Ontario Parks

Natural Fire Regimes in Ontario

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EXECUTIVE SUMMARY

This *Natural Fire Regimes in Ontario* report will help inform decisions regarding preliminary fire management goals, objectives and options for maintaining and restoring fire-dependent ecosystems in protected areas. This report provides a summary of how ecosystems interacted with fire in the past, under a minimum of human influence, and how fire processes can be used as a tool to help restore ecological integrity to protected area landscapes. It has been prepared as part of a tool kit supporting fire management planning for provincial parks and conservation reserves.

The report provides a compilation and synthesis of existing research based on a comprehensive literature review. It uses Ontario's Ecological Land Classification (ELC) framework to analyze and describe natural fire regimes and fire effects for relatively homogeneous groupings of ecosites (based on similar site, vegetation, and fire regime characteristics) in the broad forest regions in Ontario. Results are discussed by forest region and are presented in a table summarizing fire regime characteristics by homogenous fire group. These tables are followed by more detailed descriptions of the fire group and its natural fire regime characteristics, vegetation responses to fire, and succession following fire. Management considerations are also discussed but are not complete and are considered introductory and general in nature.

This report should assist park planners, ecologists, and fire managers in developing management direction for fire use and fire response by providing answers to critical restoration questions regarding the natural role of fire on the landscapes throughout Ontario. Other issues to consider when managing fire on the landscape are also discussed.

RÉSUMÉ

Le rapport *Natural Fire Regimes in Ontario* (Les régimes de feu d'origine naturelle en Ontario) fournit des renseignements sur les décisions prises concernant les buts, objectifs et options de gestion préliminaire des incendies pour préserver et remettre en valeur des écosystèmes dépendant du feu dans les zones protégées. Ce rapport explique comment les écosystèmes ont interagi avec le feu par le passé, avec une influence humaine minimale, et comment les ressources de feu peuvent être utilisées comme un outil pour aider à restaurer l'intégrité écologique du paysage des zones protégées. Le rapport fera partie d'une trousse d'outils appuyant les nouvelles lignes directrices de planification sur la gestion du feu dans les parcs provinciaux et les réserves de conservation.

Le rapport fournit une compilation et une synthèse de la recherche actuelle à ce sujet en se fondant sur une analyse documentaire détaillée. Il se sert du programme de classification des terres écologiques de l'Ontario pour analyser et décrire les régimes de feu d'origine naturelle et les répercussions du feu pour des groupes d'écosites relativement homogènes (ayant des caractéristiques de site, de végétation et de régime de feu similaires) dans les vastes régions forestières de l'Ontario. Les résultats sont discutés par région forestière et sont présentés dans des tableaux résumant les caractéristiques des régimes de feu par groupe de feu homogène. Les tableaux sont suivis de descriptions plus détaillées des groupes de feu et des caractéristiques de leur régime de feu d'origine naturelle, de leur végétation, des interventions en cas d'incendie et de la succession suivant les incendies. Des options de gestion sont également discutées mais elles ne sont pas complètes et sont de nature générale et préliminaire.

Ce rapport devrait aider les planificateurs de parcs, les écologistes et les gestionnaires des incendies à orienter leurs décisions de gestion concernant l'utilisation du feu et les mesures d'intervention en fournissant des réponses à des questions très importantes sur le rôle naturel du feu et la remise en valeur du paysage ontarien. D'autres points de gestion du feu à l'échelle du paysage sont également discutés.

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INTRODUCTION

Fire is an ecological process fundamental to maintaining the diversity and ecological integrity of many ecosystems in Ontario. However, fire also has the capacity to cause significant and widespread ecological, economic, and social impacts. Long term fire suppression to protect these values has negatively impacted ecosystem health by causing shifts in species composition, accumulations of biomass, insect infestations, poor regeneration, and degradation of wildlife habitat. Fire suppression has also caused significant accumulations of flammable fuels, which in turn, threaten the surrounding landscape.

In light of increasing concerns about maintaining ecosystem health, and in recognition of the importance of reducing the risks associated with fire, the Ontario Ministry of Natural Resources (MNR) has recently developed policy and planning tools to support the reintroduction of fire as an ecological process on the landscape. Restoring fire safely and effectively will require detailed planning, technical skill, and sound decision making. In addition, an understanding of the natural role of fire will be critical to achieving positive ecological benefits in disturbance-dependent ecosystems.

This report provides a general description of the natural fire regime and scale of fire effects for fire-dependent ecosystems across Ontario. The report focuses on principles, generalities and broad scale fire effects on vegetation, rather than on detailed site specific responses and includes:

- an overview of fire and fire disturbance regimes;
- a compilation, review, and synthesis of pertinent literature reflecting the current state of knowledge of fire regimes, fire ecology, and fire effects for the fire dependent ecosystems of Ontario;
- a comparison of fire regimes, fire ecology and fire effects across Ontario; and
- a summary of restoration challenges and future information needs.

Protected area planners and ecologists and fire managers can use this report to guide decisions regarding preliminary fire management goals, objectives and options for maintaining and restoring fire-dependent ecosystems across Ontario. Those requiring a more detailed description of fire regimes and fire effects for the region are referred to textbooks on the subject (Wein and MacLean 1983; Wright and Bailey 1982; Johnson 1992; Frelich 2002).

The report is organized into nine sections. The introduction is followed by a section that outlines the background and rationale for the report. The next section reviews fire ecology and fire regimes, followed by a section that explains the landscape approach used for the fire regime analysis. The next four sections describe the fire regime characteristics by homogeneous fire group for each broad forest region (i.e., Boreal West, Boreal East, Great Lakes-St. Lawrence, and Deciduous). The final section provides a summary of the report and an overview of other, related management considerations.

Each regional fire regime section begins with a table that summarizes the natural fire regime characteristics by homogenous fire group. Each table includes a list of the ecosites (or community series) corresponding to each fire group and a short description of the mean fire return interval and/or fire cycle. Next, detailed fact sheets describing the fire group, natural fire regime characteristics, vegetation responses to fire, and succession following fire are provided. Management considerations are also discussed but are not complete and are considered introductory and general in nature.

Much of the information provided in the fact sheets was obtained from extensive review of available scientific literature (anecdotal information was not specifically reviewed). Where information for a specific forest region was available it was reported; otherwise information from other geographically and climatically similar areas was used. Unfortunately, gaps remain in our understanding of the role of fire for some groups and/or regions and it was only possible to provide general or incomplete discussions. As new information becomes available (e.g., fire history, fire ecology, best management practices for prescribed burning and prescribed fire etc.), the fact sheets will be updated and made available.

BACKGROUND AND RATIONALE

Fire is a key ecological process affecting all aspects of ecosystem management. The MNR faces a complex challenge in managing fire to achieve beneficial effects and reduce unwanted impacts. Recently, initiatives have been undertaken to research the role of fire, and to develop the policy and planning tools necessary to plan and carry out fire management that successfully incorporates the ecological role of fire.

Fire management strategy

In 2004, MNR approved and implemented the *Forest Fire Management Strategy for Ontario* (MNR 2004a). The strategy balances the protection of human values with the recognition that fire plays a critical role in disturbance-dependent ecosystems. It establishes the need for MNR's fire management program to work with partners to maintain and restore fire-dependent sites and habitats through managed fire response and use of fire through prescribed burning and prescribed fire. In particular, the strategy recognizes that parks and protected areas that contain fire-dependent ecosystems will not continue to represent the natural heritage they were designed to protect without exposure to fire in the coming decades. To ensure that fire management in large Wilderness Class and Natural Environment Class parks achieves these natural heritage objectives, a distinct Parks Zone was created (Appendix 1). Provincial parks not included in the Parks Zone are to be managed according to the surrounding fire management zone unless alternate direction is provided in their Park Management Plan.

Fire policy for parks and conservation reserves

In 2004, the *Fire Management Policy for Provincial Parks and Conservation Reserves* was also released (MNR 2004b). The new policy represents a joint effort between Ontario Parks, Field Services Division, and the Aviation and Forest Fire Management Program. The goal of this policy is to advance the management of fire in provincial parks and conservation reserves to restore and maintain the ecological integrity of Ontario's natural heritage represented within these areas, while preventing personal injury, value loss, and social disruption associated with forest fires. The policy is consistent with natural heritage protection objectives established for provincial parks and conservation reserves, and complements the *Forest Fire Management Strategy for Ontario* (MNR 2004a).

The policy directs protected area planners and ecologists to consider and document the role of fire in their protected area and to develop preliminary fire management objectives and options through the preparation of a Statement of Fire Intent. This Statement of Fire Intent is an internal MNR document that will form the basis for further planning. The policy also establishes responsibilities for approving fire management plans.

Fire management planning guidelines for protected areas

The *Fire Management Planning Guidelines for Provincial Parks and Conservation Reserves* are currently being finalized. These guidelines will assist protected area managers in preparing a Statement of Fire Intent, providing fire management direction within protected area planning documents, and developing fire management plans where required. The *Natural Fire Regimes in*

Ontario will assist MNR staff in preparing these documents by providing a conceptual understanding of the natural fire disturbance regimes of the province at the landscape scale.

This report helps answer critical restoration questions regarding where, when, how frequently, and how intense. Given the complexities of fire occurrence, its spatial and temporal variation, and the effects of fire at different scales (e.g., species, population, community, ecosystem), the report does not set site specific restoration goals or objectives, nor does it describe specific options for achieving desired future conditions. Rather, it provides a picture of how ecosystems interacted with fire in the past, under a minimum of human influence, and how fire processes can be used to help restore ecological integrity to the environment in the future.

FIRE AND FIRE REGIMES

Major natural disturbances such as forest fire, windthrow, insect infestation, and disease play a key role in the distribution of successional and structural types on the landscape (Attiwill 1994). Together with environmental factors such as physical geography and climate, ecosystems are constantly changing in response to these disturbances (Frelich and Lorimer 1991; Zhang et al. 1999). However, human activities in the 19th and 20th centuries have altered natural disturbance regimes and the effects of these alterations are not fully understood (Thompson 2000).

The ecological role of fire

Fire is a primary natural disturbance essential to the maintenance or regeneration of many of Ontario's ecosystems (Bergeron and Brisson 1990; Weber and Stocks 1998; Wolf 2004). In these ecosystems, fire initiates and influences the composition, structure, and pattern of vegetation on the landscape by reducing competition, creating seedbeds, releasing nutrients, and triggering seed release or vegetative reproduction. In a natural fire regime, this fire disturbance maintains a shifting mosaic of different successional and structural types (Davis et al. 2003).

The extent of fire effects for a given area will depend on the kind of fire regime present. A fire regime is normally described by the following characteristics: frequency, cycle, magnitude, type, spatial extent, and seasonality. These terms are defined as follows (Sousa 1984; Johnson and Gutsell 1994; Skinner and Chang 1996; Pyne et al. 1996; Li 2000; CIFFC 2003; Le Goff and Sirois 2003; MNR in prep):

Frequency: The frequency describes the average number of fires that occur within a given time period and is often expressed in terms of return intervals. The **fire return interval** is the average number of years between two successive fire occurrences.

Cycle: The fire cycle is the length of time necessary to burn an area equal to the area or landscape of interest and is equal to the **fire rotation**. The size of the area must be clearly specified. For example, if the area of interest is 100,000 hectares and it takes fifty years for fires to burn 100,000 hectares within that area, the fire cycle would be 50 years. This does not imply that the entire area will burn in one cycle; some sites may burn several times and others not at all. This landscape-scale index may incorporate very different fire intervals and include many different physical environments and forest types.

Magnitude: The magnitude of a fire is described in terms of its intensity and severity.
Fire intensity refers to the rate of heat energy released from a fire per unit time and can be a major determinant of the effects of fire. **Fire severity** describes the effects of fire on a site as determined by various fire characteristics (e.g., fire intensity, flame height and length, duration of fire etc.). It can be measured after a fire in various terms, including percent of plants killed, effects on soil organisms, loss of soil nutrients, decreased water quality, smoke emissions, damage to property etc.

Type of fire: There are three main types of fire: surface fires, ground fires, and crown fires. Each type of fire is described by the vertical location of the fuels that are primarily supporting the fire. **Surface fires** burn in the surface fuel layer, excluding the crowns of the trees. **Ground fires** (or subsurface fires) burn in the ground fuel layer mostly by smouldering combustion. Fires in duff, peat, dead moss and lichens, and punky wood are typically ground fires. **Crown fires** burn through the crown fuel layer, usually in conjunction with surface fire. Crown fire can be classified according to the degree of dependence on the surface fire phase (i.e., intermittent crown fire or active crown fire).

Spatial extent: The spatial extent refers to the size or area covered by a fire and the spatial patterns created.

Seasonality: The seasonality, or timing, of a fire is the period of the year during which fires are likely to start and spread. Seasonality is important in relation to the moisture content of fuels, the phenology of the vegetation, and the resulting fire effects. The vegetation found in a given ecosystem has adapted over time to the season or seasons in which the fires generally occur.

Fire regimes can also be characterized in terms of synergies with other disturbances such as insects, disease, and blowdown (Hobbs and Huenneke 1992; Li 2000). Frequent low-intensity surface fires may discourage insect outbreak by controlling stand density and reducing competitive stress on residual trees. Conversely, fire may encourage insect attack on damaged trees. Fires inhibit some fungi through the effects of smoke, but encourage decay by opening wounds for entry of decay organisms. By opening the landscape, intense fires may also increase the susceptibility of remaining trees to wind damage (Agee 1994).

Principles of fire occurrence and behaviour

Knowing when and where a fire is likely to occur and behave is essential to sound fire management decision making. The probability of fire in any given terrestrial plant community during the year, as well as its frequency, intensity and spatial extent, is a function of the interaction of many abiotic and biotic factors (Figure 1). Abiotic factors include climate, local weather conditions, frequency and seasonality of ignition sources, physical fire breaks, topography, and soil texture. Biotic factors include the physical and chemical characteristics of the fuel, fuel load and rate of fuel accumulation (Appendix 2) (Grimm 1984; Sousa 1984). Since each of these factors may vary over space and time, there is considerable heterogeneity in local fire regimes and consequently in the effects of fire on vegetation (Sousa 1984). Detailed treatments on the fundamentals of fire and fire behaviour can be found in several excellent publications, including Brown and Davis (1973); Chandler et al. (1983), Whelan (1995), Pyne et al. (1996), and other works.

