects on Atmosphere*
  - *Effects on Terrestrial Ecosystems*
  - *Effects on Aquatic Ecosystems*
  - *Effects on Human Health*

The History of Nitrogen

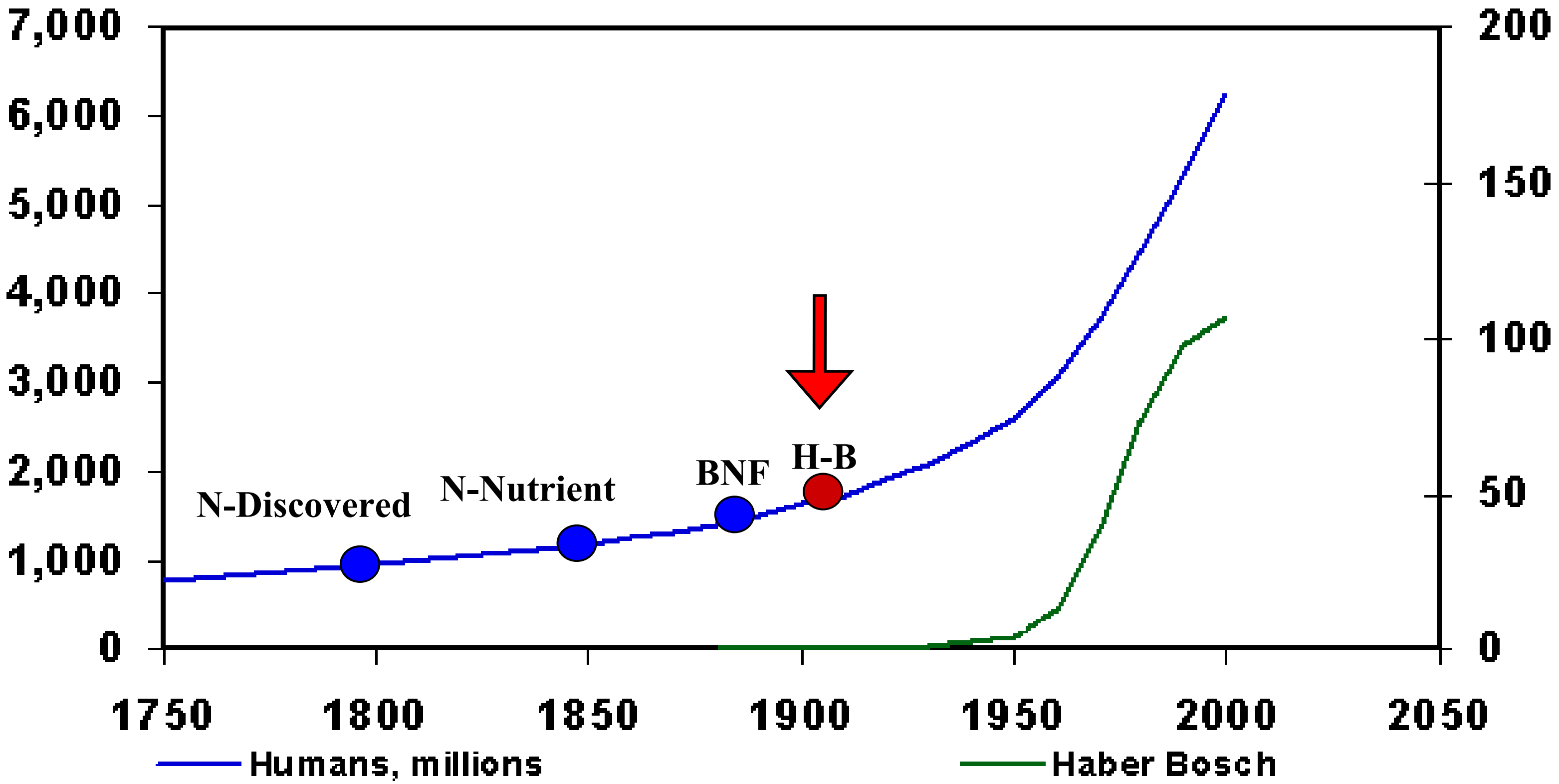
--Awareness of major N processes--



Galloway and Cowling, 2002

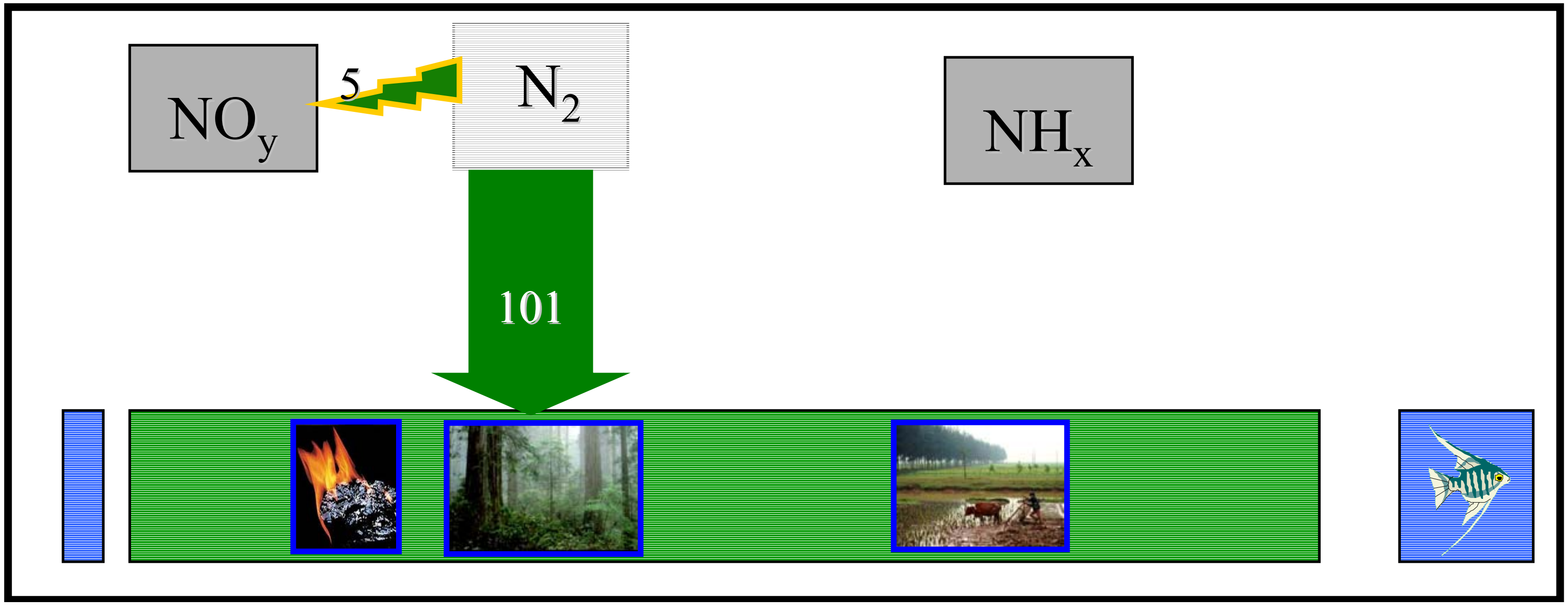
Haber-Bosch Process - 1913

-- $N_2 + 3H_2 \rightarrow 2NH_3$ --



Galloway JN and Cowling EB. 2002; Galloway et al., 2002a

The Global Nitrogen Budget Before Intensive Human Alteration (TgN/yr)



Galloway et al., 2002b

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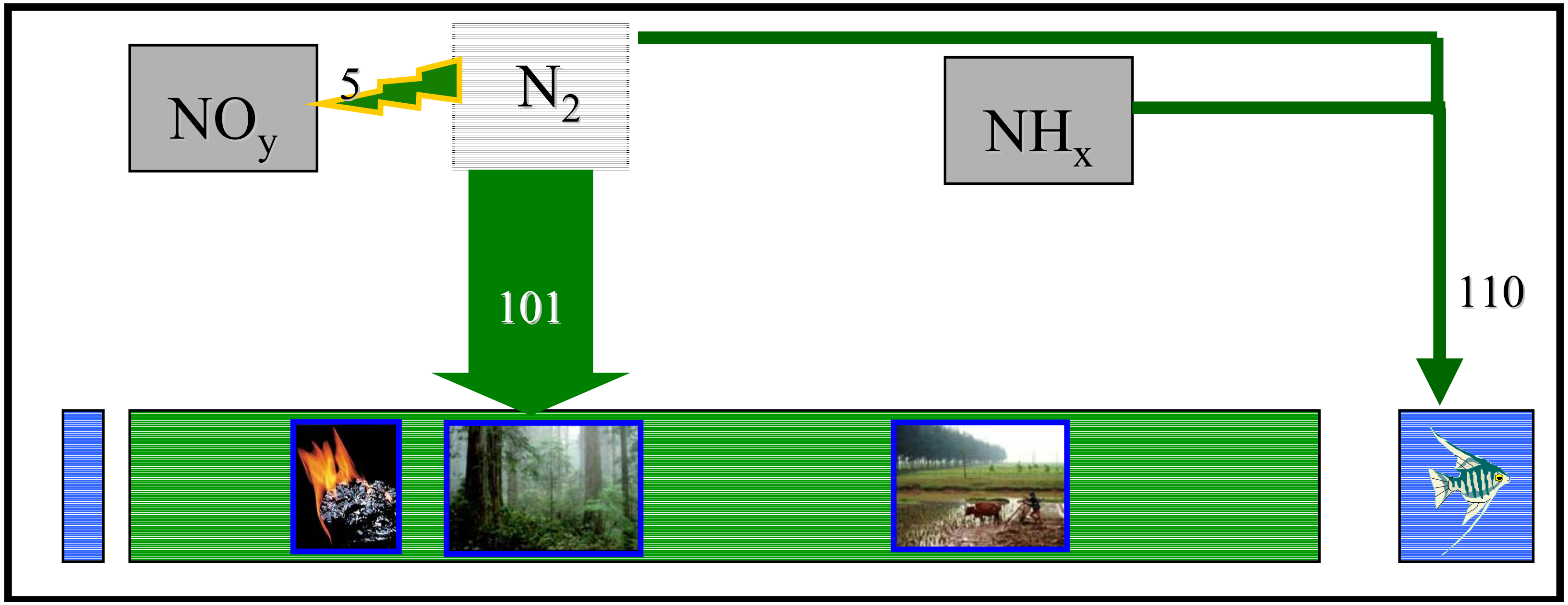

