

Climate Change Impact on Landscape Fire and Forest Biomass Dynamics

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Forest biomass is one of the largest renewable energy sources in Canada. The dynamics of forest biomass are influenced by climate conditions and disturbance regimes (both natural and anthropogenic) at different scales. The objective of this study is to quantify and to develop improved scientific understanding of the dynamics of forest biomass production at the landscape scale influenced by various fire regimes that result from different climate change scenarios predicted by Canadian GCM and RCM models, through applications of spatially explicit models.

Biomass dynamics without fire

Since a forest landscape is a spatial mosaic of forest stands, the estimation of biomass dynamics at the stand scale appears to be essential for understanding landscape scale biomass dynamics. To evaluate these potential effects of fire regimes and climate change, biomass dynamics without fire need to be understood first. This knowledge base exists largely due to the considerable effort of developing biomass equations through field measurement in the 1980s for different geographical regions and tree species. Eighteen equations were selected for describing the biomass dynamics of major tree species in the Prairie Provinces of Canada: ten for canopy trees; six for understory vegetation; and two for belowground biomass. A comparative study revealed that biomass predictions for medium-sized trees are more consistent than those of small and large trees, and more attention should be paid to large-sized trees due to their significant contribution to biomass estimates.

Biomass equations are generally unsuitable for being directly used in climate change related research because they cannot demonstrate the effect of climatic variables. The results of a tree-ring analysis by Sauchyn and Beaudoin (1998) were used to improve the capacity of biomass equations in climate change research, i.e., biomass estimation is modified by a scale factor of $(precipitation - 140.22) / 220.83$.

Biomass dynamics subject to fire disturbances

The understanding of landscape scale biomass dynamics was obtained from the integration and synthesis of the research results obtained from the stand scale studies, together with the relationships of fire behaviour and weather variables, landscape structure, topography, and climate conditions. The integration and synthesis were conducted through using a refined spatially explicit model for landscape dynamics (SEM-LAND) (Li 2000, 2003). The SEM-LAND model is a FWM (Canadian Forest Fire Weather Index System) (Forestry Canada Fire Danger Group 1992, Hirsch 1996) and FBP (Canadian Forest Fire Behavior Prediction System) (Van Wagner 1987) relationship driven, raster-based simulation model at 1 ha resolution and yearly time step. It simulates a fire process in two stages: initiation and spread. The model has the following basic equations:

$$P_{Initiation} = P_{Baseinitiate} \times F_{Weather} \times F_{Fuel} \quad [1]$$

$$P_{Spread} = \begin{cases} 0 & (R \geq R_{Crit}) \\ P_{Basespread} \times F_{Weather} \times F_{Fuel} \times F_{Slope} \times (1 - FSE) & (R < R_{Crit}, S < S_{Crit}) \\ P_{Basespread} \times F_{Weather} \times F_{Fuel} \times F_{Slope} & (R < R_{Crit}, S \geq S_{Crit}) \end{cases} \quad [2]$$

where F_{Fuel} and $F_{Weather}$ are the scale factors calculated according to the FBP system representing the influence of fuel type and weather conditions, F_{Slope} is the scale factor due to slope, R is the daily precipitation, R_{Crit} is the critical value of daily precipitation and any precipitation that reaches or exceeds this value could stop a fire, FSE is the fire suppression efficiency, S_{Crit} is the critical value of fire size and any fire that reaches or exceeds this value can escape from fire suppression, $P_{Baseinitiate}$ and $P_{Basespread}$ are the baseline fire probabilities for initiation and spread stages, and they are characterized by a logistic equation:

$$P_{Base} = k / (1 + \exp(a - b \times Age)) \quad [3]$$

where a , b , and k are parameters, and Age is the forest stand age, or time since last burn. The model was validated by the observations from a study area of 7,432 ha in Alberta.

