# Fire-smart forest management: A pragmatic approach to sustainable forest management in fire-dominated ecosystems

by Kelvin Hirsch[1], Victor Kafka[2], Cordy Tymstra[3], Rob McAlpine[4], Brad Hawkes[5], Herman Stegehuis[6], Sherra Quintilio[7], Sylvie Gauthier[8] and Karl Peck[9]

Sustainable forest management in many of Canada's forest ecosystems requires simultaneously minimizing the socioeconomic impacts of fire and maximizing its ecological benefits. A pragmatic approach to addressing these seemingly conflicting objectives is fire-smart forest management. This involves planning and conducting forest management and fire management activities in a fully integrated manner at both the stand and landscape levels. This paper describes the concept of fire-smart forest management, discusses its need and benefits, and explores challenges to effective implementation.

**Key words:** forest fire management, fire-smart forest management, landscape fire assessment, sustainable forest management

La pratique du développement durable dans plusieurs des écosystèmes forestiers du Canada doit minimiser des les impacts socio-économiques des incendies de forêt tout en maximisant leur effets bénéfiques sur le plan écologique. Afin de réaliser de concert ces deux objectifs qui semblent contradictoires, une approche pragmatique pourrait être la solution: l'aménagement forestier intelli-feu (c.-à-d. fire-smart). Cette approche vise la planification et la réalisation des activités d'aménagement forestier et de gestion des incendies de façon intégrée, tant au niveau des paysages qu'au niveau des peuplements. Cet article présente le concept d'aménagement forestier intelli-feu, sa nécessité et ses avantages, ainsi que les défis qui se posent face à sa mise en pratique.

**Mots-clés** : aménagement forestier durable, aménagement forestier intelli-feu, évaluation des incendies au niveau du paysage, gestion des incendies de forêt



## Introduction

Fire is an important natural disturbance in most of Canada's forests as it has played a significant role in determining the biodiversity, health, and landscape metrics of these ecosystems since the last ice age. The impact of wildfires can be either positive or negative depending on societal values and the subsequent land and resource management objectives within an area at a particular moment in time. Although forest managers have long recognized the ecological importance of fire, most fire management policies and practices focus on fire exclusion because of fire's potential impact on public health and safety, property, and the production of wood fibre. The increasing emphasis on systems-based, landscape level approaches to forest management (e.g., sustainable forest management[10]) has, however, resulted in a renewed acknowledgement of the potential benefits of fire and the detriment of excluding fire from some ecosystems. The challenge for managers is no longer simply how to control fire in the most efficient way but instead to know where, when, and how to minimize its economic and social impacts as well as simultaneously maximize its ecological benefits. This paper describes the concept of fire-smart forest management, why and how it could assist in achieving this goal, and some challenges to effective implementation.

## Fire-Smart Forest Management: The Concept

Fire-smart forest management provides practical approaches aimed at achieving sustainable forest management in fire-dominated ecosystems. Its objective is to use forest management practices (e.g., site preparation, regeneration, stand tending, harvest scheduling and systems, 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 (Fig. 1). Fire-smart forest management considers opportunities to (a) decrease the fire behaviour potential of the landscape, (b) reduce the potential for fire ignitions, and (c) increase the capability of fire suppression

[1]Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, 5320-122 Street, Edmonton, AB, T6H 3S5. E-mail: khirsch@nrcan.gc.ca
[2]Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, 5320-122 Street, Edmonton, AB, T6H 3S5. E-mail: vkafka@nrcan.gc.ca
[3]Alberta Land and Forest Service, Forest Protection Division, Provincial Forest Fire Centre, 10th Floor, 9920-108 Street, Edmonton, AB, T5K 2M4. E-mail: Cordy.Tymstra@gov.ab.ca
[4]Ontario Ministry of Natural Resources, Aviation and Fire Management, 70 Foster Drive, Suite 400, Sault Ste. Marie, ON, P6A 6V5. E-mail: rob.mcalpine@mnr.gov.on.ca
[5]Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, 506 West Burnside Road, Victoria, BC, V8Z 1M5. E-mail: bhawkes@nrcan.gc.ca
[6]Alberta Land and Forest Service, Woodlands Forest Area, 5020-52 Avenue, Whitecourt, AB, T7S 1N2. E-mail: Herman.Stegehuis@gov.ab.ca
[7]Alberta Land and Forest Service, Forest Management Division, 8th Floor, 9920-108 Street, Edmonton, AB, T5K 2M4. E-mail: Sherra.Quintilio@gov.ab.ca
[8]Natural Resources Canada, Canadian Forest Service, Quebec Region, 1055 du P.E.P.S., Sainte-Foy, QC, G1V 4C7. E-mail: sgauthier@nrcan.gc.ca
[9]Alberta Land and Forest Service, Northwest Boreal Region, 9621 – 96 Avenue, Peace River, AB, T8S 1T4. E-mail: Karl.Peck@gov.ab.ca

[10]Sustainable forest management has been defined as management to maintain and enhance the long-term health of forest ecosystems, while providing ecological, economic, social, and cultural opportunities for the benefit of present and future generations (Canadian Standards Association 1996). It is often considered synonymous with other terms such as multiresource management (Behan 1990) and ecosystem management (Interagency Ecosystem Management Task Force 1995).

