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A FireSmart approach to integrated fire and forest management in the boreal forest region of Canada

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A FireSmart approach to integrated fire and forest management in the boreal forest region of Canada

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Executive Summary

Our objectives were to 1) further our understanding of integrated fire and forest management planning and 2) develop decision support systems that can be used to enhance the ability of fire and forest managers to work together to develop, evaluate, and implement integrated fire and forest management policies and strategies that will contribute to the sustainable management of Canada's boreal forest.

We developed a burn probability model that predicts when and where fires might occur, the performance of the initial attack system and the growth of fires that escape initial attack to predict the probability that each point on the landscape will burn given the fuel, weather, topography and level of fire protection. We applied that model to the area surrounding Miller Western International's Whitecourt Forest in Alberta and the Romeo Malette Forest (RMF) in Ontario. We then addressed the need to develop and evaluate strategies for mitigating problems associated with areas in which the burn probability is high.

The spatial and temporal optimization of fuel management activities poses very difficult mathematical modelling challenges due to the spatial nature of the problem and the fact that fire occurrence, control and spread are stochastic or random processes. We developed a heuristic hierarchical planning system that is designed to produce near optimal spatially explicit integrated fire management and harvesting strategies.

FireSmart strategies strategically fragment forest landscapes to mitigate potential fire losses but there is no guarantee they will not do so in ways that are detrimental to wildlife and other aspects of ecosystem health. We therefore developed a framework for evaluating the impact of FireSmart strategies on wildlife.

One of our most significant accomplishments was the development of a shared understanding of integrated fire and forest management planning, some of the strengths and weaknesses of the approach, and the creation of a widespread commitment to continue research on this important area. Our findings and their potential implications for integrated fire and forest management include;

1. burn probabilities can vary both across the landscape and by fuel type within a forest management unit,

2. FireSmart strategies may produce more habitat than current practices but not as much as not harvesting at all in some forest management units,

3. the inclusion of protection values in forest management planning can change the spatial and temporal harvest scheduling decisions and those changes can fragment the forest and reduce the fire spread potential in the forest.

Introduction

Fire is a natural component of many forest ecosystems and is particularly important in the boreal forest region of Canada. Fire and forest managers seek to achieve a healthy balance between the detrimental impacts of fire on public safety, property and forest resources, the beneficial impacts of fire on natural forest ecosystem processes, and the cost of achieving that balance.

Fire activity across any landscape, be it a forest management unit, a forest region, or a province, is shaped by many complex interacting processes that are influenced by human behaviour, forest vegetation or fuel, weather and topography. Canadian fire managers have traditionally focussed on fire prevention, detection and suppression and to a lesser extent, they have worked with others to manipulate forest vegetation or fuels to reduce the likelihood of fires occurring and to decrease the rate of spread and intensity of any fires that do occur.

Wildfire has had a significant impact on public safety and property across North America in recent years and "Wildland Urban Interface" or WUI fire problems (e.g., Kamloops, Kelowna and California in 2003) have captured the attention of fire and forest managers and the public. The fact that some of the more spectacular losses have been attributed to fuel build-ups that resulted from previous suppression efforts has contributed to the development of new initiatives, most notably FireSmart in Canada[1] and FireWise in the United States, that have emerged to complement traditional fire suppression practices with a heightened emphasis on fuel management and the "fire-proofing" of structures in and near WUI areas.

Hirsch et al. (2001) describe FireSmart forest management as the "use [of] forest management practices (e.g., site preparation, regeneration, stand tending, harvest scheduling ... block layout and design, and road construction) in a proactive and planned manner to reduce both the area burned by undesirable wildfires and the risk associated with the use of prescribed fire". This report describes how we used their approach to further our understanding of FireSmart forest management planning and developed decision-making aids that fire and forest can use to help develop and evaluate FireSmart strategies for integrated fire and forest management in the boreal forest region of Canada.

Objectives

Fire can reduce harvest levels and increase delivered wood costs. Our objectives were to 1) further our understanding of integrated fire and forest management planning and 2) develop decision support systems that can be used to enhance the ability of fire and forest managers to work together to develop, evaluate, and implement integrated fire and forest

[1] The FireSmart program is administered by Partners in Protection, a coalition of government agencies and other groups interested in fire in wildland urban interface areas. Their program is described on their web site (http://www.partnersinprotection.ab.ca). FIREWISE is a coalition of American wildland fire agencies with similar interests and their program is described on their web site (http://www.firewise.org).

management policies and strategies that will contribute to the sustainable management of Canada's boreal forest.

