NORTHERN FORESTS AND GLOBAL C CYCLES IN A CHANGING ENVIRONMENT[1]

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The boreal forest biome consists of a broad complex of forested and partially-forested ecosystems which form a circumpolar belt through northern Eurasia and North America. Significant C has accumulated in forest biomass, forest soils including litter and coarse woody debris, and the organic soils associated with peat formation (Apps et al., 1993). Additional C stores are retained in undecomposed wood products and landfill material derived from forest biomass. The non-forested tundra and polar regions also contain significant biogenic C (estimates range from 55 to 256 Pg C) of both contemporary and post-glacial origin and these regions represent a region for future (and past) forest expansion.

Table 1: Contemporary boreal forest biome areas and C pools (from Apps et al., 1993). (Totals may not agree due to rounding errors)

	AREA (Mha)		CARBON POOLS (Pg C)					
	Area	Peat-land	Plant Biomass	Plant Detritus	Forest Soil	Peat	Forest Products	Total
Alaska	52	11	2	1	10	17	<0.1	30
Canada (Boreal Forest)	304	89	8	N/A[1]	65	113	0.2	186
Canada (Cordilleran)	72	3	6	N/A[1]	16	4	0.3	27
Russia	760	136	46	31	100	272	2.9	451
Scandinavia	61	20	2			13		15
Total	1249	260	64	32	199	419	3.4	709

The circumpolar boreal biomes - boreal forests (including boreal peatlands), arctic tundra and other polar regions - have played an important role in the global C cycle during past climatic changes. Presently, it is estimated that they act as global atmospheric sink of ca. 0.5 Pg C yr^{-1} (Apps et al., 1993). This estimate includes the following terms: net release of 0.17 Pg C yr^{-1} from global tundra; net uptake of 0.65 Pg C yr^{-1} boreal forest ecosystem biomass, detritus and soils; net peatland uptake of 0.05 Pg C yr^{-1}; and 0.06 Pg C yr^{-1} annual accumulation in undecomposed forest products.

The boreal biome sinks and sources listed are of the same order of magnitude and sign as that required to balance the global C budget and the observed latitudinal gradient. This is in contrast to earlier global C assessments. The tundra source (for which there are contradictory reports) was also required by Tans et al., (1990) to match the observed latitudinal gradient of atmospheric CO_2.

[1] Adapted from M.J. Apps *et al.*, 1993. See this reference for details and references not listed here.

Identification of the cause of the boreal sink is critical. The concern surrounding the 'missing' C sink - that which is required to balance known global C sources and sinks with the observed atmospheric increase - is closely associated with the sustainability of the sink terms. At the present time, only ca 50% of the additional C flux to the atmosphere known to be due to human activity (fossil-fuel burning and land-use changes) remains in the atmosphere; the biosphere is presently reabsorbing the other 50 %. Can we rely on this biospheric sink to continue in the future? Can we assume that the processes responsible for the present sink will maintain their present strength or is it possible that the sink mechanism will saturate, or worse, change to a source mechanism providing positive feedback to the atmospheric increase? We think not.

Kurz and Apps (1993) have argued that the primary mechanism responsible for the boreal forest ecosystem sink is a structural mechanism - not a change in biological processes. Simply stated, Kurz and Apps argue that the boreal forest ecosystems are presently aging - i.e., the average age is increasing - because of changes in disturbance regimes (wildfire, insect-induced mortality and harvesting) over the past century (Kurz et al., 1993). As the forest ages, its C stores increases and this structural change, Apps and Kurz (1991) have shown, is adequate to provide a Canadian sink of the order of 0.1 Pg yr^{-1} for a reference year (1986). Aging of the global boreal forest cannot continue indefinitely. Even in the absence of climate change and an unchanging disturbance regime, the C sink strength will be reduced and vanish in the decades ahead. If in addition, disturbance regimes (fire, insect-induced mortality, windthrow, and harvesting) increase in intensity and frequency, they will be accompanied by transient C-releases (see e.g., Apps and Kurz., 1993) followed by longer-term response by younger forests whose spatial structure and growth characteristics will depend on the then-prevailing climatic and environmental conditions (Apps, 1993).

The impacts of global change (increased atmospheric CO_2, climate change and shifts in land-use) must be factored in on top of the natural dynamics mentioned above. Current equilibrium projections of boreal forest response to a doubled-CO_2 global environment show major changes in the distribution of boreal vegetation. Some vegetation response models show C increases relative to present C pools (i.e., a net long-term C sink) but others, particularly those in which moisture stress plays a significant role, predict a decrease (i.e., a net long-term C source). However, these vegetation models assume that the forest ecosystems have reached equilibrium with the new (and assumed stable) climate system - a process that will take millennia (Schlesinger, 1990).

In the short-term (< 200 years), the response and C cycle dynamics to rapid climate change will be dominated by transient phenomena. Even if the climate conditions were to be stabilized at the doubled-CO_2 projections, the rapidity of these changes will produce non-linear responses as ecosystems lose synchrony with their environment. Because of the stand-replacing role that disturbances play in boreal ecosystem dynamics, C storage and exchanges during such transients will not be a simple linear change between two steady-state or equilibrium states (Apps, 1993). Rather the transient response of terrestrial C storage to climate change over the next century will likely be accompanied by large C exchanges with the atmosphere, regardless of the long-term (equilibrium) changes in terrestrial C storage. A number of recent analyses support this notion of short-term, non-linear transient releases of CO_2. These include global vegetation model simulations (Smith and Shugart, 1993; Nielson et al., 1993) as well as an examination of global soil pool dynamics in a warming environment (Townsend et al,, 1992). Human activities have the potential to accelerate the changes through non-sustainable resource practises, and through continued and accelerated air pollution. Although presently contributing to increased regional forest productivity through nutrient inputs (Kauppi et al., 1990), continued increases in air pollution will likely lead to soil acidification and forest decline in various regions, further exacerbating any climate-

induced transient C fluxes. Experimentally, the contemporary release of C in the arctic tundra observed by Oechel et al., 1993 and cited above, may be an indication that transient ecosystem behaviour is already taking place in these regions.

The most challenging problem facing contemporary terrestrial research is that of *scaling*. The requirements are for the scaling of observational data (usually limited to site-specific measurements) and of processes that regulate ecosystem dynamics over the entire range of spatial scales - from individual trees to forest stands, to landscapes and to the biome level. This scaling challenge has a temporal dimension as well - processes which govern C dynamics at the small scale operate on very fast time scales, but the issues with which the global C science must grapple are on the scale of decades to centuries. Two major present initiatives in which Canadian terrestrial scientists play a leading role, attempt to address some of these scaling questions. BOREAS - BOReal Ecosystem-Atmosphere Study - is a one-year 'snapshot' of the dynamics of a 1000 Km slice through the mid-continental boreal forest of Canada; spatial scaling of seasonal processes is a central theme of both theoretical and experimental activity. NBIOME- Northern Biosphere Observation and Modelling Experiment - is a longer-term study of the terrestrial ecosystems of Canada. It has a 100 year projection horizon and explicitly deals with both spatial and temporal scaling challenges to investigate vegetation dynamics, the carbon cycle and influence of disturbance regimes on the structure and function of terrestrial ecosystems over the next 100 years.

Selected Publications

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