Data from a study area in west-central Alberta were used in this investigation of forest biomass dynamics. The area is 31,444 ha in size and dominated by lodgepole pine (50.4%). The empirical evidence showed that the fire cycle was 105 years before 1900 and 632 years after 1900. The simulated fire regime without human intervention was about 106 years. Among simulated fires, about 86% of fires were less than 10 ha, and about 3% fires were larger than 1,000 ha.

Fire suppression on fire size distribution

A lightning fire process under fire suppression was simulated in three stages. Stage one began when a fire ignition occurred, and lasted until it had been detected, reported, and fire crews arrived on the scene. The fire was initiated and spread freely during this stage. The second stage was from the beginning of the initial attack, until the fire had been stopped by suppression operations or the fire had escaped from the fire suppression effort. The P_{Spread} would be reduced by fire suppression efforts during this stage. The third stage was from the beginning of a fire escaping from suppression efforts until it had finally stopped. During this stage, the fire-spread process would be unconstrained again. This three-stage fire suppression description was intended to capture the broader picture that could be implemented in the fire regime simulators for the investigation of possible long-term consequences of fire suppression on the dynamics of fire regimes and forest ecosystems.

The simulation results showed that fire suppression could alter the distribution of fire sizes. Figure 1 shows the simulated fire size distributions with and without fire suppression. A large number of intermediate sized fires appeared to become small fires under fire suppression, and the resulting fire size distributions were closer to observed fires from 1961 to 1995 in Alberta (see Figure 2).

Forest age distribution and fire pattern

The accuracy of biomass estimation could be influenced by the uncertainty in estimating the size of burned area (such as irregular fire shapes and sizes, and remnants to account for the observation that up to 50% of total area of a fire event could be residuals), uneven tree mortality within burned areas (determined by the fire intensity and fuel consumption across the landscape), and the estimate of forest age distribution (both current and burned forest age distributions). The ultimate question to address was whether these factors could influence biomass estimates significantly.

It was well known that the theoretical negative exponential forest age distribution (Van Wagner 1978) was not always supported by empirical observations. There is a need to explain this discrepancy for a better landscape scale estimate of biomass. Four models and associated model experiments were employed to investigate this issue systematically (Li and Barclay 2001). The results indicated that a stable age distribution such as negative exponential can always be achieved as long as age-specific mortalities are constant over time. Any departure from this condition would cause instability of the age distribution. In forest landscapes subject to large and irregular fire disturbances, therefore, we could expect to frequently observe a departure from theory predicted negative exponential age distribution. The SEM-LAND model can display this explicitly and hence provide an explanation for the discrepancy between theory and practice. Figure 3 shows the forest age distribution dynamics under different fire cycles, and different shapes of forest age distributions can be observed at different times.

Effect of fire on tree/stand mortality

Based on the approach described in Ryan and Reinhardt (1988), we also investigated the effect of tree and stand mortality on the estimate of forest biomass for the Fort a la Corne area of Saskatchewan with a size of 132,742 ha. The fire intensities were calculated from the Fort a la Corne weather station data of fire seasons (May to August) from 1990 to 1999. The simulation results did not show a significant difference with and without considering tree and stand mortality. This was probably due to the favourable weather pattern for fire spread in the region.

Climate change impact on fire regimes and biomass dynamics

Using the climate scenario predicted by the coupled global climate model (CGCM1), we were able to simulate the altered fire regimes and associated forest biomass dynamics at the landscape scale using the methodology described in Li et al. (2000). The results suggested that in the areas suffering from a significant warming scenario like west-central Alberta, the fire activities are likely to be increased and thus result in lesser timber supply and biomass. Therefore, forest biomass dynamics could be significantly influenced by the fire disturbance regimes, resulting from climate change scenarios.

This study has also improved our understanding of fire regimes. The burned area-related fire regime descriptors such as fire frequency, cycle, and size distribution were treated traditionally as independent. The results from this study so far have demonstrated that fire frequency and size distribution are correlated without human intervention (Li et al. 1999); and point-based fire frequency and fire cycle definitions are the special cases of area-based definitions from a computational perspective (Li 2002). The detection of these quantitative interrelationships can simplify the preconditions for estimating regional fire regimes to make up for the incomplete empirical observations.