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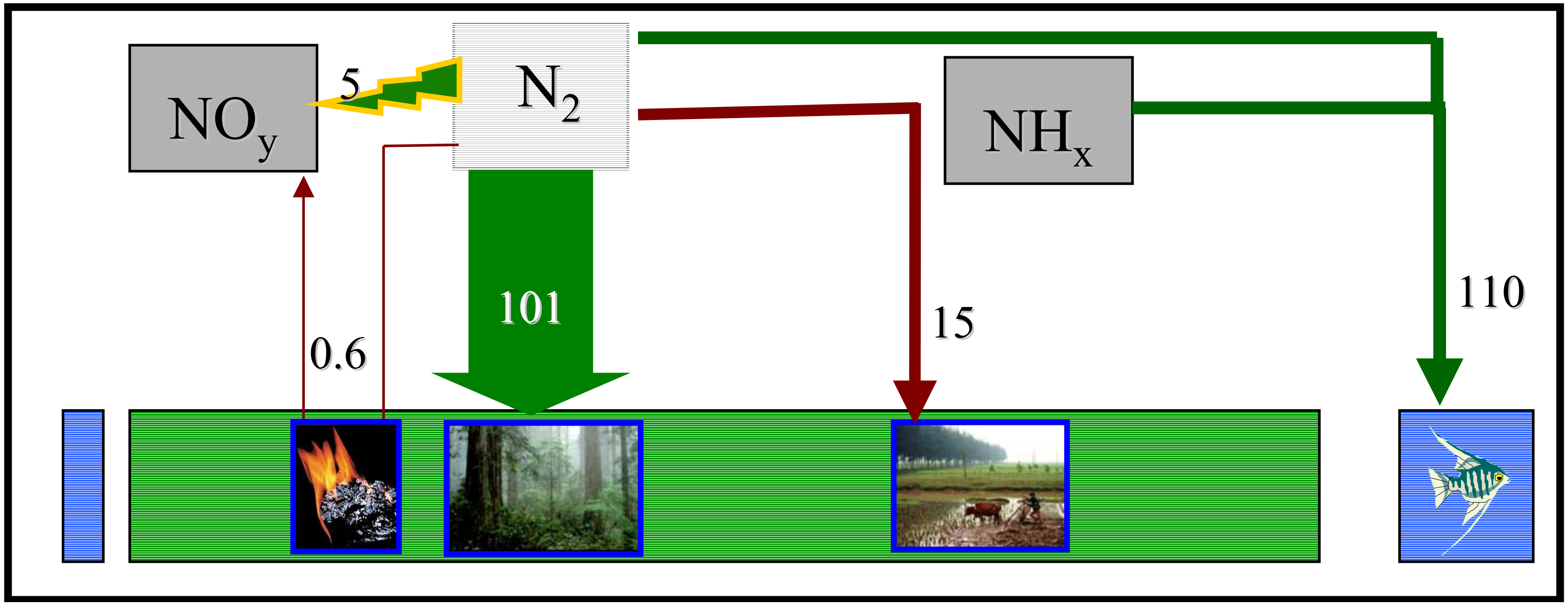
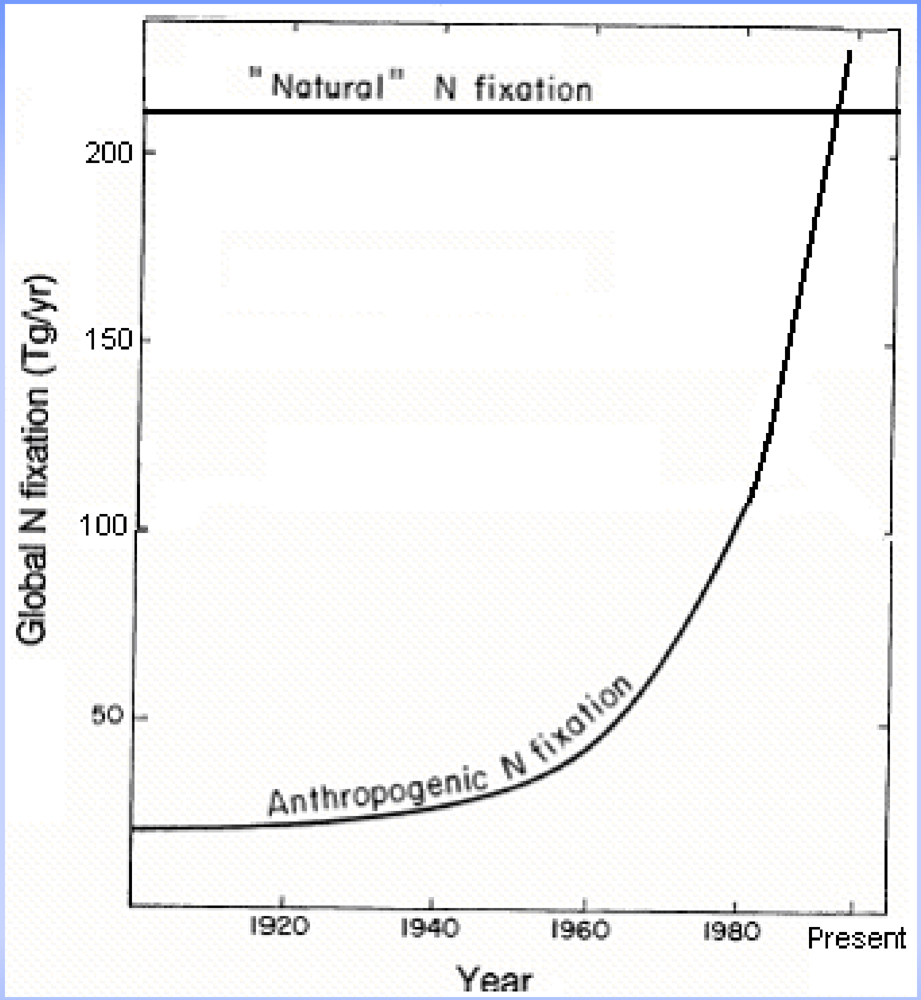
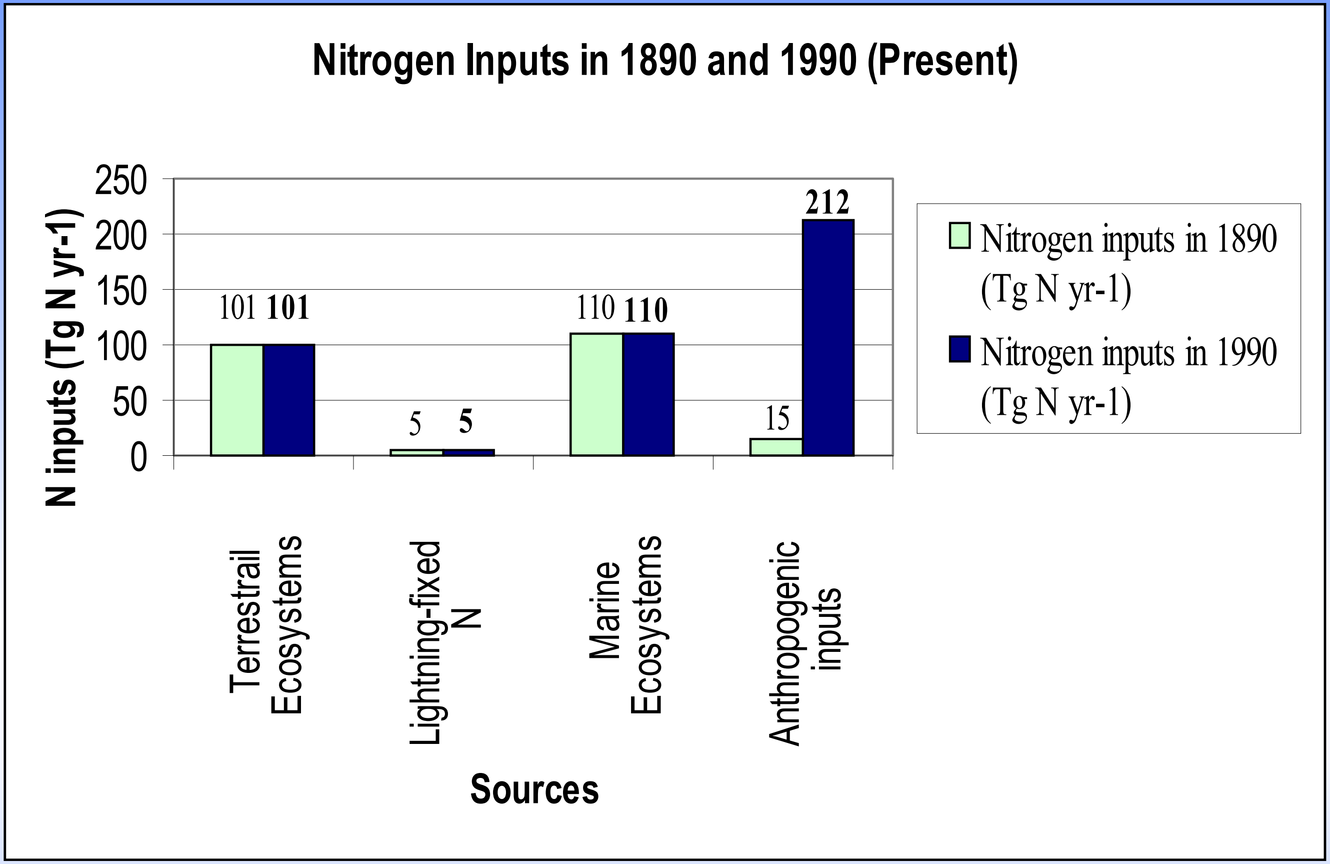


Galloway et al., 2002b



Human alteration to the global N-cycle compared to natural rates (Modified from Vitousek, 1994).



The 1990 values for natural N-fixation are assumed to be the same as in 1890. This assumption does not consider however the decrease in natural terrestrial N fixation expected due to a conversion of natural grasslands and forests to croplands (Smil, 2001; Galloway and Cowling, 2002; Vitousek et al., 1997).

Global Sources of Reactive Nitrogen

	ANNUAL RELEASE OF FIXED NITROGEN (Tg)
ANTHROPOGENIC SOURCES	
Fertilizer	81
Legumes and other plants	40
Fossil fuels	21
Biomass burning	40
Wetland draining	10
Land clearing	20
Total from Anthropogenic sources	**212**
NATURAL SOURCES	
Microorganisms, algae, lightning, etc.	216

(From Vitousek et al Galloway et al., 1995; Capone, 2001; and Smil, 1999; IFA DATA BANK, 2002)

Reasons for N Usage

Grain/Fabric Production

Meat Production

Energy Production

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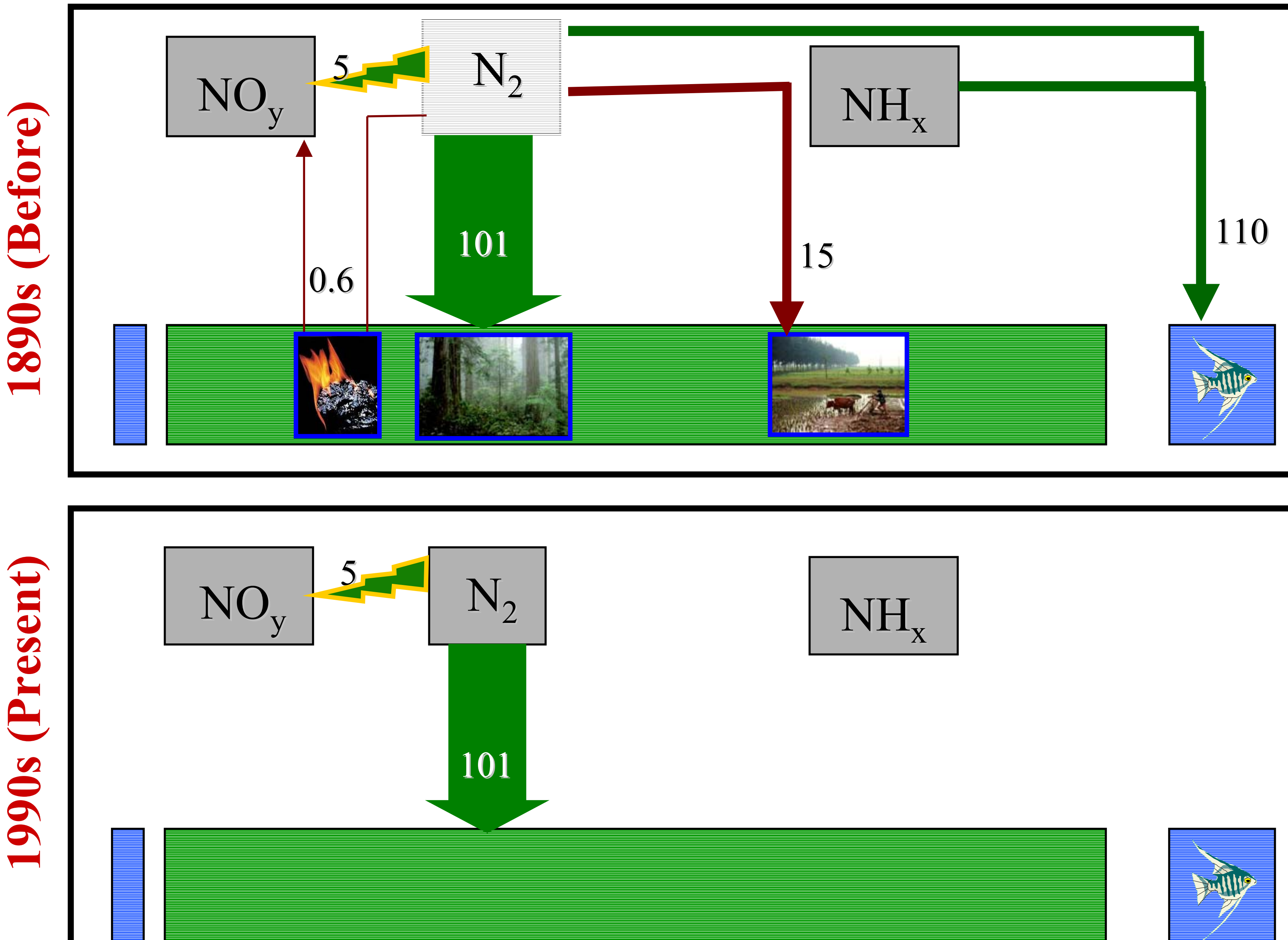
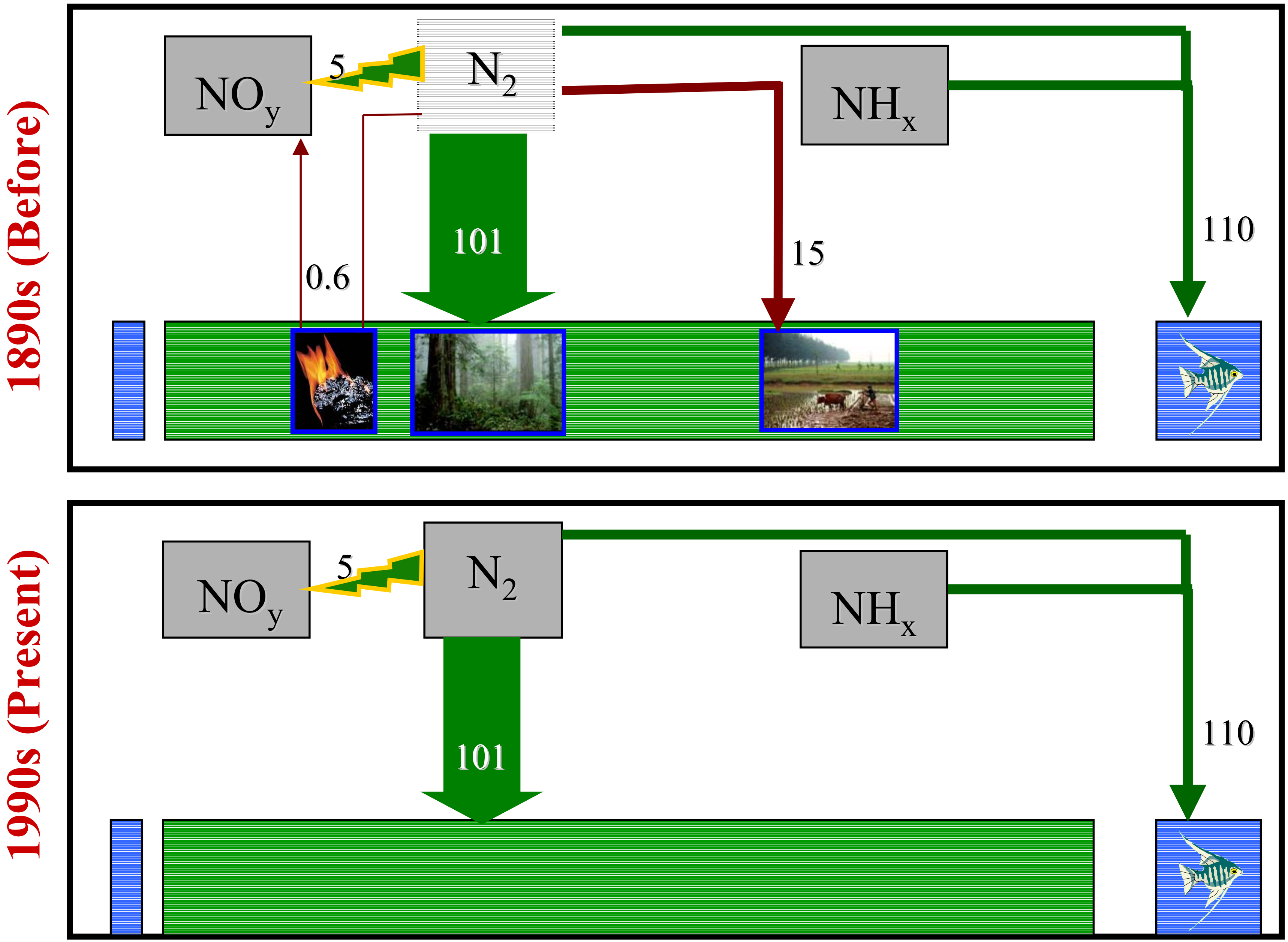


