Nitrogen & Phosphorus Pollution
Quiz: Galloway et al. 2008

1. List and describe two ways that reactive Nitrogen (Nr) is created by human activity.
New Vocab: Galloway et al. 2008

- Radiative forcing – strength of a greenhouse gas
- Haber-bosch process – inorganic process of creating ammonia from N2
- Denitrification – process of soil bacteria converting nitrates to N2
- NOx – NO (nitric oxide) or NO2 (Nitrogen dioxide) – air pollutants
Why do plants need Nitrogen?
Nitrogen fixing bacteria convert $N_2$ to $NH_4$ (ammonium), which plants can use directly.
Global Nitrogen Fixation (Tg/yr)

Nitrogen fixing bacteria convert N$_2$ to NH$_4$ (ammonium), which plants can use directly.
## Major nitrogen fixing crops

<table>
<thead>
<tr>
<th>CROP</th>
<th>LB/ACRE NITROGEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>196</td>
</tr>
<tr>
<td>Ladino Clover</td>
<td>178</td>
</tr>
<tr>
<td>Sweet Clover</td>
<td>116</td>
</tr>
<tr>
<td>Red Clover</td>
<td>112</td>
</tr>
<tr>
<td>White Clover</td>
<td>103</td>
</tr>
<tr>
<td>Soybeans</td>
<td>98</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>89</td>
</tr>
<tr>
<td>Lespedeza</td>
<td>85</td>
</tr>
<tr>
<td>Vetch</td>
<td>80</td>
</tr>
<tr>
<td>Garden Peas</td>
<td>71</td>
</tr>
<tr>
<td>Winter Peas</td>
<td>54</td>
</tr>
<tr>
<td>Peanuts</td>
<td>42</td>
</tr>
</tbody>
</table>
Global Nitrogen Fixation (Tg/yr)

- **Legume Crops and Green Manures**
- **Synthetic N Fertilizer**
- **Lightning**
- "Natural" biological N fixation

Year:
- 1920
- 1940
- 1960
- 1980

Background
Where do we get Nitrogen fertilizer?

Saltpeter (potassium nitrate) used to be mined in Chile

\[ \text{\[\rightarrow KNO_3\]} \]
Where do we get Nitrogen fertilizer?

Saltpeter (sodium nitrate) used to be mined in Chile

Haber Process

\[
\text{methylene} + \text{steam} \rightarrow \text{hydrogen} + \text{carbon monoxide}
\]

\[
\text{hydrogen} + \text{oxygen} \rightarrow \text{water}
\]

This reaction removes oxygen from the air to leave nitrogen

\[
\text{nitrogen} + \text{hydrogen} \rightarrow \text{ammonia}
\]

\[
N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)
\]

450 °C
200 atmospheres
iron catalyst
Fritz Haber

German chemist, invented the process for creating ammonia from atmospheric $N_2$

2-3 billion people would not be alive without this process

Fertilizer Production

• ~100 million tons of nitrogen fertilizer produced per year

• Nitrogen fertilizer production accounts for about 2% of greenhouse gas emissions (Haber process is methane ($\text{CH}_4$) powered)
Fertilizer costs (and food costs!) respond to fossil fuel prices

Cost of natural gas  
Cost of fertilizer
Solutions? Over-use of fertilizer is common.
London smog is primarily NOx particulates.
Fossil fuel combustion emits CO$_2$ and ++++, including NOx.
Sources of Anthropogenic NOx

- Motor Vehicles: 56%
- Utilities: 22%
- Industrial/Commercial/Residential Fuel Combustion: 17%
- All Other Sources: 5%

Source: NASA
Nitrogen cycle + humans *(yellow arrows)*
Rapid changes to N cycle

Vitousek et al., 1997
Links between changing Nitrogen and other forms of global change
Feeding the world – extensification vs. intensification

**Extensification:**
Expand cropland area

![Diagram showing cropland in use and total suitable land (million ha)](image)

**Sources:** FAO data and Fischer et al. (2000)
Feeding the world – extensification vs. intensification

Intensification:
Add resources to crops
• Fertilizers
• Water
• Crop cultivars & GMOs
Nitrogen cycle (without humans)

Atmospheric Nitrogen ($N_2$)

Plants

Asimilation

Nitrifying Bacteria

Denitrifying Bacteria

Nitrogen-fixing bacteria living in legume root nodules

Decomposers (aerobic and anaerobic bacteria and fungi)

Ammonification

Nitrogen-fixing soil bacteria

Ammonium ($NH_4^+$)

Nitrification

Nitrites ($NO_2^-$)

Nitrifying bacteria

Nitrates ($NO_3^-$)

$N_2O$ (Nitrous oxide)
Global totals, anthropogenic emissions, for year 2000
Nitrous Oxide ($N_2O$) Emissions

$N_2O$ lasts for $>100$ years in the atmosphere.

Greenhouse gas is $\sim300x$ more potent than $CO_2$. 

Phosphorus cycle
Why do plants need Phosphorus?
Where do we get phosphates for fertilizer?

Florida mines provide 75% of phosphates used in the U.S. Florida’s phosphate mines use an estimated 100,000 gallons of water *per minute*
Phosphorus cycle with the human component
Susceptible ecosystems
What sorts of ecosystems are most sensitive to N addition?

• Nitrogen limited ecosystems

Grasslands in Wyoming

Florida Everglades
What sorts of ecosystems are most sensitive to P addition?

- **Phosphorus limited ecosystems**
  
  - No phosphate addition (Nitrogen only)
  
  - Phosphate addition (& Nitrogen)
What sorts of ecosystems are most sensitive to N addition?

- Coastal marine ecosystems
N addition affects all ecosystems

Galloway et al., 2008
Impacts of Nitrogen in the Northeast U.S.

<table>
<thead>
<tr>
<th>THE CASCADE EFFECT OF NITROGEN POLLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air Quality</strong></td>
</tr>
<tr>
<td>• Elevated ground-level ozone</td>
</tr>
<tr>
<td>• Increased concentrations of particles in air</td>
</tr>
<tr>
<td>• Reduced visibility</td>
</tr>
<tr>
<td>• Increased acid rain and nitrogen deposition</td>
</tr>
<tr>
<td><strong>Forests</strong></td>
</tr>
<tr>
<td>• Increased acidity of forest soils</td>
</tr>
<tr>
<td>• Nitrogen saturation of forest ecosystems</td>
</tr>
<tr>
<td>• Ozone damage to forests</td>
</tr>
<tr>
<td><strong>Water Quality</strong></td>
</tr>
<tr>
<td>• Elevated acidification of lakes and streams</td>
</tr>
<tr>
<td>• Groundwater contamination</td>
</tr>
<tr>
<td>• Over-enrichment of coastal ecosystems</td>
</tr>
<tr>
<td><strong>Other</strong></td>
</tr>
<tr>
<td>• Increased production of greenhouse gases contributing to global climate change</td>
</tr>
<tr>
<td>• Adverse human health effects from particulate matter and ground-level ozone</td>
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</tbody>
</table>
Wastewater treatment is an effective means of reducing nitrogen loading. Wards Island wastewater treatment system
Guess what else is good at reducing N content in rivers and streams?

**Wetlands** – another good example of a useful ecosystem service
Small Groups Discussion

• Go through remaining questions from Galloway

• 2. Galloway et al highlight uncertainty in our estimates of where reactive N ends up in ecosystems – why do you think we have such a poor understanding of fluxes?

• 3. Give one example of how the N cycle interacts with climate change