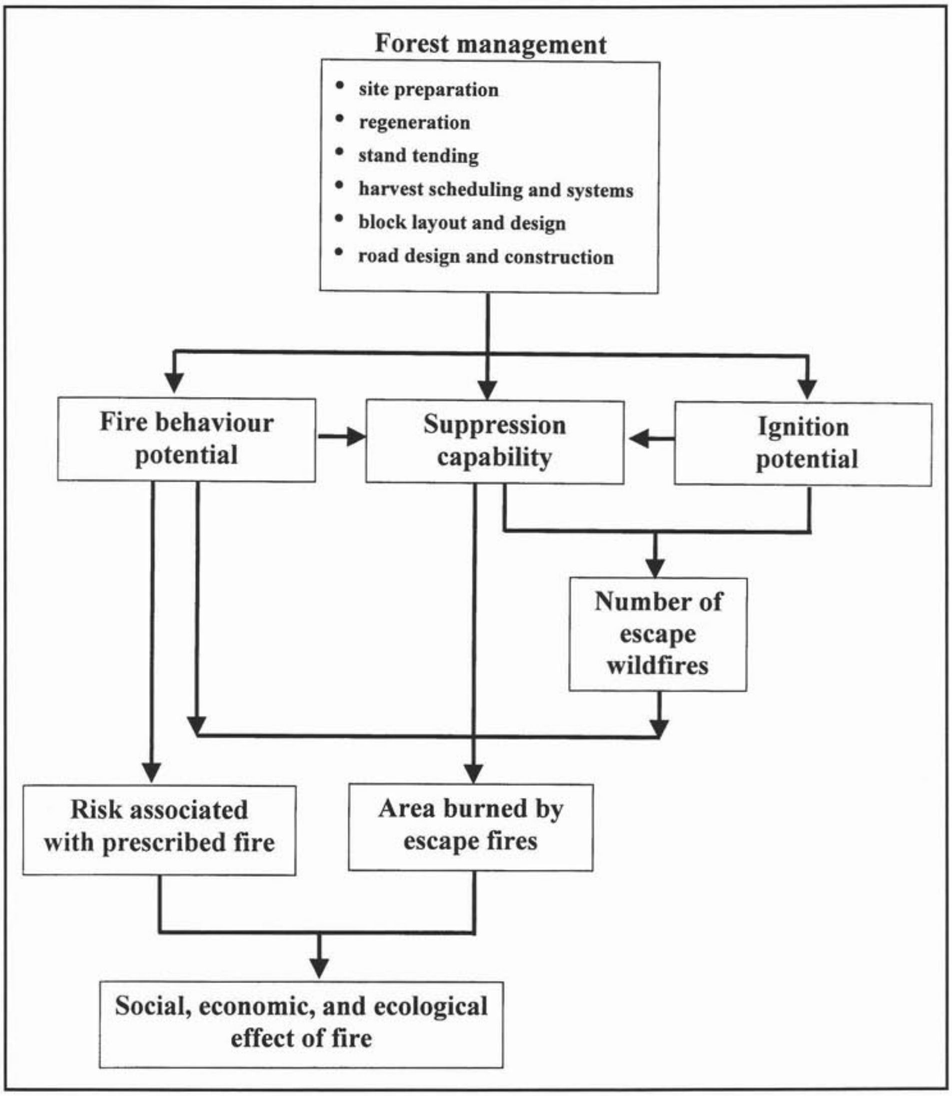


**Fig. 1.** A conceptual representation of fire-smart forest management showing how forest management activities can influence the area burned by wildfires and the risk associated with prescribed fire in order to balance the ecological, social, and economic effects of fire.

resources. This will occur primarily through altering the forest fuels and will result in a decrease in the number and size of escape fires and the constraints associated with human and natural ignition prescribed burning.

Fire-smart forest management incorporates knowledge and understanding of the historic role and ecological significance of fire into all strategic and operational forest management activities at the stand and landscape levels. It requires a spatial assessment of the current fire environment (Taylor *et al.* 1998, Tymstra 1998, Kafka *et al.* 2000) and how it may change over time under different forest management practices and disturbances. Given that fire-smart forest management is a new concept, exploration of possible approaches has just begun. For example, Hirsch and Kafka (1999) provide a list of stand- and compartment-level techniques that can reduce fire behaviour potential. The Province of Alberta has also developed approaches to assess and reduce wildfire threat, and these approaches are being incorporated into their detailed forest management planning guidelines (Alberta Environment 2000) and operational ground rules. Later in this paper, two examples are provided to illustrate the range of fire-smart forest management practices, but clearly many other practical techniques exist and will be developed as fire and forest managers put their collective expertise to work on this question.