Galloway and Cowlingl., 2002

The Global Nitrogen Budget Before and After Intensive Human Alteration (TgN/yr)



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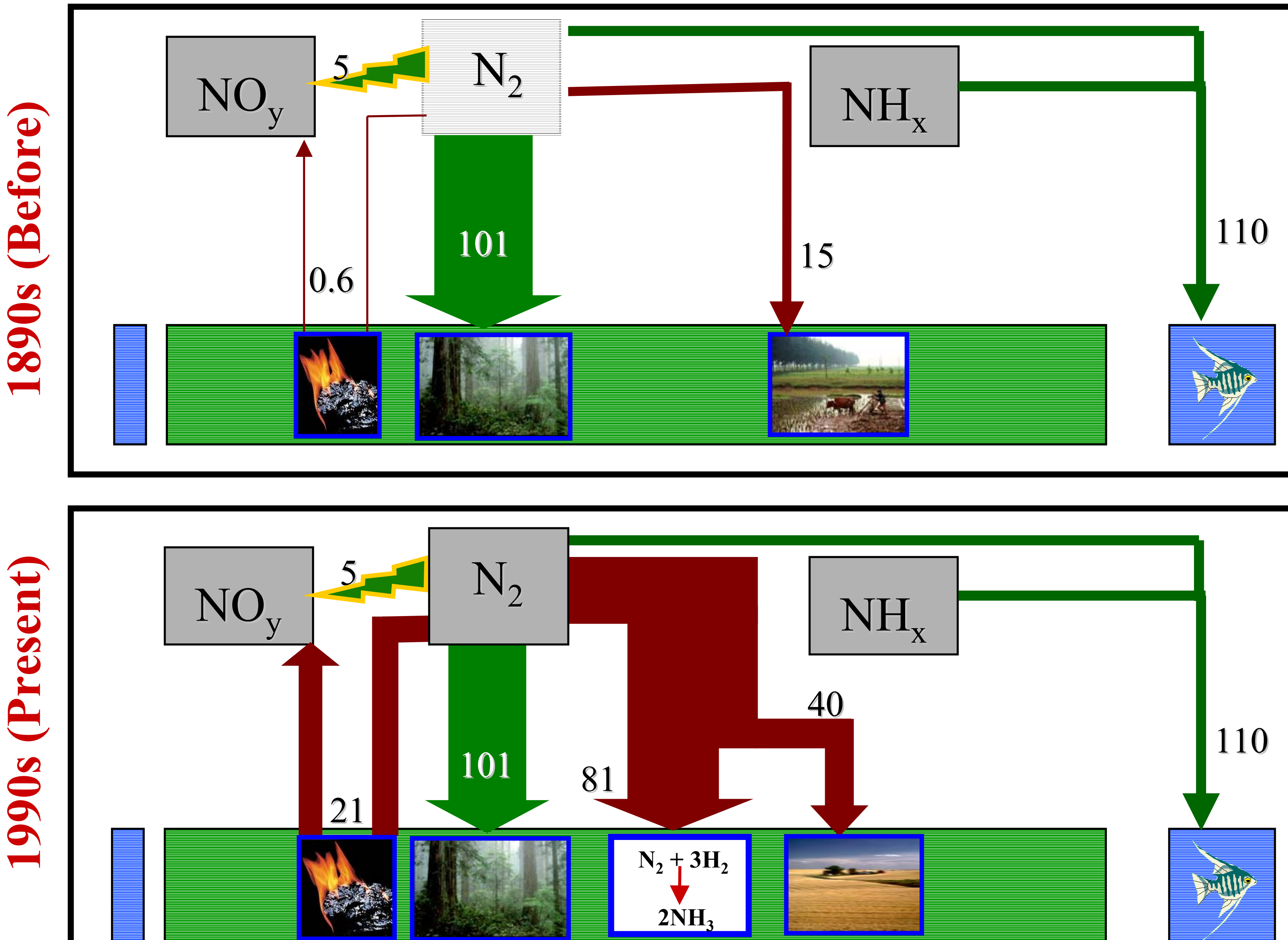

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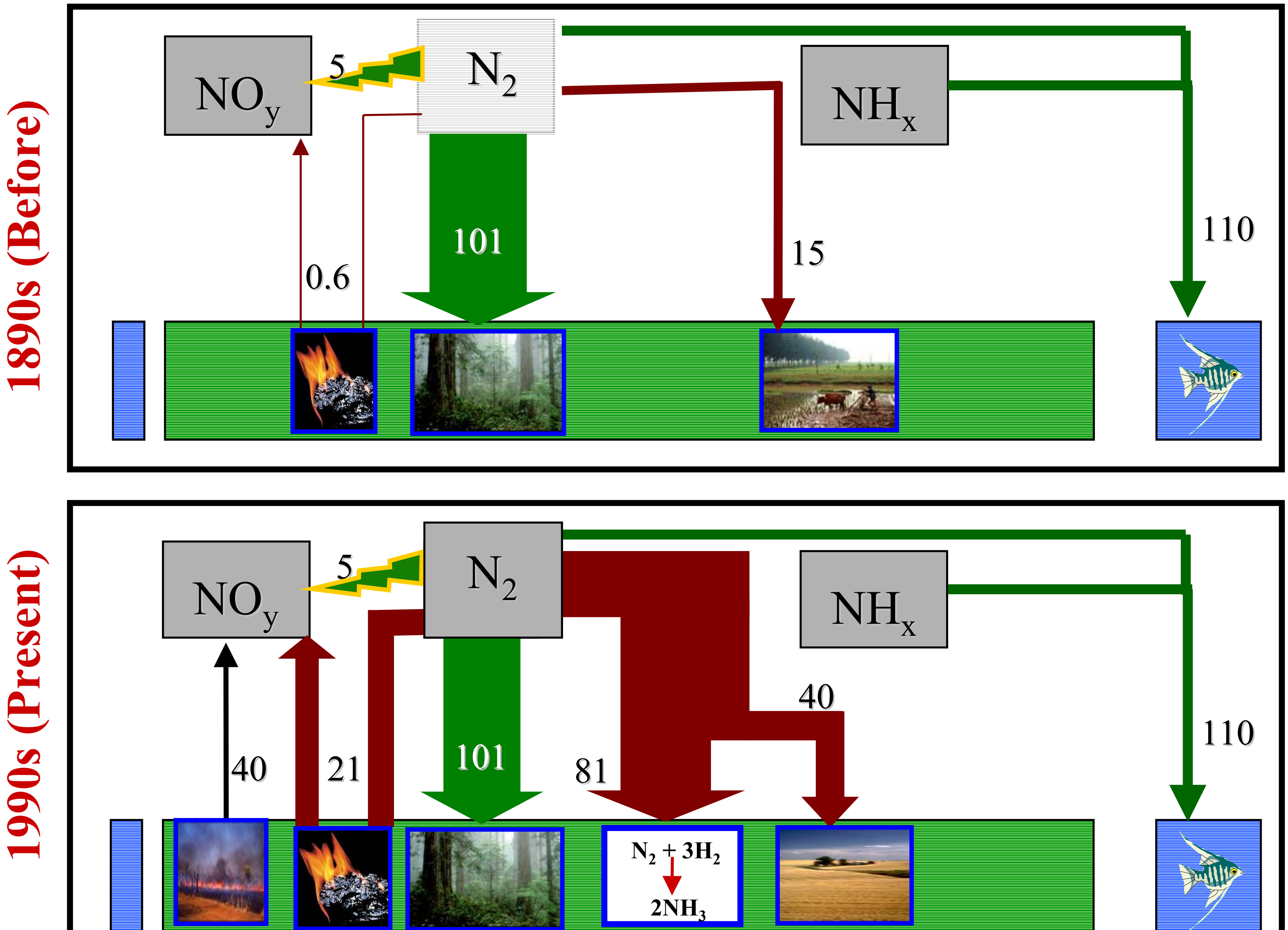

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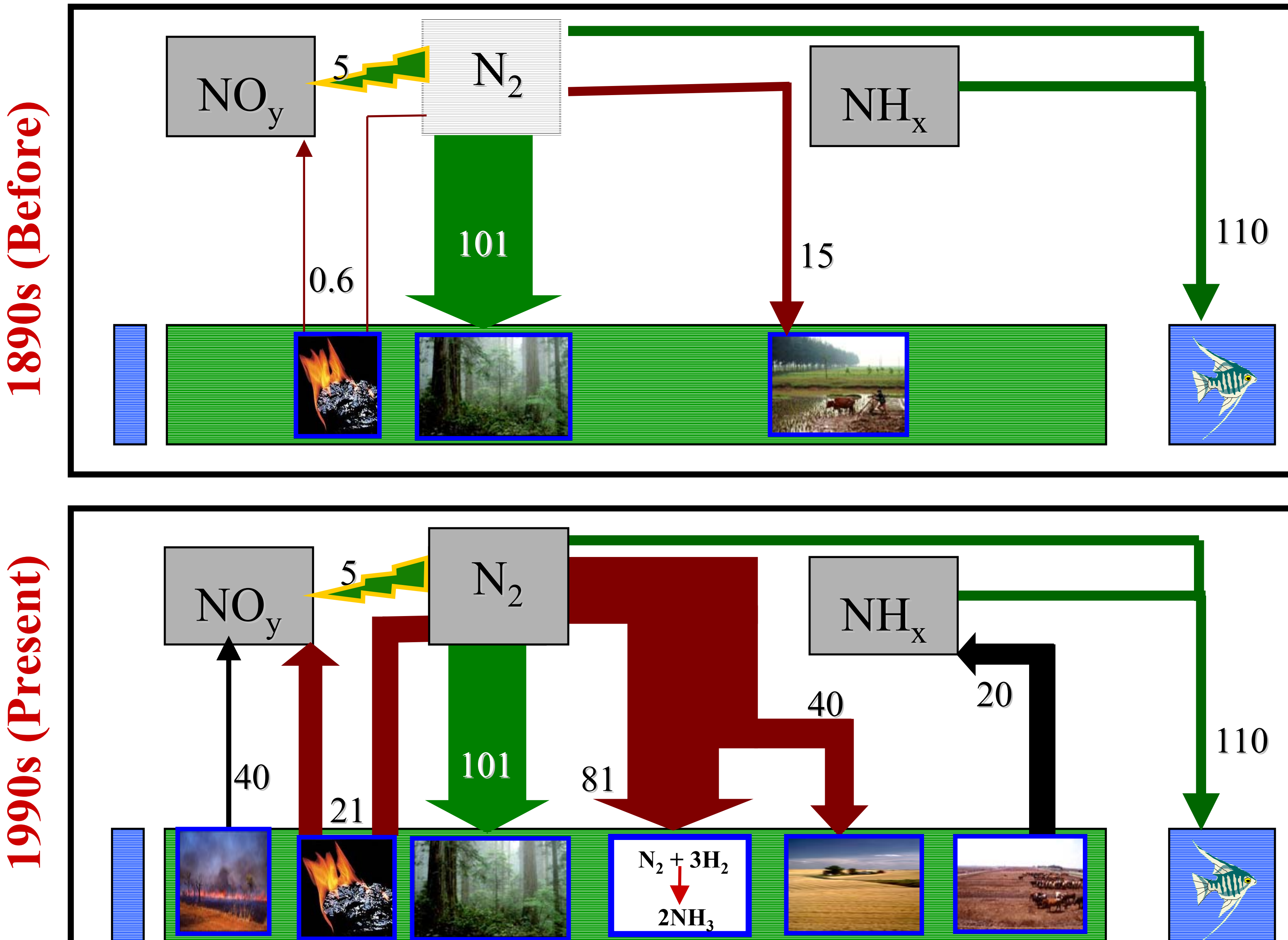

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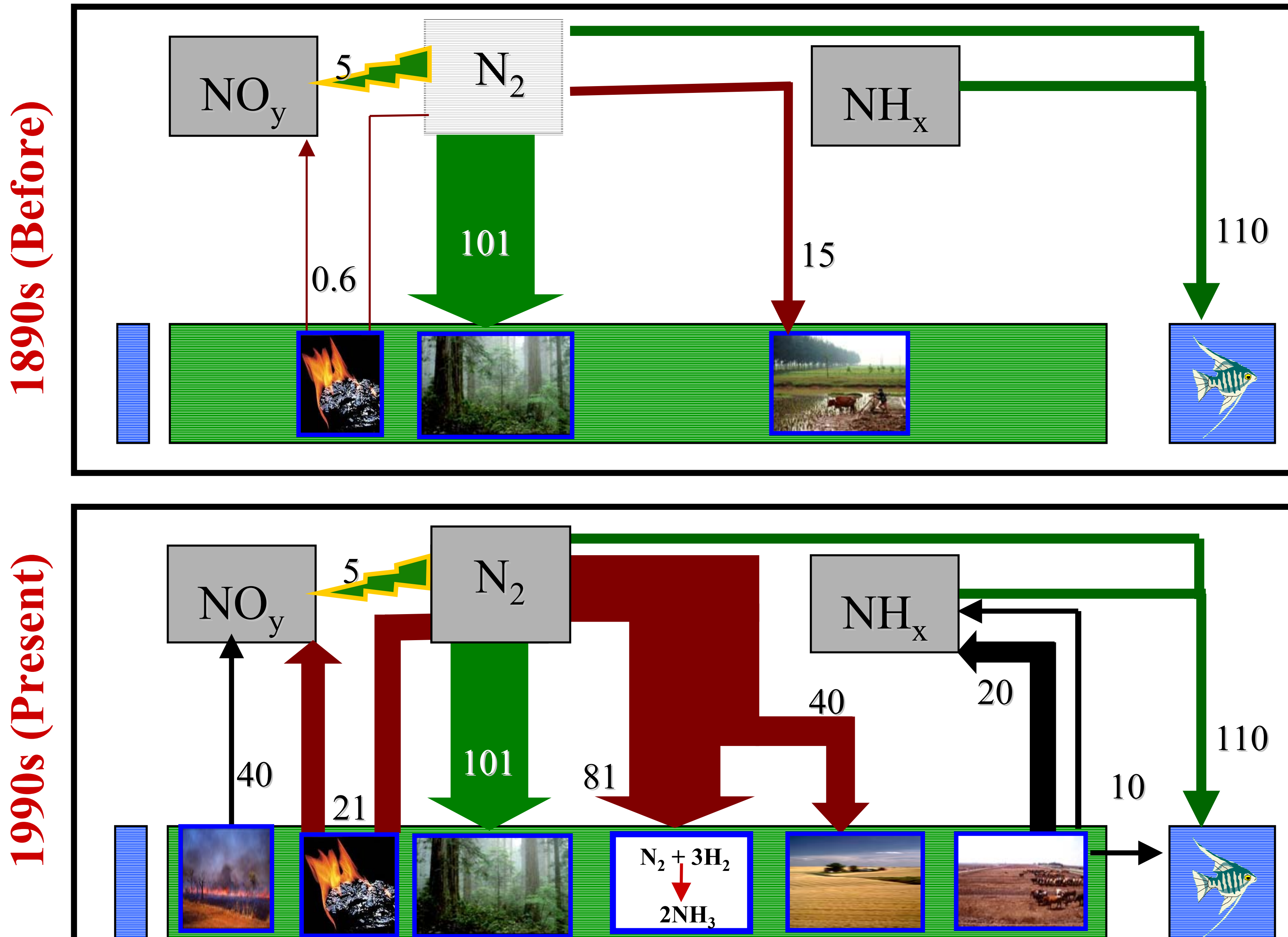

