Vulnerability of Northern Forests and Forestry: The Disturbing Influence of Climate

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Outline

- Global Perspective: human perturbations to the carbon cycle
- Stand and forest Carbon Budgets
- Past Changes as drivers of present and future net forest fluxes
- Historical influences for Canada
- Vulnerability during the Kyoto Commitment period
Human Perturbations to the Global Carbon Cycle

Only half of human emissions stay in the atmosphere: 7.9 up but only 3.2 remains.

Data for 1990s from IPCC 2001

6.3 ± 0.8
F Fuel, Cement

1.6 ± 0.8
Land-Use Change

2 to 4
Land uptake

1.7 ± 0.5
Oceans

3.2 ± 0.1 GtC/yr
Airborne Fraction

6 GtC/yr - equivalent to burning all of Canada’s forests twice a year. Completely. Every 6 months.
Mitigation Opportunities: How can we influence the atmospheric GHG balance?

Reduce emissions

3.2 ± 0.1 GtC/yr Airborne Fraction

6.3 ± 0.8 F Fuel, Cement

1.6 ±0.8 Land-Use Change

2 to 4 Land uptake

1.7 ± 0.5 Oceans

Increase Sinks

Surface biosphere

Atmosphere
Increases in atmospheric $\text{CO}_2$

Role of Biosphere?:
- only $\sim 50\%$ stay in atmosphere...now
- possible surprises
- vulnerable

Data from Keeling (pers comm. 1993)
Atmospheric C Changes over Time and Space

Northern ecosystems?

Flying Carpets
Matthews and Trivett
Carbon in the Circumpolar Boreal Forest

- **Biomass**: 64 Pg C
- **Peat**: 420 Pg C
- **Detritus**: 32 Pg C
- **Products**: 3.2 Pg C

**Net flux**: Sink ~ 0.5 Gt C yr⁻¹

Carbon Budget: stand level

- Large pool does not mean large flux
- Net flux is a complex balance
- That varies from stand to stand:
  - Species
  - Age
  - Local climate
  - Site productivity
  - Management
- And other components

- Important to note that: 
  Changes in pools = Net of fluxes in and out

- FOREST budget is a sum over stands of all kinds, ages, etc
Stand level C dynamics

Impacts of global Change?

- Change in C stock is removal from or addition to atmosphere

Change in C stock at the stand level

- C carrying capacity

- Stand break-up phase?

Increased early growth rate (CO2?)

- Biomass + detritus + soils

Decreased fertility (degradation?)

- Decreased/delayed growth rate (degradation?)

Maximum growth rate

Soils and detritus outputs > inputs

Soil & detritus left onsite

Impacts of global Change?

- Increased fertility (N)

- Increased early growth rate (CO2?)

- Decreased fertility (degradation?)

- Decreased/delayed growth rate (degradation?)
Stand level C dynamics

Impacts of global Change - changes in disturbance rates?

Death of a stand causes large change with both Immediate emissions Delayed emissions

But, some may have gone into wood products
Agents of (stand) mortality

- Chain saw!
- Fire
- Insects
- Other – wind throw, flooding...
Disturbances affect C stocks differently and play out differently over time.

- Insects leave nearly all dead biomass C to decay on site.
- Fire leaves up to 80% dead biomass C to decay on site.
- Harvesting leaves little dead biomass C to decay on site.
Hence keeping track of *demographics* is extremely important

- Essential in scaling from a stand paradigm to the forest paradigm
- Age-class distribution is a record of the past birth and death statistics

![Diagram showing fraction of area vs stand age. The histogram indicates a distribution with a peak around the middle age-class, decreasing towards younger and older age-classes. A note in green states: Most useful for forest composed of even-aged stands.]
Scaling up to forest level

**Age Class Distribution**

**Fraction of area** $f_i$

**Carbon Density** $C_i$ ha$^{-1}$

Sum over age classes to get total:

$$C = \sum C_i \times f_i$$

*older forests have more C.....*
Changes to the disturbance regime cause changes to the **forest scale** net carbon budget (sources or sinks).

Simplistic view – must account for changes in many ecosystem components and effects of different disturbance types.