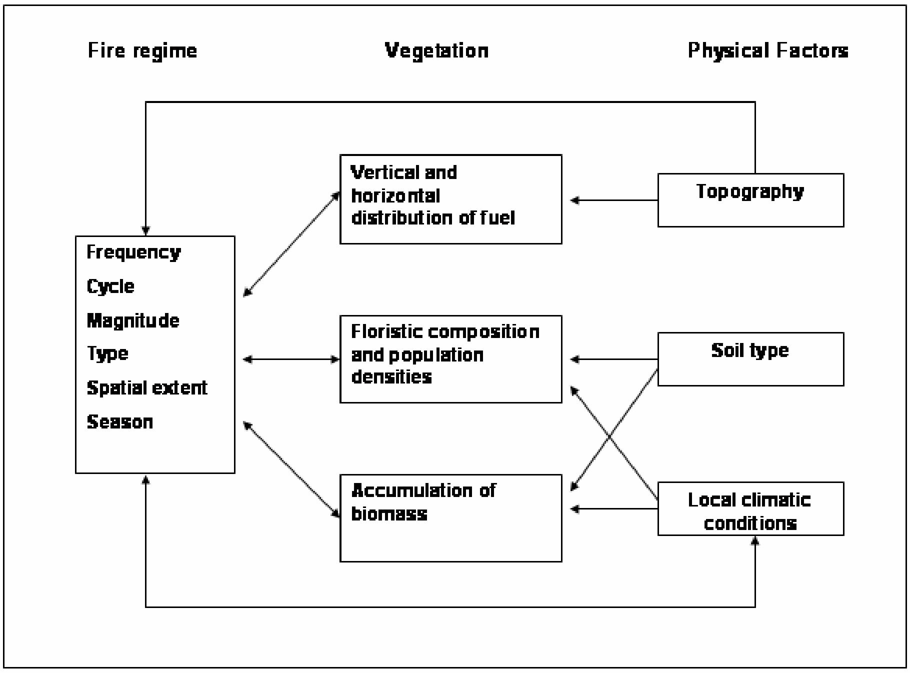


Figure 1. Schematic diagram illustrating the interactions between fire regime, the vegetation, and physical environment (modified from Whelan 1995)

Fire ecology and effects

Fire effects on vegetation can vary significantly between fires and even within different areas of the same fire. Vegetation responses to fire and post-fire succession are influenced by the characteristics of the fire, including fire behaviour, intensity, and duration, the pattern of fuel consumption, and the amount of subsurface heating. Vegetation responses post-fire also depend upon the characteristics of the plant species on the site, their susceptibility to fire, and the means by which they recover after fire (Miller 2000). A summary of the effects of fire on plant mortality and individual plant and community responses to fire follows.

Plant mortality

The probability of plant tissue being killed by fire is a function of the temperature experienced by the plant cells, the duration of exposure, and the state of the cells (especially whether they are hydrated and metabolically active) (Whelan 1995; Miller 2000). Dormant plant tissues (including seeds) which are in a dehydrated state can tolerate a much more severe fire than can tissues that are metabolically active and fully hydrated. The likelihood that a whole plant will be killed by fire will depend upon the amount of injury to its component parts and the particular tissues affected by the heat. Some plant tissues and structures are more important for survival than others (e.g., cambium, meristematic tissue, seeds) (Whelan 1995). Plant mortality often results from injury to several different parts of the plant, such as crown damage in combination with high cambial mortality. Plants may not die for several years and death often results from secondary agents such as disease, fungus, or insects. The resistance of plants to these agents is often decreased by injury and wound sites may provide entrance points (Miller 2000).

Plant responses to fire

Plants may tolerate exposure to fire in two ways: 1) cells within critical tissues have a higher lethal temperature and are able to withstand the biochemical degradation associated with heat; and 2) critical tissues are protected and prevented from reaching lethal temperature. Since most plant cells die if exposed to temperatures in the range of 50 to 55 °C, protection of critical tissues from excessive heat is likely the key to survival by plants exposed to intense fires (Whelan 1995).

There are several ways in which the tissues critical to post-fire recovery of a plant are protected from lethal temperatures during fire (Wright and Bailey 1982; Abrams 1992; Whelan 1995; Thompson 2000; Li 2000; Miller 2000)(See Appendix 3 for a list of plant species referred to in this report) :

- cambium and meristematic cells can be shielded from radiant heat by an insulating bark (e.g., white pine, red pine, oak spp.);
- dormant buds in below ground stems and meristematic cells insulated by the overlying soil (e.g., root and stem collar sprouting in oak spp., aspen spp., white birch);
- sensitive tissues such as seeds and buds can develop at such a height above ground that they would be unlikely to suffer intense heat (e.g., jack pine, black spruce); and
- seeds can be protected by serotinous cones (e.g., jack pine, black spruce), insulating fruits, and by burial in the seedbank (e.g., pin cherry, annual and perennial forb species).

There are also several ways in which plants can tolerate and/or exploit post-fire conditions (Whelan 1995; Miller 2000):

- increased productivity (e.g., prairie spp.);
- increased flowering (e.g., big bluestem, little bluestem, side-oats grama, indian grass);
- improved post-fire seed dispersal (e.g., due to increased wind and surface water flow); and
- improved seedling establishment (e.g., white pine, red pine, *Rubus* spp., *Ribes* spp., *Prunus* spp.).

Other adaptations to fire include fire-resistant foliage (related to resin or oil levels), adventitious or latent axillary buds, and rapid growth and development that allows a complete life cycle between fires (Whelan 1995; Pyne et al. 1996; Miller 2000).

The United States Forest Service maintains an excellent, easy to use, computerized Fire Effects Information System (FEIS) that summarizes and synthesizes information on fire ecology and fire effects, including related biological, ecological, and management information. Information is categorized according to plant species, wildlife species, and plant community. In the plant species category, information on the following is available: taxonomy, distribution and occurrence, value and use, botanical and ecological considerations, fire ecology, fire effects, and references. The site is accessible at the following address: http://www.fs.fed.us/database/feis/

Community and landscape level responses to fire

At the landscape level, fire results in the development of a mosaic of patches differing in size, age, shape, and tree species composition (Heinselman 1981). Definite patterns of post-fire plant succession exist, but vary between different sites and conditions. Herbs, grasses, and shrubs typically regenerate vigorously in the first few years following fire. However, the effect of fire on tree regeneration varies with species, largely because of different methods of seed dispersal, seed survival, sprouting capacity and seedling requirements (Ahlgren and Ahlgren 1960).

Successional patterns following fire are dependent on numerous factors, including fire intensity, season, soil moisture, and the pre-fire vegetation (i.e., available seed supply). The pattern differs among forest ecosystems, and both within and between forest regions (Figure 2) (Thompson 2000). Fire often resets the successional sequence but not all fires are equal. High-intensity fires may be stand-replacing and completely reset succession, while low intensity surface and ground fires may remove surface vegetation or understorey leaving the canopy intact. Therefore, fire intensities and fire intervals characteristic of a site determine the seral stage most observed on the landscape (Chang 1996). Periodic, low intensity surface burning has been found to cause development of an uneven-aged stand, made up of even-aged groups of trees of various age classes. Infrequent, high-intensity, stand-replacement fires result in larger patches of stands of more even age (Skinner and Chang 1996). A detailed description of community and landscape scale fire effects is beyond the scope of this report, but is covered in Ahlgren and Ahlgren (1960), Wright and Bailey (1982), and Wein and MacLean (1983).

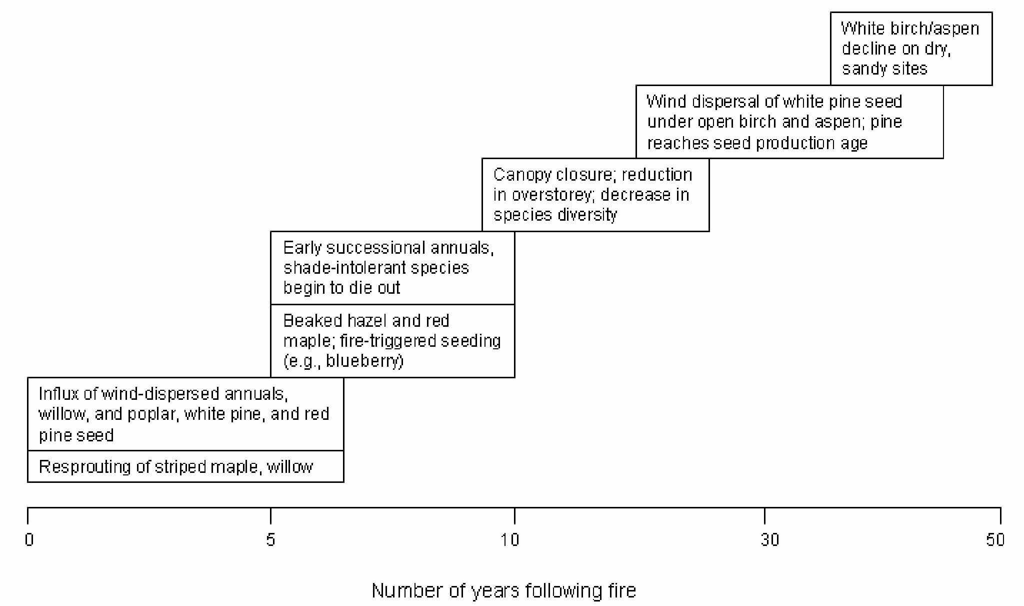


Figure 2. Successional sequence following fire in white pine and red pine communities (Kershaw 1993).

Anthropogenic factors that influenced changes in fire regimes

Humans influence natural fire disturbance patterns through anthropogenic ignitions, surface fuel production, fuel fragmentation, and fire suppression (Guyette et al. 2002; White and Jentsch 2001). These activities modify the spatial and temporal patterns of ignition and the pattern of fire spread. Many factors during the 1800s and early 1900s combined to dramatically alter fire regimes in Ontario and these factors have contributed to the vegetation patterns visible on the landscape today.

Aboriginal burning

Regular manipulation and maintenance of ecosystems by Native American activities is well documented (Day 1953, Lewis 1980; Dey and Guyette 2000; Parshall and Foster 2002). Throughout North America, the extent and abundance of the tall grass prairies, oak and pine savannas, barrens, and other such ecosystems so often noted by early European settlers were largely the result of Aboriginal burning practices. Periodic fires of low to moderate intensity were ignited in the spring or fall to promote the production of grasses and forbs that provided habitat and forage for large game and fowl (Dey and Guyette 2000). The frequency and extent of prehistoric Aboriginal burning is not well known and probably never will be, but their activities undoubtedly influenced ignition frequency and patterns of fire occurrence (Parshall and Foster 2002).

European settlement, land conversion, and resource extraction

The activities of European settlers also affected disturbance regimes, drastically altering the extent and composition of forests (Palik and Pregitzer 1992). During the early stages of European settlement, pioneers adopted Aboriginal burning practices for similar objectives, such as clearing for agricultural development, improved grazing conditions for livestock, enhancing berry and nut production, and increasing browse for wild game (Dey and Guyette 2000). Later, settlers continued to provide sources of ignition through carelessness with campfires along trade routes in the mid-1700s (Guyette and Dey 2000), and associated with prospecting, logging, and the railroad in the late 1800s and early 1900s (Alexander 1980; Parshall and Foster 2002). Logging slash and debris from land-clearing increased the surface fuel loads contributing to more intense, widespread fires that might have otherwise occurred, thus increasing the total area burned and reducing the fire cycle (Cwynar 1977). Access routes such as roads and railways have also been associated with fires, both small and large, that are of anthropogenic origin (Thompson 2000).

Fire exclusion policy

The move toward fire suppression in Ontario began in 1917 in response to a large fire that devastated the settlements of Matheson and Cochrane in northcentral Ontario (Li 2000). At the time, there was little recognition of the natural or beneficial role of fire on the landscape, and total exclusion became the goal for forest resource managers (Heinselman 1981). Since then, increasingly effective fire suppression across the province has led to significant increases in the average fire return interval in some areas, a reduction in the final size of fires, and over the long-term, caused an accumulation of flammable biomass. Fire suppression has nearly eliminated slow-spreading, low-intensity surface fires from the landscape (Thompson 2000; Davis et al. 2003). The ecological legacy of this lack of fire has been older forests, succession toward fire-sensitive, shade-tolerant species, and the gradual depletion of fire-tolerant, shade-intolerant species (Carleton 2000; Scheller et al. 2005)(Figure 3). Beginning in the 1980s, fire managers began to recognize these effects of long-term fire suppression. As a result, MNR recently changed its policy to include an objective to promote understanding of the ecological role of fire and to use its beneficial effects in resource management (MNR 2004a; MNR 2004b).

Modern fire regimes

Modern fire regimes in many of Ontario's ecosystems have changed dramatically since the mid-1800s. Ward and Tithecott (1993) indicate that fire cycles today are significantly longer than those prior to European settlement and fire exclusion policy. In addition to the effects of long-term fire suppression, Ontario's ecosystems are fragmented by agricultural lands, resource extraction activities (e.g., logging, mining), transportation and utility corridors, and urban areas producing a fuels complex that lacks the continuity it possessed in presettlement times. All of these human impacts on fire appear to be altering ecosystem processes and structure at all scales and the effects of which are not fully understood (Thompson 2000).

Approaches to reconstructing natural fire regimes

Fire history may be reconstructed using a variety of methods and information sources, including:

- historical land surveys (Lorimer 1980; Whitney 1986; Zhang et al. 1999);
- early descriptions by travelers, naturalists, and foresters (Day 1953);
- fire scar analysis (Heinselman 1973; Woods and Day 1977; Cwynar 1977; Alexander et al. 1979; Dey and Guyette 2000);
- sedimentary charcoal and pollen analysis (Cwynar 1978; MacDonald et al. 1991; Clark and Royall 1996; Parshall et al. 2002);
- reconstructions of disturbance history in old-growth stands (Frelich and Lorimer 1991);
- current age class structure (Van Wagner 1978); and
- theoretical models (Li 2000).