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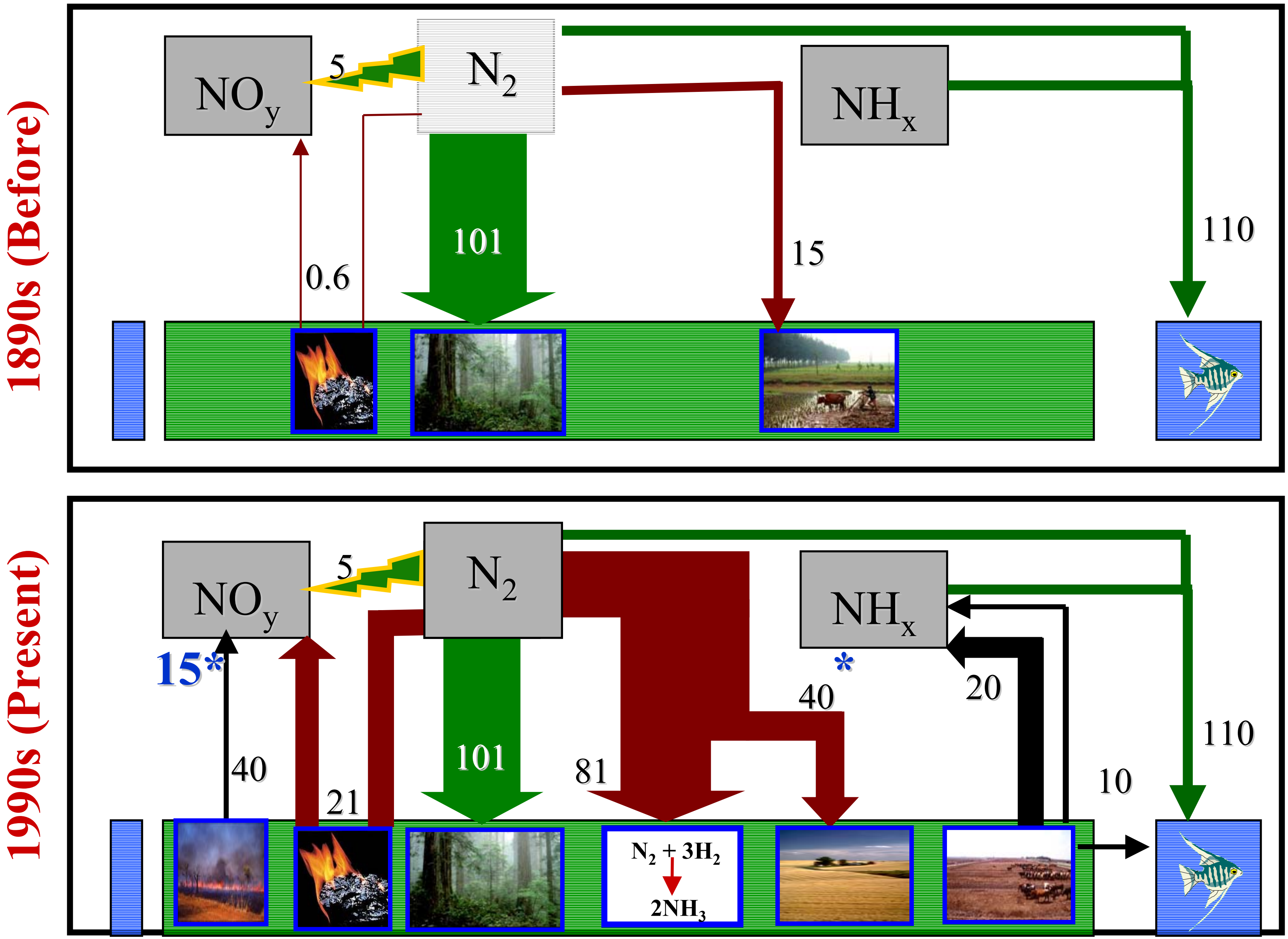

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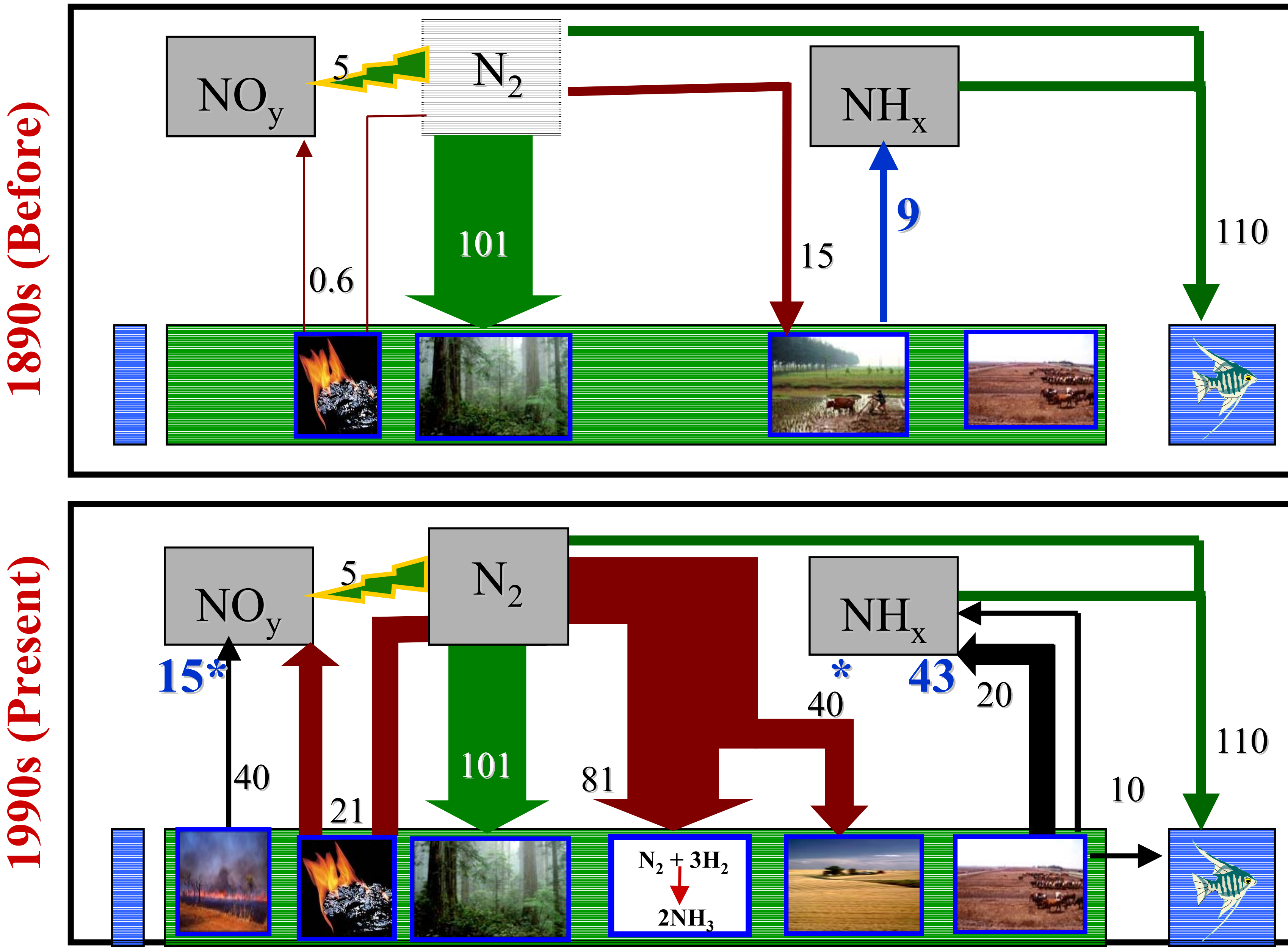

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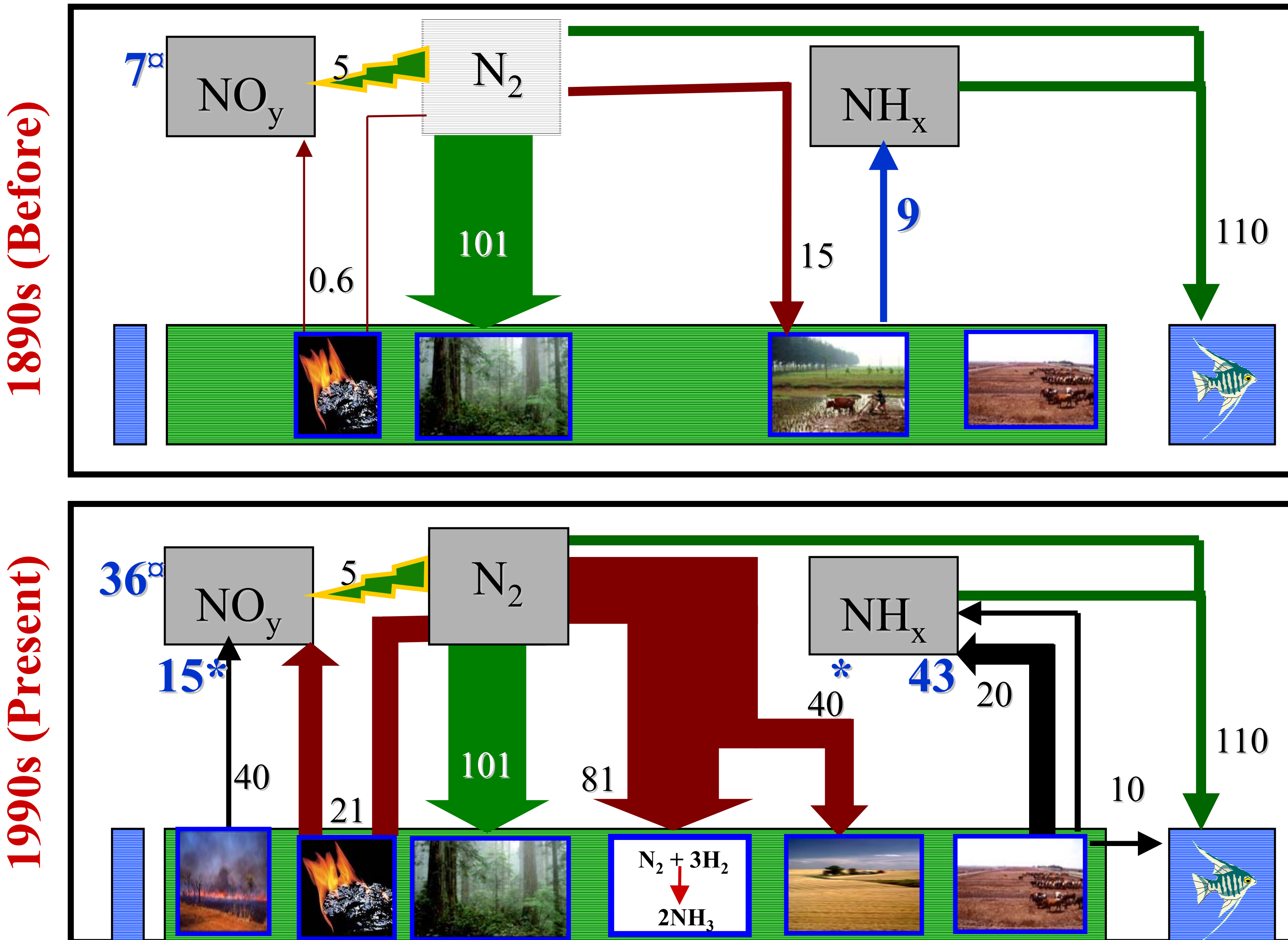
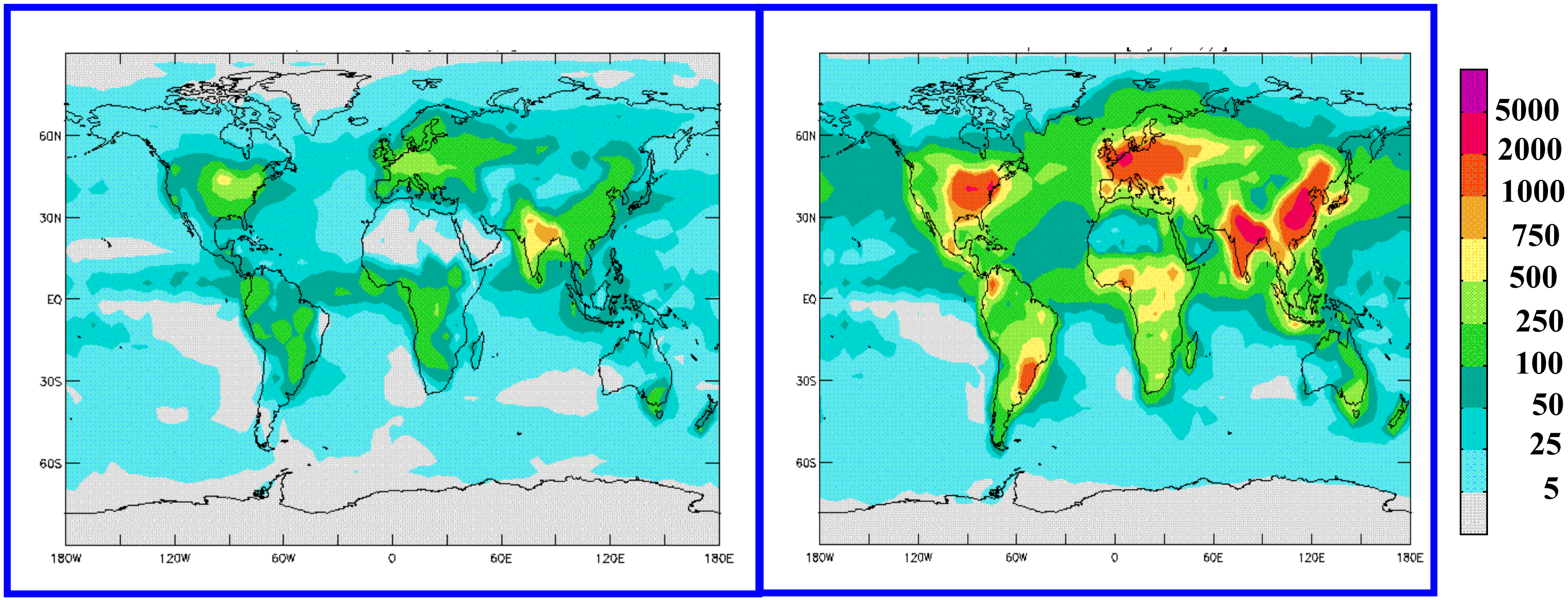


Galloway and Cowlingl., 2002

Nitrogen Deposition
Past and Present
(mg N/m²/yr)



1890 **1993**

Galloway and Cowling, 2002; Galloway et al., 2002

Mid-way Summary

Summary

- Humans have doubled the transfer from the atmospheric N pool to biologically available forms on land (and water)
  - *Food production accounts for 75%*
- Nr is widely dispersed
- Nr is accumulating in ecosystems and the atmosphere.