## Fire-Smart Forest Management: Need and Benefits

### Minimizing the Socioeconomic Impacts of Fire

One of the objectives of fire-smart forest management is to reduce the area burned by large, unwanted wildfires in order to minimize their socioeconomic impacts. In this way, fire-smart forest management builds on the primary reason why forestry agencies in Canada were created – namely, to prevent and control forest fires (Murphy 1985). In the late 19$^{th}$ and early 20$^{th}$ centuries the focus of Canadian forestry on resource extraction combined with European views of fire (Pyne 1997) meant that forest fires were seen as "the enemy." Fire was viewed as a major threat to public safety, having destroyed numerous communities across Canada (e.g., Miramichi, NB in 1825; Lac St. Jean, PQ in 1870; Vancouver, BC in 1886; Fernie, BC in 1908; Matheson, ON in 1916; Haileybury, ON in 1922). It was also seen as wastefully consuming readily accessible timber; consequently, early foresters, who desired fully regulated forests, sought the elimination of uncertainties such as fire.

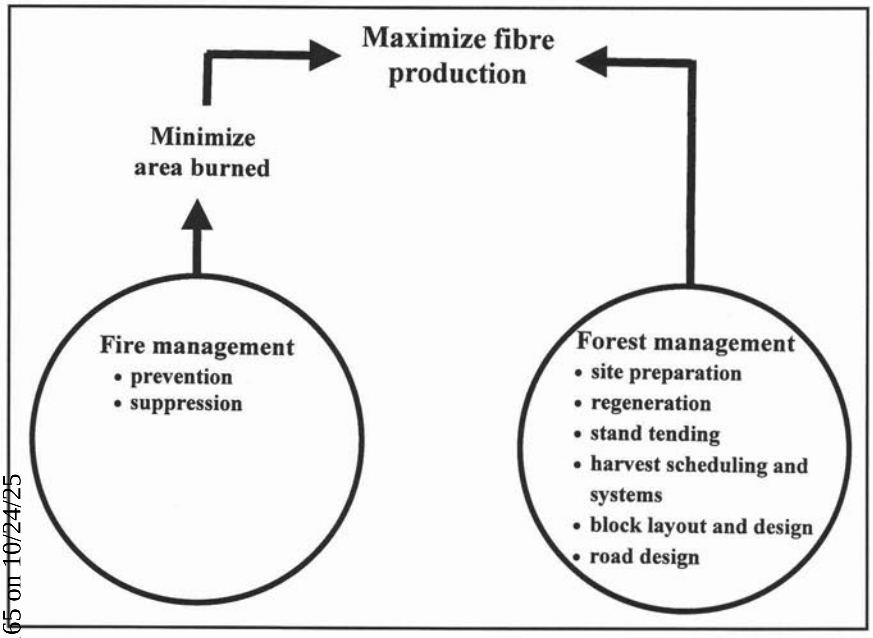


**Fig. 2.** A conceptual illustration of the relationship between fire management and forest management under sustained-yield policy.



In the mid-20th century, under a philosophy of sustained yield, forest management practices in Canada focused primarily on stand level activities aimed at efficiently maximizing fibre production (Fig. 2). Given that fire management[11] is not an end unto itself but instead provides mechanisms by which desired goals can be achieved, fire management concentrated on wildfire prevention and suppression (i.e., primarily aggressive initial attack) in order to minimize area burned and secure timber supply. A number of researchers (Van Wagner 1983, Reed and Errico 1986, Martell 1994, Boychuk and Martell 1996, Martell and Boychuk 1997) reported that in fire-dominated forests significant gains in annual allowable cut could be realized through relatively small reductions in the average annual area burned.

Large, uncontrolled, unplanned wildfire continues to be undesirable in many parts of Canada. The extensive allocation of available timber resources has heightened the concern of the forest industry and forest-based communities about the economic and social impact of wildfire. Until recently, the chance of a forest company closing due to a wildfire was very low because there was always more wood available from a nearby uncommitted area; however, in many parts of Canada such a buffer stock is no longer present, creating wood supply uncertainties for numerous companies. Increasing urbanization in or near forest areas (Hirsch 1999), the potential impact of smoke on public health and the economy (Sandberg 1987), and the effect of wildfire emissions on the global carbon cycle under a changing climate (Stocks *et al.* 1996) are other reasons to minimize the area burned by wildfire.

The need to control all wildfires and the belief that this was possible was founded in an attitude of human mastery of nature (Cortner and Moote 1999). It has also been fuelled by unprecedented technological developments in transportation (e.g., airplanes and helicopters), equipment (e.g., power-pumps), and communication that has allowed for the rapid detection and reporting of fires as well as faster and stronger initial attack and sustained action. In the last few decades the effectiveness of fire suppression organizations has risen to the point where the vast majority of actioned[12] wildfires are contained at a very small size; however, a small percentage of fires continue to escape initial attack and account for almost all of the area burned in Canada (Table 1). The firefighting expenditures and area burned during recent fire seasons (e.g., Alberta in 1998, Ontario in 1995, Quebec in 1997, Saskatchewan in 1995, and Manitoba in 1989) support the suggestion that there is both an economic and physical limit to the effectiveness of forest fire suppression. Further improvements in fire suppression may continue to increase effectiveness but will do so at a decreasing rate because of the diminishing marginal returns from suppression expenditures (McAlpine and Hirsch 1999). Faced with the reality that traditional approaches to fire suppression are nearing their maximum level of effectiveness a new paradigm, called fire-smart forest management, is required to attain further reductions in the socioeconomic impact of fire.