We focussed on the fuel management aspects of FireSmart forest management, the modification of forest fuel complexes to reduce fire incidence, decrease fire spread potential and enhance fire suppression effectiveness. Fuel management can include 1) Fuel Reduction; decreasing fuel loads by thinning or the use of prescribed fire, 2) Fuel Conversion; replacement of flammable fuels with less flammable fuels, or 3) Fuel Isolation; the use of roads, cut blocks and fuel breaks to fragment continuous tracts of flammable fuels. Although fuel management can be and often is carried out independently of timber production, we focussed on the development of FireSmart strategies that may entail carrying out fuel management and timber production such that they complement each other.

Model Development and Analysis

In order to develop and evaluate FireSmart strategies for integrated fire and forest management, fire and forest managers require;

1. spatially explicit burn probability maps that indicate the probability that any point in the forest management unit will burn given recent human behaviour patterns, the current forest vegetative mosaic, the level of fire protection (LOP) and other features of the forest landscape in and near the forest management unit and,

2. an ability to describe and evaluate road building, harvesting, silviculture, fuel management and fire suppression strategies that might mitigate fire losses by altering the composition and arrangement of the vegetative mosaic and reducing burned area.

We focussed our efforts on the following three areas with a view to developing decision support systems that address such needs.

1) Burn probability modelling

We built on the work of Hirsch and Kafka (1999) and developed a burn probability (BP) model that predicts when and where fires might occur, the performance of the initial attack system and the growth of fires that escape initial attack to predict the probability that any point on the landscape will burn given the fuel, weather, topography and level of fire protection.

2) Assessing the impact of FireSmart strategies on forest ecosystems

FireSmart strategies strategically fragment forest landscapes to mitigate potential fire losses but there is no guarantee they will not do so in ways that are detrimental to wildlife and other aspects of ecosystem health. We therefore developed a framework for evaluating the impact of FireSmart strategies on wildlife.

3) Deciding when and where to implement fuel management activities

Once fire and forest managers have used a burn probability model to predict burn probabilities across the landscape they will want to develop and evaluate fuel and other forest management strategies that may entail, for example, prescribing when and where to build roads that might serve as fuel breaks as well as transportation routes, when and where to harvest stands that may serve as fuel breaks as well as sources of industrial fibre and when and where to modify existing forest stands or establish fuel breaks to increase the effectiveness of fire suppressing forces and slow fire spread.

The spatial and temporal optimization of fuel management activities poses very difficult mathematical modelling challenges due to the spatial nature of the problem and the fact that fire occurrence, control and spread are stochastic or random processes. Given the virtual impossibility of identifying optimal fuel management strategies, we developed a spatially explicit decision support system that fire managers can use to assess the impact of implementing specific fuel management treatments they identify and wish to evaluate, such as, for example, the conversion of one or more forest stands or the establishment of a particular fuel break.[2] We also developed a heuristic hierarchical planning system that is designed to produce near optimal spatially explicit integrated fire management and harvesting strategies.

Burn probability modelling

Wenbin Cui developed a burn probability mapping system that predicts the probability that any point on the landscape will burn during the next fire season and applied it to both Millar Western's Whitecourt Forest in Alberta and Tembec's Romeo Malette Forest in Ontario. He built on the model developed by Hirsch and Kafka (1999) and related the burn probability across the landscape to fuel, weather, topography, fire occurrence patterns and the level of fire protection. He did so by simulating the ignition of fires, the ability of initial attack forces to contain them at small sizes and by modelling the growth of fires that escape initial attack.

Annual fire occurrence was assumed to have a Poisson probability distribution and historical patterns were used to allocate simulated fires to subseasons and points on the landscape. The probability that a fire escapes initial attack depends upon the initial attack response time and the predicted fire intensity and the growth of fires that escape initial attack is simulated using the WILDFIRE fire spread model (Todd, 1999). The probability distribution of the burning time of an escaped fire is assumed to be

[2] That DSS was developed by Sanchez-Guisandez (2004) working on a closely related SFMN supported research project entitled "Decision support systems for flammable wildland urban interface landscapes" (SFMN project code: martellddeci8) and will be described in our final report on that project.

exponential with a mean based on historical fire data. Wenbin Cui and Sherra Quintilio produced the burn probability map for the Whitecourt area shown in Figure 1.