Next Questions

- What are the consequences of Nr accumulation?
- What is projected for future?
- How can science and policy respond?

Effects on the Atmosphere

- Related to:
  - ↑ emissions, transport, reaction, deposition of N gases
- N_2O
- NO_x (NO and NO_2)
- NH_3

Effects on the Atmosphere

- N_2O
  - Contributes minorly to greenhouse effect
  - Unreactive in troposphere
    - destruction of O_3 in stratosphere (UV)

- NO
  - Humans responsible for 80%
  - Unreactive in stratosphere
    - formation of O_3 in troposphere (smog)
  - Acid rain (input to aquatic systems, destroys artifacts)

Effects on the Atmosphere

- NH_3
  - Humans responsible for 70%
  - Highly reactive in troposphere (neutralizing agent)
  - Dry and wet deposition (Also NO)
  - Unreactive in troposphere
    - destruction of O_3 in stratosphere (UV)

- NO_2
  - Reactive in troposphere
    - Contributes to formation of O_3 (smog)
    - Acid rain

Effects on Terrestrial Ecosystems

- N is the limiting nutrient in most terrestrial ecosystems (temperate and polar)
- **<u>N-saturation</u>**
  - Leaching (NO_3)
    - Cation depletion
  - ↑ denitrification
  - ↑ w/ ↓ in productivity
  - Nutrient imbalances
- Nr deposition increases and then decreases forest and grassland productivity
  - N. Europe and US (examples)
- Nr additions probably decrease biodiversity across the entire range of deposition

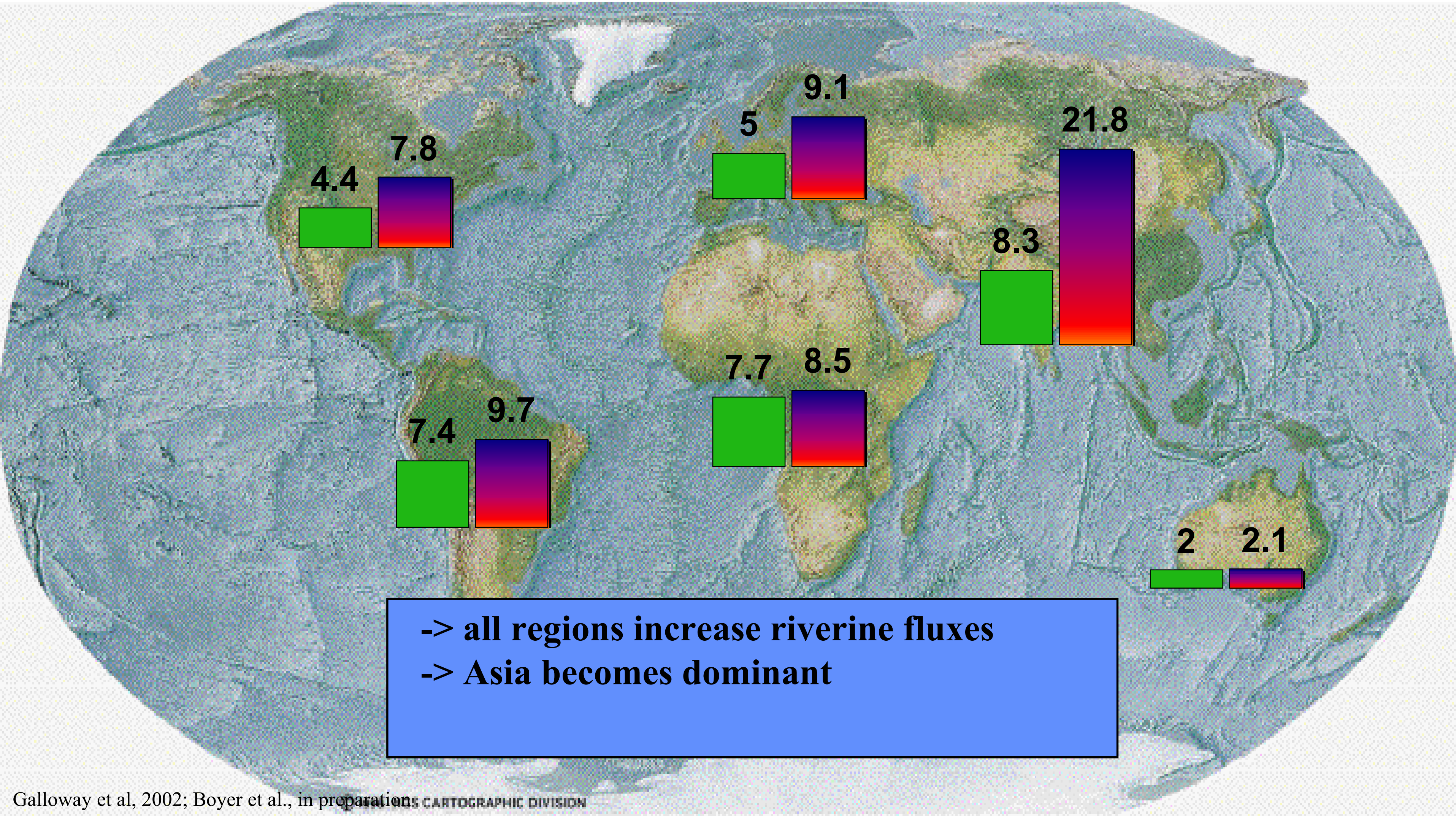
Effects on Aquatic Ecosystems

- Freshwater Ecosystems: Surface water acidification
  - Tens of thousands of lakes and streams
  - Significant biodiversity losses
  - Negative feedbacks to forested ecosystems

Effects on Aquatic Ecosystems

- Marine/Estuarine Ecosystems:
  - N enrichment due to agricultural practices
  - Eutrophication
    - Biodiversity losses, emissions of N_2O to the atmosphere
  - Most coastal regions are impacted (Mississippi river and Gulf of Mexico Dead Zone)

Nr Riverine Fluxes
1890 (left) and 1990 (right)
TgN/yr

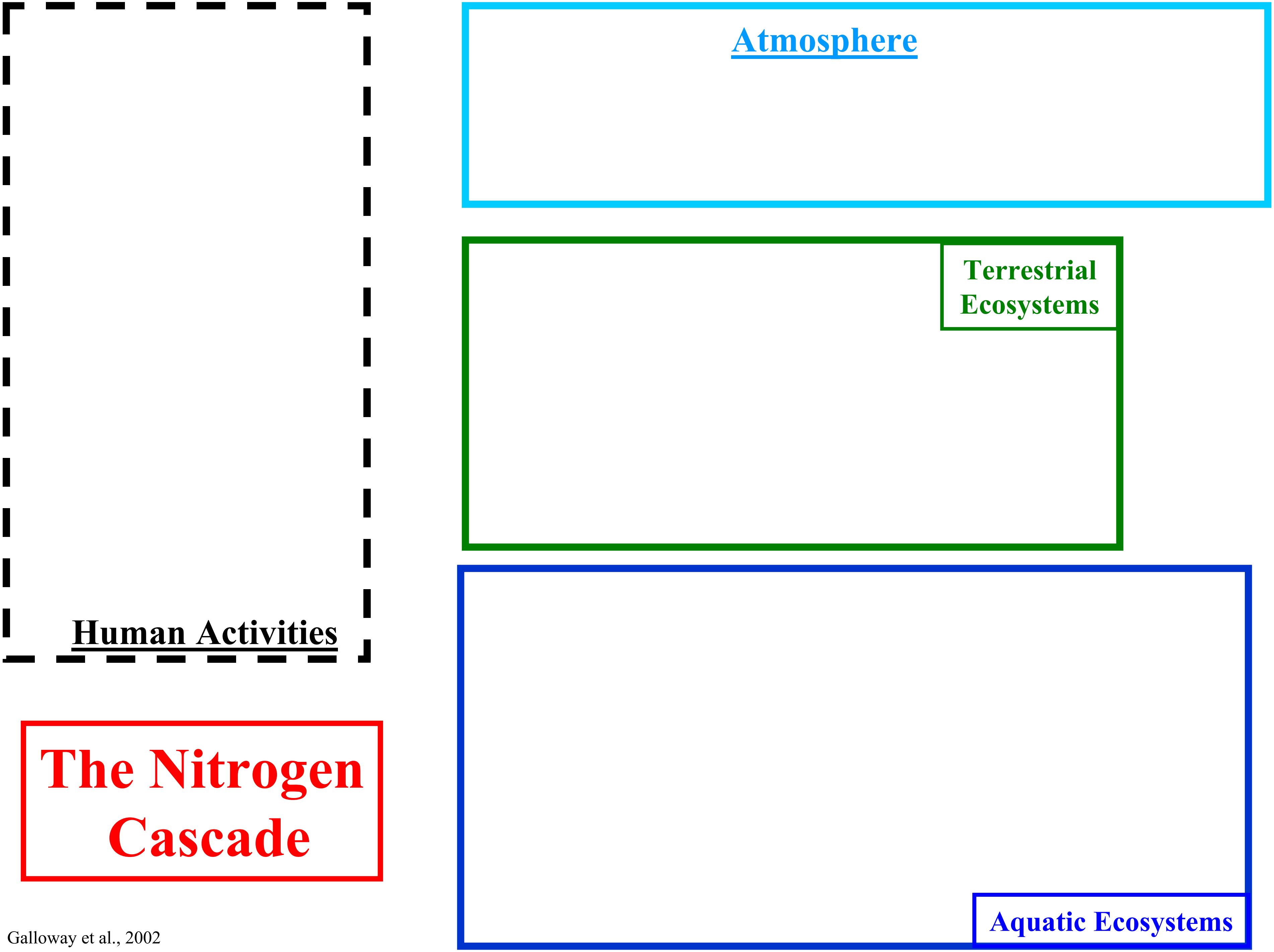


-> all regions increase riverine fluxes
-> Asia becomes dominant

Galloway et al, 2002; Boyer et al., in preparation

There are significant effects of Nr accumulation within each reservoir

These effects are linked temporally and biogeochemically in the Nitrogen Cascade



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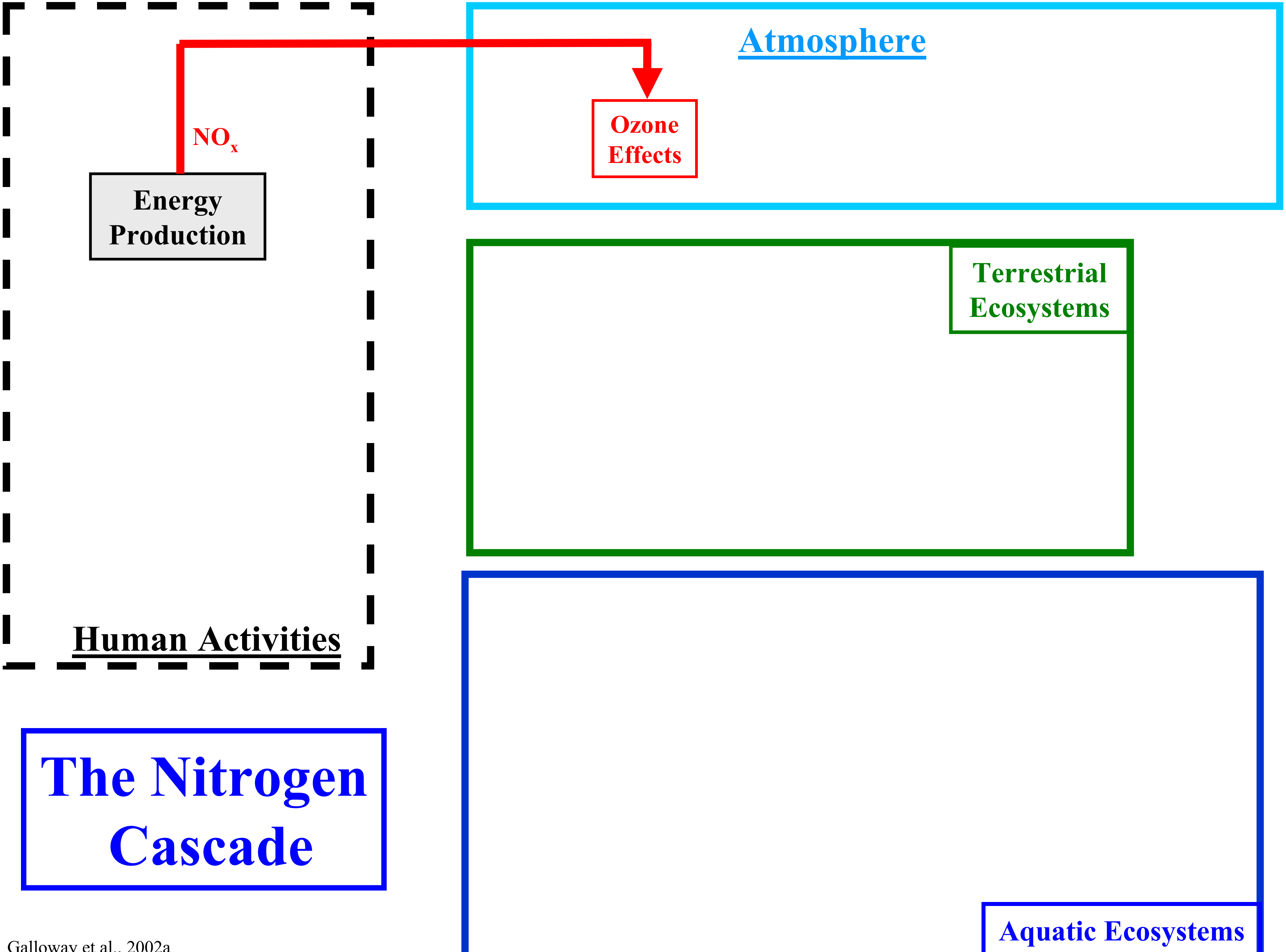