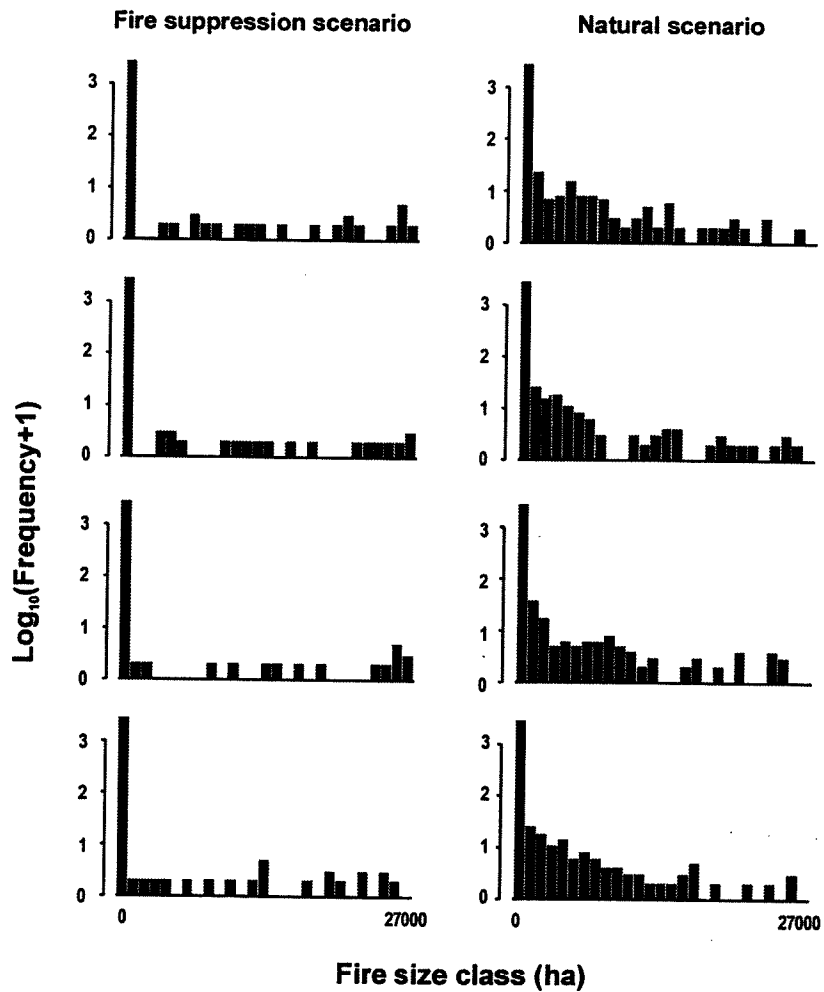


Figure 1. Simulated fire size distributions with and without fire suppression.

