Influence of potential climate change on forest landscape dynamics of west-central Alberta

C. Li, M.D. Flannigan, and I.G.W. Corns

Abstract: Changes in climatic conditions may influence both forest biomass accumulation rates and natural disturbance regimes. While changes in biomass accumulation of forests under various climatic conditions have been described by yield equations, large uncertainties exist with regard to disturbance regimes. Under the doubling carbon dioxide scenario, global warming impacts have been predicted from simulation results of the first generation of coupled global climate model (CGCMI). The calculated fine fuel moisture code (FFMC) distribution from the simulation results showed a one-point increase compared with the distribution under current climate conditions. The impact of predicted changes in FFMC distributions on fire disturbance patterns, forest volume, and landscape structure was investigated by using the spatially explicit model for landscape dynamics (SEM-LAND). The simulation results showed increases in fire disturbance frequency and decreases in forest volume. The simulations also showed decreases in landscape fragmentation and landscape diversity, whereas total availability of core habitat for wildlife increased.

Résumé : Les changements dans les conditions climatiques peuvent influencer le taux d'accumulation de biomasse forestière et le régime de perturbations naturelles. Alors que les variations dans l'accumulation de biomasse dans les forêts soumises à des conditions climatiques variées ont été décrites par des équations de rendement, il existe de sérieuses incertitudes quant au régime de perturbations. Considérant le scénario qui fait doubler la quantité de dioxyde de carbone, les impacts du réchauffement global ont été prédits à partir des résultats du modèle climatique global de première génération. La distribution de l'indice du combustible léger calculé à partir de la simulation montre une augmentation d'un point comparativement à la distribution qui correspond aux conditions climatiques actuelles. L'impact des changements prédits dans la distribution de l'indice du combustible léger sur les patrons de perturbation par les feux, le volume de bois et la structure du paysage, a été étudié à l'aide d'un modèle (SEM-LAND) de la dynamique du paysage explicite du point de vue spatial. Les résultats de la simulation montrent une augmentation de la fréquence des perturbations dues au feu et une diminution du volume de bois. Les résultats de la simulation montrent aussi une diminution dans la fragmentation et la diversité du paysage, tandis que la disponibilité totale d'habitats fauniques en forêt profonde a augmenté.

[Traduit par la Rédaction]

Introduction

Various predictions of fire regime changes under the potential climate change scenarios have been reported in the literature. Under the projected global warming for the next century, fire frequency may increase (e.g., Clark 1988). In Canada, fire seasonal severity rating may increase by 46% (Flannigan and Van Wagner 1991), and fire season length may increase 28 or 29 days (Wotton and Flannigan 1993); in the United States, lightning fire ignitions may increase 44%, area burned may increase 78% (Price and Rind 1994), and frequent small fires may appear in some ecosystems (Swetnam 1993). Stocks et al. (1998) also predicted large increases in the areal extent of extreme fire danger in Canada and Russia under a 2 × CO_2 climate scenario. On islands on Lac Duparquet in the southern boreal forest of Quebec, however, Bergeron (1991) observed that reduced drought frequency caused a 34% decrease in fire frequency during 1870–1989 than the preceding 74 years. Bergeron and Flannigan (1995) predicted that under climate change the average fire weather index (FWI) would increase over western Canada but decrease over eastern Canada. Regions with increased and decreased FWIs were also found over large regions of the Northern Hemisphere for the next century (Flannigan et al. 1998).

These predictions were obtained mainly through two approaches. One is historical data analysis, in which historical records of fire occurrence are stratified by warm and cool periods and fire frequency is then calculated for these different climatic regimes. However, such fire frequency estimates are dependent upon the sampling design during the compilation of historical fire records (Johnson and Gutsell 1994). The other approach is modeling of changes in potential fire behavior using simulation results of general circulation models (GCMs). However, the interaction between fire disturbance and vegetation has not been taken into account.

We propose that the understanding of the linkage between fire disturbance patterns and vegetation dynamics should be emphasized in research. Among fire disturbance descriptors, for example, a significant correlation between fire frequency and size distribution has been demonstrated under natural

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C. Li,[1] M.D. Flannigan, and I.G.W. Corns. Northern Forestry Centre, Canadian Forest Service, 5320 - 122 Street, Edmonton, AB T6H 3S5, Canada.

[1] Corresponding author. e-mail: cli@nrcan.gc.ca

conditions (Li et al. 1999). The rate of forest biomass accumulation is affected by weather conditions, so climate change will influence forest productivity directly. As catastrophic disturbances, forest fires create new patches on landscapes and interrupt normal processes of forest biomass accumulation. Since fire behavior is largely determined by weather conditions, any changes in climate would probably alter the general pattern of fire disturbances. Therefore, climate change could alter existing fire disturbance patterns and, thus, influence forest biomass accumulation in an indirect way.