### An Example of Using Fire-Smart Forest Management to Reduce the Area Burned by Wildfires

Most large wildfires result when the number of ignitions exceed the available set of initial attack resources and/or when the fire behaviour (e.g., intensity, rate of spread, size) is so extreme that direct suppression efforts are ineffective (e.g., Hirsch *et al.* 1998) or not possible for safety reasons. Once a wildfire has escaped initial attack, the fire environment[13] plays a large role in

[11]Fire management can be defined as the "activities concerned with the protection of people, property and forest areas from wildfire and the use of prescribed burning for the attainment of forest management and other land use objectives, all conducted in a manner that considers environmental, social, and economic criteria" (Canadian Interagency Forest Fire Centre 2000).

[12]Some fire management agencies have areas in which wildfires are observed or attacked only on a limited basis.

[13]The fire environment is defined as the "surrounding conditions, influences, and modifying forces of topography, fuel, and fire weather that determine fire behaviour" (Canadian Interagency Forest Fire Centre 2000).

**Table 1. Number of fires and area burned in Canada (1990-1995) by size class.***

| Size class | Fires | | Area burned | |
|---|---|---|---|---|
| | Number | Percent of total | ha | Percent of total |
| ≤ 0.1 ha | 26010 | 48.77 | 1707 | 0.01 |
| 0.1–1 ha | 15432 | 28.93 | 10015 | 0.06 |
| 1.1–10 ha | 7415 | 13.90 | 27995 | 0.16 |
| 10.1–100 ha | 2554 | 4.79 | 92938 | 0.52 |
| 100.1–1,000 ha | 1043 | 1.96 | 395984 | 2.22 |
| 1 000.1–10 000 ha | 579 | 1.09 | 2342683 | 13.16 |
| >10 000.1–100 000 ha | 282 | 0.53 | 10216346 | 57.37 |
| >100 000 ha | 20 | 0.04 | 4719708 | 26.50 |
| Total | 53335 | | 17807376 | |

*Source: Canadian Council of Forest Ministers (1997).

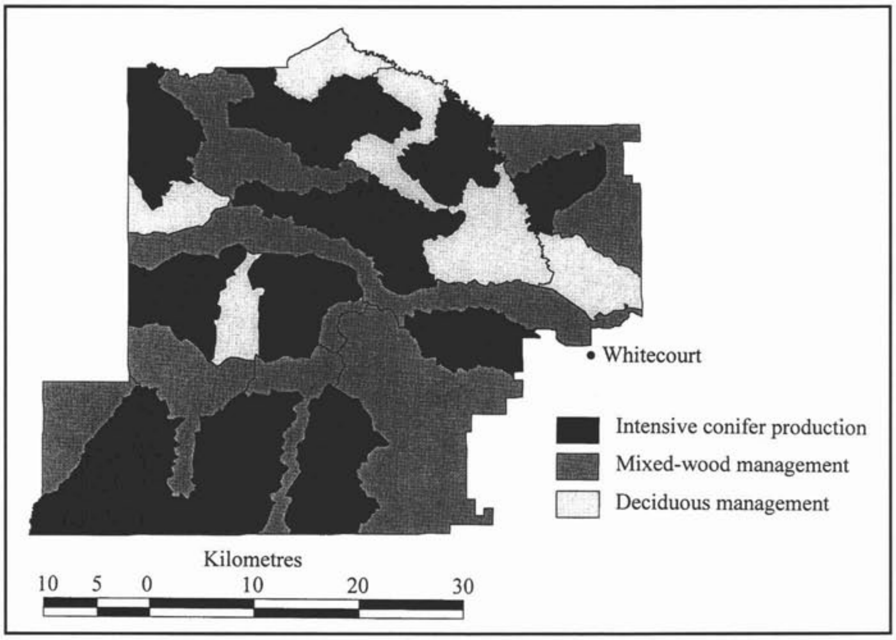


**Fig. 3.** An example of fire-smart forest management being used to create strategically located impediments to fire spread in a central Alberta forest. The location and forest management objectives for each compartment were developed by forest managers based on information about existing fuels, historic fire weather, fire incidence, fire spread, and local knowledge of topography and values-at-risk.

determining its final size. Clearly, it is not possible to modify the weather or topography; therefore, altering the forest fuels through conversion, reduction, and isolation (Pyne *et al.* 1996) is the only proactive option available that can help reduce the potential rate of spread and intensity of a large wildfire. At the landscape level one possible fire-smart strategy would be to create relatively large, strategically located areas that could reduce the continuity of highly flammable fuels (Fig. 3) and serve as anchor points for fire suppression, especially indirect attack. These areas would consist of low flammability fuels, such as deciduous or mixed-wood forests, and could be combined with roads, lakes or rivers, or other impediments to fire spread. Conceptually, this is similar to installing fire doors in a building to help reduce the likelihood that a fire will spread from one compartment to the next. Making these types of fuel changes may not be immediately feasible across all of Canada (Amiro *et al.* 2001), but over time (e.g., 20 to 30 years) they could be established in commercial forest areas, thereby helping to reduce the size of wildfires burning under extreme fire danger conditions.