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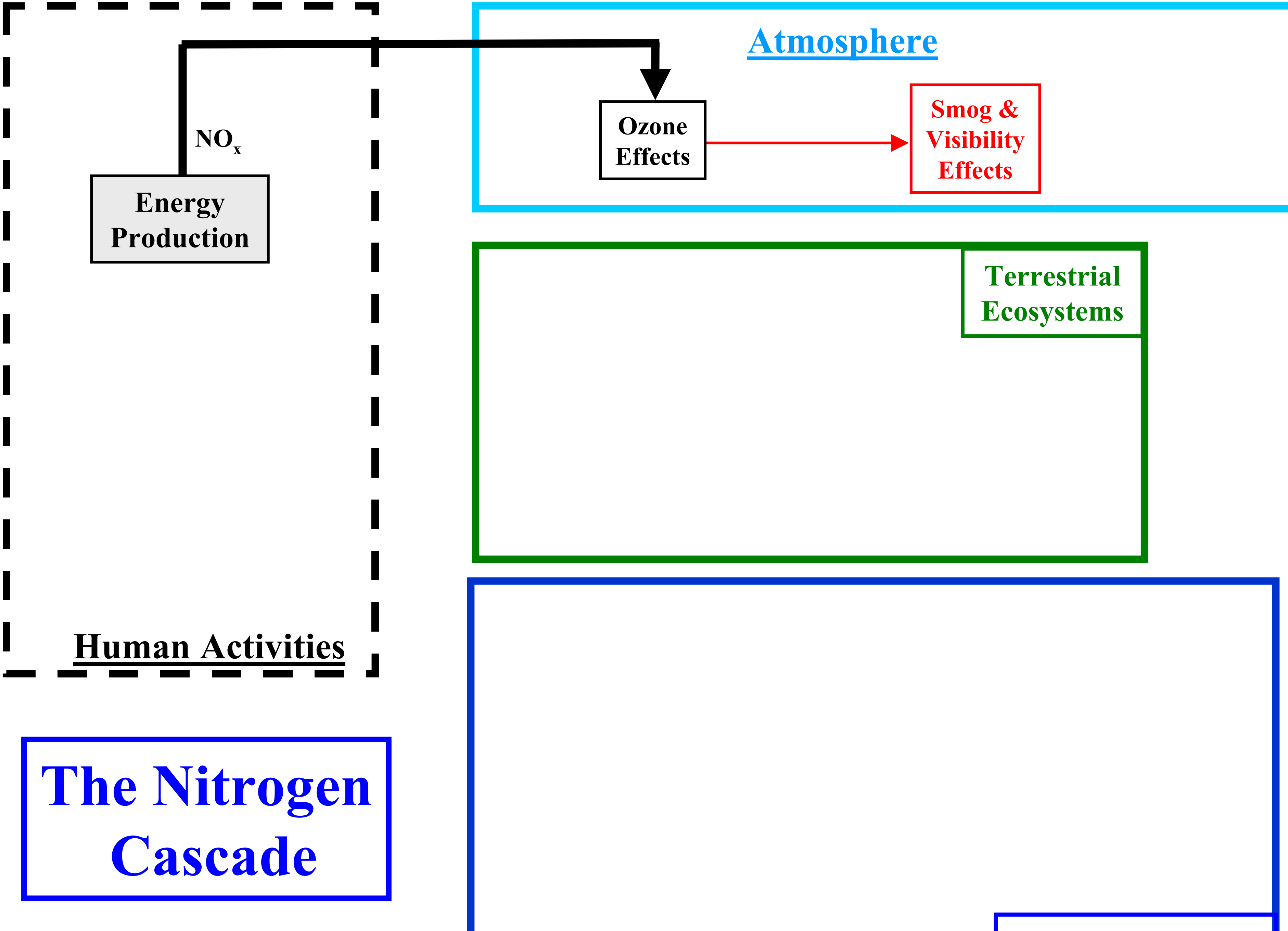

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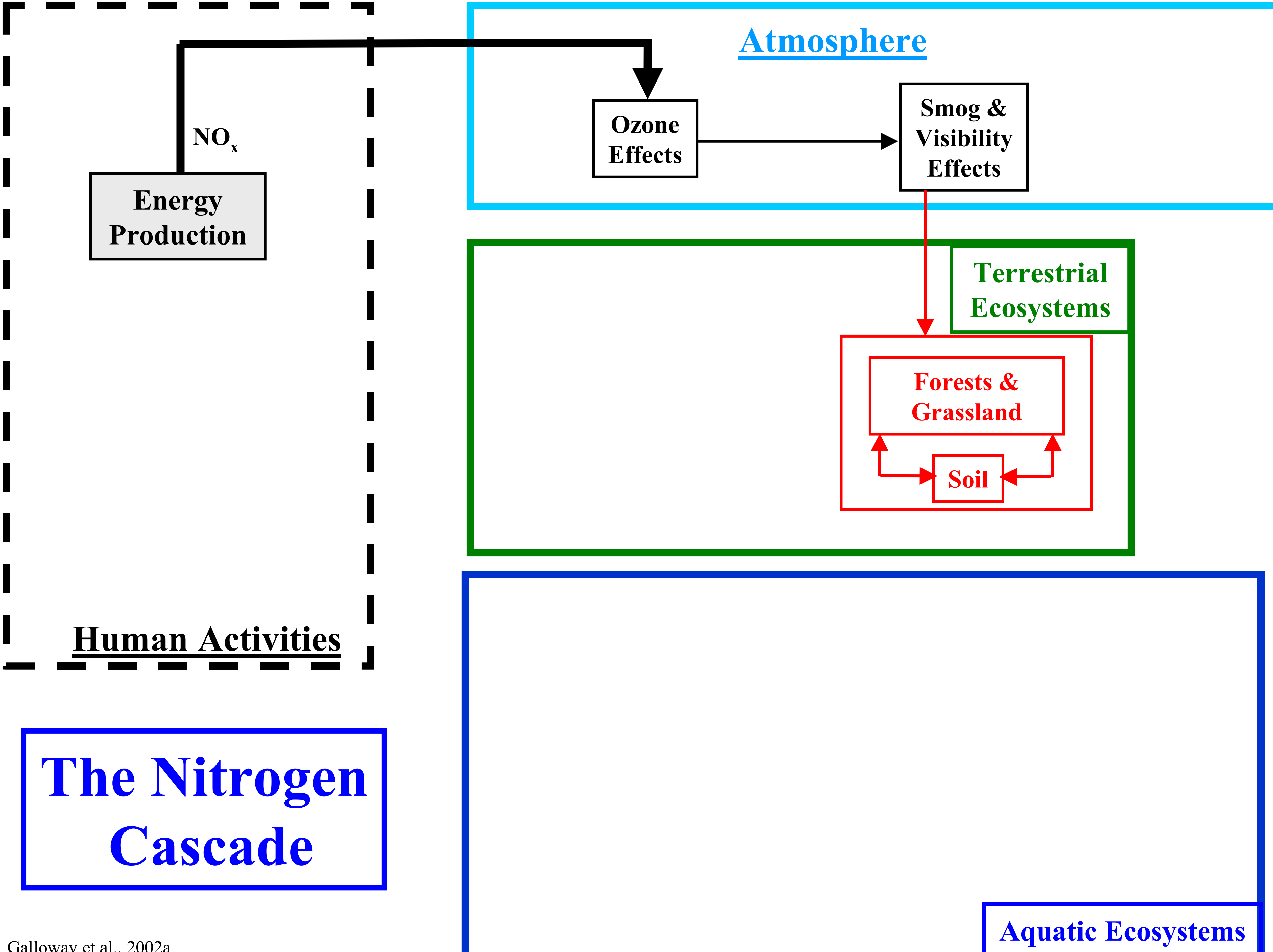

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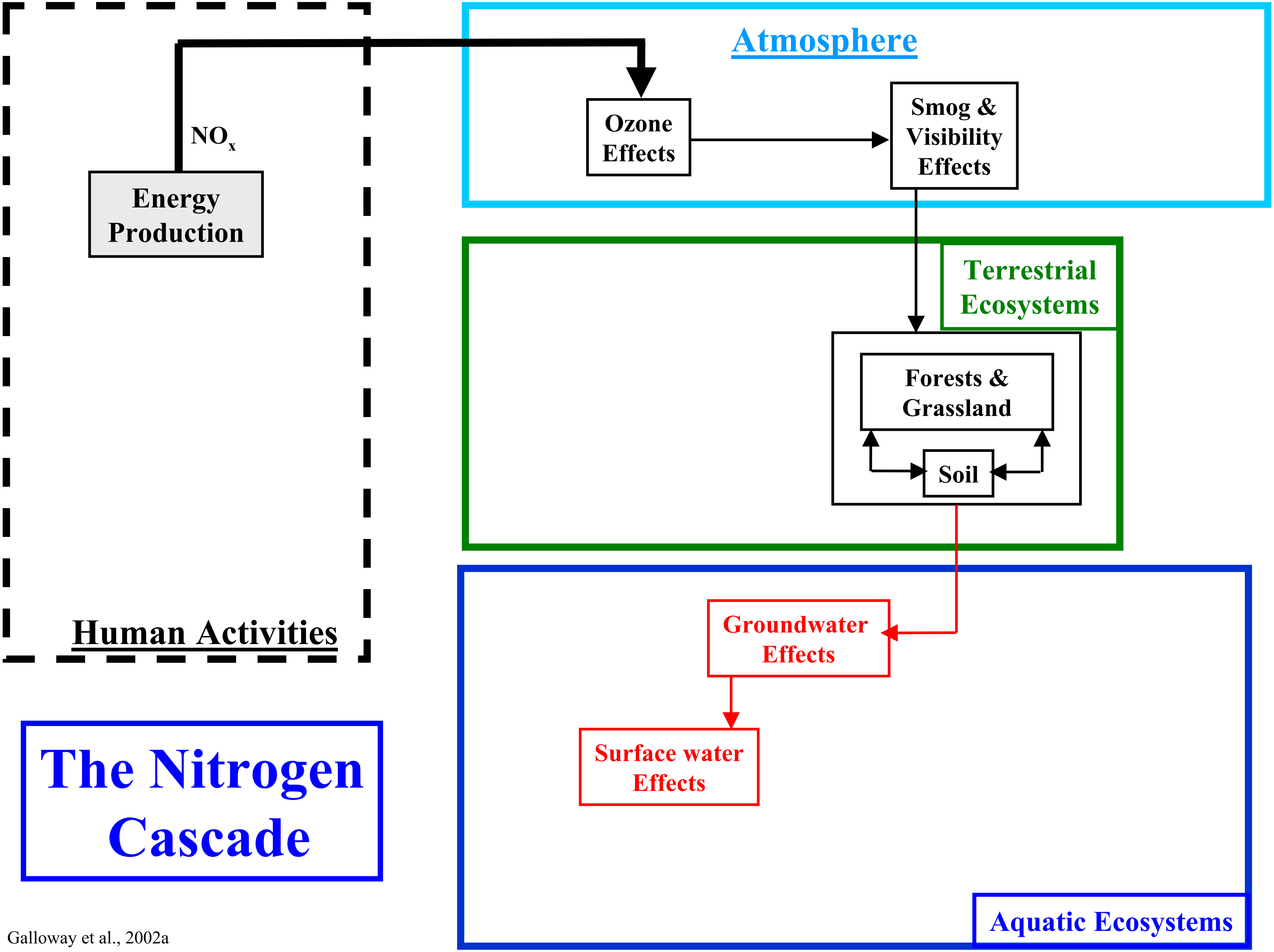

