Disturbance Effects on Ecosystem Carbon Balance in Tropical and Boreal Forests

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Why study the effect of disturbance?

• Disturbance can be a primary controller of ecosystem carbon balance, and humans have a major impact on the rate of disturbance.

• The active management of disturbance may provide a mechanism for increasing carbon sequestration.

• Good long term precision of eddy covariance makes it particularly well suited to comparative studies of the effect of disturbance.
Where to study disturbance?

### Distribution of Carbon Pools

<table>
<thead>
<tr>
<th></th>
<th>Area ($10^{12}$ m$^2$)</th>
<th>Plant C (kg C m$^{-2}$)</th>
<th>Soil C (kg C m$^{-2}$)</th>
<th>Total C ($10^{15}$ gC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tropical forest</strong></td>
<td>18.1</td>
<td>11.5</td>
<td>10.4</td>
<td>400</td>
</tr>
<tr>
<td>Temperate forest</td>
<td>9.2</td>
<td>8</td>
<td>11.8</td>
<td>170</td>
</tr>
<tr>
<td><strong>Boreal forest</strong></td>
<td><strong>15</strong></td>
<td><strong>9.5</strong></td>
<td><strong>14.9</strong></td>
<td><strong>370</strong></td>
</tr>
<tr>
<td>Desert</td>
<td>18.2</td>
<td>0.3</td>
<td>5.6</td>
<td>110</td>
</tr>
<tr>
<td>Tundra</td>
<td>11</td>
<td>0.8</td>
<td>21.6</td>
<td>250</td>
</tr>
<tr>
<td>Wetland</td>
<td>2.9</td>
<td>2.7</td>
<td>68.6</td>
<td>210</td>
</tr>
<tr>
<td><strong>Global</strong></td>
<td></td>
<td></td>
<td></td>
<td>~2000</td>
</tr>
</tbody>
</table>

Tropical and boreal forests account for about 50% of terrestrial carbon, yet have been studied less.

Schlesinger 1997
Tropical forest

Brazilian Amazon: 6 million km$^2$

Area Affected by Deforestation: 10% (1988)

Selective Logging: 10,000-15,000 km$^2$yr$^{-1}$

Nepstad et al. 1999
Skole and Tucker 1997
LBA-Ecology Sites

Santarem, Para

LBA = Large Scale Biosphere-Atmosphere Experiment in Amazonia
Experimental Plan

Logged Site (km 83, USP/UCI)

Tapajos River

Control Site (km 67, Harvard)

Wind dir

INDEX MAP
Sahtor, PA

60 km

16 km
Logging Detail

- Tower
- 700 ha selectively logged in 2001
- Highway to town
- Winds E to W
- 4km

4km
Tower
700 ha selectively logged in 2001
Highway to town
4km
Tower Measurements

**METEOROLOGY**

PAR (up/down)
Radiation (short and long wave, up and down)
Rain

**PROFILES**

Wind (6 levels cups and 2D Sonics)
Temperature (6 levels)
CO$_2$/H$_2$O (12 levels)

**FLUXES (64 meters)**

Momentum/Heat  sonic anemometer
CO$_2$/H$_2$O  Infrared Gas Analyzer
Sonic anemometer looks **East**, the most common wind direction.
Elevator to raise and lower eddy flux sensors.
SITE IS LOGGED

Time Line

Select site

Infrastructure Installed

Ground-Based Measures begin

Tower measure begins

Soil chambers installed

July 1999
July 2000
July 2001
July 2002

Measurements to characterize logging

Undisturbed Baseline

SITE IS LOGGED

Logged Forest

Second tower installed
Carbon Balance - Results from undisturbed baseline period

- From allometry, forest was **not gaining or losing** large amounts of carbon prior to logging
  \(0 +/- 1.5 \text{ T C ha}^{-1} \text{ yr}^{-1}\)

- Tower-based annual sum using a **u* filter of 0.2 ms}^{-1} was 0.1 \text{T C ha}^{-1} \text{ yr}^{-1}, in agreement with the allometry.