This paper attempts to address the question of how forest landscapes could be altered by potential climate change scenarios, by bringing the studies of the dynamics of forest biomass and fires together. Our efforts were mainly to explore the landscape consequences of the two processes interacting with each other under the influences of different weather conditions. We shall present a brief overview on descriptors of Canadian forest fire danger rating system (CFFDRS) in relation to weather conditions, as well as the first-generation coupled global climate model (CGCMI) and a model experiment that provided the description of potential fire behavior under a climate-change scenario. The results were then used as input information of a spatially explicit model for forest landscape dynamics (SEM-LAND) that enabled us to explore the potential forest landscape dynamics. The model validation and sensitivity analysis of the SEM-LAND has been summarized in Li (2000).

Fire behavior under global warming

It has been widely recognized that fire behavior could be altered under various climatic conditions. Empirical data have shown a general pattern that frequent small fires were more frequent under dry and warm climate conditions, whereas less frequent but more widespread fires occurred during wet and cool periods (e.g., Clark 1988; Swetnam 1993). Exceptions were also observed, such as the study of Bergeron (1991) mentioned at the beginning of this paper. Bergeron and Flannigan (1995) further predicted different scenarios for eastern and western Canada by calculating the FWI. The assumptions for this approach include that (*i*) weather conditions will influence the probability of fire ignition; (*ii*) wind conditions will influence the process of fire spread; (*iii*) weather conditions will change the moisture content of fuel; and (*iv*) the potential fire behavior is correlated to the level of fuel moisture content. The first three assumptions have been widely tested in fire behavior studies, and the fourth assumption may still need to be further investigated, because the potential fire behavior might also be influenced by other factors such as the spatial configuration of different fuels and the presence of fire ignition sources.

Canadian forest fire behavior

The Canadian FWI system (Van Wagner 1987) describes how various weather conditions can be translated into a number of indexes of fuel moisture codes that are important in predicting potential fire behavior. The indexes include the fine fuel moisture code (FFMC), the duff moisture code (DMC), and the drought code (DC). They represent the moisture content of fuels with different dry mass: about 0.25, 5, and 25 kg/m^2, respectively. The three fuel moisture content codes, especially the FFMC, are important in estimating the instantaneous rate of fire spread (ROS) at a given point, and the ROS is one of the primary products of the Canadian forest fire behavior prediction system (FBP) (Forestry Canada Fire Danger Group 1992; Hirsch 1996). Without a wind effect, a fire will spread in all directions with the same speed, and would result in a circular fire shape on level terrain.

When wind is present, however, a fire will have a higher rate of spread in the downwind direction than in other directions, which typically results in an elliptical fire shape (Alexander 1985). Alexander (1985) then proposed a simplified empirical approach where the length/breadth ratio of an elliptical fire shape was assumed to be proportional to wind speed when the fuel type is homogeneous. This method adequately describes wind effects on fire shape but is less capable of estimating the details of fire behavior within an elliptical fire shape. The inclusion of forest age as a factor affecting probability of fire spread may provide a more realistic estimation of final fire shape than the one offered by the fixed elliptical fire shape assumption (Li and Apps 1995; Li et al. 1997; Li 2000). The ROS will vary according to fuel type. A total of 16 discrete fuel types were identified in the FBP system and organized into five major groups: coniferous, deciduous, mixedwood, slash, and open. The calculation of the ROS is then based on the fuel type, and the ROS is a key factor that determines fire intensity. Therefore, a spatially heterogeneous distribution of fuel type may contribute to the nonuniformly distributed fire intensity across a landscape.

In summary, one can calculate fire behavior potential based on these physical relationships, with appropriate input of weather conditions. The weather conditions under the scenario of climate change (expressed as $2 \times CO_2$) can be obtained from running GCMs.