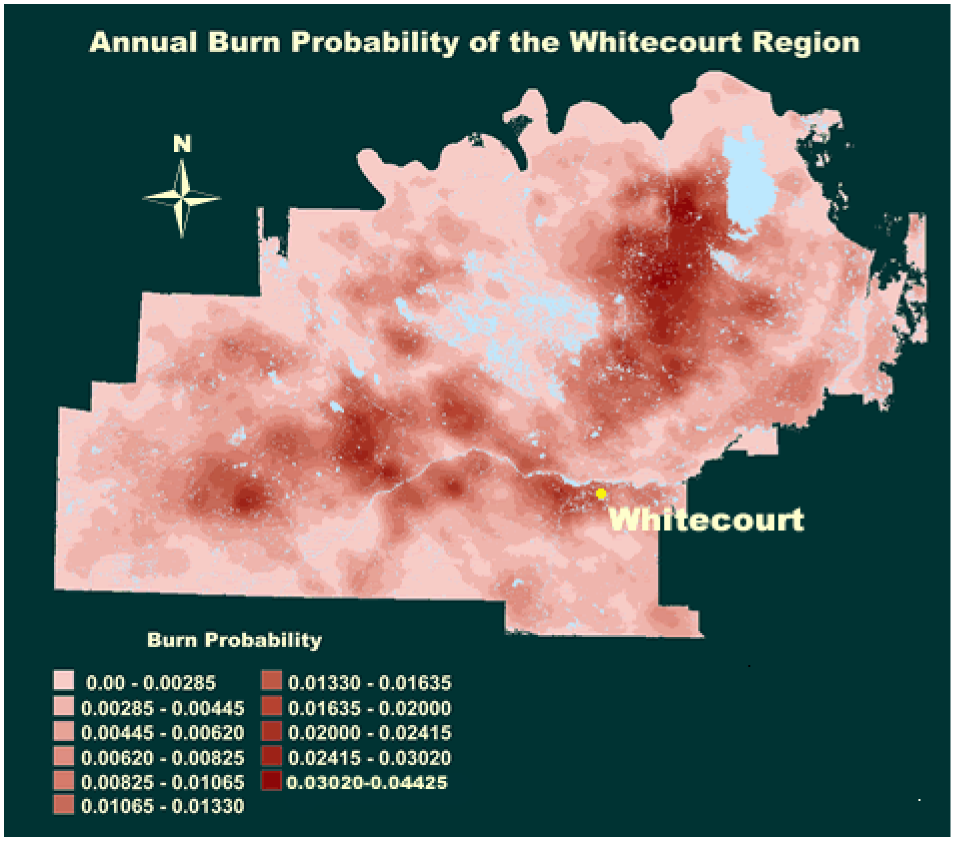

Figure 1. Burn probability map for the Whitecourt area in Alberta that includes Miller Western's Whitecourt Forest.

Jennifer Johnson (2003) and Wenbin Cui applied the BP modelling procedure to the 628,907 ha Romeo Malette Forest (RMF) in Northeastern Ontario. To minimize the impact of edge effects on their results, they delineated a larger 2,028,224 ha rectangular study area that included the RMF.

The study area was partitioned into 50 m by 50 m cells and Caputo's (1999) forest fuel coverage maps were used to determine the fuel type of each cell. Historical fire report data provided by the OMNR was used to determine where each lightning-caused and people-caused fire had occurred during the 1976-99 period. They produced the BP map shown in Figure 2 which is based on 10,000 iterations or simulated fire seasons and they carried out sensitivity analyses of the fire ignition pattern and weather on the burn probability.