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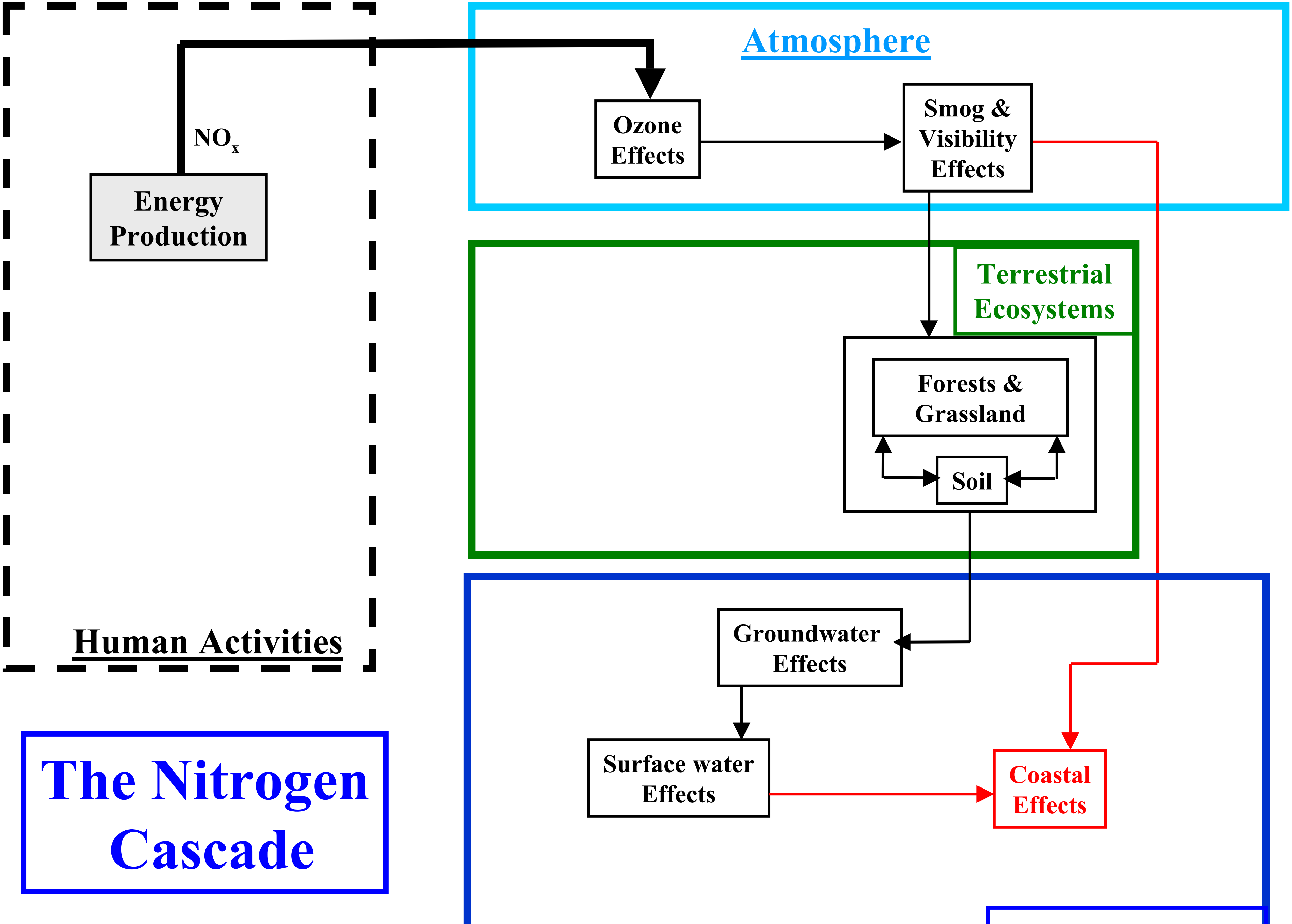

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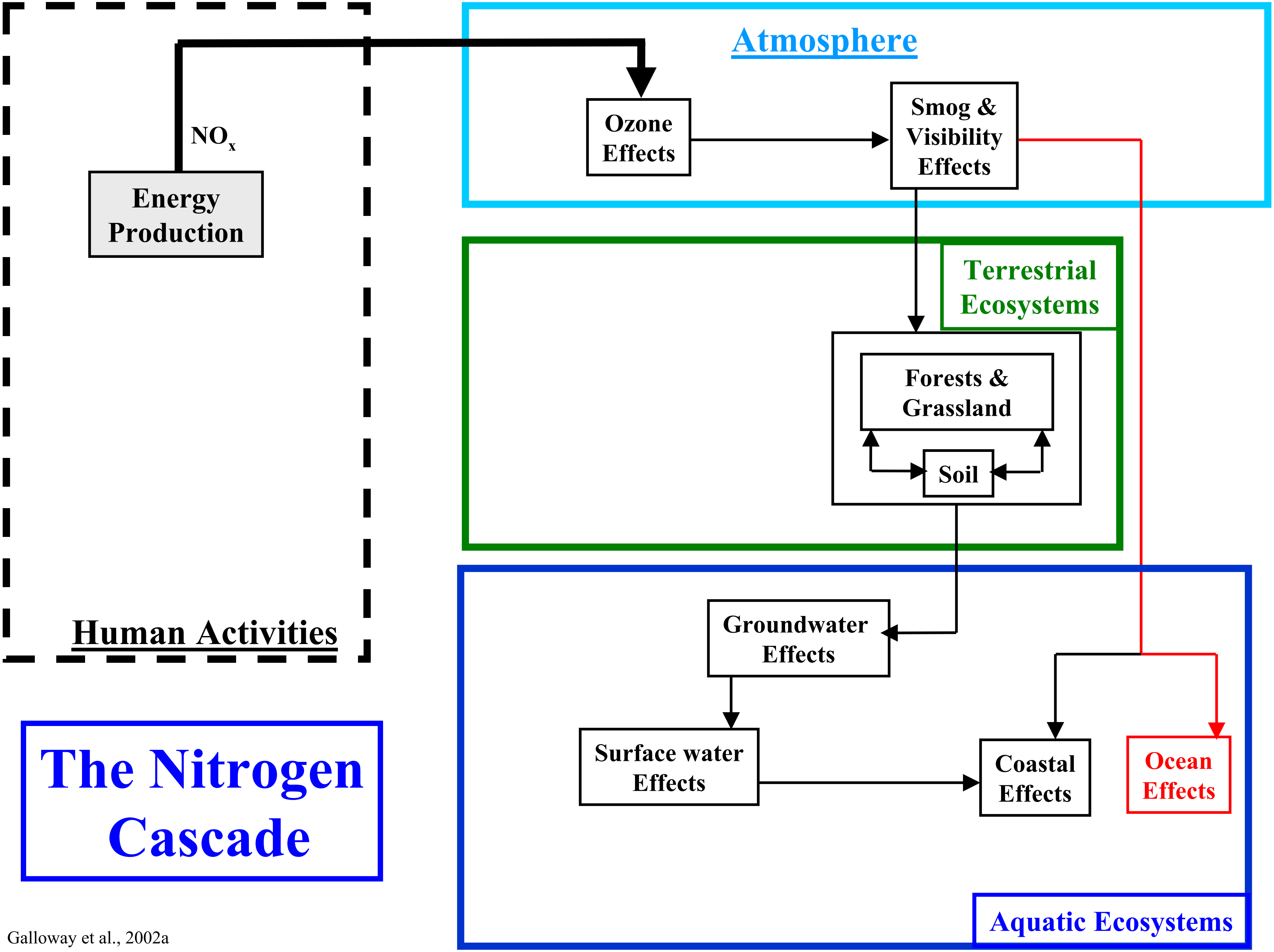

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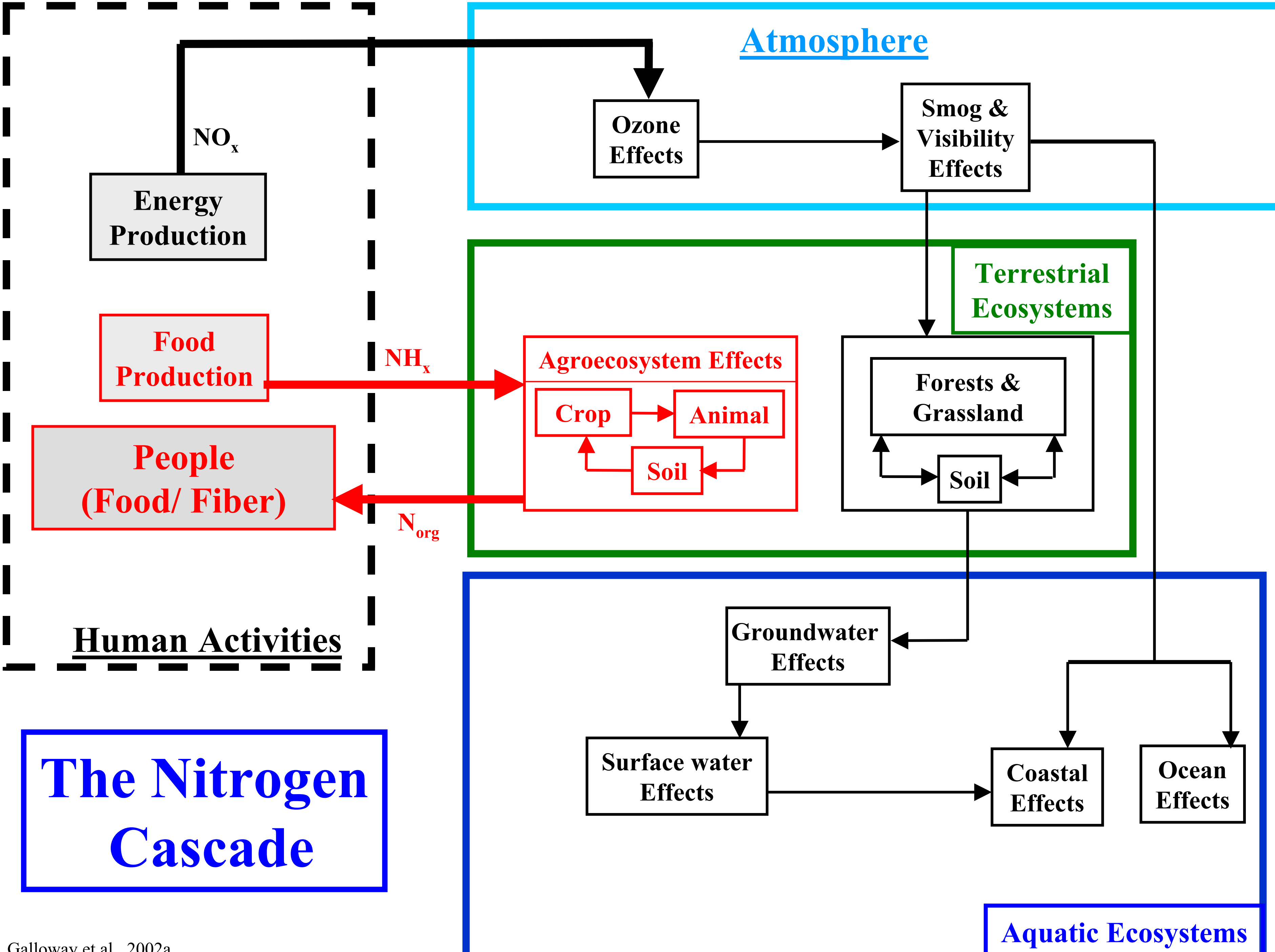

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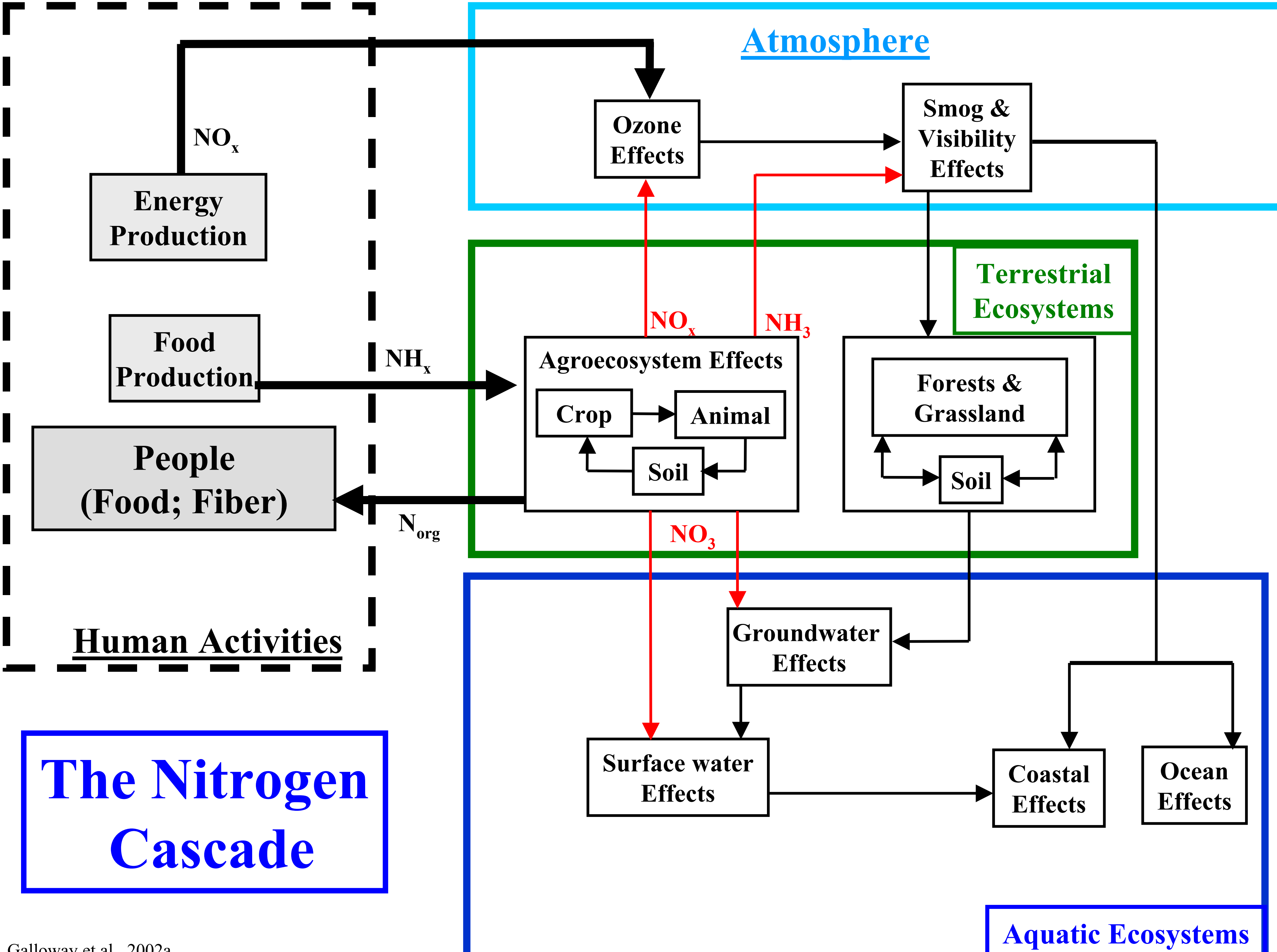