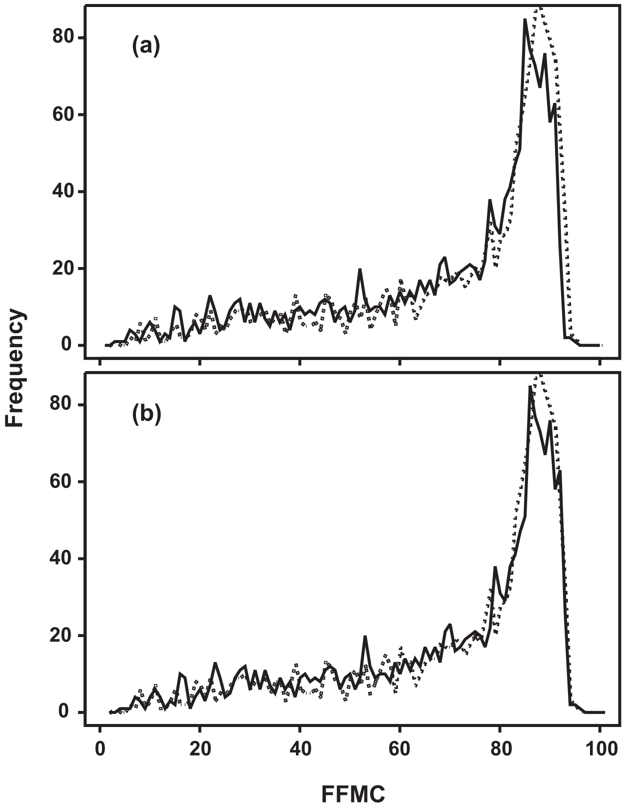
Canadian GCM and simulated FFMC distribution

One of the Canadian GCMs is a first-generation coupled global climate model, often called CGCMI. It is a coupled atmosphere–ocean model with a transform grid spacing of 3.75 × 3.75° and full diurnal and annual cycles (Flato et al. 2000). The model is a transient GCM model, i.e., the model output is available at times between $1 \times CO_2$ and $2 \times CO_2$. The spatial resolution of this GCM is about 400 km, which means topographical features like the Rocky Mountains are not resolved well. This simulation is not a forecast but rather is a possible outcome. Despite the shortcomings of GCMs they are one of the best tools in assessing the impacts of climatic change.

We used this model to estimate fire weather conditions under the $2 \times CO_2$ scenario: the mean temperature change for west-central Alberta (our study area, see the next section) increases by 3–4°C, and the precipitation ratio increases by up to 10%. This resulted in a calculated decrease mean in FWI of about 20%, but the maximum FWI increases by at least 50%. The changes in calculated FWI indicated that variation in fire behavior potential would be increased.

In this study, the fire season was defined as 1 May to 30 September. Historical daily weather conditions in Edson (west-central Alberta) from 1980 to 1989 (expressed as $1 \times CO_2$)

Fig. 1. The daily fine fuel moisture code (FFMC) distribution moves by one-point increase under a 2 × CO_2 scenario: (*a*) the daily FFMC distributions under 1 × CO_2 and 2 × CO_2 scenarios and (*b*) the daily FFMC distribution after a one-point increase of the 1 × CO_2 scenario. Solid and broken lines indicate 1 × CO_2 and 2 × CO_2 scenarios, respectively.



were used as initial conditions for the designed GCM simulation. The simulation was used to obtain a prediction of daily weather conditions under the 2 × CO_2 scenario. The simulation was run from 1980 until 2099, and the results of the 2090–2099 simulation were used as an approximation of weather conditions under the 2 × CO_2 scenario. Three simulations were available from the GCM output; the average daily values from the three simulations were used in this analysis.

Since FFMC is crucial in calculating the ROS, the results from the CGCMI simulation were translated into the daily FFMC by using the formulas of the FWI system, and thus, a daily FFMC distribution was compiled to represent the altered fire behavior potential. This distribution was then compared with the daily FFMC distribution of the observations during the 1980s (1 × CO_2). Figure 1 shows the comparison of the two daily FFMC distributions. Figure 1*a* is the original FFMC distributions under both 1 × CO_2 and 2 × CO_2 scenarios. A two-sample Kolmogorov–Smirnov test (Venables and Ripley 1994) performed on the two data sets indicated that the two distributions are significantly different (D = 0.0869, $p < 0.01$, n = 1530). Figure 1*b* is the one-point increase of the FFMC distributions under a 1 × CO_2 scenario against the FFMC distributions under a 2 × CO_2 scenario. We examined whether this one-point increased FFMC distribution under a 1 × CO_2 scenario within a particular range of FFMC values from 75 to 95 was significantly different from the one under a 2 × CO_2 scenario, by applying the two-sample Kolmogorov–Smirnov test. The result of the test indicated that the two distributions were not significantly different (D = 0.0352, p = 0.6132, n = 847). This statistical test suggested that the daily FFMC distribution may increase one point (i.e., towards higher FFMC values) under a 2 × CO_2 scenario, especially for the FFMC values from 75 to 95. The FFMC scale is not linear in terms of impact on fire behavior, for example, it is hard to get a widely spreading fire until FFMC is about 88. Furthermore, a one-point difference between FFMC 94 and 95 is much different than an FFMC change of 80–81. Therefore, we investigated how fire disturbance patterns and their associated forest dynamics could be changed with this predicted daily FFMC distribution, by applying the SEM-LAND model on a study area in west-central Alberta.