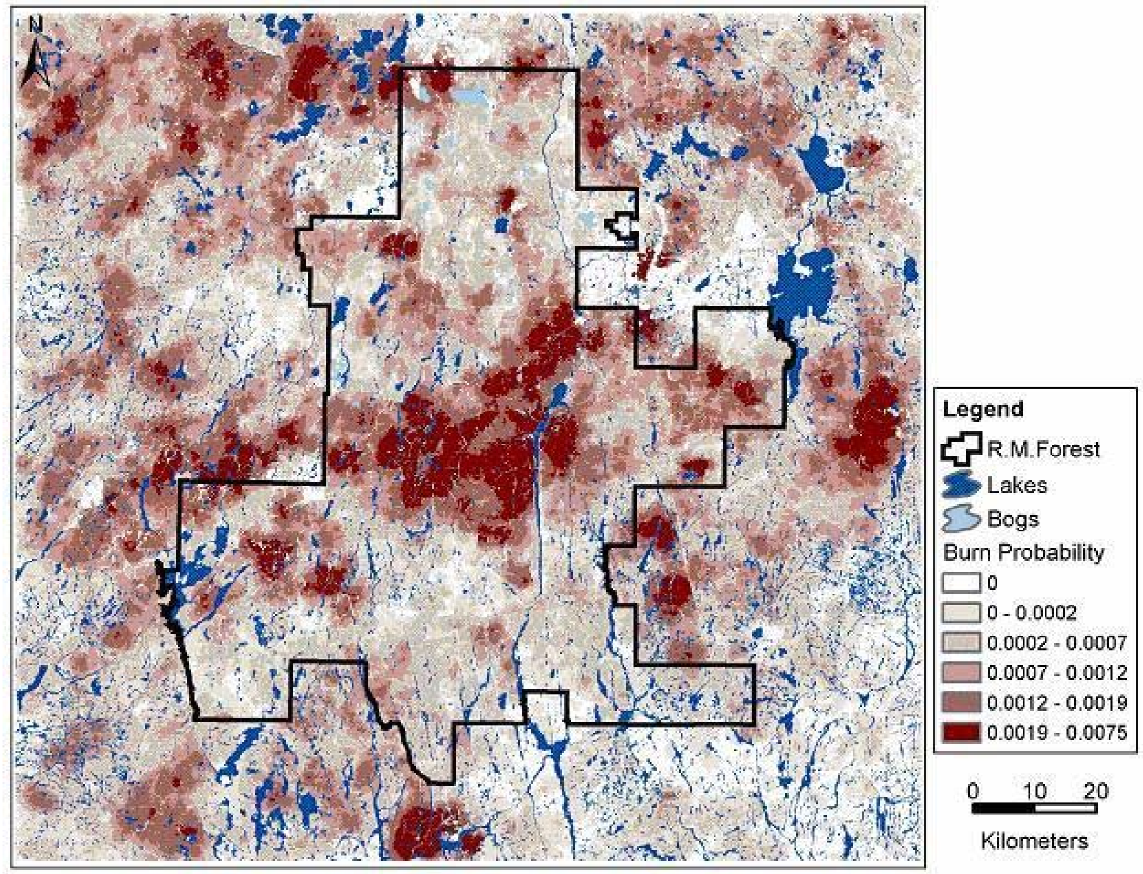

Figure 2. Predicted burn probability for the Romeo Malette Forest study area (from Johnson 2003).

Assessing the impact of FireSmart management strategies on Millar Western's Whitecourt Forest

Our first industrial partner was Millar Western Industries of Alberta with which we collaborated on an investigation of the potential impact of FireSmart strategies on wildlife. Hirsch and Kafka (1999) had worked with Millar Western in the past and demonstrated how changes in the vegetation or fuel types of specific stands could influence significantly, the growth of fires that might occur in Millar Western's Whitecourt forest. Our objectives were to continue this work and focus on assessing the potential impact of such strategies on wildlife populations and developing heuristic procedures for developing good or optimal FireSmart strategies.

As was noted above, one of the objectives of FireSmart forest management is to modify forest management practices to reduce the area burned by wildfires and to decrease risks associated with the use of prescribed fire (Hirsch et al. 2001). FireSmart strategies can include changing the composition of fuels in the forest which could change the way wildlife species use habitat. Espinoza's primary objective was to investigate the potential impact of such FireSmart forest management strategies on wildlife habitat and she used the indirect approach of assessing the potential impact of FireSmart forest management strategies on habitat suitability for four wildlife species in Alberta.

She used the Integrated Forest Management Model (InForM) developed by Cui to predict how FireSmart forest management strategies might shape the landscape over time and then investigated their impacts in terms of the suitability of those landscape for habitat for the Canada Lynx (*Lynx canadensis*), the three-toed woodpecker (*Picoides trydactylus*), the Brown Creeper (*Certhia americana*) and the American Marten (*Martes americana*).

Figure 3 is a schematic representation of the InForM model. The left hand side of the diagram shows the input information required to generate the outputs shown on the right side. The fire spread module inputs are ignition density data, daily fire weather records, level of protection data, burn probability data and fuel inventory data. The harvesting and regeneration modules use user-defined rules that stipulate how to harvest and regenerate the landscape. Forest succession can also be modeled using transition probability matrices. The habitat suitability modules predict the landscape's ability to support wildlife by calculating separate habitat suitability indices for each species. The data used were obtained from Millar Western's 1998 detailed forest management plan. InForM models the harvest, fire ignition, initial attack success, the spread of escaped fires and post fire and post harvest regeneration. She used a 200 year planning to produce predictions of the following forest attributes for the entire forest landscape every 50 years: fires, burn probabilities, fuel inventories, age structure, species composition and habitat suitability for each of the four wildlife species described above.

