Global Change Drivers: LAND-USE CHANGE

Global Change Lecture #12, S. Saleska, 12-October-2010

I. What is Land-Use Change?

II. Land-use change, a driver of climate change:
   A. Changes in greenhouse gas emissions from the land (especially CO₂) (effects only at global scale)
   B. Changes in energy and water balance at land surface (effects at different scales)

III. Direct effects of Land-use change: from local to global

* With thanks to Jon Foley.

I. What is Land-Use Change?

A process by which human activities transform the landscape
I. What is Land-Use Change?

II. Land-Use change, a driver of climate change
II. Land-Use change, a driver of climate change

A. Changes in greenhouse gas emissions from the land (especially CO$_2$)

Part 1. Tropical Deforestation is a major contributor to CO$_2$ increases in the atmosphere
Part 2. Long-term Legacies of Northern Hemisphere land-use change for atmospheric CO$_2$

(a two-part story of land-use change and carbon cycling spanning thousands of miles and hundreds of years)

Part 1: Land-use change in the tropics: Biomass burning, conversion to agriculture

Conversion to agriculture or pastureland is the primary driver of tropical deforestation
Ongoing deforestation in Amazônia – contributes to CO2 emissions:

Carbon fluxes from Global deforestation:

Global Range (1990s)

Ongoing deforestation in Amazônia – contributes to CO2 emissions:

Rate (by area) of deforestation in the Brazilian Amazon: slowing?

Source: Brazilian space agency (INPE) (http://www.inpe.br/noticias/imagens/deforestacao_prodes_maior.jpg)

Amazon-only (1990s): 0.5 (0.3 - 1.1)
Summary of Part 1:

Land-use change in the tropics (mostly deforestation) is a substantial contributor to global CO₂ emissions

(In the decade of the 1990’s: about 1 – 2 PgC/yr compared to about 7 PgC/yr from fossil fuel burning )
Part 2: Legacies of past land-use change in Northern Hemisphere

A Large Terrestrial Carbon Sink in North America Implied by Atmospheric and Oceanic Carbon Dioxide Data and Models

S. Fan, M. Gloor, J. Mahlman, S. Pacala, J. Sarmiento, T. Takahashi, P. Tans

Concluded that North America takes up 1.7±0.5 PgC yr⁻¹

The general report of a large CO₂ sink in the northern hemisphere is robust, and has been understood since at least 1990.

“I went to the woods because I wished to live deliberately, to front only the essential facts of life, and see if I could not learn what it had to teach, and not, when I came to die, discover that I had not lived.”

- Henry David Thoreau, Walden (1854)
Percent of Land in Farms by County: 1860

Source: USGS, Land Use History of North America

Percent of Land in Farms by County: 1950

Source: USGS, Land Use History of North America
Land-Use Changes in Central Massachusetts

Source: USGS, Land Use History of North America
Changing Landscapes in Central Massachusetts

Pre-Settlement Forest - 1700 A.D.

An Early Settler Clears a Homestead - 1740 A.D.

Height of Forest Clearing and Agriculture - 1830

“Old-Field” White Pine Forest on Abandoned Farmland - 1910 A.D.

A Vigorously Growing Forest of Hardwoods, 1930 A.D.

The Modern Forest Landscape (Harvard Forest, 1990s)
Harvard Forest, MA: carbon uptake today is the legacy of 100s of years of land use changes

Harvard Forest, MA cumulative record of whole-forest flux data for 10 yrs

forest is gaining organic matter, ~ 2 tonnes C ha/yr

More reading on the socio-ecology in the history of land-use change in New England

*Changes in the Land: Indians, Colonists, and the Ecology of New England*
  - William Cronon (1983)

*Thoreau’s Country: Journey through a Transformed Landscape*
  - David R. Foster (1999)
Summary of Part 2:
Legacies of *past* land-use change make Northern Hemisphere a carbon sink

2-part story of land-use change

- Tropical forests are a source of carbon to the atmosphere *today* because of deforestation *today*.
- Temperate forests are a sink for atmospheric carbon *today* because of past deforestation (they are today taking up again what they released yesterday).
II. Land-Use change, a driver of climate change

II.A. Other GHGs also important: Increased emissions mostly due to land-use changes

Nitrous oxide: increasing mainly due to biomass burning and agricultural fertilizer use

Almost ALL anthropogenic methane sources related to land-use changes

<table>
<thead>
<tr>
<th></th>
<th>Oil (Tg CH₄ per year)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>115</td>
<td>100–200</td>
</tr>
<tr>
<td>Bogs/Tundra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swamps</td>
<td>40</td>
<td>10–100</td>
</tr>
<tr>
<td>Termites</td>
<td>10</td>
<td>5–20</td>
</tr>
<tr>
<td>Ocean</td>
<td>5</td>
<td>1–25</td>
</tr>
<tr>
<td>Freshwaters</td>
<td>5</td>
<td>0–100²</td>
</tr>
<tr>
<td>Hydrates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Anthropogenic sources