Each of these methods or sources has its advantages and limitations related to data constraints or interpretive difficulties (Table 1). Area effects on estimates of fire return intervals or fire cycles (Arno and Peterson 1983; Johnson and Gutsell 1994), assumptions regarding flammability of fuels and fire behaviour across heterogeneous landscapes (Gosz 1992); and adequacy of approaches for understanding long term burn patterns (Clark 1990) are among the many challenges associated with assessing fire regimes at appropriate and relevant spatial and temporal scales.

Figure 3. A view of the town of Jasper from Old Fort Point in 1915 (top photo), and again from the exact location in 1998 (bottom photo). Fire suppression across North America has increased the average fire return interval in many areas and has resulted in the accumulation of flammable fuels and succession to older forests.

Scale of analysis

The effects of fire and the consequences of different fire regimes vary among ecosystems and among their component species, both spatially and temporally. The magnitude of this variation depends on the scale of observation (Chang 1996). The scale of observation should be large enough to accommodate the random distribution of fires in space and time, and should be partitioned into relatively homogenous groups based on ecological conditions (e.g., landforms, soils, vegetation) known to influence fire regimes (Dickmann and Cleland, unpublished).
Changing the scale of observation changes the subset of ecological patterns, processes, and relationships that are perceived. As a result, studies of the same phenomena, conducted at different scales, can produce different results (Wiens 2001). The value and indeed the challenge in describing natural fire regimes is providing a summary of fire effects at appropriate and relevant spatial and temporal scales, representative of long-term trends over broad areas, even in view of highly variable responses (Brown 2000).

Table 1. Limitations associated with reconstructing natural fire regimes (Cwynar 1977; Cwynar 1978; Van Wagner 1978; Whitney 1986; Clark 1990).

Source/Methodology	Limitations
Historical land surveys	• reflect a very small sample time interval therefore may give little assurance of long-term trends • may overlook unusual climatic events conducive to windthrows or spread of fire • do not always take into account multiple fire events on the same site • tend to document only the more high-severity fires
Fire scar analysis	• lack of record for lower intensity, sub-lethal fires • evidence is destroyed by major fires or by logging • fire frequencies do not account for burn area • fire history of a site is limited to the longevity of the trees • fire history for eastern North America includes period of European settlement
Charcoal and pollen analysis	• fire frequency is recorded for the catchment (rather than at the stand scale) • difficult to distinguish individual fires and usually not feasible to determine size or spatial extent • may underestimate the fire return interval for areas in the catchment that are less prone to fire (e.g., due to slope, aspect, vegetation composition) • quantity of charcoal eroded into a lake from a given fire varies with the amount and pattern of subsequent precipitation, variation in wind velocity and direction, and rate of soil stabilization by vegetation recovery

LANDSCAPE APPROACH TO FIRE REGIME ANALYSIS

The landscape-level ecosystem approach to assessing fire regimes is based upon significant evidence that fire occurrence and behaviour is related to the conditions, processes, and spatial dimensions of particular categories of landscape ecosystems defined by integrating biotic and abiotic factors. Each distinct regional landscape deserves special attention because of the spatial and temporal heterogeneity of disturbance type, intensity, and spatial extent (Zhang et al. 1999; Cleland et al. 2004a).

Ecological regions of Ontario

An essential first step in assessing the natural fire regimes of Ontario is reducing the inherent landscape heterogeneity. This is achieved by identifying ecologically homogenous areas within which fire regimes can be analyzed and reported. For this report, the province has been divided into four distinct forest regions based on the Ecological Land Classification (ELC) framework (Racey et al. 1996; Chambers et al. 1997; Lee et al. 1998; Taylor et al. 2000)(Figure 4):

- Boreal West;
- Boreal East;
- Great Lakes-St. Lawrence; and
- Deciduous.

The ELC framework was chosen because it describes relatively homogeneous ecosystem units based on vegetation composition and structure, soil moisture and fertility, and physical site characteristics. The Ontario ELC framework also represents a common language for describing, interpreting, and reporting ecosystem conditions.

For this analysis, fire regimes of the Hudson Bay Lowlands were not included because: 1) no ELC framework exists for the ecozone; and 2) fires in the Hudson Bay Zone receive a monitored response unless they pose a threat to a community, negatively impact a value, and/or cause social disruption (MNR 2004a). Therefore, fire is generally allowed to fulfill its natural role in the far north unless it threatens Aboriginal communities.

Identification of homogenous fire groups

Landscape heterogeneity was further reduced by identifying homogenous fire groups within a forest region. For this analysis, ecosites are grouped according to fire regime category (see description below) and mean fire intervals are determined within relatively homogeneous groupings of ecosites based on similar site, vegetation, and fire regime characteristics (i.e., frequency, intensity, type, fire effects on vegetation). Because fire regimes are the result of complex interactions between abiotic and biotic conditions (e.g., fuel type and distribution, weather, cause and pattern of ignitions etc.), identifying homogeneous fire landscapes was a difficult and complicated task.

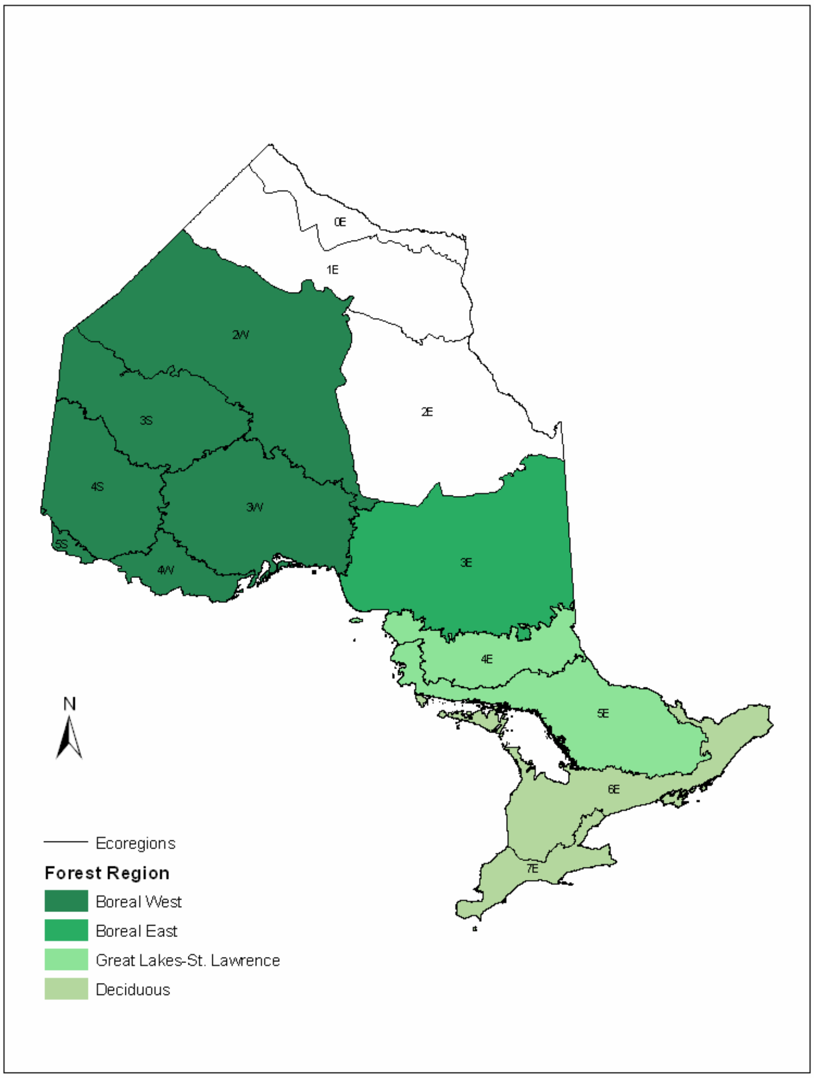


Figure 4. Ecoregions of Ontario. Forest regions are based on the ELC framework (Racey et al. 1996; Chambers et al. 1997; Lee et al. 1998; Taylor et al. 2000).

Fire regime categories

The fire regime classification used in this report is a modified version of simple classifications based on fire severity by Morgan et al. (1996) and Brown (2000) (Table 2). More detailed information (e.g., fire return interval, fire cycle) is reported where available but not combined with fire severity into classes. The advantage of using fire severity as the primary factor for describing fire regimes is that it relates directly to the effects of disturbance, especially on survival and structure of the dominant vegetation. It also facilitates communication among resource managers and others about the role of fire on the landscape (Brown 2000). The classification is intended for broad scale applications and reflects the effects of typical, but not all, fires in a given ecosystem (Morgon et al. 1996; Brown 2000).

LANDSCAPE APPROACH TO FIRE REGIME ANALYSIS

In this report, prairie and savanna are considered to have 'maintenance' fire regimes because grasses re-establish so rapidly that there is little difference between burned and unburned vegetation within the first three years after fire (Morgan et al. 1996).

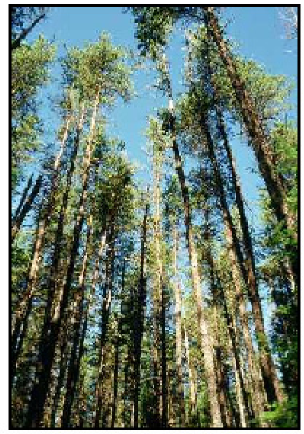
Natural fire frequency and cycle

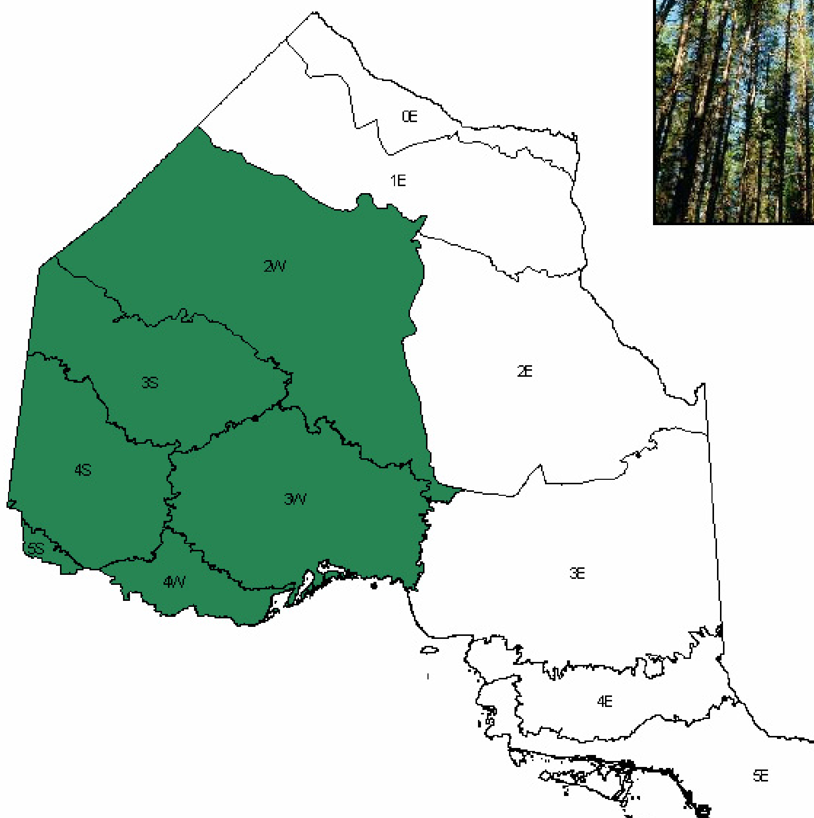
This is a stand or landscape level estimate of natural variability described in terms of fire return interval or fire cycle for a particular fire group based on published fire history literature. Sprugel (1991) suggests there has been considerable controversy and debate over what is meant by 'natural' disturbance and what benchmark, if any, can be used as a reference condition. In this report, 'natural' disturbance refers to the disturbance regime prior to the influence of European settlers and includes ignitions caused by lightning and those caused by Aboriginals since these causes are often not distinguishable using historical or scientific evidence. Several fire history studies have been completed within Ontario and the adjacent provinces and Great Lakes states, but only reconstructions based on empirical methods are cited.

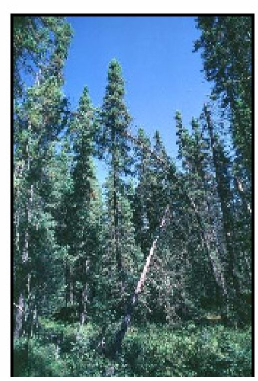
Table 2. Fire regime classification based on fire severity (modified from Morgan et al. 1996 and Brown 2000).

Class	Description
Maintenance	Fires burn in the understorey and maintain an ecosystem at a particular successional stage. They are generally non-lethal to the dominant vegetation and do not substantially change the structure of the dominant vegetation. Approximately 80 percent or more of the canopy cover survives the burn.
Stand-replacement	Fires kill aboveground parts of the dominant vegetation, changing the aboveground structure substantially. Approximately 80 percent or more of the canopy cover is killed or consumed by the fire.
Variable	Fires of intermediate effects. Severity of fire either causes selective mortality in dominant vegetation by favouring species that require sunlight over shade-tolerant species, and by favouring fire-resistant and fire-dependent species over non-fire-dependent types, or varies between maintenance and replacement.
Non-fire	Natural fires very seldom occur and are not one of the primary disturbance factors affecting vegetation structure, composition, and succession.

BOREAL WEST FOREST REGION







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BOREAL WEST FOREST REGION

Fire is a major natural disturbance in the Boreal West forest region. Fire is most frequent and has greatest severity in coniferous forests compared to the less flammable deciduous forests. Fires in conifer stands can be large, stand-replacing crown fires or high-intensity surface fires that burn tens of thousands of hectares, but smaller fires (<100 ha) are the most frequent. The intensity of both surface and crown fires is affected by the amount and distribution of fuel available, soil and fuel moisture, and by the rate of fire spread. These three criteria are controlled in turn, by many other factors, including: time elapsed since the last fire (or by the amount of fuel accumulated); weather, particularly wind and degree of moisture in the vegetation; forest management activity; extent of damage or mortality caused by disease and insect infestation; species composition and stand age; and, in the longer term, climate (Thompson 2000).