### Maintaining and Maximizing the Ecological Benefits of Fire

A second objective of fire-smart forest management is to manage fire on the landscape in a manner that maximizes its ecological benefits. Emerging philosophies, such as sustainable forest management, are based on a holistic, landscape-level view of the forest and emphasize the need for a balanced relationship between economic utilization and ecosystem health now and in the future. This has added significant complexity to resource management. From a fire perspective, sustainable forest management must now consider the short- and long-term risks associated with both the presence and absence of fire on a wide range of forest commodities and processes. Fire is a landscape disturbance, and thus the integration of fire and forest management is a natural and essential component of landscape management.

The vital ecological role of fire in Canadian forest ecosystems, especially the boreal region (Wright and Heinselman 1973, Wein and MacLean 1983, Johnson 1992), has long been recognized. Forest fires have occurred since vegetation colonized land after glacial retreat at the end of the last Ice Age (Campbell and Flannigan 2000). Plant and animal species have adapted to fire over the millennia to the extent that fire is periodically needed to maintain ecosystem health, structure, and integrity. Fire serves numerous functions in the ecosystem, such as initiating and concluding vegetation succession; influencing age structure and species composition; creating a spatial vegetation mosaic; modifying the distribution and diversity of insects and diseases; influencing nutrient cycling, moisture coefficients and energy fluxes; maintaining the productivity, diversity and stability of the systems; and regulating the type, distribution and loading of fuels. These functions, which create diverse habitats, are largely determined by the fire regime (i.e., frequency, intensity, severity, size and pattern, and seasonality).

Fire regimes are a result of both natural and human activity over thousands of years. It is generally recognized that North American natives used fire for protection and the creation of post-fire habitats for game hunting purposes (Lewis 1982, Murphy 1985). The arrival of Europeans in North America initially produced an increase in human-caused fires, but in the last 50 to 70 years fire prevention programs, changes in land use, and an enhanced ability to find and suppress fires may have reduced the number of wildfires and area burned. Forest management practices have also modified fire regimes by allowing greater public access to the forest and by altering fuel complexes. Although there have been suggestions that harvesting can emulate some spatial fire patterns (Hunter 1993) or approximate stand structures similar to those created by fires (Bergeron *et al.* 1999), it cannot replicate all of the benefits of fire (Loucks 1970, Carleton 2000).

Wildfires can have severe short-term socioeconomic impacts, but the ecological consequences of having no fire, like in Scandinavia (e.g., Ostlund *et al.* 1997), or the wrong type of fire, as in the western US (e.g., Arno and Brown 1991), is becoming increasingly evident. A major challenge is how to reintroduce fire into forest areas through prescribed burning[14] (Kiil and Chroscewicz 1970, Day *et al.* 1990, Weber and Taylor 1992). Many resource managers are reluctant to use fire because the potential or perceived risk to other values (e.g., life, property, timber) should the fire escape is too high (Foster 1967). Events like those in Bandelier National Monument near Los Alamos, New Mexico in May 2000 or Yellowstone Park in 1988 exemplify the difficulties that exist. An innovative way to address this problem is to use fire-smart forest management practices not only to limit the size of wildfires, but also to create opportunities that would allow more use of prescribed fire by minimizing the risk to resource values, infrastructure, and public health and safety.



### An Example of Using Fire-Smart Forest Management to Reduce the Risk Associated with Prescribed Burning

In order to have fire on the landscape where and when it is most ecologically beneficial, it will be necessary to minimize the potential for an escape prescribed burn and/or the size of a possible excursion. This can occur at a landscape level by creating fuel treatments as identified above; however, at the stand level numerous actions can also be taken. For instance, cut-block boundaries could be designed to follow natural fuel type changes, topography, and hydrology so they could serve as fireguards. Skid trails or roads could be placed around the perimeter of the block to function as secure ignition lines and landings could be located to facilitate centre-fire ignition patterns. Road building equipment could be used to create temporary water sources for use in fire control and mop-up. Cut-blocks could be oriented according to the prevailing wind direction to maximize the number of possible burning days and minimize potential control problems at the head of the fire. Note also that prescribed burning would be especially useful in managing non-productive forest stands and if used strategically could have the added benefit of eliminating hazardous fuels that pose an ongoing threat to commercial forests.

## Challenges to Implementation

Fire-smart forest management is a simple concept and although implementation should be readily possible, there are some significant challenges to overcome. In the last few decades, cultural norms, government policies, and organizational structures produced a separation between fire management and forest management to the point where the two disciplines were often practised in isolation of each other. Under sustained-yield forestry, this may have been acceptable, but to achieve sustainable forest management the integration of forest and fire management planning and operations is essential. Fortunately, recent advances in information technology have led to the development of many useful tools that can be used to gain insights into how forest management policies and practices may influence the fire regime and vice-versa. Some examples of fire oriented models include

- fuel type and hazard mapping models (e.g., Hawkes *et al.* 1995, Alberta Environment 2000),
- fire behaviour prediction models (Forestry Canada Fire Danger Group 1992),
- fire growth models (e.g., Richards 1995, Todd 1997),
- the Spatial Fire Management System (Lee *et al.* 1997),
- wildfire threat assessment models (e.g., Hawkes *et al.* 1997, Chatto 1998, Sneeuwjagt 1998), and
- level of protection models (Martell *et al.* 1995, McAlpine and Hirsch 1999).