- Annual CO2 exchange in tropical forest is **extremely sensitive to the treatment of nocturnal fluxes**
  \((-5.2 \text{ to } +1.0 \text{ T C ha}^{-1} \text{ yr}^{-1})\).
Carbon Balance - Results from undisturbed baseline period

Graph showing the carbon balance over a period from July 2000 to June 2001. The graph includes two curves, one representing $u^* = 0.3$ and the other $u^* = 0.2$. The un-filtered annual sum is shown by a green line, and the biometry is indicated by a red line. The graph indicates a change in the carbon balance after a period of 1 year.
**Seasonality** - Results from undisturbed baseline period

- Canopy photosynthesis and evapotranspiration **do not decline** in the dry season. Hydraulic lift redistributes water in the soil column, and may help trees avoid drought stress.

- Soil respiration is **controlled by moisture**, with a rapid increase following litter rehydration.

- **Seasonal cycle** of net CO2 exchange was the **opposite** of what we expected. Daily carbon gain is **greatest in the dry season**; forest lost carbon throughout the wet season.
Respiration is correlated with litter and soil moisture
**Seasonality** - Results from undisturbed baseline period

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• 2-3 trees ha\(^{-1}\) removed
• 5 T C ha\(^{-1}\) wood removed
• 15 T C ha\(^{-1}\) slash introduced
8% impacted by roads/skid trails
GAP MAP

• 10-15% gaps created

600 m
Original tower

Second tower

Wind dir

gaps

Post-Logging IKONOS Image

600 m
Average Daily Cycles of NEE

BLUE: PRE-LOGGING
GREEN: POST-LOGGING

OCT/NOV/DEC

JAN/FEB/MAR

Dry Season

Wet Season
Cumulative NEE

BLUE: PRE-LOGGING
GREEN: POST-LOGGING

2000/2001
2001/2002

$u^*$ filtered at 0.2 m s$^{-1}$
Fire plays an integral role in boreal forest ecosystems

Lightning-induced fire in a stand of black spruce between BOREAS NSA and Churchill in 1994

Dominant disturbance in many regions

Fire returns every 50 to 200 years

Maintains boreal landscape as spatial mosaic of forest patches in different successional stages
How does forest CO$_2$ cycle recover after fire?

Objective

1989 burn:
11 years after fire
1930 burn:
~70 years after fire
Experimental design: 7 identical, solar powered, automated towers running year round

Temperatures are -40 C in winter, +40 C in summer
Logistical challenges

Solar power

**Sunlight**
- Summer - ~20 hours
- Winter - ~4 hours
Logistical challenges

Sites are several km from nearest road
Logistical challenges

Access to sites during 6 months of winter is limited.

Data is transmitted via GOES satellite link, every 3 hours.
Logistical challenges

Equipment box is buried beneath soil, and covered by snow during winter.

Box temperature remains about 20°C when ambient temp is -40°C.
More deciduous

More evergreen

Nocturnal freeze; Deciduous begin senescence
Daytime freeze; Evergreen shutdown
Nocturnal above freezing; Evergreen turn on

13-year old (1988) CO₂ Flux
21-year old (1981) CO₂ Flux
39-year old (1963) CO₂ Flux
70-year old (~1930) CO₂ Flux

Air T

August 2001 | January 2002 | June 2002

Figure 1 Goudien et al. DOE-TCP progress report June 2002
Spring 2002 at 39-year old stand (mix of evergreen and deciduous)

Evergreen rapidly turns on with above freezing days and nights

Deciduous rapidly leafs out after a couple of warm days

Net CO₂ Exchange (µmol m⁻² s⁻¹)

Air Temp (°C)
Comparison of Summer Diurnal CO$_2$ fluxes
Pilot Study 1999, 2000

Mean CO$_2$ flux ($\mu$mol m$^{-2}$ s$^{-1}$)

Time of day (hour)

1981
1989
1964
1930
1850
Age of forest (years since burn)

Net ecosystem CO$_2$ exchange

$t$ C ha$^{-1}$ 75 d$^{-1}$
Conclusions

• Eddy covariance, within the context of a well designed experiment, is suited for studying disturbance.

• Preliminary data indicate that selective logging in a tropical forest has a modest, transient affect on carbon exchange

• Preliminary data indicate that time since recovery has a large impact on boreal stand carbon balance
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