The world forest sink closes the global carbon cycle

Overview

- Data sources and methods
- Regional carbon estimates and dynamics
- Forest sink and the global carbon cycle
- Uncertainty, data gaps and future improvements
Global Forest Carbon Analyses

Data sources

- Forest inventories for boreal and temperate regions
- Permanent plots for tropical intact forests
- Tropical land-use change (emission and regrowth) (R. Houghton)
- FAO area statistics for the tropics
**IPCC accounting methods**

The good practice guidance (IPCC, 2003)

Definition of forests: Forests remain forests plus new forests

**Stock-change method for boreal and temperate forests**

Variable carbon density method for tropical intact forests

$$\text{Carbon Change} = \Delta + \text{HWP}$$

- **Carbon Stock (t1)**
- **C uptake**
- **Carbon losses to harvest and decay**
- **Harvested wood product (HWP)**
- **Carbon Stock (t2)**
- **Change in stocks** $\Delta$
Estimated carbon stocks and changes for 15 regions

- 4 boreal regions
- 8 temperate regions
- 3 tropical regions

Estimated carbon stocks and changes for 5 carbon pools:
- Living biomass
- Dead wood
- Litter
- Soil
- Harvested wood products

Estimated carbon stock and changes for 2 time periods:
The area covered by this study represents 95% of the world’s forests.

**Global Total Forest Area**

1990: 4190 Mha

2007: 4063 Mha

- Boreal: 1135 Mha
- Temperate: 557 Mha
- Tropic intact: 1392 Mha
- Tropic regrowth: 212 Mha
- Lost area: 767 Mha
- Excluded area: 2007

**Global established forests:**
Forests outside the area of tropical land-use change, including boreal, temperate and tropical intact forests.

**Tropical regrowth:**
The areas have been previously deforested. Separate LUC emissions are included before forest regrowth C uptake.
Global Forest Carbon Stocks (2007)

Total global forest C stock = 861 Pg C
(vs. 816 Pg C in the atmosphere)
**Annual C sinks in established forests**

<table>
<thead>
<tr>
<th>Region</th>
<th>1990-1999</th>
<th>2000-2007</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal forests</td>
<td>0.5</td>
<td>0.5</td>
<td>+1%</td>
</tr>
<tr>
<td>Temperate forests</td>
<td>0.7</td>
<td>0.8</td>
<td>+16%</td>
</tr>
<tr>
<td>Tropic intact forests</td>
<td>1.3</td>
<td>1.0</td>
<td>-23%</td>
</tr>
<tr>
<td>Global total</td>
<td>2.5</td>
<td>2.3</td>
<td>-8%</td>
</tr>
</tbody>
</table>

- **Boreal forests**: Increased sinks in European Russia due to abandoned farmlands and reduced harvesting; reduced sinks due to increasing disturbances in Siberia and Canada, and forest transition in some regions of Northern Europe.
- **Temperate forests**: Increased sink due to increased biomass density and forest areas, e.g., productive ages of forests recovering from historical land use (U.S.), low harvest rates and expanded forest lands (Europe), intensive afforestation programs in the past decades (China).
- **Tropical intact forests**: Decreased sink was caused by deforestation reducing intact forests and a severe Amazon drought in 2005. However, the excess C gain over loss resulted from progressively enhanced productivity.

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**Note**: The data reflects changes in C sinks from 1990-1999 to 2000-2007. The changes are shown as percentage increases or decreases.
Carbon Sinks in Biomass and other Pools

- Biomass
- Necromass (Deadwood, litter, soil, HWP)

Deadwood in boreal forests

1990-2007

64%

36%
Carbon Sinks and Sources (Pg C yr\(^{-1}\)) in the World’s Forests

Pan et al. (2011) Science
# Global Forest Carbon Balance, 2000-2007

## Forest land

<table>
<thead>
<tr>
<th>Biome</th>
<th>(Pg C yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Temperate</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>Tropical (intact)</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>Total</td>
<td>2.3 ± 0.5</td>
</tr>
</tbody>
</table>