From a forest management perspective, forest planning models such as the Strategic Forest Management Model (Davis 1999) and Woodstock and Stanley (Feunekes and Cogswell 1997) can be used to evaluate the impact of fire on timber supply. There are also many models and research studies that allow a discipline-specific assessment of fire on non-timber resources (Beverly and Williamson 1994). If, however, sustainable forest management is to be achieved, it will be necessary to develop and use comprehensive, systems-based planning models (e.g., Johnson *et al.* 1998) that not only allow discipline independent assessments of natural disturbances (e.g., fire, insects, diseases) but also collective analyses of a wide range of resource management objectives. Research to address knowledge gaps in existing theories and models and the impact of fire-smart forest management practices on biodiversity, wildlife habitat, recreational use, and other forest values is also required.

A second major obstacle to implementation will be the ability to shift the attitudes of resource management professionals and the general public. Sustainable forest management requires beliefs that are significantly different from the profit driven, reductionist mindset prevalent in sustained yield management (Cortner and Moote 1999). Knowledge, attitudes, and, in turn, policies will have to shift so that there is a greater balance

[14]Prescribed burning is defined as "the knowledgeable application of fire to a specific land area to accomplish predetermined forest management or other land use objectives" (Canadian Interagency Forest Fire Centre 2000). It includes both manager-ignited fires and natural-ignition fires that are allowed to burn in designated areas under a range of predetermined conditions.

between ecological stewardship and economic development. Resource managers and the public will have to embrace fire as an important component of the ecosystem and accept the uncertainty and potential socioeconomic impacts associated with fire. For example, when wildfires do occur allowing a considerable portion of the dead-standing forest habitat to evolve untouched, rather than be salvaged, represents a first step in maintaining the effect of fire in the forest ecosystem. Attitudes towards fire will have to continue to shift from being negative and reactive to proactive and adaptive. Rather than ignore the potential for wildfire and/or view it as a disaster when it occurs, it will be necessary to acknowledge that wildfire will occur and that actions can be taken prior to ignition to mitigate possible negative effects. Society will also have to give resource managers the mandate and support to take reasonable risks in the present (e.g., conducting prescribed burns and monitoring some wildfires) in order to ensure future risks (e.g., ecological degradation and catastrophic wildfires) are minimized. Fire-smart forest management practices will continue to evolve and will take time to implement, but it is necessary to initiate actions now if a balance among the ecological, social, and economic effects of fire is to be attained.

## Acknowledgements

The authors thank the many individuals who have expressed an interest in attempting to integrate fire and forest management, especially J. Russell and R. Hilts (Millar Western Industries), L. Van Damme (KBM Forestry), and T. Gooding (Forestry Corp). We also appreciate the constructive feedback provided by D. Martell, B. Todd, M. Hirsch and M. Flannigan and the editorial review conducted by B. Laishley.

## References

**Alberta Environment. 2000.** Forest management planning manual: guidelines to plan development (draft version). Alberta Environ., For. Manage. Div., Edmonton, AB. (unpublished).

**Amiro, B.D., B.J. Stocks, M.E. Alexander, M.D. Flannigan and B.M. Wotton. 2001.** Fire, climate change, carbon and fuel management in the Canadian boreal forest. Intl. J. Wildland Fire (in press).

**Arno, S.F. and J.K. Brown. 1991.** Overcoming the paradox in managing wildland fire. Western Wildlands, Spring: 40–46.

**Behan, R.W. 1990.** Multiresource forest management: a paradigmatic challenge to professional forestry. J. For. 88 (4): 12–18.

**Bergeron, Y., B. Harvey, A. Leduc and S. Gauthier. 1999.** Forest management guidelines based on natural disturbance dynamics: stand- and forest-level considerations. For. Chron. 75(1): 49–54.

**Beverly, J. and T. Williamson. 1994.** Wildland fire management economics: post 1982 literature review and bibliography. Nat. Res. Can., Can. For. Serv., Econ. Studies Div., Ottawa, ON. Working Paper (unpublished). 44 p.

**Boychuk, D. and D.L. Martell. 1996.** A multistage stochastic programming model for sustainable forest-level timber supply under risk of fire. For. Sci. 42(1): 10–26.

**Campbell, I.D. and M.D. Flannigan. 2000.** Long-term perspectives on fire-climate-vegetation relationships in the North American boreal forest. *In* E. Kasischke and B. Stocks (eds.). Fire, Climate and Carbon Cycling in the Boreal Forest. Chapter 9. Springer-Verlag New York, Inc. New York, NY.

**Canadian Council of Forest Ministers. 1997.** Compendium of Canadian forestry statistics 1996. Nat. Res. Can, Can. For. Serv., Ottawa, ON.

**Canadian Interagency Forest Fire Centre. 2000.** Glossary of forest fire management terms (revised 2000). Can. Interagency For. Fire Cent., Winnipeg, MB. 63 p.