- Energy
  - Mining: 35 25–45
  - Coal mining, venting: 40 25–70
- Landfills: 40 30–70
- Biomass burning: 55 50–70
- Other: 540

Chapin et al., (2008)
II. Land-Use change, a driver of climate change

B. Changes in energy and water balance at land surface (effects at different scales)

1. The “urban heat island” (local) effect
2. Large-scale changes in land use

1. Urban Heat Islands

Urbanization is a land-use change which:
- concentrates energy consumption (and hence, waste heat dissipation)
- removes vegetation (and hence, removal of heat by latent heat flux in evapotranspiration)
- Local Urban Heat Island effects can be large (2-10 °C, depending on city size and wind speed)
- Because measurements in cities can bias large-scale estimates of surface temperature, they are carefully corrected in temperature trends
2. Large-scale changes in land-use

Energy Balance effects

Recently burned Alaskan black spruce forest
→ Exposes high-albedo (reflective) snow-covered surface
→ COOLING effect of burning
→ opposite direction of warming effect of CO2 released

Chambers (1998)

2. Large-scale changes in land-use

Combined Energy and water Balance effects
(in presence of landscape-scale heterogeneity)

Rising wet air forms clouds, increasing precipitation over native vegetation
Subsiding dry air reduces precipitation over cropland

More absorbed sunlight, more sensible heat, causes more rising air...

... Drawing moist air from irrigated cropland...

Native Heathland (woody shrubland) (DARK) Wheat cropland (LIGHT)

... causing subsidence over cropland (subsiding air is dry)

Chambers (1998)
Hypothetical (model-derived) effect of biome removal on Surface Radiation and water vapor budgets, and hence, climate

<table>
<thead>
<tr>
<th>Biome Removed</th>
<th>Local effect</th>
<th>Global effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical forest</td>
<td>-0.47 C</td>
<td>-0.22 C</td>
</tr>
<tr>
<td>Boreal forest</td>
<td>0.18 C</td>
<td>0.10 C</td>
</tr>
<tr>
<td>Temperate forest</td>
<td>-0.94 C</td>
<td>-0.22 C</td>
</tr>
</tbody>
</table>

Mechanisms of impact:

- Dark vegetation (e.g. forest) changed to lighter vegetation (e.g. crops or rangeland) increases albedo → causes cooling
- Removing deep-rooted vegetation limits/reduces evapotranspiration → reduces recycling to precipitation → causes heating
- Which mechanism more important depends on ecosystem type – in northern biomes, planting trees could add to warming!

Snyder et al. (2004)

Possible (i.e. modeled) global temperature effects of different kinds of land changes

Temperature differences relative to no-land-change climate change (A2 emissions scenario)

Bala, Caldeira et al., 2007
Possible (i.e. modeled) global temperature effects of different kinds of land changes

Temperature differences relative to no-land-climate change (A2 emissions scenario)

III. Direct effects of Land-use change: from local to global

A. Land clearing / degradation

B. Transformations of the hydrologic cycle follow from land use changes

C. Excess Nutrient loading following from fertilization of farmland
Global change, so far:

Agriculture

Climate Change

Source: Center for Sustainability and the Global Environment (SAGE), UW-Madison
1) Land Clearing / Degradation

- massive changes to Earth’s land
  - ~40% of land converted to agriculture
    - ~18 million km² in crops
    - ~30 million km² in pastures, rangeland
  - and ~80% of land has human disturbance
  - today, ~40% of global photosynthesis now in human hands

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Deforestation & Disease

- *Anopheles darlingi*
- most efficient vector of New World malaria infected by *Plasmodium vivax* and *Plasmodium falciparum*
- widely distributed across Latin America
- highly anthropophilic

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Center for Sustainability and the Global Environment (SAGE)
University of Wisconsin, Madison

Image Source: http://sagebiomarcel.com
2) Water Degradation

- Massive increases in water use
  - Water use tripled in 50 years
  - Mostly due to agriculture
    - 70% irrigation, 20% industry, 10% domestic
  - ~50% of available freshwater flow already co-opted
    - Result: dry rivers, groundwater depletion
Deforestation & Water Resources

Tocantins River upstream of Porto Nacional
- precipitation did not change
- discharge increased by 24-28%

3) Excess Nutrient Pollution

- massive release of excess nutrients
  - doubling natural nitrogen, phosphorus flows
  - polluted lakes and rivers
  - coastal “dead zones”

Source: Costa et al. (2003)
University of Wisconsin, Madison
And So On...

- **greenhouse gas emissions**
- **soil degradation**
- **reduced biodiversity**
- **novel biological threats**
- **agriculture, already has altered the biosphere as much as we expect from future climate change...**
- **combined impacts in the future?**

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Conceptual Framework for comparing land-use and trade-offs of ecosystem services (from Foley, et al., 2005)

“Flower” diagrams indicate 8-dimensions of ecosystem services: perhaps a middle ground (far right) is best able to support a diverse portfolio of ecosystem services?
Summary of Land Use change as a Global Change Driver

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