SUMMARY

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Summary:

The goal of this report is to document the role of wildfire in the boreal forest ecosystem and summarize the available information on carbon loss from combustion and biotic flux changes (primary production and organic matter decomposition) following forest fires. The impact of climatic warming and insect infestations on forest susceptibility to fire is also among the topics covered within this report.

Forest fires from natural origin, such as those set by lightning, are responsible for the majority of the burned area in North America, and possibly also in Russia. Wildfires play a fundamental ecological role in the boreal forest by controlling, in interaction with climate and local growing conditions, the age structure and species composition of boreal forests, as well as carbon exchanges between forests and the atmosphere.

Forest fires release carbon (CO_2, CH_4 and particulates) directly into the atmosphere through the combustion of biomass and organic matter from upper ground layers (e.g. litter and humus). In the boreal region of North America, fire burns between 0.2 and 7.6 Mha of forest per year (mean 2.0 Mha, 1959-1997), the majority of the area burning during a limited number of large fire years. This results in a total direct carbon loss (TgC or 10^{12}gC) which varies greatly from one year to another. For example, it has been shown to vary from 3 to 115 $TgC.yr^{-1}$ (mean 26.4 $TgC.yr^{-1}$, 1959-1995) in Canada (Amiro et al., 2001). The estimation of the total direct loss of carbon is very sensitive to burned area values, which are reliable for North America (since 1970) but not for Russia, except for a few recent estimates based on satellite imagery.

When related to unit of burned area, the direct carbon loss estimated for Canada and Russia is identical (13.0 $tC.ha^{-1}.yr^{-1}$, Amiro et al. 2001 and Shvidenko and Nilsson 2000), whereas that for Alaska is almost a twofold higher (20.2 $tC.ha^{-1}.yr^{-1}$, French et al. 2003). This difference, as well as the uncertainty associated with these estimates, comes from a controversy regarding the importance given to the combustion of the forest floor (litter, humus and peat) and the use of different approaches to characterize the spatial and temporal pattern of fire severity (degree of burning), which varies according to fire type (surface or crown fires), the humidity degree and density of combustibles, and the presence of ladder fuels, among others.

In addition to leading to the release of significant amounts of carbon during the combustion of biomass, forest fires cause an additional loss of carbon into the atmosphere by initially reducing net primary production (NPP) and modifying the organic matter decomposition rate (or heterotrophic respiration, R_h). Generally speaking, this indirect carbon loss resulting from forest fires is little known and documented.

By temporal follow-up of NPP changes (satellite observations of normalized difference vegetation index or NDVI), some authors have observed a decline of 30 to 80% of boreal forest NPP in Canada and Alaska the year immediately following a fire. Other studies suggest that a loss of such a magnitude could go on for up to 3 to 10 years after a fire. The number of years required for a burned forest to recover its pre-fire productivity level in boreal regions varies considerably in the literature, from 2 to 50 years. The only study having carried out a temporal follow-up (1982-1998) of the NPP of burned stands (n = 61) from satellite images of NDVI from Canada and Alaska, establishes the recovery period to 9 years on average (2-14 years). The other studies regarding the impact of fire on NPP rely on a chronosequence approach. This approach, which compares stands of different ages, does not allow direct estimation of the post-fire decline in NPP or the recovery period since the pre-fire NPP is not exactly known.

Many studies assume that soil heterotrophic respiration is stimulated by the additional plant residues input and increased soil temperature observed following a fire. This hypothesis is generally based on indirect observations, such as the relationship between soil CO_2 effluxes and temperature. There exists few direct observations of the

effect of forest fires on soil respiration, and these are generally contradictory, showing either higher or lower values of soil respiration rates following a forest fire or by comparison to control sites.

Compiled studies on the temporal pattern of net ecosystem production (NEP) during a forest life cycle indicate that forests behave as net sources of carbon for the atmosphere after a fire, turning back into net sinks at variable ages (>1 to 24 years) to finally be in equilibrium with atmospheric CO_2 at maturity. These studies suggest that the indirect loss of carbon (decline in NPP and the respiration of combustion residues) is compensated at variable ages according to the forest type (mean of 32 years, varying between 12 and 70 years). The amount of carbon released during a fire (direct loss from combustion) would be almost four times more important than the indirect loss and compensated at an age at least four times older. Combining this information for the indirect and direct carbon loss, we estimate that boreal stands recover all the carbon lost after 160 years on average (varying between 60 and 350 years). Compared to the duration of the fire cycle in boreal forests, which lasts 130 years on average (varying between 20 and 439 years), this suggests that the carbon budget of boreal forests is close to zero (in balance) during a forest life cycle.

The duration of the fire cycle (the reciprocal being the fire frequency) remains one of the fundamental properties of the natural fire regime in regard to the carbon budget of forests. In terms of the impact of climatic warming on the future fire frequency, the results of modelling studies using climatic forecast of an atmosphere $2xCO_2$ as input to the Canadian forest fire weather index system indicate a general increase in fire activity in response to climatic warming, except in Eastern Canada in the case of Flannigan et al. (2001)' study. Several authors consider that such an impact is already underway, relying on the large increase in burned areas during the last two decades in North America. However, empirical studies, based on dendrochronology or analysis of charcoal accumulation rates in lake sediments during the Holocene, show that rising temperature has a variable effect (upward or downward) on fire frequency.

Insect infestations affect an area equivalent to that of forest fires in Canada. However, the impact of insect infestations on forest carbon budgets has not yet been the subject of thorough scientific studies, contrary to that of forest fires. In addition to having a potential impact on the carbon loss of boreal forests during defoliation, insects could increase the susceptibility of disturbed forests to fire, by contributing to the presence of ladder fuels and to a greater proportion of dead trees.