The relatively short fire cycles of the boreal create a forest mosaic mainly composed of pure or mixed, even-aged stands at different stages of recovery following fire. Consequently, forest structure largely reflects the length of time since the last fire (Arsenault 2001; Bergeron et al. 2001). Bergeron (1991) suggests that a regime of large and very intense fires tends to homogenize the effects of fire among all topographical units and fuel types throughout the landscape and that only stands located near effective fire breaks may present more variable behaviour.

The fire regimes of the Boreal West are very similar to those of the Boreal East. The cooler, more humid climate in the east results in lower fire frequency than in the drier west (Thompson 2000; Bergeron et al. 2001). However, when there are droughts in the Boreal East, the existence of large fuel loads that have accumulated through many moist years may result in very large fires. Indeed, several large fires have burned in the east (Thompson 2000).

Table 3. Mean fire interval (MFI) and fire cycle (FC), in years, by homogeneous fire group for ecosites in the Boreal West Forest Region (Ecoregions 2W, 3S, 3W, 4S, 4W, 5S). See Appendices 4 and 5 for descriptions of fire history studies and Racey et al. (1996) for descriptions of ecosites.

Homogeneous Fire Group	**Corresponding Ecosites (Northwest FEC)**	**Fire Regime Type**		
		Maintenance	**Stand Replacement**	**Variable**
Aspen-Birch, Aspen-Birch-Fir	ES 16, ES 17, ES 19, ES 23, ES 28, ES 29			MFI:55-120, FC:70-210
Jack pine	ES 13		MFI:15-35, FC:50-187	
Upland Jack pine-Black spruce	ES 12, ES 14, ES 20, ES 22, ES 25, ES 26		MFI:30, FC:50-135	
Lowland black spruce	ES 31, ES 34, ES 35, ES 36			MFI:171, FC:150-6000
Red pine-White pine-Jack pine	ES 11			MFI:22-35, FC:129-258
Red pine-White pine	ES 15, ES 18, ES 24			MFI:12-300
Fir-spruce mixedwood	ES 21, ES 27, ES 32		MFI:27-65, FC:63-83	
Cedar and hardwood lowlands	ES 30, ES 33, ES 37, ES 38			MFI:183, FC:150-6000

STAND-REPLACEMENT FIRE REGIMES

Jack pine

Stand and Soil Characteristics

Jack pine occurs as a canopy dominant on upland sites in pure stands or in association with black spruce and occasionally white birch and trembling aspen. Shrubs typically include blueberry spp., twinflower, bush honeysuckle, prickly wild rose, and beaked hazel. The understorey consists of abundant feathermoss, lichen, and conifer litter. Soils are dry to moderately fresh, coarse to fine sandy (Racey et al. 1996).

Natural Fire Regime Characteristics

Prior to settlement, jack pine stands usually experienced a fire regime of short interval, high-intensity surface or crown fires that generally resulted in stand replacement. In the Sachigo Hills of northwestern Ontario, Lynham and Stocks (1991) report an average fire return interval of 20 years, with a range of 5-30 years between major fires. In the Great Lakes states, jack pine stands burned at mean intervals of approximately 28 years (Heinselman 1973; Simard and Blank 1982), and with fire cycles ranging from 50 to 187 years (Heinselman 1980; Whitney 1986; Zhang et al. 1999). Major stand-replacing fires in the Boundary Waters Canoe Area occurred in years with summer drought (Heinselman 1973). Heinselman (1981) also suggested that, on the xeric glacial outwash sand plains of central Wisconsin and lower Michigan and in other dry sites, many jack pine areas apparently had regimes of short interval, moderate intensity surface fires that killed only portions of stands in the range of every 15 to 35 years.

Vegetation Responses to Fire

Jack pine is an early to mid-successional species that almost exclusively originates after fire (Cayford 1970). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). These stands normally become mature and decadent at 70 to 80 years of age and produce a large amount of fuel as stand vigour declines, thus predisposing them to another fire (Day and Carter 1991).

Though well-adapted to fire, mature trees can easily be girdled and fire may destroy an established jack pine stand if of sufficient intensity. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger stands tend to be more susceptible to crown fires than older stands whose crowns are often thinner and higher from the ground and understorey vegetation (though the presence of a black spruce understorey of varying heights can aid in the crown fire propagation process in mature stands)(Rouse 1986c; Stocks 1989). Young jack pine stands are especially susceptible to early spring fires (Rudolph and Laidly 1990).

Succession After Fire

The high-intensity, stand-replacing fires typical of jack pine communities completely reset succession and promote jack pine establishment by temporarily eliminating competing vegetation and creating a mineral soil seedbed (Ahlgren and Ahlgren 1960; Cayford and McRae 1983). Although jack pine seed usually germinates following fire, most of the seedlings will die unless the organic matter on the site has been reduced to a depth less than 1.3 cm thick. Therefore, the probability of successful jack pine establishment increases with fire severity (Rudolph and Laidly 1990).

Most germination of jack pine occurs the first and second season following fire, with most seedling mortality occurring between the first and second growing season (Rudolph and Laidly 1990). After 15 years post-fire, a dense, vigorous, even-aged jack pine-aspen community often dominates the burn site, with black spruce establishing in the understorey. As jack pine matures, it continues to dominate the spruce and shade-tolerant hardwood understorey, but is unable to regenerate due to low light levels, severe root competition, and increasing accumulation of organic matter. At approximately 75 years, jack pine begins to decline thus creating openings in the canopy that release suppressed black spruce, balsam fir, and shade-tolerant hardwoods (Day and Woods 1977). In the absence of fire or other disturbance, the original jack pine community is replaced by longer lived and more shade-tolerant species, except on the poorest, driest sites where jack pine may persist and form an edaphic climax (Heinselman 1973; Rudolph and Laidly 1990; Johnson 1992). If fires recur in less than 10 to 15 year intervals, jack pine is unable to survive long enough to produce viable seed thus maintaining barrens and openlands on the landscape (Cleland et al. 2004b).

Management Considerations

In the absence of fire, jack pine stands will slowly convert to black spruce, balsam fir, and tolerant hardwoods approximately 75 to 100 years following fire. Woods and Day (1977) recommend that fire should be reintroduced to jack pine stands between 80 and 120 years, depending on the site quality. Prescribed burns and prescribed fire can be undertaken in jack pine communities to promote regeneration (McRae 1979). However, there is only modest literature on prescribed burning done in conjunction with seed tree systems for natural regeneration of jack pine following harvesting and the practice has never become seriously operational in Canada or the United States (Van Wagner 1993). The largest obstacle to the widespread use of prescribed burning in jack pine appears to be the limited number of days when the weather is appropriate to conduct a burn and the widespread acceptance of other chemical, mechanical and silvicultural methods of jack pine regeneration (Rouse 1986c).

There is very little information regarding prescribed burning or fire to meet regeneration objectives in an established stand of jack pine. However, the following observations that have been reported in the literature on prescribed burning in jack pine slash should be considered:

- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970);
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988);
- if seed trees are being used, the prescribed burn should be timed early enough in the season so that seedlings become well-established before winter, or late enough in the season so that seeds overwinter before germinating (Carey 1993);
- successful establishment of jack pine is limited primarily by the depth of organic matter and, therefore, progressively increases with greater fire severity (Rudolph and Laidly 1990); and
- mature and immature jack pine forests have very different stand and fuel characteristics (e.g., density and vertical continuity) and, therefore, exhibit different fire behaviour (Stocks 1987; Stocks 1989).

STAND-REPLACEMENT FIRE REGIMES

Upland Black spruce – Jack pine

Stand and Soil Characteristics

Black spruce and jack pine occur as canopy dominants on upland conifer sites with balsam fir, trembling aspen, and white birch associates. Shrubs commonly include blueberry spp., twinflower, creeping snowberry, bush honeysuckle and dwarf raspberry. The understorey consists of a low number of shrubs and herbs and a groundcover of conifer litter, feathermoss, and lichen. Soils are typically dry to moist with a wide range in soils textures (Racey et al.1996).

Natural Fire Regime Characteristics

Prior to suppression, upland black spruce-jack pine communities experienced frequent large, high-severity, stand-replacing fires that usually killed the canopy trees and prevented the development of uneven-aged stands (Viereck and Johnston 1990; Cleland et al. 2004a). In Ontario, a fire return interval of 30 years and a fire cycle of 60 to 135 years have been suggested (Maclean and Bedell 1955; Chandler et al. 1983; Bergeron et al. 2001). In other regions, fire cycles range from 50 years in northern Minnesota (Heinselman 1981) to 130 years in Québec (Chandler et al. 1983; Cogbill 1985; Payette et al. 1989; Bergeron et al. 2001; Parisien and Sirois 2003; Bergeron et al. 2004).

Vegetation Responses to Fire

Both black spruce and jack pine are well adapted to thrive in fire-prone landscapes, however they differ in certain aspects of their life history strategies that enable them to survive recurrent fire (Le Goff and Sirois 2004). Jack pine is a shade-intolerant, moderately long-lived early to mid-successional species that begins seed production at an earlier age than black spruce (Cayford 1970; Le Goff and Sirois 2004). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). Though well-adapted to fire, fire can easily girdle or kill an established jack pine stand. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger trees tend to be more susceptible to crown fires than older ones whose crowns are often thinner and higher from the ground and understorey vegetation (though the presence of a black spruce understorey of varying heights can aid in the crown fire propagation process in mature stands)(Rouse 1986c; Stocks 1989).

In contrast, black spruce is a shade-tolerant, long-lived species that is capable of vegetative reproduction through layering (Viereck and Johnston 1990; Day and Carter 1991; Le Goff and Sirois 2004). It is well adapted to regeneration following fire due to early and frequent seed production, and persistent semi-serotinous cones that retain viable seed for up to three years and open when exposed to the heat of fire (Ahlgren and Ahlgren 1960). After fire, a large seed supply is released onto burned-over seedbeds, allowing rapid seedling establishment and development of an even-aged stand (Day and Carter 1991). Delayed seedfall and delayed germination are additional adaptations that ensure seed availability and allow black spruce to establish during post-fire years with favourable growing conditions (Thomas and Wein 1985). Despite these adaptations, black spruce is easily killed by both surface and crown fires because of its thin bark and shallow roots (Ahlgren and Ahlgren 1960; Viereck and Johnston 1990).

Succession After Fire

The frequent, high-intensity, stand-replacing fire typical of upland black spruce-jack pine sites tends to completely reset succession. Post-fire composition is characterized by even-aged pure or mixed stands dominated by trembling aspen, white birch, jack pine, or black spruce. In the absence of fire this first cohort of trees is replaced at maturity (approximately 100 years following a fire) by a second cohort dominated by more shade-tolerant conifers such as balsam fir, white cedar, white spruce, and black spruce. In this successional stage, stands are often uneven-aged and have a more irregular canopy. In the late-seral stage (greater than 225 years following a fire), treefall gaps and insect infestation permit the self-maintenance of heterogeneous stands of conifers (Bergeron et al. 2001).

Areas that experience recurring fires in less than 10 to 15 years tend to favour the establishment of early-seral aspen and white birch and prevent the establishment of black spruce and jack pine. Conversely, fires occurring in rotations greater than 60 to 100 years lead to replacement of jack pine by black spruce, as well as white spruce, white cedar, balsam fir, and white birch (Frelich and Reich 1995).

Management Considerations

Upland black spruce-jack pine stands are mid-seral communities dominated by trees 15 to 100 years old (Cleland et al. 2004a). Because jack pine has a shorter life span than black spruce and can only regenerate without fire under some particular conditions (Conkey et al. 1995), the perpetuation and maintenance of this seral community on the landscape requires a fire return interval that does not exceed the longevity of jack pine (Le Goff and Sirois 2004). With continued fire suppression, the jack pine component of these stands will be increasingly at risk of local extinction. Further, sites will become increasingly susceptible to fire as they age, become decadent, and the thinning process becomes more rapid and severe (Woods and Day 1977). Prescribed burning is a viable resource management tool for regenerating these upland black spruce-jack pine sites and for reducing fire hazard (Archibald and Baker 1989). The following observations regarding fire in black spruce and jack pine have been reported in the literature:

- fire should be excluded from young stands since there is a high probability that black spruce will not regenerate adequately before 40 years of age (young stands produce only sporadic amounts of seed and if crown fire occurs, it may be intense enough to destroy large amounts of an already limited seed supply) (Woods and Day 1977);
- fire may be permitted in stands older than 40 years, but ideally would be excluded until stands reach 90 to 120 years (thus permitting adequate black spruce regeneration without an unnecessary increase in fire frequency and maintaining the aesthetic quality of the black spruce stands);
- fires that completely remove the surface organic layer exposing mineral soils usually provide good seedbeds for black spruce and jack pine (Viereck and Johnston 1990; Rudolph and Laidly 1990);
- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970);
- mature and immature jack pine forests have very different stand and fuel characteristics (e.g., density and vertical continuity) and, therefore, exhibit different fire behaviour (Stocks 1987; Stocks 1989); and
- build-up of dead balsam fir trees increases the flammability of a forest because the dead trees provide a dry aerial fuel and the newly exposed understorey is drier than usual (Furyaev et al. 1983).

STAND-REPLACEMENT FIRE REGIMES

Fir-spruce mixedwood

Stand and Soil Characteristics

Balsam fir, white spruce, and black spruce dominate the main canopy in association with trembling aspen and white birch. Jack pine and balsam poplar may also occur. Shrubs typically include mountain maple, beaked hazel, bush honeysuckle, fly honeysuckle, and dwarf raspberry. The understorey consists of a moderate to high number of shrubs and herbs and a ground cover of deciduous litter, conifer litter, feathermoss, and wood. Soils are fresh to moist, silty to clayey or loamy (Racey et al. 1996).

