Ecosystem Mass Balances and Models of Terrestrial Nutrient Cycling

OCN 401 - Biogeochemical Systems

20 September 2012

Reading: Schlesinger, Chapter 6
Outline

1. Ecosystem mass balances
   • The watershed concept
   • Hubbard Brook Forest: a classical ecosystem-scale study

2. Budgets
   • Chemical budgets for forests
   • Continental-scale budgets
   • Estimates of uncertainty

3. Models
   • From budgets to predictive models
   • Models that track mass fluxes through time
Stochastic = random, unpredictable
Irruption = sudden increase

Factors Controlling Ecosystem Operation

Groffman et al. (2004)
BioScience 54:139
Ecosystem (Landscape) Mass Balances

The mass balance for any material in an ecosystem can be represented by a simple equation:

\[
\text{Input} - \text{Output} = \text{Change in Storage}
\]

Each of these terms (input, output, storage) can have multiple components.

However, there is a fundamental controlling concept (Conservation of Mass):

\textbf{THINGS HAVE TO ADD UP!}
A Water Balance
Subsurface Hydrologic Zones

- VADOSE ZONE
- GROUNDWATER ZONE
- Water Table
- River or Lake

Two Subsurface Hydrologic Zones:
- VADOSE ZONE (Unsaturated Zone)
- GROUNDWATER ZONE (Saturated Zone)
Groundwater Flow & Residence Times

USGS circular 1139
Small Watershed Concept

Precipitation Collector
Ridge Line
Evapotranspiration

Precipitation

Topographic Divide
Stream Gaging Station

Soil
Mantle
Bedrock

Stream Flow

Water Budget at Hubbard Brook:
Precipitation (100%) = Streamflow (60%) + Evapotranspiration (40%)
Hubbard Brook Forest:
A Classical Ecosystem-scale Study
Example of a weir at Hubbard Brook:

Weather station (note treated watersheds on ridge):
Hubbard Brook Forest

[Graph showing water amount (cm) for different months with streamflow and precipitation data.]
Mass-Balance Modeling at Hubbard Brook


Input - Output = Change in Storage
Nitrogen: Pre- and Post-Cut

Forest

Organic N

 decomposition → NH₄⁺ → nitrification → 2H⁺NO₃⁻ → leached

Cut

Organic N

 decomposition → NH₄⁺ → nitrification → 2H⁺NO₃⁻ replaces Ca, Na, K, Mg → leached
Element Flux and Disturbance Over Time

Undisturbed system:
constant flux through time ("control")

Disturbed system:
dramatic modification of flux, then recovery back to behavior like undisturbed system
## Chemical Budgets for Forests

If positive, then export of material (e.g., due to Ca release from weathering)

If negative, then import of material (e.g., due to atmospheric input)

<table>
<thead>
<tr>
<th></th>
<th>Ca</th>
<th>Cl</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Columbia</td>
<td>15.8</td>
<td>2.9</td>
<td>-2.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Oregon</td>
<td>41.2</td>
<td>---</td>
<td>-1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>11.7</td>
<td>-1.6</td>
<td>-16.7</td>
<td>0.0</td>
</tr>
<tr>
<td>North Carolina</td>
<td>3.9</td>
<td>1.7</td>
<td>-5.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>Venezuela</td>
<td>14.2</td>
<td>-1.4</td>
<td>8.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Where does the N come from?
Cultivated and Uncultivated Systems in a Continental-Scale N Budget

Figure 6.19  The nitrogen budget for west Africa in 1978. All flux estimates are in units of $10^6$ kg/yr. Pool-values are in $10^6$ kg and increments to the pools are in parentheses. Modified from Robertson and Ross wall (1986).
Many Budgets Contain Estimates of Uncertainty

**Table 7. A budget for atmospheric NH₃.**

<table>
<thead>
<tr>
<th>Inputs:</th>
<th>'Best' estimate</th>
<th>Potential range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic animals (Table 4)</td>
<td>32</td>
<td>24—40</td>
</tr>
<tr>
<td>Sea surface (text)</td>
<td>13</td>
<td>8—18</td>
</tr>
<tr>
<td>Undisturbed soils (Table 3)</td>
<td>10</td>
<td>6—45</td>
</tr>
<tr>
<td>Fertilizers (Table 6)</td>
<td>9</td>
<td>5—10</td>
</tr>
<tr>
<td>Biomass burning (text)</td>
<td>5</td>
<td>1—9</td>
</tr>
<tr>
<td>Human excrement* (Warneck 1988)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Coal combustion* (Warneck 1988)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Automobiles* (Warneck 1988)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL INPUTS</strong></td>
<td><strong>75</strong></td>
<td>50—128</td>
</tr>
</tbody>
</table>

| Outputs:                        |                |                 |
| Wet deposition on land         | 30              |                 |
| (Warneck 1988)                 |                 |                 |
| Dry deposition on land         | 10              |                 |
| (Warneck 1988)                 |                 |                 |
| Wet deposition on sea surface  | 16              |                 |
| (Duce et al. 1991)             |                 |                 |
| Reaction with OH radical       | 1               |                 |
| (Warneck 1988)                 |                 |                 |
| **TOTAL OUTPUTS**              | **57**          |                 |

* incremented to represent current human and automobile populations.

Tg = teragram = 10^{12} g
Higher nutrient availability
...leads to
higher plant nutrient content
...leads to
lower nutrient reabsorption before leaf-fall
...which reflects
lower nutrient-use efficiency
Models, As Well As Budgets, Often Track Mass Fluxes Through Time

- The CENTURY model describes grassland soil development
- Boxes = pools of plant C residue in soil
- Arrows = C fluxes between soil pools
- Turnover times ranges from 0.5 y (fresh metabolic C) to 1,000 y (“passive soil”)
- Each arrow is represented by an equation describing flux
The model simulates the time-course of grassland soil development over 10,000 years.

Grass production and soil C accumulation is closely linked to P availability during the first 800 yr.

After that, they are related to increases in soil N mineralization.
Lecture Summary

- Element flux at the ecosystem scale is an integrating measure of ecosystem function -- thus we determine *Ecosystem Mass Balances*

- **Budgets** are descriptions of material flux from one functional unit (or reservoir) to another

- **Models** may be superficially similar to budgets, except that simultaneous equations are used instead of purely descriptive data to describe the time course of material flux through a system

- With both budgets and models there is often added insight by the simultaneous examination of fluxes of several linked materials (e.g., C, N, P) through the system