## LUC in tropics

<table>
<thead>
<tr>
<th>Land class</th>
<th>(Pg C yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforestation emissions</td>
<td>-2.8 ± 0.5</td>
</tr>
<tr>
<td>Regrowth (after LUC)</td>
<td>1.7 ± 0.5</td>
</tr>
<tr>
<td>Total</td>
<td>-1.1 ± 0.7</td>
</tr>
</tbody>
</table>

**Global net forest sink = 1.2 ± 0.9**  
(Net sinks in temperate and boreal zones)
The Global Carbon Budgets (1990-2007)

7.0 Pg C yr\(^{-1}\)

-3.6

Fossil fuel emission

-2.2

Ocean sink

Atmosphere

8.3

“Missing Carbon”??

-2.4

Terrestrial ecosystems

The residual C flux to the terrestrial biosphere is dominated by forest uptake and non-forest biomes are collectively neither a major sink nor source

Ocean sink

LUC emission

1.3

-1.6

Global Forest C Budgets

2.9

The Global Carbon Budgets (1990-2007)
## The Global Carbon Budget (PgC yr\(^{-1}\))

<table>
<thead>
<tr>
<th>Sources and Sinks</th>
<th>1990-1999</th>
<th>2000-2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuel and cement (1)</td>
<td>6.5±0.4</td>
<td>7.6±0.4</td>
</tr>
<tr>
<td>Land-use change (2)</td>
<td>1.5±0.7</td>
<td>1.1±0.7</td>
</tr>
<tr>
<td>Total sources</td>
<td>8.0±0.8</td>
<td>8.7±0.8</td>
</tr>
<tr>
<td><strong>Sinks:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmosphere (2)</td>
<td>3.2±0.1</td>
<td>4.1±0.1</td>
</tr>
<tr>
<td>Ocean (3)</td>
<td>2.2±0.4</td>
<td>2.3±0.4</td>
</tr>
<tr>
<td>Forest land (4)</td>
<td>2.5±0.4</td>
<td>2.3±0.5</td>
</tr>
<tr>
<td>Total sinks</td>
<td>7.9±0.6</td>
<td>8.7±0.7</td>
</tr>
<tr>
<td><strong>Residual (5):</strong></td>
<td>0.1±1.0</td>
<td>0.0±1.0</td>
</tr>
</tbody>
</table>
Data gaps, uncertainty, and suggested improvements in global forest monitoring

- Land monitoring should be greatly expanded in the tropics and in un-sampled regions of northern boreal forests.

- A globally consistent approach to remote sensing and forest inventory is required to combine ground truth of forest C densities from inventories and reliable forest area from remote sensing.

- Improved methods and greater sampling intensity are needed to estimate non-living C pools, including soil, litter, and dead wood.

- Better data are required in most regions for estimating lateral C transfers in harvested wood products and rivers.
The total C sink in the world’s forests outside areas of tropical land-use change was 2.4 Pg C yr\(^{-1}\), or about 1/3 of annual fossil fuel emissions. The global forest sink is comparable to the entire terrestrial carbon sink deduced from fossil fuel emissions and land-use change sources minus ocean and atmospheric sinks.

The global forests play the large role in regulating atmospheric carbon levels (gross carbon uptake is \(\sim 4.0\) Pg.C yr\(^{-1}\), though a net sink is only 1.1 Pg.C yr\(^{-1}\)). The tropics is the most dynamic area for C exchange, but also with the greatest uncertainty in the estimates.
The forest C sink is found in every continent on Earth, suggesting overall favorable conditions for forest growth, which may imply a global driver such as rising atmospheric CO₂ fertilizing growth.

Extensive areas of relatively young forests have potential to continue sequestering carbon in the future.

Tropical biomass and boreal soils hold largest carbon pools and sinks. Warming and increased wildfires in the boreal zone, deforestation and extreme droughts, coincident with fires in the tropics, are likely the greatest risks to the continued large C sink in the world’s forests.
Thank You!