Fire disturbance patterns and forest dynamics

The study area

A 7432-ha area (Athabasca Working Circle Compartment 24) of the Weldwood of Canada Ltd. (Hinton Division) in the Rocky Mountain foothills of west-central Alberta, was chosen as our study area. Lodgepole pine (*Pinus contorta* ssp. *latifolia* Dougl.) dominated forests occupy 58% of the study area, whereas hardwood (primarily trembling aspen, *Populus tremuloides* Michx.) dominated forests are uncommon (only about 1% coverage) (C. Li, unpublished data). Other forest types include black spruce (*Picea mariana* (Mill.) BSP) (16%), white spruce (*Picea glauca* (Moench) Voss) (4%), and balsam fir (*Abies balsamea* (L.) Mill.) (2%). The rest of the area (19%) is covered by other vegetation types, such as timbered muskegs, open muskeg or swamp, and brushland.

Two different fire regimes were identified based on a fire-origin map: one with a fire cycle of 106 years appeared before 1900; the other with a much longer fire cycle was shown after 1900 (0.28% of the study area was burned by three fires since then; see Li 2000). This dramatic change in fire cycle could be a result of many factors, such as a successful fire suppression program, less fire ignition sources, and a wetter climate.

The Alberta vegetation inventory (AVI) has data layers of vegetation cover type, forest age, site index, and the digital elevation model (DEM) for the study area, which was used in the SEM-LAND simulation experiment as an initial landscape structure.

Simulation experiment using SEM-LAND model

The SEM-LAND model

The SEM-LAND model was designed to simulate the dynamics of a forest landscape under various disturbance regimes (Li 2000). The current version of the model contains mainly three components: forest growth, fire disturbance, and forest regrowth after fires.

A forest landscape was simulated as a grid of rectangular cells. Each cell represents an area of 1 ha that could be covered by a specific type of forest, a lake, or a type of non-

Fig. 2. The procedure for calculating the scale factors for the baseline fire probability.

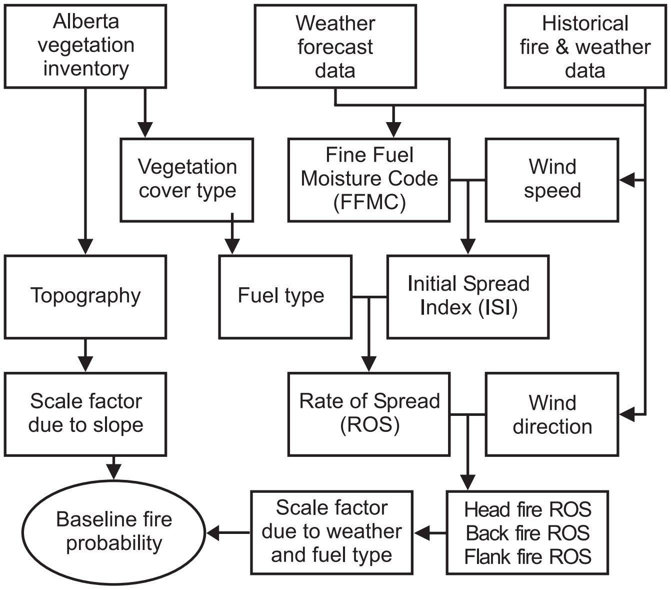
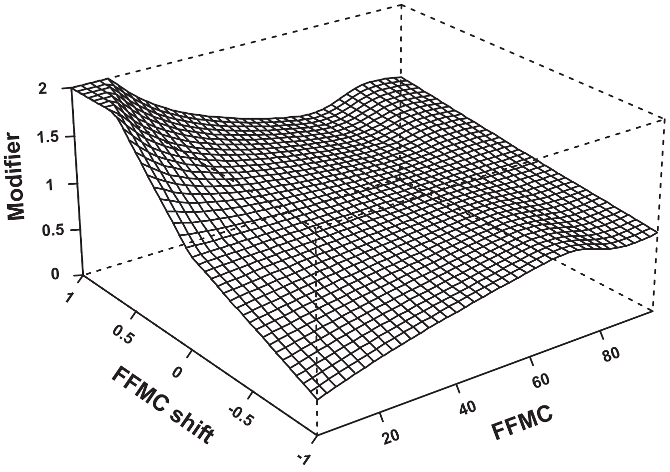


Fig. 3. The scale factor for the baseline fire probability under different fine fuel moisture code (FFMC) values for the fuel type C-3 (mature jack or lodgepole pine).



forest cover. The forest growth in a given cell was expressed according to the projected inventory under average climatic conditions, which was published by the Alberta Forest Service (1984).