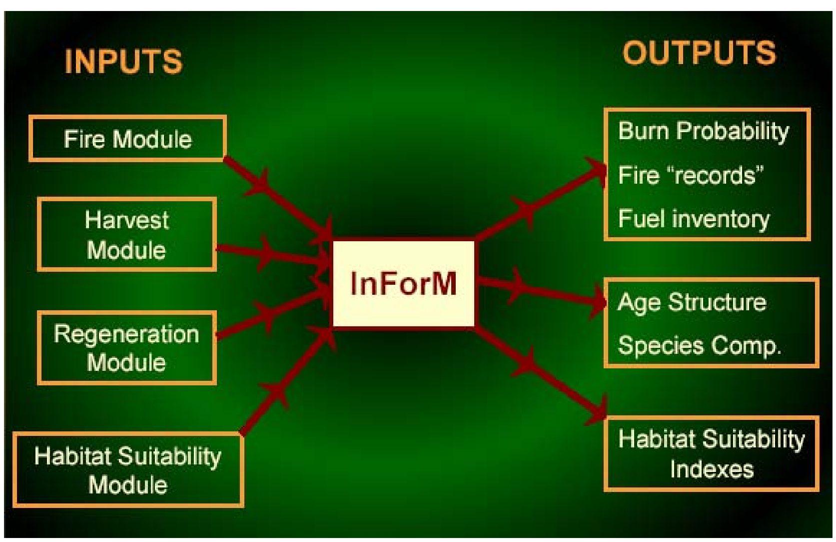

Figure 3. Schematic representation of the Integrated Forest Management Model (InForM).

She considered harvesting strategies characterized by 1) harvesting stands with the highest burn probability and older than the required harvest age first, 2) a natural succession scenario with no harvesting activity, and 3) a strategy similar to Millar Western's current harvest levels. Habitat suitability models were used to assess the landscape's ability to support wildlife based on food, cover and denning habitat needs over a 200 year planning horizon.

Optimizing the timing and location of harvesting and fuel treatment activities

Espinoza assessed the potential impact of applying Cui's aspatial timber harvesting strategies on wildlife and that model can also be used to assess the impact of such strategies on harvest flows. Fire and forest managers also need the capability of developing and evaluating spatially and temporally explicit strategies for both timber harvesting and fire management.

Forest management planners have developed a broad array of methodologies for dealing with deterministic spatially explicit harvest scheduling in forests that are not threatened by fire. The inclusion of uncertain fire losses complicates spatially explicit forest management planning significantly and would render most if not all existing approaches, computationally intractable[3].

Furthermore, current methods for dealing with forest level planning deal with fire as an exogenous variable. In simple terms, forest managers assess potential fire losses and incorporate them in their forest management planning systems using approaches like, for example, the Model III framework developed by Reed and Errico (1986). There is no provision for them or their fire management counterparts to work together and decide simultaneously upon both harvesting activities and levels of fire protection. Given the computational challenges characteristic of deterministic spatially explicit forest management planning, the prospects are indeed, daunting.

Mauricio Acuna and Cristian Palma, working under the supervision of Andres Weintraub in the Department of Industrial Engineering at the University of Chile, developed a spatially explicit heuristic procedure for treating fire as an endogenous variable and thereby making it possible for fire and forest managers to work together to develop truly integrated fire and forest management plans. Their approach was as follows.

Their study area was a 17,270 ha portion of Millar Western's Whitecourt forest. They developed a hierarchical spatially explicit planning methodology which uses a heuristic procedure to assign a fire protection value to each forest stand or cutting block. Harvesting decisions are based on the value of the wood produced but influenced in part, by the protection value that would be "earned" if specific cutting blocks were harvested. This is achieved by the inclusion of a constraint which stipulates that the sum of the

[3] Martell et al. (1998) review some of the spatially explicit forest management planning methods that have been developed and the computational challenges typically associated with their use.

protection values of all the cutting blocks harvested must exceed some specified minimum level. Their harvest planning system was composed of three subsystems.

1. A fire activity subsystem that models fire occurrence and spread based on spatially explicit descriptions of the vegetation or fuel, weather and topography. That information is used to predict the probability that a fire will start in each cell and to estimate fire propagation times from each point (cell in the regular grid) to its neighbouring points.

2. A heuristic procedure for assigning a "protection value" to each cutting block associated with interrupting fire spread. It is estimated by considering all pairs of cells in a rasterized coverage of the forest management unit, the probability that a fire will ignite in each cell, the time required for a fire to spread from that cell to every other cell, and the value of the timber growing in the other cells. The protection value of a cell is the sum of the protection values of all the paths that pass through that cell.