Natural Fire Regime Characteristics

Prior to settlement, fir-spruce mixedwoods experienced a regime of large, high-severity, stand-replacing fire (Bergeron 1991; Cleland et al. 2004a). Average fire return intervals reported in the literature range from 27 years in the northern Clay Belt region of Québec (Dansereau and Bergeron 1993) to 65 years in northern Minnesota (Swain 1973). Fire cycles reported in the literature include 63 years and 83 years for the Clay Belt region of Québec (Bergeron 1991; Bergeron et al. 2004). Heinselman (1981) suggested lightning caused most fires, especially in the months of July and August.

Vegetation Responses to Fire

Fir-spruce mixedwood stands are late-seral communities composed of shade-intolerant hardwoods and shade-tolerant conifers (Cleland et al. 2005). Species in these mixedwoods have several adaptations to fire, including (MacLean 1960; Alexander and Euler 1981; Frelich and Reich 1995): (1) root and stump sprouting and abundant seed with long dispersal distance (e.g., trembling aspen and white birch); (2) serotinous cones stored high in the canopy (e.g., black spruce and jack pine); and (3) serotinous cones that retain viable seed for several years following fire (e.g., black spruce). As a result of these adaptations, black spruce, jack pine, trembling aspen, and white birch are capable of re-establishment following fire, even those that result in complete mortality over a large area, because a live seed source is not necessary. White spruce and balsam fir, however, require live seed trees in the refugia of unburned areas or in stands adjacent to the burn in order to re-establish (Alexander and Euler 1981). Despite these adaptations to fire, most species in fir-spruce mixedwoods are easily killed by fire due to their thin bark and shallow roots (Frank 1990; Nienstaedt and Zasada 1990; Viereck and Johnston 1990; Duchesne and Hawkes 2000) and because surface fires often spread to into the canopy due to the highly flammable fine fuels concentrated under the trees which often produce flames that reach the low-growing, flammable, lichen-draped branches (Uchytil 1991).

Succession After Fire

The stand-replacing fires typical of fir-spruce mixedwood stands tend to reset succession. Post-fire composition is characterized by even-aged pure or mixed stands dominated by trembling aspen, white birch, jack pine, or black spruce. In the absence of fire this first cohort of trees is replaced at maturity (approximately 100 years following a fire) by a second cohort dominated by more shade-tolerant conifers such as balsam fir, white cedar, white spruce, and black spruce. In this successional stage, stands are often uneven-aged and have a more irregular canopy. In the late-seral stage (greater than 225 years following a fire), treefall gaps and insect infestation permit the self-maintenance of heterogeneous stands of conifers (Bergeron et al. 2001). However, given the nature of the fire cycle (e.g., 63 to 83 years) it is unlikely that large portions of the landscape will be found in these late-seral stages (Day and Harvey 1981).

The demographic transition from even-aged stands of stand-replacing fire origin to uneven-aged stands dominated by conifer depends on the timing of heavy wind events and insect and disease infestations that create canopy openings and the rate at which the pioneer species approach senescence (Frelich and Reich

1995). Time since disturbance also strongly influences both succession and fire regime in fir-spruce mixedwoods. In the decades following a fire, less flammable aspen and birch dominate but the probability of fire often increases as stands age due to the general increase of fuel along the forest floor (often due to repeated spruce budworm attacks) and development of fuel ladders. Fire probability also increases along a successional gradient due to higher proportions of conifers, particularly shade-tolerant, short-lived balsam fir (Cleland et al. 2005).

Management Considerations

Fir-spruce mixedwood stands are fire-dependent communities that would lose their character, vigour, and diversity in the absence of fire (Alexander and Euler 1981). Long forest cycles have important consequences on stand age distribution, and consequently, on the composition and structure of forest on the landscape. In the absence of fire disturbance, forest structure and composition are closely related to secondary disturbances, particularly spruce budworm outbreaks and windthrow, both of which are becoming more abundant as forests age following fire (Bergeron et al. 2001). Prescribed burning and prescribed fire are techniques that can be used to renew overmature stands, reduce fire hazards, manage wildlife habitat, and convert stands in areas killed or infested with spruce budworm (Alexander and Euler 1981; Furyaev et al. 1983; McRae 1996). Alexander and Euler (1981) reported the following effects of fire on boreal mixedwoods which should be considered when planning for fire:

- fires that remove little duff tend to favour the hardwoods since their regeneration mechanisms are not as dependent on the resulting seedbed conditions;
- density and pattern of black spruce (and to some extent white spruce) following fire will vary according to depth of burn due to preferences for seeding in on exposed mineral soil;
- short return intervals may promote aspen-birch or shrubs over spruce-fir because hardwood species are able to sprout and sucker at an earlier age than that at which conifers are able to produce abundant seed;
- long return intervals may promote spruce over the hardwoods because of the longer lifespan of conifers and the pathologically induced short rotations inherent to aspen and birch; and
- failures in conifer regeneration following fire can often be attributed to unsatisfactory seedbed conditions, inadequate seed source, or a combination of these factors.

Other observations reported in the literature that may be useful for fire management planning include:

- among mixedwood species, balsam fir and white spruce would be disadvantaged by large fires because they rely on the presence of survivors on the landscape to reseed (Bergeron et al. 2004);
- very intense fires, important for duff removal and seedbed preparation for some conifer species, may in some cases kill the root systems and the seed banks of hardwood species (Bergeron et al. 2004);
- balsam fir is usually rare or absent for the first 30 to 50 years after fire, but gradually establishes thereafter under the canopy of post-fire pioneers (Day and Harvey 1981); and
- build-up of dead balsam fir trees increases the flammability of a forest because the dead trees provide a dry aerial fuel and the newly exposed understorey is drier than usual (Furyaev et al. 1983).

VARIABLE FIRE REGIMES

Aspen-Birch, Aspen-Birch-Fir

Stand and Soil Characteristics

Trembling aspen, white birch, and occasionally balsam fir dominate the main canopy in association with white spruce, black spruce, and jack pine. Shrubs may include mountain maple, beaked hazel, fly honeysuckle, twinflower, and showy mountain ash. The understorey is typically shrub and herb rich with a ground cover of deciduous and conifer litter, feathermoss and wood. Soils vary from dry to moist with a wide range of soil textures (Racey et al. 1996).

Natural Fire Regime Characteristics

Prior to human intervention, seral aspen and birch stands likely experienced a variable fire regime of low intensity surface fires and higher intensity fires, depending on the amount of fuel on the forest floor (Duchesne and Hawkes 2000). In Quetico Provincial Park, Woods and Day (1977) reported an average fire return interval of 70 to 80 years. Day and Carter (1991) estimated the mean fire interval between fires causing regeneration in Temagami District to have ranged from 66 years in stands dominated by aspen to 104 years in stands dominated by white birch. In the Clay Belt region of Québec, the mean fire return interval for hardwood mixedwood stands ranged from approximately 55 to 120 years (Bergeron 1991). A fire cycle ranging from 70 to 210 years has been suggested for these communities in the Great Lakes forest region (Cwynar 1977; Heinselman 1981; Zhang et al. 1999). In Boundary Waters Canoe Area, aspen-birch stands experienced a fire regime similar to those of adjacent conifer stands, with severe surface fires or even crown fires (in aspen-birch-conifer stands) with fire cycles of perhaps 80 years (Heinselman 1981). Fires likely occurred most frequently during spring and fall when fuels were dry and leaf litter was deep (Duchesne and Hawkes 2000).

Vegetation Responses to Fire

Aspen and white birch are generally considered to be short lived, shade intolerant, pioneer species (Safford et al. 1990; Laidly 1990; Perala 1990). Since neither aspen nor white birch is capable of reproducing under its own shade, a major stand disturbance is required to maintain these early-successional communities on the landscape (Rouse 1986a; Day and Carter 1991). Fire is considered to be the primary natural disturbance responsible for regeneration in both species as it creates suitable seedbeds and reduces competition (Day and Carter 1991). Both aspen and white birch rapidly colonize open sites created by fire, but usually persist for only one generation before being replaced by more shade-tolerant species (Safford et al. 1990; Laidly 1990; Perala 1990).

Aspen and birch-dominated stands burn only under specific site and climatic conditions, such as in early spring before flushing, following an unusually severe drought, or late in stand history when the proportion of conifers has increased. Fires in young stands are typically low intensity fires, while those in older stands with abundant fuels burn with greater intensity. Due to the high moisture content and lush understorey, crown fires in adjacent conifer stands often stop at the boundary of large aspen or white birch stands, or become slow-moving ground fires. The presence of conifers, whether in the understorey or the canopy, generally increases the flammability of aspen-birch stands (Foster and King 1986; Duchesne and Hawkes 2000).

Although aspen-white birch forests do not readily burn, aspen and white birch trees are particularly susceptible to fire because their thin bark is highly flammable and has little heat resistance (Duchesne and Hawkes 2000). Even low intensity surface fires can ignite bark, girdle and kill sufficient trees to open the stand to light and warming thereby stimulating root suckering (Ahlgren and Ahlgren 1960; Day and Carter 1991). Moderate-intensity fires easily top-kill most mature aspen and white birch and high-intensity fires may kill roots near the soil surface or damage meristematic tissues thus reducing sucker regeneration.

Deeper roots, however, are not damaged by severe fire and remain capable of resprouting. On surviving trees, basal wounds caused by fire serve as entrance points for wood-rotting fungi (Rouse 1986a; Laidly 1990).

Succession After Fire

Regeneration of both aspen and white birch is rapid and results in the formation of an even-aged overstorey (Day and Carter 1991). Both species are capable of re-establishing by means of root suckers and seed blown in from adjacent stands, though aspen tends to recolonize primarily through extensive suckering from lateral roots and white birch tends to seed in on fire-prepared seedbeds (Laidly 1990; Perala 1990; Safford et al. 1990; Day and Carter 1991). Sprouts, and seedlings if a seed source is nearby, will appear within the first year following fire. Sucker densities peak in either the first or second post-burn year and then decline rapidly thereafter. Even-aged aspen stands can develop within a decade (Brown and DeByle 1989). In the absence of recurring fire or other disturbance, aspen and white birch reach maturity and are replaced by more shade-tolerant species such as red maple, black spruce, and balsam fir (Woods and Day 1977).

Management Considerations

In the past, fire played an important role in maintaining aspen and white birch communities in a mosaic pattern and increasing regional vegetation diversity (Day and Carter 1991). Today, however, the presence of seral aspen and white birch on the landscape is threatened by the lack of fire due to suppression. In protected areas where the perpetuation of early successional communities may be desired, prescribed burning and prescribed fire offer an economical and ecologically sensitive means of regenerating aspen and white birch in a manner that closely mimics the natural disturbance and regeneration process (Brown and DeByle 1989; Duchesne and Hawkes 2000). Woods and Day (1977) recommend that fire be allowed to burn in aspen-birch stands in Quetico at approximately 70 to 80 years. However, the timing and intensity of burning will be important to regeneration success for two reasons:

- the vigour of a sucker stand will be greater if the parent stand is killed in early spring before the root system has expended its reserves on new growth (Van Wagner 1993); and
- fires of moderate to high intensity are required to ensure adequate spread and sufficient mortality to the overstorey (Brown and DeByle 1989).

In some cases managers can increase their chances of success by cutting trees (especially conifers) to increase the surface fuel loading and continuity (Brown and DeByle 1989).

Red pine-White pine-Jack pine

Stand and Soil Characteristics

Red pine, white pine, and jack pine occur as canopy dominants in association with aspen, white birch, white spruce, and black spruce associates. White cedar may be locally abundant. Shrubs may include bush honeysuckle, twinflower, blueberry spp., bearberry, and prickly wild rose. The understorey generally consists of a low number of shrubs and herbs and a groundcover of bedrock, conifer litter, feathermoss, and lichen. Soils are very shallow, dry to fresh, sandy to fine loamy (Racey et al. 1996).

Natural Fire Regime Characteristics

Prior to settlement and fire protection, mixed jack-white-red pine forests likely experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. There is little to no information on the natural fire regime in Boreal West, but Burgess and Methven (1977) reported an average return interval of 33 years for low to moderate intensity fires in mixed pine stands at the Petawawa Forest Experiment Station at Chalk River and Dominy (1981) reported an average fire return interval of 13 years and a fire cycle of 36 years near Sault Ste. Marie. In the Clay Belt region of Québec, Bergeron and Brisson (1990) suggest a return interval of 30 years for low-intensity fires and 70 years for stand-replacing fires on islands, and Bergeron (1991) reports a fire return interval of approximately 100 years on islands and 160 years on lakeshores. Researchers in the Great Lakes states have reported similar regimes for mixed pine, with average fire return intervals for low to moderate intensity surface fires of 22 years in Pictured Rocks National Lakeshore in Upper Michigan (Loope 1991) and high-intensity, stand-replacing fires ranging from 27 years at Mack Lake in northern lower Michigan (Simard and Blank 1982) to 35 years in Itasca State Park in northern Minnesota (Spurr 1954). Fire cycles have been reported to range from 129 to 258 years in upper and lower Michigan (Whitney 1986; Zhang et al. 1999).

Vegetation Responses to Fire

Mixed jack-white-red pine stands are typically fire-maintained seral types. Each of these pine species has regeneration requirements that are generated by fire, however jack pine is most restrictive in its requirements (due to its cone serotiny) and white pine is least restrictive (due to its greater tolerance to shade) (Wright and Bailey 1982). Fire is necessary for regeneration in pine because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species to provide light (Maissurow 1935; Van Wagner 1970; Wright and Bailey 1982).

Neither white pine nor red pine individuals can tolerate fire until they are 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant because their bark is still thin and their limbs are too close to the understorey vegetation and can easily ignite (Wright and Bailey 1982; Rouse 1988). High-intensity surface fires and crown fires can kill mature white and red pine trees. Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature trees need to survive in order to reseed the burned area (Heinselman 1981).

Though well-adapted to fire, fire can easily girdle or kill established jack pine. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger trees tend to be more susceptible to crown fires than older ones whose crowns are often thinner and higher from the ground and understorey vegetation (Rouse 1986c; Rowe 1983; Stocks 1989).