A fire process was simulated as two stages: initiation and spread (Li and Apps 1995, 1996). The initiation stage starts from a fire ignition until most trees in a cell are burned. Whether a fire ignition would result in a fire initiation will be determined by a fire initiation probability, which is a function of weather and forest conditions in the cell. Once a fire is initiated, it has the potential to spread to its neighboring cells. Whether a given cell would be burned because of its adjacency to a burning cell will be determined by a fire spread probability, that is a function of weather, topography, and forest conditions in the cell. The fire-spread process will continue until it stops in all directions or reaches the boundary of the landscape. Fires from outside the region were not allowed to spread into the study area in this simulation.

The baseline fire initiation and spread probabilities represented the overall susceptibilities of fire initiation and spread for the landscape. They were assumed to be dependent on time since last fire for the forest stands younger than 30 years and to be independent of time since last fire once a stand reached 30 years. The baseline fire probabilities were modified by a number of scale factors such as slope, weather, and fuel type. The simulation of a fire disturbance incorporated the known physical relationships summarized in the FBP system, and used the ROSs calculated for various fuel types under different wind speeds as approximations of scale factors for the baseline fire probability. Figure 2 summarizes the procedure of calculating these scale factors.

After a fire, the forest cover type was assumed to remain unchanged. This was a black box type assumption based on the published succession pathways of favoring self-replacement for closed-crown forest types in the boreal forest (e.g., Payette 1992). This assumption is suitable for the study area, because coniferous forest types are dominant. These forest tree species have been adapted to the frequent fire environment. A detailed description of the SEM-LAND model can be found in Li (2000).

Simulation experiment

The simulation experiment was carried out for two different scenarios. One was for the common situation in the boreal forest with a fire cycle of about 100 years. It was achieved by using the observed daily FFMC distribution of the 1980s ($1 \times CO_2$) as model input. For every individual fire ignition event, the FFMC value was randomly sampled from the distribution. The other scenario was for the potential $2 \times CO_2$ situation from the climate change prediction. Since the predicted daily FFMC distribution was about a one-point increase compared with the distribution under $1 \times CO_2$ situation as examined in the previous section, the baseline fire probability under $2 \times CO_2$ situation was modified by a scale factor, *F*, calculated as

$$F = \frac{\mathrm{ROS}_{2 \times \mathrm{CO}_2}}{\mathrm{ROS}_{1 \times \mathrm{CO}_2}}$$

Figure 3 shows how the *F* value changes with different FFMC values for the fuel type C-3 (mature jack or lodgepole pine) under different FFMC distributions. Although the higher *F* values are in the range of lower FFMC values, they may not have a significant impact on baseline fire probabilities because of low values of ROS corresponding to the lower FFMC values. In contrast, in the situations of higher FFMC values, even a slight change in *F* value would cause significant modification to the baseline fire probabilities because of high values of ROS corresponding to the higher FFMC values.

Various curves for the *F* value can be calculated for different types of fuels, and the scale factors represented by these curves were used in the simulation experiment. The daily wind speed distribution was assumed to remain unchanged under the $2 \times CO_2$ scenario (Flato et al. 2000), so the observed daily wind speed distribution during the 1980s was used in the simulations under both scenarios. The wind direction was randomly determined for each individual fire

Fig. 4. The dynamics of mean forest age (*a*) and mean gross volume (*b*) under the 1 × CO_2 and 2 × CO_2 scenarios. Solid lines are the simulation results for 1 × CO_2, and broken lines are the results for 2 × CO_2.