3. A spatially explicit mixed integer linear programming forest planning model that maximizes the present net worth with decision variables that stipulate when and where to harvest. The model considers potential losses of wood that may result from fires, expressed as the annual burn fraction, and the impact that harvesting can have on interrupting fire spread when it is associated with management decisions to achieve minimum "protection" levels.

This hierarchical system seeks a good or near optimal solution as follows. Information that describes the initial state of the forest serves as input to the fire module which is used to estimate a) the "protection value" of each cell and b) the fraction of the forest that will burn each year. The protection values generated by heuristic procedure are included in the spatial harvest scheduling model. However, since the spatially explicit harvesting decisions prescribed by the harvest scheduling model will modify the forest vegetation, the fire spread potential and the average annual fraction of forest burned, the spatial model harvest scheduling "decisions" are fed back into the fire module to generating revised landscape fuel type information that is used to calculate revised protection values and burn fractions based on the revised post harvest fuel types. That iterative process continues until some convergence criterion is satisfied. Figure 4 illustrates how the iterative hierarchical planning scheme operates.

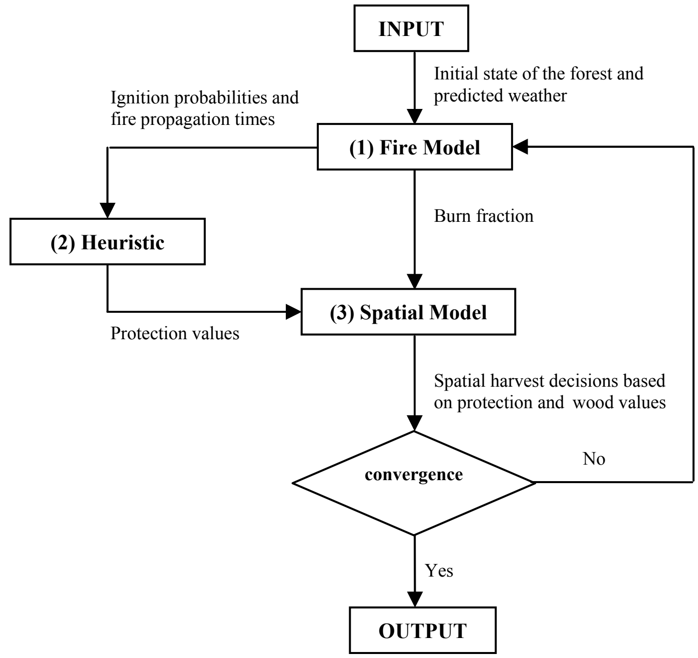

Figure 4. Iterative hierarchical planning framework.

Figure 5 illustrates the protection values that procedure assigned to 464 stands in a portion of Millar Western's Whitecourt Forest.

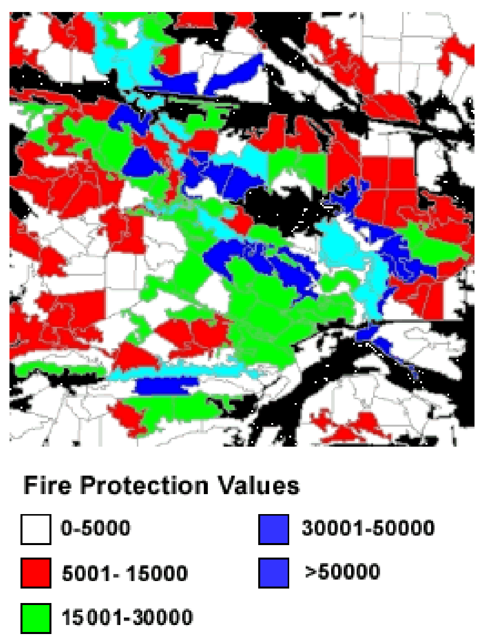

Figure 5. Protection values assigned to Millar Western cutting blocks.

Findings and Management Implications

We participated in workshops with representatives of Millar Western International and the Forest Protection Division of the Alberta Ministry of Sustainable Resource Development in Whitecourt Alberta (June 2000), with Tembec, the Forestry Research Partnership and the Ontario Ministry of Natural Resources in Mattawa Ontario (October 2002), and a with representatives of all five groups at a third workshop in Toronto (February 2003). All of those organizations made very significant contributions to our research by providing us with background information and data and by explaining how they managed fire and forest management activities in the areas under their jurisdiction. One of our most significant accomplishments was the development of a shared understanding of integrated fire and forest management planning, some of the strengths and weaknesses of the approach, and the creation of a widespread commitment to continue research on this important area. Our findings and their potential implications for integrated fire and forest management are as follows.