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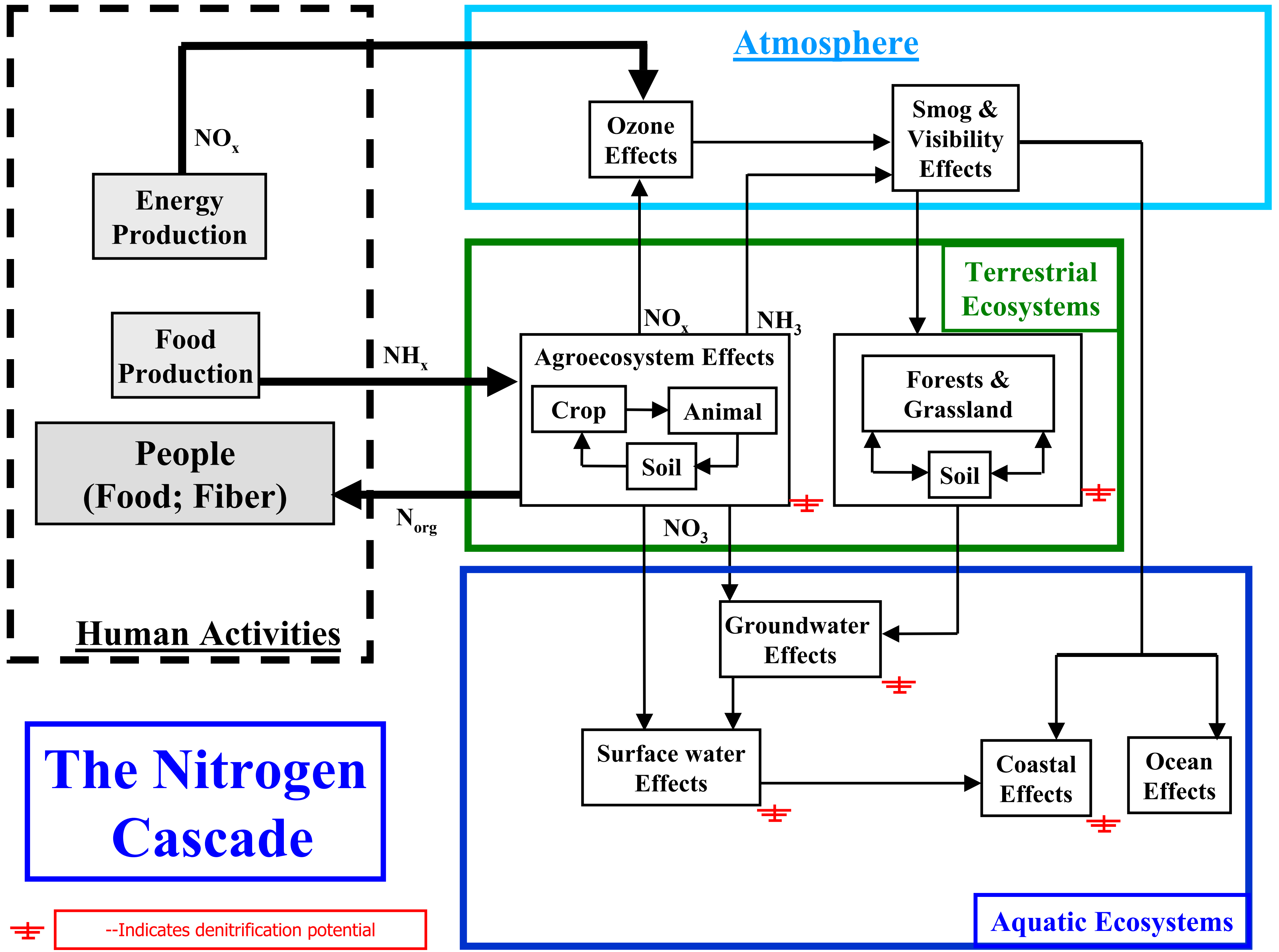
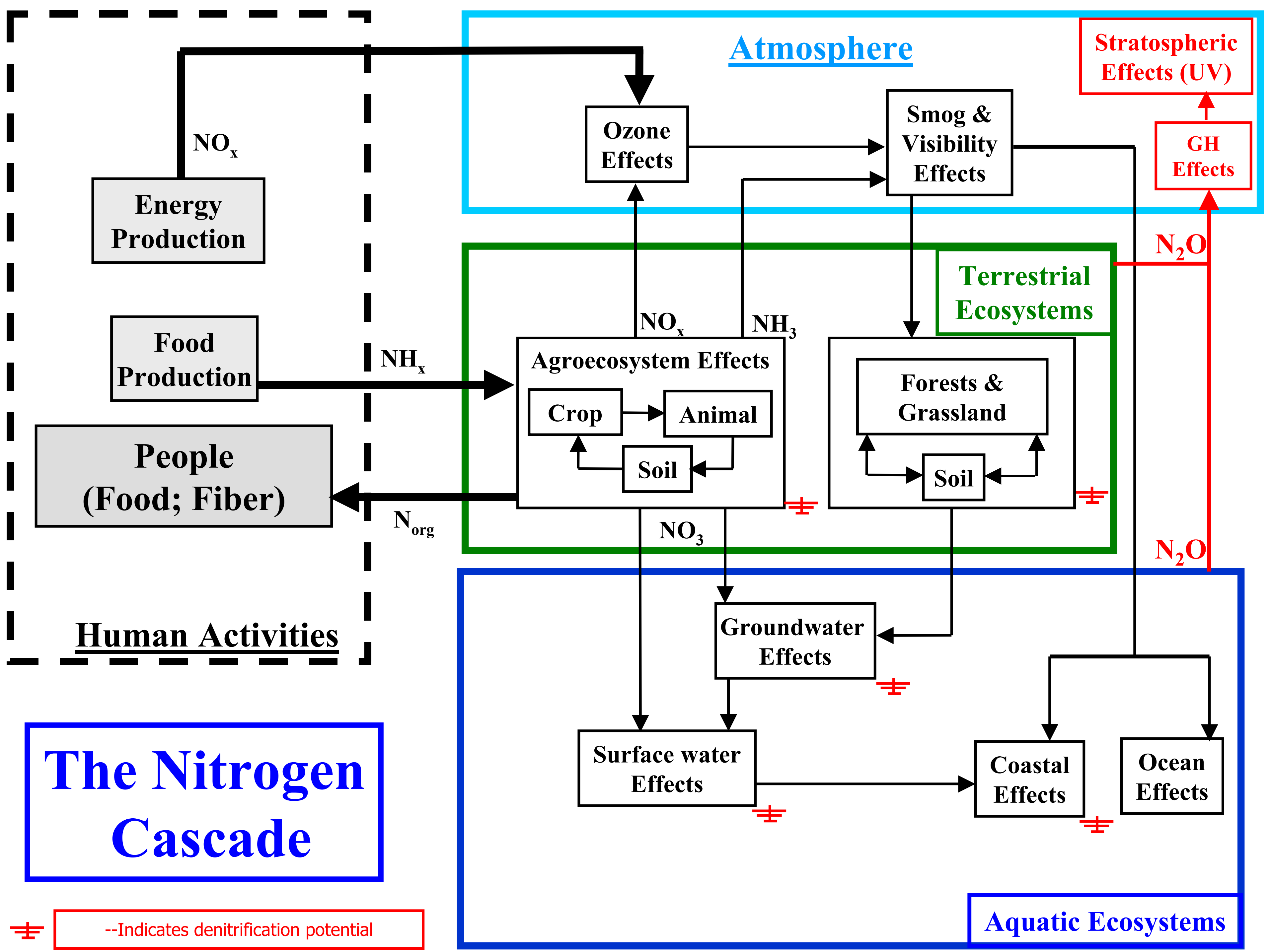

Atmosphere
Ozone Effects
Smog & Visibility Effects
NOx
Energy Production
Food Production
NHx
People (Food; Fiber)
Norg
Terrestrial Ecosystems
NOx
NH3
Agroecosystem Effects
Crop
Animal
Soil
Forests & Grassland
Soil
NO3
Groundwater Effects
Human Activities
Surface water Effects
Coastal Effects
Ocean Effects
The Nitrogen Cascade
Aquatic Ecosystems
--Indicates denitrification potential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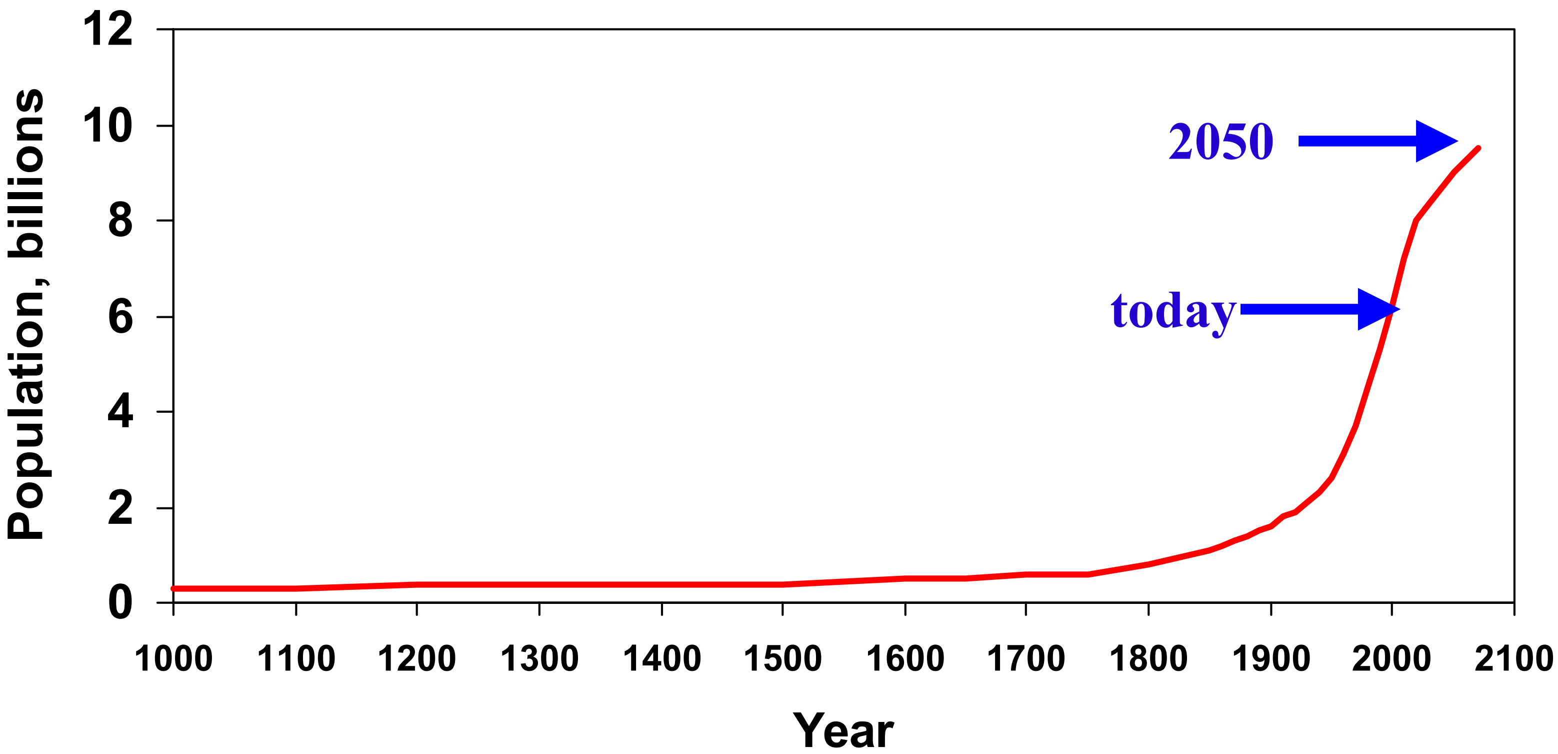
Take Home Message

- Food and energy production results in creation of ~180 Tg of new Nr, most of which is released to the environment.
- We know where some of it goes and we generally know what it does when it gets there.
- We do not know:
  - *How much is <u>stored</u> in ecosystems vs. how much is <u>denitrified</u> to N_2.*
  - *How to <u>feed</u> and <u>fuel</u> the global population without releasing excess N to environmental reservoirs.*
- **We know another thing--Nr creation will increase in the future, as will Nr accumulation and an intensification of the N Cascade--but how much?**

Nr Creation Rates by Food and Energy Production in 2050



Approaches and Solutions

- Food and Energy are required and will increase in demand given the rising human population
- Developing regions will be major consumers (and producers) of Nr.

Approaches and Solutions

- Surface waters - agriculture
  - Lowering N fertilizer use …?
  - On-farm controls
  - Restoration of wetlands
    - Nitrogen Farming
- Energy production – NO_x emissions
  - "Technology leap"
  - Developing countries – ↑ per capita income
    - Transportation and Energy

Approaches and Solutions

- **Generation of electricity:**
  - natural gas combined cycle, combined heat and power cogeneration, and zero-emission distributed power (wind or small hydro and fuel cells)
- **Transportation:**
  - advanced public transportation, advanced electric propulsion vehicles (ie.hybrid electric cars)
  - policy strategies to reduce NOx emissions
    - tax credits and subsidies for the introduction of low-polluting technologies,
    - promoting increased public transportation

Main Challenge

Maximize food and energy production while maintaining environmental and human health.

Discussion

Activity

Discussion - Protein

- Fertilizer use efficiency
  - 2kg of protein/person/year to survive
  - Human pop. (~5.3 billion) produced ~110 Tg of N/yr but only required 11 Tg/yr (at 2kg/person)
- Fate of “excess” N:
  - Some consumed as excess
  - Most distributed to environment w/o being consumed
    - Excretions

Discussion - Protein cont'd

- Fertilizer use efficiency
  - Some of the harvested food used to feed animals - to produce even MORE protein
- Efficiency of growing plant protein to feed humans is ~14%, and the efficiency of growing animal protein to feed humans is 4%
  - Remaining N is recycled to agroecosystems or lost to the environment
  - Health issues associated w/protein consumption and environmental effects

Discussion - Eutrophication

- Eutrophication of the Gulf of Mexico
  - How plausible is action plan in US vs. developing nations?
  - Agriculture vs. Fishery
  - ?’s

Discussion

- How can you link all you’ve learned so far?
  - Idea of Global effort to prevent environmental damage
- How can you contribute in your daily life?

Activity

- Importance of Communication
  - Spread the word!
    - Children and general public
- Create a poster or brochure aimed to a specific audience (children, fishermen, farmers, general public, etc.)