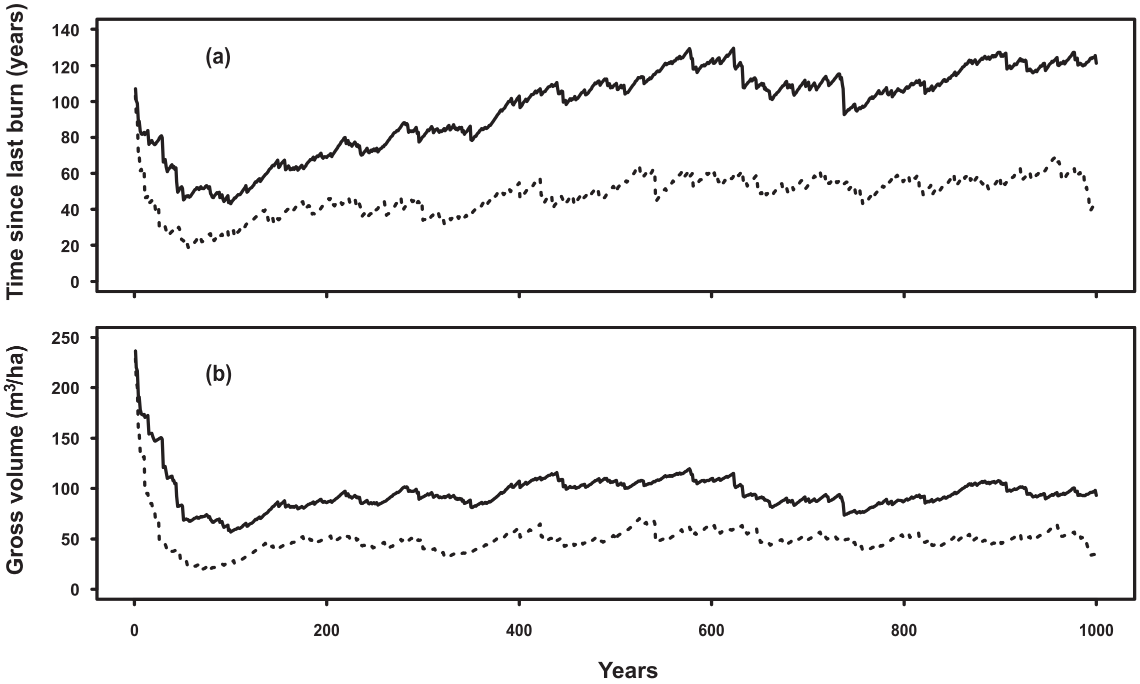


Table 1. The comparison of fire disturbance patterns under the 1 × CO_2 and 2 × CO_2 scenarios for a 1000-year simulation.

Items	1 × CO_2	2 × CO_2
Fire cycle (year)	108.08	64.84
Mean annual fire number	0.37	0.38
Mean annual burned area (ha)	75.17	122.19
No. of years with annual burn >1000 ha	2	15

from eight directions. This treatment was reasonable for the purpose of comparing simulation results, although it was not a true representation of the real world. For the same reason, the fire ignition sources were assumed to be unchanged under climate change scenario.

Since most forest stands in the study area were older than 80 years, a single fire initiation might result in a large area been burned, given the conditions of weather favors the spread process and without any fire management operation. Therefore, the model behavior needs a period of time to stabilize. Ten replications were carried out for the stochastic simulation for each scenario, and the 1000-year simulation results of forest volume and fire disturbances were averaged at each year of the simulations. A number of landscape indices were calculated from the simulated forest age-mosaic maps (with an interval of 20 years) by using FRAGSTATS (McGarigal and Marks 1995). The indices were used to investigate how the landscape structure could be altered under the climate change scenario.

Fire disturbance patterns and associated forest dynamics

Table 1 summarizes a number of characteristics for fire disturbance patterns under the two scenarios. While having small changes in the mean annual fire number, the mean annual burned area would be significantly increased under the 2 × CO_2 scenario of potential climate change. The number of years with mean annual burned area larger than 1000 ha is significantly higher under the 2 × CO_2 scenario (15) than that under the 1 × CO_2 situation (3), during the 1000-year simulation. Thus, the fire cycle is shortened, i.e., the fire frequency increases.

