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

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Focusing primarily on boreal forest ecosystems, this talk examines the role of stand-replacing disturbances in a changing climate and poses the hypotheses that:
1) Present and near-term future carbon budgets at the forest scale are constrained by the historical and present disturbance regime;
2) Changes in these regimes due to global change has a larger near-term impact on boreal forest carbon stocks than the direct influence of climate change itself; and
3) Our ability to manage forest ecosystem carbon stocks is heavily dependent on our ability to influence the disturbance regime.

The increase in the natural disturbance regime throughout the 20th century has tended to switch the forest ecosystems of boreal Canada (and perhaps boreal Russia) from a sink to a source of atmospheric carbon. Much of this phenomenon is a legacy of changes in the natural disturbance regime that occurred up to 100 years ago (an age-class legacy). For this reason, the efficacy of near-term management interventions in influencing the near-term carbon balance of boreal systems is low, and strongly subject to climatic/weather variability and other factors. The same legacy of past disturbance regimes is responsible for the sink in temperate North America (and possibly Europe), but the disturbance regime was dominated by human actions, in a different direction (reduction), leading to a sink rather than a source while these forest systems recover from previous (anthropogenic) disturbance.

Global perspective: human perturbations to the carbon cycle

[Insert human perturbations to the carbon cycle graphic as Figure 1 - slide 3 from Powerpoint]

Figure 1 illustrates human perturbations to the global carbon cycle. Fossil fuel emissions account for about 6.3 Gt/C/year, which is the equivalent of burning all the forests of British Columbia twice a year. If 7.9 GtC are emitted and only 3.2 GtC remain; the rest (about half) is taken up somehow (about 2 GtC in the oceans and remainder on land). How might this terrestrial uptake change in the future? What could cause the terrestrial biosphere to become a source of carbon rather than a sink?

The assumptions used in the IPCC and other analyses of climate change are simplistic with regard to this issue. In general, we understand that in order to influence the greenhouse gas balance we can reduce emissions and/or increase sinks, but we are not clear about how best to accomplish this, particularly on the sink side. There are many possible surprises that change carbon uptake; it is not a smooth process but rather one characterized by hiccups and gulps. The living biomass of the Northern Hemisphere's land masses dominates carbon uptake and it is a very dynamic system.

Stand versus forest carbon budgets

It is important to recognize the difference between the carbon budget at the stand level and at the forest level. It is also key to realize that a large *pool* does not necessarily mean a large *flux*. Changes in the pool equal the net of carbon fluxes in and out.

[insert slide 7 from Powerpoint as Fig 2]

Figure 2 illustrates the carbon in the circumpolar boreal forest. Net flux varies by species, age, local climate, site productivity, and forest management. A forest's carbon budget is a sum over stands of all kinds and ages. Stand level carbon is quite dynamic, changing as the stand matures. Early in the stand's life, it is removing carbon from the atmosphere. At some point, the stand reaches its carrying capacity and comes to steady state. In this mature state, it will cause no net change in carbon stock. When the stand reaches its break up phase, it will become a source of carbon to the atmosphere.

Impacts of global change on forest carbon stores

Human inputs of nitrogen into the system can increase fertility and this N fertilization could increase carbon carrying capacity. CO_2 fertilization might increase early growth rate but not long term carbon carrying capacity, which is limited by nitrogen and water availability. Some global changes decrease fertility, such as compacting of soils, degrading the system and resulting in less carbon uptake. Such changes have significant impacts in the growing phase but not on the mature state.

When the stand dies, it causes a large increase in immediate emissions. However, if some of the material goes into wood products, that amount would not be released immediately to the atmosphere (unlike any fraction that is burned). Any material left to decompose would also delay emissions. Agents of mortality include harvesting, fire, insects, strong winds, and flooding. Different agents affect carbon stocks differently. For example, fire leaves up to 80% of the dead biomass carbon to decay on site, and insects leave nearly all of it, while harvesting leaves little dead biomass carbon on site.

Keeping track of demographics (birth and death) is extremely important and is essential in scaling from the stand to the forest level. The age-class distribution is a record of birth and death statistics. It is easiest to keep track of and draw information from even-age stands; 95% of Canada's forests are even age. In the tropics, however, only about 3% of stands are even age due to the ecology of system (dominated by gap phased dynamics). Mortality in the tropics is thus randomly distributed over ages and the fixed rotation age for harvesting is different. "Normal" age class applies to plantation forests, which are heavily managed; it doesn't apply to random distributions as are common in the tropics. The age class distribution determines total carbon stored; a greater proportion of older age trees means more carbon. Changes to the disturbance regime cause changes in the forest-scale net carbon budget (sources or sinks).

[Insert Figure 3: "Net Ecosystem Flux 1920-1995" - slide 19 from powerpoint]

Figure 3 shows data based on actual disturbances from 1920 to 1995. Fire and insects are the main agents of change with logging making a relatively small additional contribution. As the figure illustrates, the forest was a net sink of over 200 TgC/yr, but the disturbance regime changed in 1970, making the forest a source of up to 100 TgC/yr. There is a large annual variation in disturbance, for example from 0.7 to 8 million hectares disturbed by fire. There is this large interannual variability in global terrestrial carbon exchange.

Canada has seen shifts in age-class structure. There are different turnover times for different pools of carbon. Carbon in the litter pool turns over rapidly, in about one year, while logs represent a long-term pool, and soils an even longer term pool.

Past changes drive present and future net forest fluxes

There is a correlation between rising temperatures and rising disturbances. The system is vulnerable to the levels of climate change projected by the IPCC. The historical disturbance regime determines the present age class distribution, and hence constrains the present carbon budget and future carbon stocks.

Future Projections

In looking at potential changes to Canadian forests, models can be useful to predict vulnerability. This means that they can project where vegetation is likely to be under stress. They do not offer a prediction of what forest will be where.

Under a business as usual scenario, Canada's forest would not be a net source or sink. But the current mountain pine bark beetle outbreak and the spruce budworm outbreak projected to occur in next five years could mean that these forests will become a net source of carbon. Scenarios constructed from data derived from 32 managed forests in Canada suggest results that range from a source of 200 $MtCO_2$ to a sink of 600 $MtCO_2$. It is more likely that the forests will become a significant source of carbon.

Conclusions

- Forest carbon budget (stocks, net fluxes) must account for demographics of forest stands.
- Disturbance regime is the primary determinant of demographics.
- Age class distribution reflects past disturbance regime.
- The disturbance regime is changing. Some of this change may be due to climate change.
- Hence the age class distribution is changing, and this results in large positive and negative swings in the annual carbon budget (sources and sinks).

- Challenge: to influence the carbon budget, we must influence the disturbance regime, and it is doubtful that we can do so.