**Canadian Standards Association. 1996.** A sustainable forest management system: guidance document. CAN/CSA-Z809-96, environmental technology: a national standard. Can. Stand. Assoc., Etobicoke, ON. 33 p.

**Carleton, T.J. 2000.** Vegetation response to the managed forest landscape of central and northern Ontario. *In* A.H. Perera, D.L. Euler and I.D. Thompson (eds.). Ecology of a managed terrestrial landscape: patters and processes of forest landscapes in Ontario. Ont. Minist. Nat. Res., UBC Press, Vancouver, BC.

**Chatto, K. 1998.** Development of a wildfire threat analysis model for south-eastern Australia. *In* III International Conference on Forest Fire Research and 14th Conference on Fire Forest Meteorology. Proceedings of a symposium held Nov. 16–20, 1998, Luso, Portugal, pp. 2243-2254. Univ. Coimbra, Coimbra, Portugal.

**Cortner, H.J. and M.A. Moote. 1999.** The politics of ecosystem management. Island Press, Washington, D.C.

**Day, D.L., C.A. White and N. Lopoukhine. 1990.** Keeping the flame: fire management in the Canadian Parks Service. *In* M.E. Alexander and G.F. Bisgrove (tech. coordinators). The art and science of fire management. Proceedings of a symposium held Oct. 24–27, 1988, Kananaskis, Alberta. pp. 35–47. For. Can. North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-309.

**Davis, R.G. 1999.** Strategic Forest Management Model Version 1.6: user guide. Ont. Minist. Nat. Res., Sault Ste. Marie, ON. OMNR Report. 223 p.

**Feunekes, U. and A. Cogswell. 1997.** A hierarchical approach to spatial forest planning. *In* System Analysis and Management Decisions in Forestry. Seventh Symposium on Systems Analysis in Forest Resources. Proceedings of a symposium held May 28–June 1, 1997, Traverse City, MI. pp. 7–13. U.S. For. Serv., North Cent. For. Exp. Stn., St. Paul, MN. Gen. Tech. Rep., NC-GTR-205.

**Forestry Canada Fire Danger Group. 1992.** Development and structure of the Canadian Forest Fire Behavior Prediction (FBP) System. For. Can., Sci. Sustainable Dev. Dir., Ottawa, ON. Inf. Rep. ST-X-3. 63 p.

**Foster, W.T. (moderator). 1967.** Symposium on prescribed burning. Can. Pulp Paper Mag. 68(1): 4–18.

**Hawkes, B.C., J. Beck, and W. Sahle. 1997.** A wildfire threat rating system for the McGreogor Model Forest. *In* 13th Conference on Fire and Forest Meteorology. Proceedings of a symposium held Oct. 27–31, 1996, Lorne, Australia. pp. 149–160. Intl. Assoc. Wildland Fire, Moran, WY.

**Hawkes, B.C., D. Goodenough, B. Lawson, A. Thomson, W. Sahle, O. Niemann, P. Fuglem, J. Beck, B. Bell and P. Symington. 1995.** *In* Forest fire fuel type mapping using GIS and remote sensing in British Columbia. Proceedings of the Ninth Annual Symposium on Geographic Information Systems, GIS95, Vancouver, B.C. pp. 647–656.

**Hirsch, K. 1999.** Canada's wildland-urban interface: challenges and solution. Initial Attack Fall: 2–4.

**Hirsch, K.G., P.N. Corey and D.L. Martell. 1998.** Using expert judgement to model initial attack fire crew effectiveness. For. Sci. 44(4): 539–549.

**Hirsch, K. and V. Kafka. 1999.** Workshop report on integrating fire and forest management on the Windfall management unit. Nat. Res. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Collaborative Research Report (unpublished).

**Hunter, M.L., Jr. 1993.** Natural fire regimes as spatial models for managing boreal forests. Biol. Conserv. 65: 115–120.

**Interagency Ecosystem Management Task Force. 1995.** The ecosystem approach: healthy ecosystems and sustainable economies: Vol I – overview. National Technical Information Service, Springfield, VA.

**Johnson, E.A. 1992.** Fire and vegetation dynamics in the North American boreal forest. Cambridge University Press, Cambridge, U.K.

**Johnson, K.N., J. Sessions, J. Franklin and J. Gabriel. 1998.** Integrating wildfire into strategic planning for Sierra Nevada forests. J. For. 96(1): 42–49.

**Kafka, V., C. Tymstra, K. Hirsch and M. Flannigan. 2000.** Assessing fire behavior potential: a comparative analysis of two spatial techniques. *In* L.F. Neuenschwander and K.C. Ryan (eds.). The joint fire science conference and workshop. Crossing the millennium: integrating spatial technologies and ecological principles for a new age in fire management. Proceedings of a symposium held June 15–17, 1999, Boise, ID. pp. 113–122. Univ. Idaho and Intl. Assoc. Wildland Fire, Moscow, ID.

**Kiil, A.D. and Z. Chrosciewicz. 1970.** Prescribed fire – its place in reforestation. For. Chron. 46(6): 1–4.

**Lewis, H.T. 1982.** Fire technology and resource management in aboriginal North America and Australia. *In* N.M. Williams and E.S. Hunn (eds.). Resource managers: North American and Asutralian hunter-gathers. pp. 45–55. Am. Assoc. Adv. Sci., Washington, D.C. AAAS Selected Symposium 67.