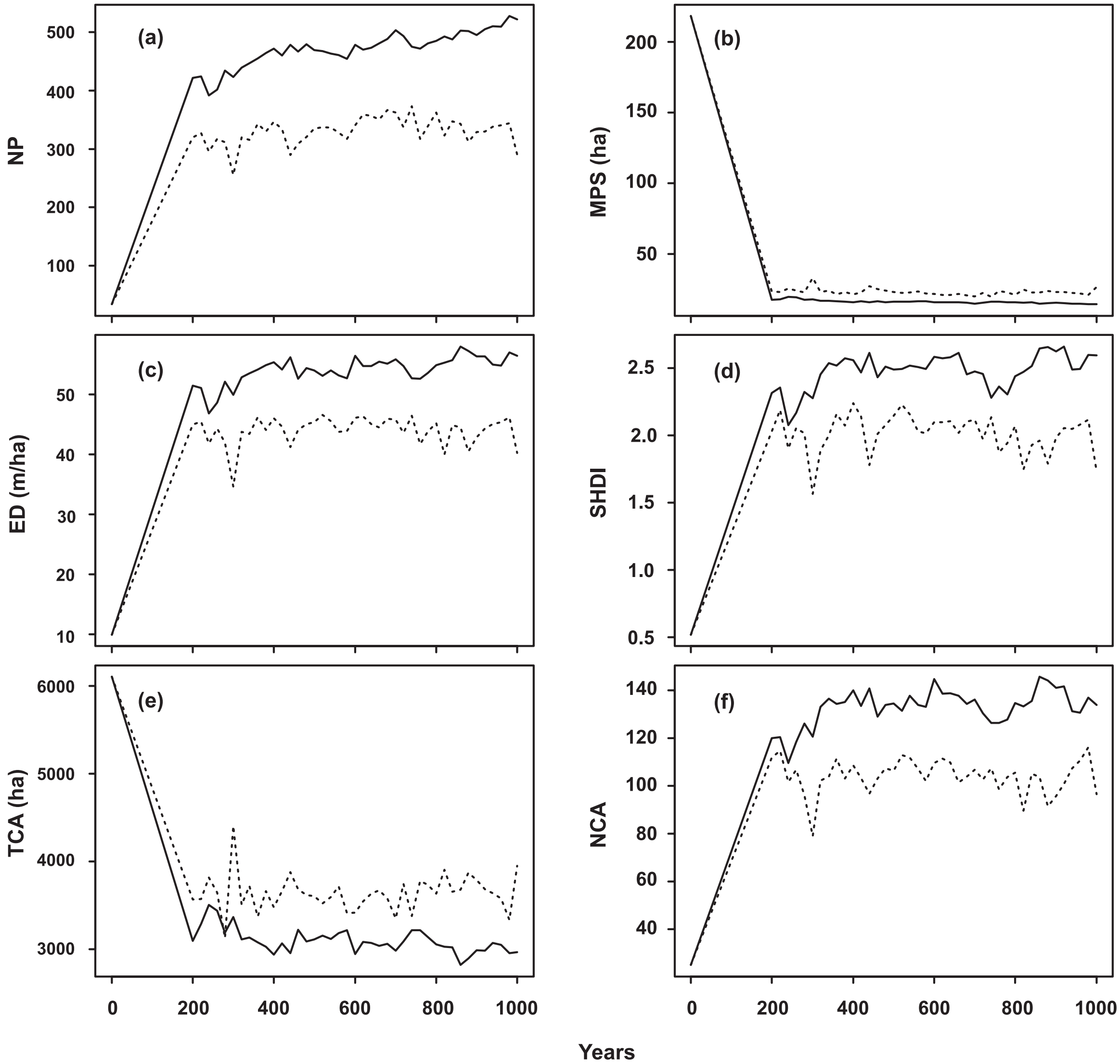
Figure 4 demonstrates the dynamics of mean forest age and mean gross volume, defined as the average volume per hectare across the landscape and provided information on standing biomass in average. According to the model, both the mean forest age and mean gross volume will be significantly lower under the 2 × CO_2 scenario than under the 1 × CO_2.

Potential changes in landscape pattern

Potential landscape structure changes were investigated mainly for landscape fragmentation, landscape diversity, and wildlife habitat availability. The level of landscape fragmentation was indicated by the number of patches (NP), the mean patch size (MPS), and the edge density (ED) defined as the average length (metres) of all edge segments involving the corresponding patch type per hectare; the landscape diversity was indicated by the Shannon diversity index (SHDI); and the wildlife habitat availability was indicated by the total core area (TCA) and the number of core areas (NCA). The formulas for calculating these indexes can be found in McGarigal and Marks (1995).

Under the 2 × CO_2 scenario, the level of landscape fragmentation is decreased, as indicated by lower NP (Fig. 5*a*) and ED (Fig. 5*c*), as well as higher MPS (Fig. 5*b*). The landscape diversity (SHDI) is decreased (Fig. 5*d*). The wildlife habitat availability of those species strongly associated with patch interiors is increased, as indicated by higher TCA (Fig. 5*e*). However, the NCA is lower (Fig. 5*f*), resulting in a higher mean core area and lower ED (Fig. 5*c*).

Fig. 5. Temporal dynamics of landscape indexes under 1 × CO_2 and 2 × CO_2 scenarios: (*a*) number of patches (NP); (*b*) mean patch size (MPS) (ha); (*c*) edge density (ED) (m/ha); (*d*) Shannon's diversity index (SHDI); (*e*) total core area (TCA) (ha); and (*f*) number of core area (NCA). Solid lines are the simulation results for 1 × CO_2, and broken lines are the results for 2 × CO_2.