Despite its low tolerance to fire, jack pine is ideally suited to regenerate following fire as a result of adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993).

Succession After Fire

The surface fires typical of mixed jack-white-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species and shrubs, to mid-seral mixed jack pine/red pine/white pine/early-mid-tolerant hardwood stands and finally, after 50 years, to mature white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998; Cleland et al. 2004a). In the absence of fire, boreal sites will continue to succeed to white spruce, balsam fir, white birch, white cedar, and black spruce (Heinselman 1973). Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of pine on fire for regeneration, fire is an ideal tool for promoting regeneration and the removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be (1) sufficient duff for pine germination is removed when its moisture content is about 60% or less, (2) competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire, (3) good 10-year-growth of red pine seedlings occurred only in open conditions, and (4) the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, the following observations reported in the literature on prescribed burning in pine should be considered:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time) (McRae et al. 1994);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control (McRae et al. 1994);
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production (McRae et al. 1994);
- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970); and
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988).

VARIABLE FIRE REGIMES

Red pine-White pine

Stand and Soil Characteristics

Red pine and white pine and occasionally white birch dominate the main canopy with balsam fir, black spruce, and trembling aspen associates. White cedar may be locally common. Shrubs typically include mountain maple, beaked hazel, bush honeysuckle, twinflower, and prince's pine. The understorey is often shrub and herb poor with a ground cover of conifer and deciduous litter, feathermoss, and wood. Soils are dry to fresh with a wide range of soil textures (Racey et al. 1996).

Natural Fire Regime Characteristics

Before fire management, white and red pine stands experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. There is little to no information on the natural fire regime in white and red pine in the Boreal West, however in the Clay Belt region of Québec the presettlement regime was characterized by low intensity fires at 30 year intervals and higher intensity, stand-replacing fires at approximately 70 year intervals (Bergeron and Brisson 1990). In the Great Lakes-St. Lawrence forest region of Ontario, low to moderate intensity surface fires occurred at mean intervals ranging from 12 to 37 years (Howe 1915; Burgess and Methven 1977; Cwynar 1977, 1978; Alexander et al. 1979; Guyette and Dey 1995b, Dey and Guyette 1996a), while high-intensity stand-replacing fires occurred at mean intervals of 46 to 85 years (Day and Carter 1991; Guyette and Dey 1995b). Studies in the Great Lakes states found similar fires regimes for white pine-red pine, with average return intervals for surface fires ranging from 22 to 36 years, and 160 years for stand-replacing fires (Frissel 1973; Heinselman 1981; Clark 1990; Loope 1991; Engstrom and Mann 1991). White pine stands with a significant shade-tolerant component growing on mesic sites or fire resistant physiographic sites (e.g., islands, valleys, lower slopes of high ridges) likely had a history of only one severe fire every 150 to 300 years (Heinselman 1973; 1981).

Vegetation Responses to Fire

White and red pine stands are typically fire-maintained seral types that occasionally survive as self-perpetuating climax under variable fire regimes (Methven 1973; Duchesne and Hawkes 2000). Both species require fire for optimal germination and establishment, though white pine is less restrictive in its requirements (Heinselman 1981; Wright and Bailey 1982). Fire is necessary for regeneration because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species to provide light (Maissurow 1935; Van Wagner 1970). Neither white pine nor red pine grows well in heavy shade and both seed-in best on mineral soil and with little or no competition from shrubs and shade-tolerant trees (Heinselman 1973).

Neither white pine nor red pine individuals can tolerate fire until they are 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant because their bark is still thin and their limbs are too close to the understorey vegetation and can easily ignite (Wright and Bailey 1982; Rouse 1988).

High-intensity surface fires and crown fires can kill mature white and red pine trees. The main cause of their mortality following fire is crown scorch (Pinto 1993), with trees sustaining more than 75 percent crown damage most likely to die within the first year post-fire (Van Wagner 1970). Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature trees need to survive in order to reseed the burned area (Heinselman 1981).

Succession After Fire

The surface fires typical of white pine-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species and shrubs, to mid-seral mixed jack pine/red pine/white pine/early-mid-tolerant hardwood stands and finally, after 50 years, to mature white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998; Cleland et al. 2004a). In the absence of fire, boreal sites will continue to succeed to white spruce, balsam fir, white birch, white cedar, and black spruce (Heinselman 1973). Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of white pine and red pine on fire for regeneration, fire is an ideal tool for regeneration and removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be (1) sufficient duff for pine germination is removed when its moisture content is about 60% or less, (2) competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire, (3) good 10-year-growth of red pine seedlings occurred only in open conditions, and (4) the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, McRae et al. (1994) suggest the following with regard to understorey prescribed burning in white and red pine:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control; and
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production.

Lowland black spruce

Stand and Soil Characteristics

Black spruce occurs on lowland sites in pure stands or in association with tamarack, balsam fir, or white cedar. Shrubs typically include labrador-tea, creeping snowberry, blueberry spp., leatherleaf, and small cranberry. The understorey is dominated by ericaceous shrubs and sedges and a ground cover of abundant feathermosses and *Sphagnum*, and patches of conifer and graminoid litter. Soils are shallow to deep organic soils (Racey et al. 1996).

Natural Fire Regime Characteristics

Lowland black spruce stands often occur as pockets surrounded by upland vegetation. As a result, the fire regime is generally driven by the return interval of the adjacent upland vegetation and by interactions of insect and disease, large-scale blowdowns, and periods of drought. Lowlands embedded within or adjacent to relatively fire-resistant landscapes experience fire less frequently than those embedded within or adjacent to fire-prone landscapes (Cleland et al. 2004a). Fire cycle and maximum longevity are probably longer on lowland sites than nearby upland sites (Heinselman 1973).

Bergeron (1991) estimated the average time since fire to be 171 years in conifer bogs near Lake Duparquet, Québec. Heinselman (1981) estimated the fire cycle to be 150 years in a large black spruce peatland in northern Minnesota. Zhang et al. (1999) estimated the fire cycle to be 194 years in stands dominated by tamarack, and 893 years in stands dominated by black spruce, and 1741 years in stands dominated by white cedar. Whitney (1986) estimated a fire cycle of 3000-6000 years in swamp conifers.

Most fires in lowlands would have occurred in July, August, or September of severe drought years when the water tables were low enough that moss layers became thoroughly desiccated. Under these circumstances, given sufficient wind, the spruce, tamarack, and cedar forests of lowlands can carry major crown fires (Heinselman 1981).

Vegetation Responses to Fire

Lowland black spruce stands are generally not as prone to fire as other forest types because of their wetter conditions. Their high water table in the spring, dense green understorey, and more humid environment make them less susceptible to fire, except in severe drought years. Another characteristic of lowland forest types that reduces their susceptibility to fire is the convex nature of the depressions they occupy. Fire tends to avoid convex depressions and seeks concave landforms such as hilltops and slopes. As a result, lowlands are often spared from even large, high-intensity forest fires, leaving unburned pockets of forest that become important seed sources for adjacent uplands (Duchesne and Hawkes 2000).

Despite their relative resistance to fire, lowlands undoubtedly burned periodically during presettlement times and wetland fires during drought in Upper Michigan and in other parts of the eastern U. S. are well documented (Loope 1991). Black spruce, tamarack, and white cedar are susceptible to fire due to their thin bark and shallow roots and can be killed by even low severity fire (Viereck and Johnston 1990; Johnston 1990a; Johnston 1990b). Crown fires are common in black spruce stands because the layering habit of black spruce and the frequent occurrence of abundant lichens on its lower branches often form a continuous fuel that is easily ignited by surface fires. Crown fires typically result in extensive mortality in black spruce stands (Viereck 1983).

Succession After Fire

There is very little information on succession after fire in lowland stands. Successional sequence after fire is complex and depends on a number of factors such as time of year, parent material, severity of burn, climate, stand age, pre-burn vegetation type, weather and presence or absence of permafrost (Viereck, 1983). Lowland conifers establish well on burned organic soils provided a seed source is available and the humus layer is not consumed (Sullivan 1994). Black spruce-*Sphagnum* stands that have been consumed by fire are often replaced by white birch and other pioneer species. These stands then succeed to a stage where both black spruce and white birch are present and then finally to a black spruce stage at which paludification begins. Recurrent fire, however, prevents many sites from reaching late-successional stages (Duchesne and Hawkes 2000).

Management Considerations

Lowland black spruce communities are capable of reproducing and perpetuating in the absence of fire. Generally, as the lowland stands develop and gradually open up there is an influx of seedlings and a release of the suppressed layerings which, together, form an uneven-aged understorey that eventually develops into the main canopy of the stand (Woods and Day 1977). As a result, prescribed burning is not necessary for management of lowland black spruce but prescribed fire may be considered since these stands are known to burn following drought cycles or due to fires in adjacent upland vegetation (Cleland et al. 2004a).

Cedar and hardwood lowlands

Stand and Soil Characteristics

Cedar, and occasionally tamarack or black spruce, dominates forested wetlands in association with balsam fir and white spruce. Shrubs commonly include dwarf raspberry, twinflower, red osier dogwood, mountain maple, and speckled alder. The understorey may consist of a low number of shrubs, a high number of herbs, and a ground cover of feathermoss, conifer litter, *Sphagnum*, and wood. Soils are typically wet organic or peaty phase (Racey et al. 1996).

Hardwood lowlands are very diverse. The main canopy is often dominated by black ash and/or white elm and can include trembling aspen, white birch, balsam poplar, white cedar, white spruce, black spruce, and balsam fir associates. Shrubs commonly include raspberry spp., serviceberry, mountain maple, showy mountain ash, and swamp red currant. The understorey often consists of moderate to high levels of shrubs and herbs and a ground cover of deciduous litter, graminoid litter, feathermoss and wood. Soils are typically fresh to very moist, fine-textured mineral soils or well-decomposed woody peat (Racey et al. 1996).

Natural Fire Regime Characteristics

Conifer and hardwood lowlands historically experienced relatively infrequent to very infrequent stand-replacement or understorey fires. The fire regimes in these lowlands were strongly influenced by fires intruding from adjacent ecosystems and by interactions of insect and disease, large-scale blowdowns, and periods of drought. Lowlands embedded within or adjacent to relatively fire-resistant landscapes experience fire less frequently than those embedded within or adjacent to fire-prone landscapes (Cleland et al. 2004a). Fire cycle and maximum longevity are probably longer on lowland sites than nearby upland sites (Heinselman 1973).

Bergeron (1991) estimated the average time since fire to be 171 years in conifer bogs near Lake Duparquet, Québec. Heinselman (1981) estimated the fire cycle to be 150 years in a large black spruce peatland in northern Minnesota. Zhang et al. (1999) estimated the fire cycle to be 194 years in stands dominated by tamarack, and 893 years in stands dominated by black spruce, and 1741 years in stands dominated by white cedar. Whitney (1986) estimated a fire cycle of 3000-6000 years in swamp conifers. There is very little information in the literature on fire cycle in hardwood lowlands, but Bergeron (1991) estimated an average time since fire of 183 years in black ash, white elm lowland forests, and Zhang et al. (1999) estimated a fire cycle of 1067 years for mixed lowland conifers and hardwoods.

Most fires in lowlands would have occurred in July, August, or September of severe drought years when the water tables were low enough that moss layers became thoroughly desiccated. Under these circumstances, given sufficient wind, the spruce, tamarack, and cedar forests of lowlands can carry major crown fires (Heinselman 1981).

Vegetation Responses to Fire

Conifer and hardwood lowlands are generally not as prone to fire as other forest types because of their wetter conditions. Their high water table in the spring, dense green understorey, and more humid environment make them less susceptible to fire, except in severe drought years. Another characteristic of lowland forest types that reduces their susceptibility to fire is the convex nature of the depressions they occupy. Fire tends to avoid convex depressions and seeks concave landforms such as hilltops and slopes. As a result, lowlands are often spared from even large, high-intensity forest fires, leaving unburned pockets of forest that become important seed sources for adjacent uplands (Duchesne and Hawkes 2000).

Despite their relative resistance to fire, lowlands undoubtedly burned periodically during presettlement times and wetland fires during drought in Upper Michigan and in other parts of the eastern U. S. are well documented (Loope 1991). Black spruce, tamarack, and white cedar are susceptible to fire due to their thin bark and shallow roots and can be killed by even low severity fire (Viereck and Johnston 1990; Johnston 1990a; Johnston 1990b). Crown fires are common in black spruce stands because the layering habit of black spruce and the frequent occurrence of abundant lichens on its lower branches often form a continuous fuel that is easily ignited by surface fires. Crown fires typically result in extensive mortality in black spruce stands (Viereck 1983).

Lowland hardwood species are also sensitive to fire due to their thin bark and shallow roots and even large individuals can be killed by moderate intensity fires (Safford et al. 1990; Perala 1990). Low-intensity fires can damage the cambium causing decay, even though the bark remains intact for several years after fire (Wade et al. 2000).