**Lee, B.S., J.B. Todd and R.M. Suddaby. 1997.** A spatial fire management system. *In* IX Silvotecna. Proceedings of a symposium held Nov. 17–18, 1997, Concepcion, Chile. (unpublished)

**Loucks, O.L. 1970.** Evaluation of diversity, efficiency and community stability. Am. Zool. 10: 17–25.

**Martell, D.L. 1994.** The optimal rotation of a flammable forest stand. Can. J. For. Res. 12: 164–173.

**Martell, D.L. and D. Boychuk. 1997.** Levels of fire protection for sustainable forestry in Ontario: A discussion paper. Nat. Res. Can., Can. For. Serv., Great Lakes For. Cent., Sault Ste. Marie, ON. NODA/NFP Tech. Rep. TR-43.

**Martell, D.L., D. Boychuk, J.I. MacLellan, B.M. Sakowicz and R. Saporta. 1995.** Decision analysis of forest fire protection in Ontario. *In* J. Sessions and J.D. Brodie (eds.). Management Systems for a Global Economy with Global Resource Concerns. Proceedings of a symposium held September 6–9, 1994, Pacific Grove, CA. pp. 138–149. Soc. Am. Foresters, Bethesda, MD.

**McAlpine, R.S. and K.G. Hirsch. 1999.** An overview of LEOPARDS: the level of protection analysis system. For. Chron. 75(4): 615–621.

**Murphy, P.J. 1985.** History of forest and prairie fire control policy in Alberta. Univ. Alberta, Fac. Agric. For., Edmonton, AB. ENR Rep. No. T/77. 408 p.

**Ostlund, L., O. Zackrisson and A.-L. Axelsson. 1997.** The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Can. J. For. Res. 27: 1198–1206.

**Pyne, S.J. 1997.** World Fire: The culture of fire on earth. University of Washington Press, Seattle, WA. 384 p.

**Pyne, S. J., P.L. Andrews and R.D. Laven. 1996.** Introduction to wildland fire (second edition). John Wiley and Sons, New York.

**Reed, W.J. and D. Errico. 1986.** Optimal harvest scheduling at the forest level in the presence of the risk of fire. Can. J. For. Res. 16: 266–278.

**Richards, G.D. 1995.** A general mathematical framework for modelling two-dimensional wildland fire spread. Intl. J. Wildland Fire 5(2): 63–72.

**Sandberg, D.V. 1987.** Prescribed fire versus air quality in 2000 in the Pacific Northwest. *In* J.B. Davis and R.E. Martin (eds.). Wildland Fire 2000. Proceedings of a symposium held April 27–30, 1987, South Lake Tahoe, California, pp. 92–94. USDA, For. Serv., Pac. Southwest For. Range Exp. Stn. Gen. Tech. Rep. PSW-101.

**Sneeuwjagt, R. 1998.** Application of wildfire threat analysis in south-western forest of western Australia. *In* III International Conference on Forest Fire Research and 14th Conference on Fire Forest Meteorology. Proceedings of a symposium held Nov. 16–20, 1998, Luso, Portugal, pp. 2155–2176. Univ. Coimbra, Coimbra, Portugal.

**Stocks, B.J., B.S. Lee and D.L. Martell. 1996.** Some potential carbon budget implications of fire management in the boreal forest. *In* M.J. Apps and D.T. Price (eds.). Forest Ecosystems, Forest Management, and the Global Carbon Cycle. pp. 89–96. NATO ASI Series, Subseries 1 Vol. 40, Global Environmental Change. Springer-Verlag, Berlin, Germany.

**Taylor, S. W, G.J. Baxter and B.C. Hawkes. 1998.** Modeling the effects of forest succession on fire behavior potential in southeastern British Columbia. *In* III International Conference on Forest Fire Research and 14th Conference on Fire Forest Meteorology. Proceedings of a symposium held Nov. 16-20, 1998, Luso, Portugal, pp. 2059–2071. Univ. Coimbra, Coimbra, Portugal.

**Todd, J.B. 1997.** User documentation for the Wildland Fire Growth Model and the Wildfire Display Program. Can. For. Sev. North. For. Cent., Edmonton, AB. Internal Report (unpublished).

**Tymstra, C. 1998.** Fire management planning: the Southern Rockies Landscape Planning Pilot Project. Alberta Environ. Prot., Land For. Serv., For. Prot. Div., Edmonton, AB. 53 p.

**Van Wagner, C.E. 1983.** Simulating the effect of forest fires on long term timber supply. Can. J. For. Res. 13: 451–457.

**Weber, M.G. and S.W. Taylor. 1992.** The use of prescribed fire in the management of Canada's forested lands. For. Chron. 68(3): 324–333.

**Wein, R.W. and D.A. MacLean, D.A. (eds.). 1983.** The role of fire in northern circumpolar ecosystems. John Wiley and Sons, New York.

**Wright, H.E., Jr. and M.L. Heinselman. 1973.** The ecological role of fire in natural conifer forests of western and northern North America. Quat. Res. 3: 317–513.