Cui and Johnson carried out a sensitivity analysis of the effect of ignition patterns on burn probability. Their base case used smoothed historical fire occurrence densities to allocate fires to cells and they compared the impact of that assumption with an alternative model based on an assumption that fires are uniformly distributed across the landscape. Their results suggested the differences are for the most part, minimal, with the exception of people-caused fire occurrence near communities. They also investigated the impact of weather on the burn probability by comparing BP estimates based on the 1980-1989 fire weather with those based on the 1990-1998 weather and found that fire weather has a significant impact on the BP.

Johnson (2003) found that the burn probability varies both across the RMF and by fuel type within the forest. Forest managers in the province of Ontario use timber harvest scheduling models such as the Strategic Forest Management Model with which they account for potential fire losses by assuming some constant average annual fraction of the forest is burned each year. Burn fractions that vary by fuel type and across the landscape could be used to refine potential fire loss estimates.

Those results could also be used to guide fire management. The Ontario Ministry of Natural Resources provides a level of fire protection that varies across the province but most forest management units receive a strategic LOP that is constant within most units. BP maps could serve as a tool to stimulate dialogue between fire and forest managers and help identify the need for more spatially explicit LOP objectives that may call for more aggressive prevention and suppression measures in some areas in response to high value wood such as intensive forest management investments and other concerns.

Espinoza and Cui predicted how much suitable Lynx habitat will be available over the next 200 years using three harvest strategies in Millar Western's White Court Forest. Their results indicate that in the long run, FireSmart strategies will produce more habitat than current practices but not as much as not harvesting at all.

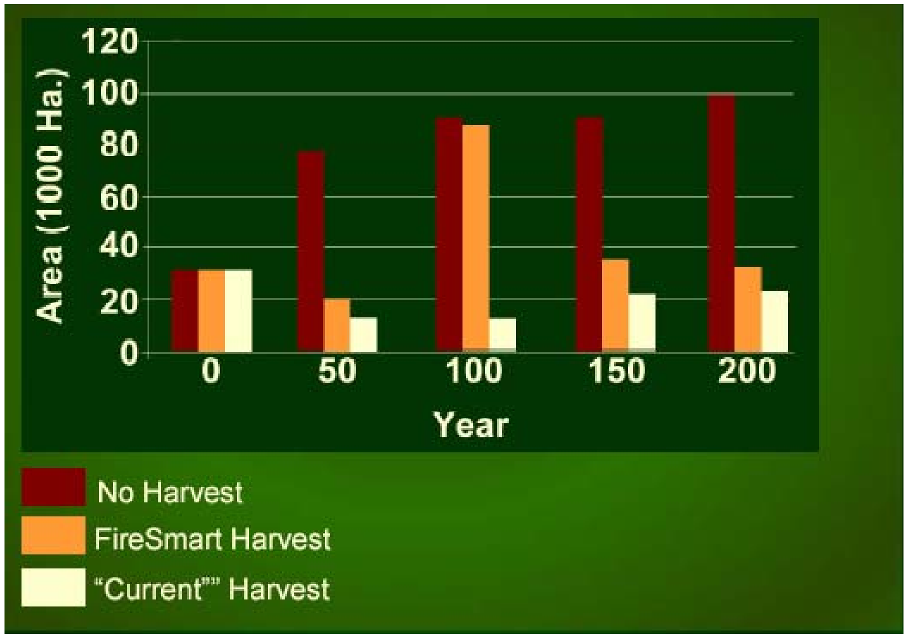

Figure 6. The impact of alternative strategies on the availability of suitable Lynx habitat.

Acuna and Palma devised a procedure for assigning protection values to each cutting unit that can be used to assess the value of cutting activities in terms of fire protection benefits as well as timber values. They found that the inclusion of protection values in their forest management planning model changes the spatial and temporal harvest scheduling decisions and, that those changes fragment the forest and thereby reduce the fire spread potential in the forest.

Further Research

We applied our model to both Millar Western's Whitecourt Forest and Tembec's Romeo Malette Forest and although the results appear to be both realistic and potentially of use to both fire and forest managers, we identified a number of issues that merit further investigation.

1. Simulating Fire Weather

There is a need for refined methods for simulating fire weather sequences that reflect the spatial and temporal autocorrelations that are characteristic of fire weather.

2. Spatially Explicit Fire Occurrence Prediction

We used existing aspatial fire occurrence prediction methods that have been developed for and are used by forest fire management agencies, and developed simple heuristic procedures to make them spatially explicit. Although our approach appears to be reasonable for short term predictions over planning horizons during which there is no significant change in fuel types, there is a need for more refined models that capture the relationships between fire occurrence at a point, the state of the forest fuel complex and day to day and year to year variation in human activities and the impact of fire prevention on human behaviour across the landscape.