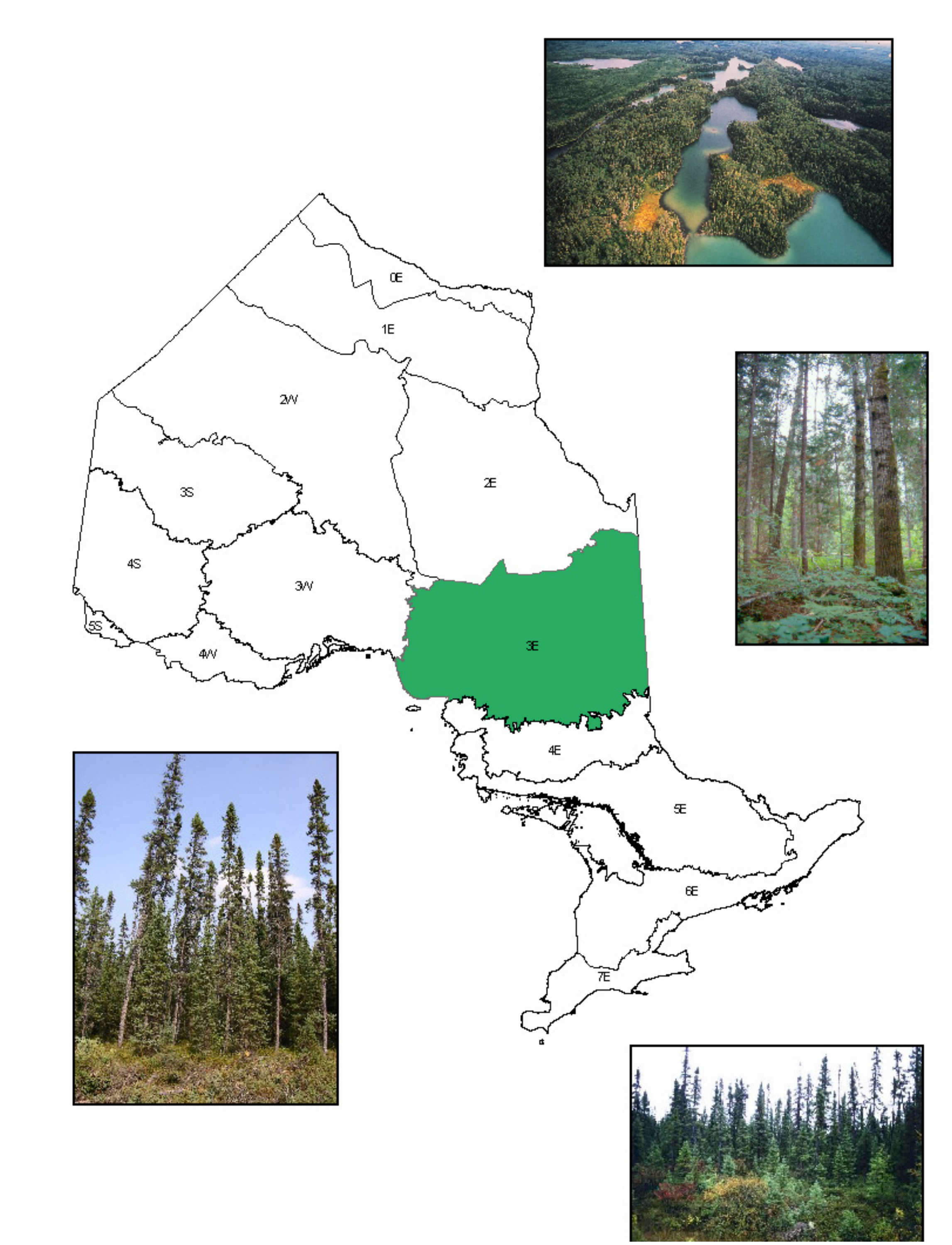
Succession After Fire

There is very little information on succession after fire in lowland stands. Lowland conifers establish well on burned organic soils provided a seed source is available and the humus layer is not consumed. Some lowland hardwood species sprout readily after damage or top-kill, including black ash, aspen, and white birch (Wright and Rausher 1990; Perala 1990; Safford et al. 1990). Others, including sugar maple, white birch, and yellow birch tend to seed in following fire (Daubenmire 1936; Maissurow 1941; Safford et al. 1990). Sprouting of understorey species depends on fire severity and the depth of perennating tissues (Sullivan 1994).

Management Considerations

Lowland cedar and hardwood communities are capable of reproducing and perpetuating in the absence of fire. As a result, prescribed burning is not necessary for management of lowland communities but prescribed fire may be considered since these sites are known to burn following drought cycles or due to fires in adjacent upland vegetation (Cleland et al. 2004a).

BOREAL EAST FOREST REGION



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BOREAL EAST FOREST REGION

Fire is a major natural disturbance in the Boreal East forest region. Fire is most frequent and has greatest severity in coniferous forests compared to the less flammable deciduous forests. Fires in conifer stands can be large, stand-replacing crown fires or high-intensity surface fires that burn tens of thousands of hectares, but smaller fires (<100 ha) are the most frequent. The intensity of both surface and crown fires is affected by the amount and distribution of fuel available, soil and fuel moisture, and by the rate of fire spread. These three criteria are controlled in turn, by many other factors, including: time elapsed since the last fire (or by the amount of fuel accumulated); weather, particularly wind and degree of moisture in the vegetation; forest management activity; extent of damage or mortality caused by disease and insect infestation; species composition and stand age; and, in the longer term, climate (Thompson 2000).

The relatively short fire cycles of the boreal create a forest mosaic mainly composed of pure or mixed, even-aged stands at different stages of recovery following fire. Consequently, forest structure largely reflects the length of time since the last fire (Arsenault 2001; Bergeron et al. 2001). Bergeron (1991) suggests that a regime of large and very intense fires tends to homogenize the effects of fire among all topographical units and fuel types throughout the landscape and that only stands located near effective fire breaks may present more variable behaviour.

The fire regimes of the Boreal East are very similar to those of the Boreal West. The cooler, more humid climate in the east results in lower fire frequency than in the drier west (Thompson 2000; Bergeron et al. 2001). However, when there are droughts in the Boreal East, the existence of large fuel loads that have accumulated through many moist years may result in very large fires. Indeed, several large fires have burned in the east (Thompson 2000).

Table 4. Mean fire interval (MFI) and fire cycle (FC), in years, by homogeneous fire group for ecosites in the Boreal East Forest Region (Ecoregion 3E). See Appendices 4 and 5 for descriptions of fire history studies and Taylor et al. (2000) for descriptions of ecosites.

Homogeneous Fire Group	Corresponding Ecosites (Northeast FEC)	Fire Regime Type		
		Maintenance	Stand Replacement	Variable
Aspen-Birch, Aspen-Birch-Conifer	ES 1r, ES 3, ES 7f, ES 7m, ES 7c, ES10			MFI:55-120, FC:70-210
Jack pine	ES 2		MFI:28-162, FC:36-187	
Black spruce	ES 5f, ES 5m		MFI:30, FC:50-135	
Upland Jack pine-Black spruce	ES 1p, ES 4		MFI:30, FC:50-135	
Spruce-fir mixedwood	ES 6f, ES 6m, ES 6c		MFI:27-65, FC:63-83	
Lowland black spruce	ES 8, ES 9p, ES 9r, ES 11, ES 12, ES 13r, ES 13p, ES 14			MFI:171, FC:150-6000
Tolerant hardwoods and hardwood mixedwoods	ES 15, ES 16, ES 17			MFI:800-1200, FC:300-2700
Jack pine-White pine-Red pine	ES 18			MFI:13-300, FC:36-258
White pine-Red pine, White pine-Conifer	ES 19, ES 20, ES 21			MFI:12-300

STAND-REPLACEMENT FIRE REGIMES

Jack pine

Stand and Soil Characteristics

Jack pine occurs as a canopy dominant on upland sites in pure stands or in association with black spruce. Shrubs typically include blueberry spp., twinflower, wintergreen, trailing arbutus, and sheep laurel. The understorey consists of a low number of shrubs and herbs, abundant ericaceous shrubs, and a ground cover of feathermosses and lichen. Soils are dry to fresh, sandy to coarse loamy (Taylor et al. 2000).

Natural Fire Regime Characteristics

Prior to settlement, jack pine stands usually experienced a fire regime of short-interval, high-intensity surface or crown fires that generally resulted in stand replacement. In the Clay Belt region of Québec, fire return intervals for pine woodland ranged from 97 years on island sites to 162 years on lakeshore sites (Bergeron 1991). In the Great Lakes states, jack pine stands burned at mean intervals of approximately 28 years (Heinselman 1973; Simard and Blank 1982), and with fire cycles ranging from 50 to 187 years (Heinselman 1980; Whitney 1986; Zhang et al. 1999). Major stand-replacing fires in the Boundary Waters Canoe Area occurred in years with summer drought (Heinselman 1973). Heinselman (1981) also suggested that, on the xeric glacial outwash sand plains of central Wisconsin and lower Michigan and in other dry sites, many jack pine areas apparently had regimes of short interval, moderate intensity surface fires that killed only portions of stands in the range of every 15 to 35 years.

Vegetation Responses to Fire

Jack pine is an early to mid-successional species that almost exclusively originates after fire (Cayford 1970). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). These stands normally become mature and decadent at 70 to 80 years of age and produce a large amount of fuel as stand vigour declines, thus predisposing them to another fire (Day and Carter 1991).

Though well-adapted to fire, mature trees may be easily girdled and fire may destroy an established jack pine stand if of sufficient intensity. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger stands tend to be more susceptible to crown fires than older stands whose crowns are often thinner and higher from the ground and understorey vegetation (though the presence of a black spruce understorey of varying heights can aid in the crown fire propagation process in mature stands)(Rouse 1986c; Stocks 1989). Young jack pine stands are also especially susceptible to early spring fires (Rudolph and Laidly 1990).

Succession After Fire

The high-intensity, stand-replacing fires typical of jack pine communities completely reset succession and promote jack pine establishment by temporarily eliminating competing vegetation and creating a mineral soil seedbed (Ahlgren and Ahlgren 1960; Cayford and McRae 1983). Although jack pine seed usually germinates following fire, most of the seedlings will die unless the organic matter on the site has been reduced to a depth less than 1.3 cm thick. Therefore, the probability of successful jack pine establishment increases with greater fire severity (Rudolph and Laidly 1990).

Most germination of jack pine occurs the first and second season following fire, with most seedling mortality occurring between the first and second growing season (Rudolph and Laidly 1990). After 15 years post-fire, a dense, vigorous, even-aged jack pine-aspen community often dominates the burn site, with black spruce establishing in the understorey. As jack pine matures, it continues to dominate the spruce and shade-tolerant hardwood understorey, but is unable to regenerate due to low light levels, severe root competition, and increasing accumulation of organic matter. At approximately 75 years, jack pine begins to decline thus creating openings in the canopy that release suppressed black spruce, balsam fir, and shade-tolerant hardwoods (Day and Woods 1977). In the absence of fire or other disturbance, the original jack pine community is replaced by longer lived and more shade-tolerant species, except on the poorest, driest sites where jack pine may persist and form an edaphic climax (Heinselman 1973; Rudolph and Laidly 1990; Johnson 1992). If fires recur in less than 10 to 15 year intervals, jack pine is unable to survive long enough to produce viable seed thus maintaining barrens and openlands on the landscape (Cleland et al. 2004b).

Management Considerations

Prescribed burns and prescribed fire can be undertaken in jack pine communities to meet one or more objectives, including seedbed preparation, opening serotinous cones, and reducing fire hazard (McRae 1979). Though there is modest literature on prescribed burning done in conjunction with seed tree systems for natural regeneration of jack pine following harvesting, the practice has never become seriously operational in Canada or the United States (Van Wagner 1993). The largest obstacle to the widespread use of prescribed burning in jack pine appears to be the limited number of days when the weather is appropriate to conduct a burn and the widespread acceptance of other chemical, mechanical and silvicultural methods of jack pine regeneration (Rouse 1986c).

There is very little information regarding prescribed burning or fire to meet regeneration objectives in an established stand of jack pine. However, the following observations that have been reported in the literature on prescribed burning in jack pine slash should be considered:

- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970);
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988);
- if seed trees are being used, the prescribed burn should be timed early enough in the season so that seedlings become well-established before winter, or late enough in the season so that seeds overwinter before germinating (Carey 1993);
- successful establishment of jack pine is limited primarily by the depth of organic matter and, therefore, progressively increases with greater fire severity (Rudolph and Laidly 1990); and
- mature and immature jack pine forests have very different stand and fuel characteristics (e.g., density and vertical continuity) and, therefore, exhibit different fire behaviour (Stocks 1987; Stocks 1989).

STAND-REPLACEMENT FIRE REGIMES

Black spruce

Stand and Soil Characteristics

Black spruce grows as a canopy dominant in upland conifer stands in association with balsam fir, jack pine, white birch, and aspen. Shrubs commonly include bunchberry, creeping snowberry, blueberry spp., twinflower, and Labrador tea. The understorey consists of low a low number of shrubs and herbs and a groundcover of abundant feathermoss with patches of S*phagnum* and conifer litter. Soils vary from fresh to moist, fine loamy to silty or clayey (Taylor et al. 2000).

Natural Fire Regime Characteristics

Black spruce stands typically experience a natural fire regime characterized by large, frequent, high-intensity crown or surface fires that usually kill the canopy trees and prevent the development of uneven-aged stands (Viereck 1983; Viereck and Johnston 1990). In Ontario, a fire return interval of 30 years and a fire cycle of 60 to 135 years have been suggested (Maclean and Bedell 1955; Chandler et al. 1983; Bergeron et al. 2001). In other regions, fire cycles range from 50 years in northern Minnesota (Heinselman 1981) to 130 years in Québec (Chandler et al. 1983; Cogbill 1985; Payette et al. 1989; Bergeron et al. 2001; Parisien and Sirois 2003; Bergeron et al. 2004).

Vegetation Responses to Fire

Black spruce is a shade-tolerant, fire-initiated species (Viereck and Johnston 1990; Day and Carter 1991). It is well adapted to regeneration following fire due to early and frequent seed production, and persistent semi-serotinous cones that retain viable seed for up to three years and open when exposed to the heat of fire (Ahlgren and Ahlgren 1960). After fire, a large seed supply is released onto burned-over seedbeds, allowing rapid seedling establishment and development of an even-aged stand (Day and Carter 1991). Delayed seedfall and delayed germination are additional adaptations that ensure seed availability and allow black spruce to establish during post-fire years with favourable growing conditions (Thomas and Wein 1985). Despite these adaptations, black spruce is easily killed by both surface and crown fires because of its thin bark and shallow roots (Ahlgren and Ahlgren 1960; Viereck and Johnston 1990).

Succession After Fire

The amount of organic material on the forest floor that is removed by fire may determine the successional sequence following fire (Viereck 1983). Low severity surface burns, such as those that occur in early spring when the subsurface humus is wet, do not provide adequate conditions for spruce seedling survival. However, severe fires which consume the humus layer, or nearly so, are much more effective in eliminating competition and preparing a seedbed suitable for spruce germination and seedling survival (Rowe 1970).