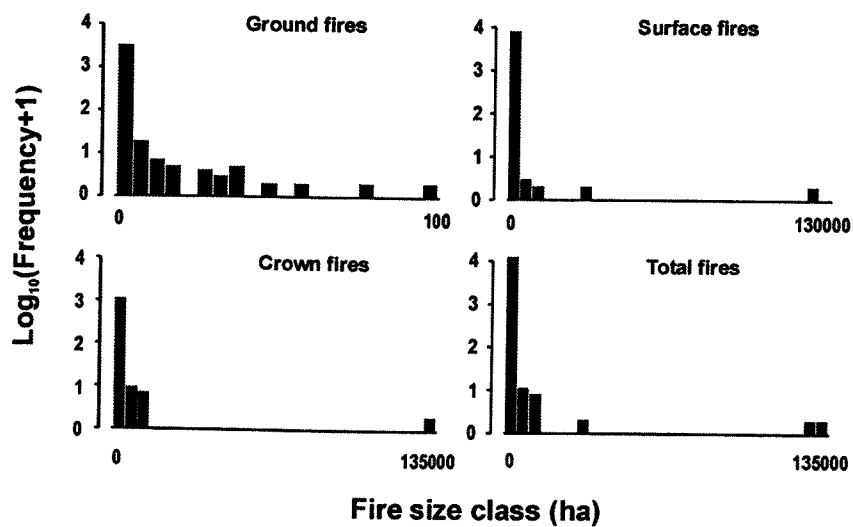


Figure 2. Observed fire size distributions in Alberta, Canada (1961-1995) for different types of fires.

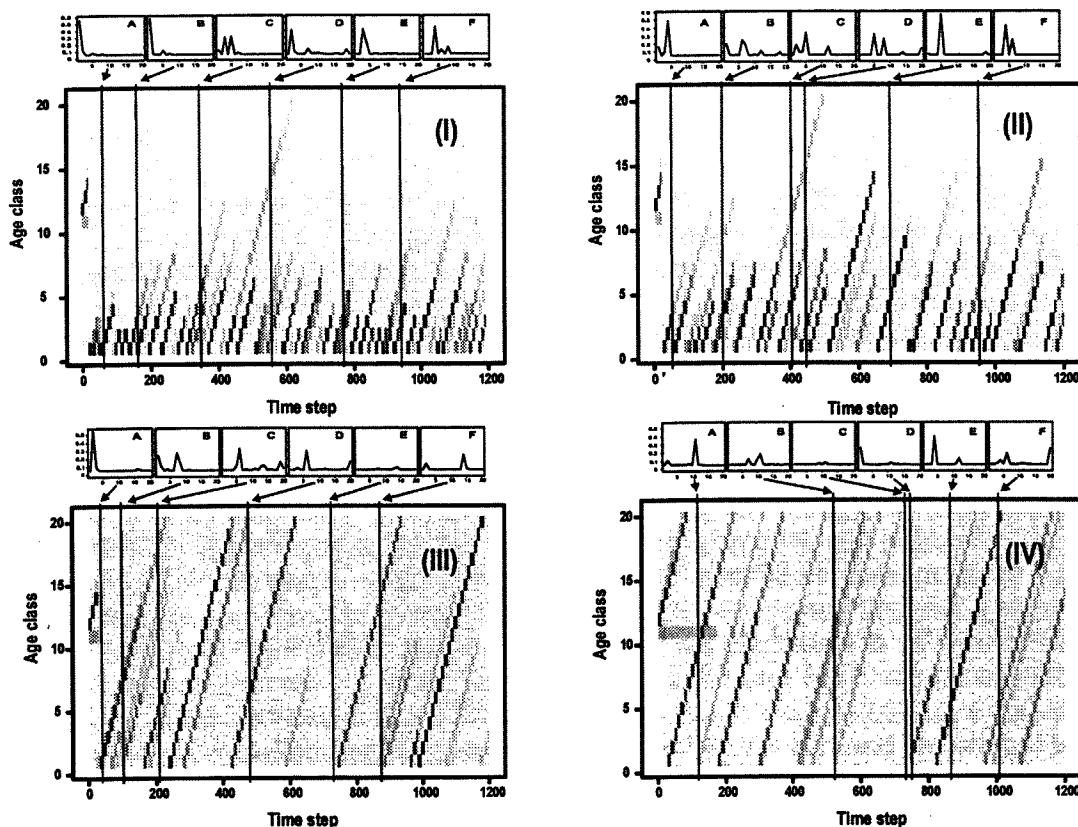


Figure 3. Simulated dynamics of forest age-distribution under fire cycles of 125 (I), 213 (II), 864 (III), and 3,800 years (IV). Each age class represents a 10-year interval, and the dark colour indicates high frequency. The small graphs associated with the four scenarios are the age class distributions at given years.

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