Discussion

The potential impact of climate change on various aspects related to human life has been addressed at different spatial contexts such as globally (IGBP Terrestrial Carbon Working Group 1998), regionally (land use planning), and locally (landscape design). It has been recognized that, in Canadian forests, the climate change will influence (*i*) growth rate of trees (e.g., Hogg 1999; Zhang et al. 1999); (*ii*) natural disturbance regimes such as fire (Weber and Flannigan 1997; Weber and Stocks 1998), which reset the process of forest biomass accumulation; and (*iii*) tree species distributions (e.g., Zoltai et al. 1991).

The potential impact of climate change has been studied by analyzing collected empirical data sets. For example, Swetnam (1993) collected a fire scar data set from giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz), which covered warm and cool periods in history. The data set was then stratified according to warm (A.D. 1000–1300) and cool (about A.D. 500–1000 and after A.D. 1300) periods. The statistical results from the stratified data sets revealed historical fire disturbance patterns in different periods. By assuming that the potential climate change scenario will be similar to the historical warm period, Swetnam (1993) was able to predict that the potential global warming may result in increased fire frequency with smaller fires in sequoia groves.

One limitation of this empirical data-based analysis approach is that the results are dependent upon the locations where the data sets were collected. For example, Bergeron's (1991) conclusion from an analysis of a data set collected from islands on Lac Duparquet in the southern boreal forest of Quebec was different from that of Swetnam (1993). Thus, Bergeron (1991) presented a different prediction of the potential climate change impact. Because of the difference in the upper limit of the area burned by a single fire event, the fire disturbance patterns on islands might be different from those on large forested areas, and this phenomenon has also been noticed on the island of Hokkaido, Japan. These results suggest that the change in fire regime with global change will depend on fuel type and location (weather and topography) with some areas showing increases in fire activity while other areas may show decreases in fire activity.

Two kinds of simulation models have been used to study the potential climate change impact: meteorological and forest landscape models. The meteorological models are those aimed at simulating changes in temperature, precipitation, etc., at a global scale. These models are called GCMs. More detailed simulations can be carried out by using regional climate models (RCMs). The general predictions of future climate conditions from GCMs can then be used to predict future vegetation cover types, based on the relationships among current climate patterns and vegetation cover types in different regions. This approach, however, does not adequately consider the impact of changing disturbance regimes that influence vegetation dynamics, and hence species composition of vegetation cover. A possible way of improvement is to include a module of vegetation dynamics into the GCMs.

Forest landscape models can be used to investigate landscape responses with regard to known fire disturbances. For instance, Baker (1995) was able to simulate the long-term response of landscapes to human intervention and global change by using the DISPATCH model. The model requires input data on distributions of fire size and fire frequency that characterize a fire regime. Two major limitations of these models, however, can be noted. First, these models require fire regime descriptors as input information; therefore, the details of every fire event such as final size and shape need to be determined before a fire event is simulated. Second, the interactions among fire events, landscape structure, and weather conditions are not included in the model design. For example, when a size has been assigned to a particular fire event, the model will spread the fire no matter what the landscape structure is, until the assigned fire size is reached. These limitations might reduce the model capability of exploring landscape dynamics in different regions under various climate scenarios.

The methodology presented in this paper is essentially to combine the above two methods, and to simulate fire disturbances and landscape dynamics under potential climate change within a single model. However, three major differences with the above two methods can be identified. First, the alteration in fire disturbance patterns under different climate scenarios was described by the changing distributions of the FFMC code, rather than the FWI values of potential fire risk. This is because the relationship between the FFMC and fire behavior has been explicitly summarized in the FBP system. Secondly, fire regimes were simulated by incorporating available results of fire behavior studies summarized in the FBP system (Li 2000), rather than predetermined from the results of empirical data analysis. Thirdly, the landscape dynamics under various fire regimes were the result of interactions among fire events, landscape structures, and weather conditions, rather than results of user-defined fire regimes. These different treatments implemented in the SEM-LAND model have ensured that simulation results on both fire and landscape dynamics are interactive. We propose that more attention be paid to this type of interactive model, because ecosystem components are interactive.

The simulation results presented in this paper are consistent with the ones reported in the literature, i.e., global warming scenarios can result in increased fire frequency, without considering human interventions. Our results showed that, under a 2 × CO_2 scenario, the climate conditions for the study area would be changed, and such changes can be translated into a one-point shift in FFMC distribution towards higher values. The shift in FFMC distribution could change the fire regime considerably, if no fire suppression action is taken. Consequently, forest biomass, the level of landscape fragmentation, and landscape diversity could be decreased, and the total availability of wildlife habitat for those species strongly associated with patch interiors could be increased. We did not consider human intervention during the current investigation because of the complexity of its impact presentation, but this will be one of our future studies.

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