3. Relating Initial Attack Success to the Level of Fire Protection

Our burn probability model is based in part, on a heuristic calibration procedure that we developed to relate initial attack success, the probability that a fire does not escape initial attack, to fuel, weather and initial attack response time. There is a need for a more comprehensive model that is based on a more fundamental understanding of fire suppression processes.

4. Predicting fire growth

The WILDFIRE model performs well but does not have spotting capabilities. Once the new Prometheus fire spread model (Anonymous 2003) has been developed and fully tested we will explore its use for burn probability modelling purposes.

5. Impact of FireSmart forest management on ecosystem integrity

We used four species to explore the potential impact of FireSmart forest management on wildlife. There is a need to expand the number of wildlife species investigated and to carry out a population analysis for species considered to be indicators of ecosystem integrity.

6. Computational Challenges

We developed a forest level planning model that incorporates estimated fire losses as an endogenous factor and a heuristic procedure for considering harvesting and fire management decision-making simultaneously. That posed enormous computational challenges and highlighted the need to explore the possibility of developing alternative approaches and for developing improved algorithms for reducing computation times using our current heuristic and others that might be developed in the future.

Conclusions

Fire and forest managers have long recognized the need for integrated fire and forest management. One of the first things that Canadian governments did as people moved into and began to exploit the resource-rich boreal forest was to establish fire control organizations that were designed to reduce the detrimental impact of fire on public safety, property and timber supplies. Analysis has shown that sound fire protection alone, can contribute to substantial increases in the productivity of timber production in the boreal forest (Reed and Errico 1986, Martell 1994, Boychuk and Martell 1996) .

The traditional approach (see for example, Reed and Errico 1986) has been to treat fire as exogenous factor and for fire and forest managers to communicate with each other but work largely independently of each other. Forest managers call for fire protection in areas where they plan to harvest or make silvicultural investments and fire managers in turn use such priorities to influence their fire management strategies.

We have explored the concept of more fully integrating fire and forest management and illustrated some of the potential benefits of such approaches. We have also shown how the principles of FireSmart management can be used to develop truly integrated fire and forest management strategies in the boreal forest region of Canada, and devised some decision-making aids that can be used to implement FireSmart forest now and identified additional research needs that we believe should be pursued in the future.

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This research was supported by the Sustainable Forest Management Network. We thank Victor Kafka of Parks Canada and Marc Parisien of the Canadian Forest Service (CFS) who shared their knowledge of spatial burn probability modelling with us and provided crucial guidance and advice, particularly during the early stages of our project. A special note of thanks is due Bernie Todd of the CFS who provided us with a copy of his WILDFIRE fire spread model which is an essential component of our burn probability mapping system.

We worked with two provincial fire management agencies and two forest products companies that deal with fire and forest management in the boreal forest region of Eastern and Western Canada. The Forest Protection Division of the Alberta Ministry of Sustainable Resource Development (ASRD) and the Aviation and Forest Fire Management Branch (AFFMB) of the Ontario Ministry of Natural Resources (OMNR) provided us with data and background information that enabled us to carry out our study. We particularly wish to thank Cordy Tymstra, Herman Stegehuis and Sherra Quintilio of ASRD who helped us gain a better understanding of fire and forest management operations in Alberta and in many other ways. Special notes of appreciation are due Jim Caputo of the Aviation and Forest Fire Management Branch of the Ontario Ministry of Natural Resources provided the forest fuels data for our study area and guidance concerning its use and Rob Janser, also with the OMNR, who organized our client workshop in Toronto.

We began our project working with Millar Western Industries near Whitecourt Alberta and are indebted to them for the considerable time and effort they devoted to providing data, responding to our many queries and hosting tours of their operations. We particularly wish to thank Jonathan Russell and Ray Hilts as well as their forest management planning support teams, particularly Laird van Damme of KBM Consulting and Ted Gooding of Forestry Corp who provided information concerning Millar Western's forest management planning procedures.

One of our objectives was to develop a partnership with a forest company with operations in the boreal forest region of Ontario and were fortunate to have developed a strong working relationship with Tembec. Like Millar Western, they provided substantial volumes of background information and data and that enabled us to develop and test a burn probability model for the Romeo Malette Forest (RMF) and they devoted considerable time and effort to responding to our many queries. We particularly wish to thank George Bruemmer, Susan Pickering and Michael Malek of Tembec. Mike Wotton of the University of Toronto and the CFS assisted us with our use of the fire weather data we used for the RMF.

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