- Older forests contain more carbon.
- Reduced disturbance rate

**Fraction of area**

**Average age**

**Stand age**
Disturbances in Canada’s forests
(1920 - 1995)

Note apparent increase after 1970

Area (Million ha)

1920 1940 1960 1980 2000

ClearCut Fire Insects Total
Shifts in age-class structure (Canada’s Forests)

Average age increasing

Average age: leveling off or decreasing
Forest Carbon : CBM-CFS2 System Diagram

Diagram:
- Atmosphere
- Inventory Data
- Decomposition
- Disturbance
- Photosynthesis
- Litterfall
- Harvest
- Forest products
- Very Fast Soil Pool
- Fast Soil Pool
- Medium Soil Pool
- Slow Soil Pool
- Decomposition
- Soil Data
- Aquatic Systems
- Litter and forest floor
- Oxidation
- Inventory Data
- Forest products
- Soil Data
- Disturbance Data
Net ecosystem C fluxes 1920 - 1995

Doing full calculation:
*Kurz and Apps, Ecological Applications 1999*

Note change after 1970

Variable Temp
Constant Temp

Source
Sink
Transfers and emissions of C

- Emissions (biomass & soil)
- Transfer (biomass to soil)
Annual Variation in NBP

1963
0.7 Mha disturbed
NBP: 242 Tg C/yr

1981
8 Mha disturbed
NBP: -43 Tg C/yr
Climate change? Management?

[Graph showing area (Million ha) from 1920 to 2000 with trends for ClearCut, Fire, Insects, and Total.]
Projected Summer Temperature Change Between 1975-1995 and 2080-2100
Combined Effects of Projected Greenhouse Gas and Sulphate Aerosol Increases - Canadian Model
## Annual Area Burned in Canada

<table>
<thead>
<tr>
<th>Year</th>
<th>1920</th>
<th>1940</th>
<th>1960</th>
<th>1980</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Area Burned (millions of hectares)</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

### 75 - 100 year fire cycle

**Fire Statistics**

BUT BUGS ARE ALSO IMPORTANT PLAYERS!
Disturbance regimes

Summary of what we have learned:

- historical disturbance regime: Determines present age class distribution and hence, constrains present carbon budget – AN AGE-CLASS LEGACY
- Changes in disturbance regimes induce forest scale sources (increases) or sinks (decreases)
- These structural changes are quasi independent of ecophysiological factors

- How will future unfold?
Potential Changes for Canada

Current climate

Source: Rizzo and Wiken, 1992

SENSITIVITY ONLY:
Changes in color represents vegetation *likely* to be under stress – i.e., *vulnerable*
The Challenge

Current climate

Climate Change Impacts

Changing Condition

Carbon stocks in today’s Forest Sector

Carbon stocks of Future Forest Sector
Past and future disturbances play a big role
The age-class legacy

- How will future C stock changes be affected by the current age-class structure of the managed forest, which is the result of past changes in disturbance regimes?
The age-class legacy

INITIAL CONDITIONS $t=0$

- **A**
  - Age class
  - Area

- **B**
  - Age class
  - Area

Graph showing biomass C over time (years): A decreases while B increases.
Changes in Natural disturbances

- Mountain Pine Beetle outbreak in BC starting now.
- Anticipated outbreak of Spruce Bud worm in next 5 years (cycle).
Conclusions

Forest carbon budget (stocks, net fluxes) must account for demographics of forest stands
Disturbance regime is primary determinant of demographics
Age class distribution reflects past disturbance regime
Disturbance regime is changing. Some of change may be climate change
Hence age class distribution is changing and this results in large + and – swings in annual carbon budget (sources and sinks)
Challenge: to influence the carbon budget, must influence the disturbance regime. Can we?
Probably not, but from the Canadian stakeholder’s perspective we’ll adapt…

..on the positive side, the effects of the OZONE-ACID RAIN-GREENHOUSE SYNDROME could mean a longer golfing season for Canadians.....
Fire Suppo-

- $500 Million spent
- Could extend fire sup-
million financial & eco-

ONLY YOU CAN POSTPONE
Fire Suppression is approaching its Physical/Economic Limits

Level of Protection Analysis for Ontario

2-3% of wildfires will continue to escape initial attack
The Terrestrial Carbon Cycle

Terrestrial sinks are transient changes in an active cycle. Nearly all the C that comes in goes back out

*Science 280: page 1393-1396*

But:

- No *a priori* reason that NBP should be positive
- Must be careful to account for disturbance loading to soil and litter pools
Improving Carbon Storage in Canadian Forests

Twelve Ways to Sequester More Carbon:
1. Protect Against Fire
2. Protect Against Disease, Insects & Other Herbivores
3. Salvage Dead and Dying Trees
4. Change Rotation Length
5. Control Stand Density
6. Enhance Available Nutrients
12 Ways To Sequester C in Forests

7. Control the Water Table
8. Select Species and Genotypes
9. Reduce Regeneration Delays
10. Select Appropriate Harvest Method (Lower Impact)
11. Manage Logging Residues
12. Establish, Maintain and Manage Reserves


Note this paper also considers some of the economic implications of these actions.