The frequent, high-intensity, stand-replacing fire typical of upland black spruce sites tends to reset succession, thus permitting seral hardwoods such as white birch and aspen to rapidly invade the burn site (Viereck 1975). After fire, black spruce quickly re-establishes as long as a seed source is available. Jack pine can also seed in vigorously and quickly overtops the slower-growing black spruce. However, black spruce is very shade-tolerant and can survive in this suppressed condition for more than 100 years (Viereck and Johnston 1990). In the absence of fire, these stands will slowly convert to hardwoods with some fir and black spruce (Woods and Day 1977).

Management Considerations

Fire plays a critical role in the perpetuation and maintenance of healthy and vigorous black spruce stands on upland sites. With continued fire suppression, black spruce uplands will become increasingly susceptible to fire as they age, become decadent, and the thinning process becomes more rapid and severe. Prescribed burning is a viable resource management tool for regenerating these upland black spruce sites and for reducing fire hazard (Archibald and Baker 1989; Woods and Day 1977). Based on their study of the ecological effects of fire in black spruce communities in Quetico Provincial Park, Woods and Day (1977) reported the following management considerations:

- fire should be excluded from young stands since there is a high probability that black spruce will not regenerate adequately before 40 years of age (young stands produce only sporadic amounts of seed and if crown fire occurs, it may be intense enough to destroy large amounts of an already limited seed supply); and
- fire may be permitted in stands older than 40 years, but ideally would be excluded until stands reach 90 to 120 years (thus permitting adequate black spruce regeneration without an unnecessary increase in fire frequency and maintaining the aesthetic quality of the black spruce stands).

The following observations regarding fire in black spruce have also been reported in the literature:

- fires that completely remove the surface organic layer exposing mineral soils usually provide good seedbeds for black spruce (Viereck and Johnston 1990);
- good seedling growth occurs after burns where the fire has not been sufficiently intense to destroy the cones in the tallest trees (Ahlgren 1959);
- prescribed fire should not be used in black spruce stands with shallow soil profiles where soil conservation is a major concern (Archibald and Baker 1989); and
- build-up of dead balsam fir trees increases the flammability of a forest because the dead trees provide a dry aerial fuel and the newly exposed understorey is drier than usual (Furyaev et al. 1983).

STAND-REPLACEMENT FIRE REGIMES

Upland Black spruce – Jack pine

Stand and Soil Characteristics

Black spruce and jack pine occur as canopy dominants on upland conifer sites with balsam fir and white birch associates. Shrubs commonly include blueberry spp., bunchberry, twinflower, creeping snowberry, and Labrador tea. The understorey consists of a low to moderate number of shrubs, a low number of herbs and a groundcover of conifer litter and abundant feathermosses and lichens. Soils are typically dry to moist, deep sands and loams but are in some cases are very shallow over bedrock (Taylor et al. 2000).

Natural Fire Regime Characteristics

Prior to suppression, upland black spruce-jack pine communities experienced frequent large, high-severity, stand-replacing fires that usually killed the canopy trees and prevented the development of uneven-aged stands (Viereck and Johnston 1990; Cleland et al. 2004a). In Ontario, a fire return interval of 30 years and a fire cycle of 60 to 135 years have been suggested (Maclean and Bedell 1955; Chandler et al. 1983; Bergeron et al. 2001). In other regions, fire cycles range from 50 years in northern Minnesota (Heinselman 1981) to 130 years in Québec (Chandler et al. 1983; Cogbill 1985; Payette et al. 1989; Bergeron et al. 2001; Parisien and Sirois 2003; Bergeron et al. 2004).

Vegetation Responses to Fire

Both black spruce and jack pine are well adapted to thrive in fire-prone landscapes, however they differ in certain aspects of their life history strategies that enable them to survive recurrent fire (Le Goff and Sirois 2004). Jack pine is a shade-intolerant, moderately long-lived early to mid-successional species that begins seed production at an earlier age than black spruce (Cayford 1970; Le Goff and Sirois 2004). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). Though well-adapted to fire, fire can easily girdle or kill an established jack pine stand. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger trees tend to be more susceptible to crown fires than older ones whose crowns are often thinner and higher from the ground and understorey vegetation (though the presence of a black spruce understorey of varying heights can aid in the crown fire propagation process in mature stands)(Rouse 1986c; Stocks 1989).

In contrast, black spruce is a shade-tolerant, long-lived species that is capable of vegetative reproduction through layering (Viereck and Johnston 1990; Day and Carter 1991; Le Goff and Sirois 2004). It is well adapted to regeneration following fire due to early and frequent seed production, and persistent semi-serotinous cones that retain viable seed for up to three years and open when exposed to the heat of fire (Ahlgren and Ahlgren 1960). After fire, a large seed supply is released onto burned-over seedbeds, allowing rapid seedling establishment and development of an even-aged stand (Day and Carter 1991). Delayed seedfall and delayed germination are additional adaptations that ensure seed availability and allow black spruce to establish during post-fire years with favourable growing conditions (Thomas and Wein 1985). Despite these adaptations, black spruce is easily killed by both surface and crown fires because of its thin bark and shallow roots (Ahlgren and Ahlgren 1960; Viereck and Johnston 1990).

Succession After Fire

The frequent, high-intensity, stand-replacing fire typical of upland black spruce-jack pine sites tends to completely reset succession. Post-fire composition is characterized by even-aged pure or mixed stands dominated by trembling aspen, white birch, jack pine, or black spruce. In the absence of fire this first cohort of trees is replaced at maturity (approximately 100 years following a fire) by a second cohort dominated by more shade-tolerant conifers such as balsam fir, white cedar, white spruce, and black spruce. In this successional stage, stands are often uneven-aged and have a more irregular canopy. In the late-seral stage (greater than 225 years following a fire), treefall gaps and insect infestation permit the self-maintenance of heterogeneous stands of conifers (Bergeron et al. 2001).

Areas that experience recurring fires in less than 10 to 15 years tend to favour the establishment of early-seral aspen and white birch and prevent the establishment of black spruce and jack pine. Conversely, fires occurring in rotations greater than 60 to 100 years lead to replacement of jack pine by black spruce, as well as white spruce, white cedar, balsam fir, and white birch (Frelich and Reich 1995).

Management Considerations

Upland black spruce-jack pine stands are mid-seral communities dominated by trees 15 to 100 years old (Cleland et al. 2004a). Because jack pine has a shorter life span than black spruce and can only regenerate without fire under some particular conditions (Conkey et al. 1995), the perpetuation and maintenance of this seral community on the landscape requires a fire return interval that does not exceed the longevity of jack pine (Le Goff and Sirois 2004). With continued fire suppression, the jack pine component of these stands will be increasingly at risk of local extinction. Further, sites will become increasingly susceptible to fire as they age, become decadent, and the thinning process becomes more rapid and severe (Woods and Day 1977). Prescribed burning is a viable resource management tool for regenerating these upland black spruce-jack pine sites and for reducing fire hazard (Archibald and Baker 1989). The following observations regarding fire in black spruce and jack pine have been reported in the literature:

- fire should be excluded from young stands since there is a high probability that black spruce will not regenerate adequately before 40 years of age (young stands produce only sporadic amounts of seed and if crown fire occurs, it may be intense enough to destroy large amounts of an already limited seed supply) (Woods and Day 1977);
- fire may be permitted in stands older than 40 years, but ideally would be excluded until stands reach 90 to 120 years (thus permitting adequate black spruce regeneration without an unnecessary increase in fire frequency and maintaining the aesthetic quality of the black spruce stands);
- fires that completely remove the surface organic layer exposing mineral soils usually provide good seedbeds for black spruce and jack pine (Viereck and Johnston 1990; Rudolph and Laidly 1990);
- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970);
- mature and immature jack pine forests have very different stand and fuel characteristics (e.g., density and vertical continuity) and, therefore, exhibit different fire behaviour (Stocks 1987; Stocks 1989); and
- build-up of dead balsam fir trees increases the flammability of a forest because the dead trees provide a dry aerial fuel and the newly exposed understorey is drier than usual (Furyaev et al. 1983).

STAND-REPLACEMENT FIRE REGIMES

Spruce-fir mixedwood

Stand and Soil Characteristics

Black spruce, balsam fir, and white spruce dominate the main canopy in association with trembling aspen and white birch. Jack pine and balsam poplar may also occur. Shrubs typically include bunchberry, dwarf raspberry, twinflower, speckled alder, and bush honeysuckle. The understorey usually consists of a moderate number of shrubs and herbs and a ground cover of deciduous litter, conifer litter, and feathermoss. Soils are dry to moist with a wide range of soil textures (Taylor et al. 2000).

Natural Fire Regime Characteristics

Prior to settlement, spruce-fir mixedwoods experienced a regime of large, high-severity, stand-replacing fire (Bergeron 1991; Cleland et al. 2004a). Average fire return intervals reported in the literature range from 27 years in the northern Clay Belt region of Québec (Dansereau and Bergeron 1993) to 65 years in northern Minnesota (Swain 1973). Fire cycles reported in the literature include 63 years and 83 years for the Clay Belt region of Québec (Bergeron 1991; Bergeron et al. 2004). Heinselman (1981) suggested lightning caused most fires, especially in the months of July and August.

Vegetation Responses to Fire

Spruce-fir mixedwood stands are late-seral communities composed of shade-intolerant hardwoods and shade-tolerant conifers (Cleland et al. 2005). Species in these mixedwoods have several adaptations to fire, including (MacLean 1960; Alexander and Euler 1981; Frelich and Reich 1995): (1) root and stump sprouting and abundant seed with long dispersal distance (e.g., trembling aspen and white birch); (2) serotinous cones stored high in the canopy (e.g., black spruce and jack pine); and (3) serotinous cones that retain viable seed for several years following fire (e.g., black spruce). As a result of these adaptations, black spruce, jack pine, trembling aspen, and white birch are capable of re-establishment following fire, even those that result in complete mortality over a large area, because a live seed source is not necessary. White spruce and balsam fir, however, require live seed trees in the refugia of unburned areas or in stands adjacent to the burn in order to re-establish (Alexander and Euler 1981). Despite these adaptations to fire, most species in fir-spruce mixedwoods are easily killed by fire due to their thin bark and shallow roots (Frank 1990; Nienstaedt and Zasada 1990; Viereck and Johnston 1990; Duchesne and Hawkes 2000) and because surface fires often spread to into the canopy due to the highly flammable fine fuels concentrated under the trees which often produce flames that reach the low-growing, flammable, lichen-draped branches (Uchytil 1991).

Succession After Fire

The stand-replacing fires typical of spruce-fir mixedwood stands tend to reset succession. Post-fire composition is characterized by even-aged pure or mixed stands dominated by trembling aspen, white birch, jack pine, or black spruce. In the absence of fire this first cohort of trees is replaced at maturity (approximately 100 years following a fire) by a second cohort dominated by more shade-tolerant conifers such as balsam fir, white cedar, white spruce, and black spruce. In this successional stage, stands are often uneven-aged and have a more irregular canopy. In the late-seral stage (greater than 225 years following a fire), treefall gaps and insect infestation permit the self-maintenance of heterogeneous stands of conifers (Bergeron et al. 2001). However, given the nature of the fire cycle (e.g., 63 to 83 years) it is unlikely that large portions of the landscape will be found in these late-seral stages (Day and Harvey 1981).

The demographic transition from even-aged stands of stand-replacing fire origin to uneven-aged stands dominated by conifer depends on the timing of heavy wind events and insect and disease infestations that create canopy openings and the rate at which the pioneer species approach senescence (Frelich and Reich

1995). Time since disturbance also strongly influences both succession and fire regime in fir-spruce mixedwoods. In the decades following a fire, less flammable aspen and birch dominate but the probability of fire often increases as stands age due to the general increase of fuel along the forest floor (often due to repeated spruce budworm attacks) and development of fuel ladders. Fire probability also increases along a successional gradient due to higher proportions of conifers, particularly shade-tolerant, short-lived balsam fir (Cleland et al. 2005).

Management Considerations

Spruce-fir mixedwood stands are fire-dependent communities that would lose their character, vigour, and diversity in the absence of fire (Alexander and Euler 1981). Long forest cycles have important consequences on stand age distribution, and consequently, on the composition and structure of forest on the landscape. In the absence of fire disturbance, forest structure and composition are closely related to secondary disturbances, particularly spruce budworm outbreaks and windthrow, both of which are becoming more abundant as forests age following fire (Bergeron et al. 2001). Prescribed burning and prescribed fire are techniques that can be used to renew overmature stands, reduce fire hazards, manage wildlife habitat, and convert stands in areas killed or infested with spruce budworm (Alexander and Euler 1981; Furyaev et al. 1983; McRae 1996). Alexander and Euler (1981) reported the following effects of fire on boreal mixedwoods which should be considered when planning for fire:

- fires that remove little duff tend to favour the hardwoods since their regeneration mechanisms are not as dependent on the resulting seedbed conditions;
- density and pattern of black spruce (and to some extent white spruce) following fire will vary according to depth of burn due to preferences for seeding in on exposed mineral soil;
- short return intervals may promote aspen-birch or shrubs over spruce-fir because hardwood species are able to sprout and sucker at an earlier age than that at which conifers are able to produce abundant seed;
- long return intervals may promote spruce over the hardwoods because of the longer lifespan of conifers and the pathologically induced short rotations inherent to aspen and birch; and
- failures in conifer regeneration following fire can often be attributed to unsatisfactory seedbed conditions, inadequate seed source, or a combination of these factors.

Other observations reported in the literature that may be useful for fire management planning include:

- among mixedwood species, balsam fir and white spruce would be disadvantaged by large fires because they rely on the presence of survivors on the landscape to reseed (Bergeron et al. 2004);
- very intense fires, important for duff removal and seedbed preparation for some conifer species, may in some cases kill the root systems and the seed banks of hardwood species (Bergeron et al. 2004);
- balsam fir is usually rare or absent for the first 30 to 50 years after fire, but gradually establishes thereafter under the canopy of post-fire pioneers (Day and Harvey 1981); and
- build-up of dead balsam fir trees increases the flammability of a forest because the dead trees provide a dry aerial fuel and the newly exposed understorey is drier than usual (Furyaev et al. 1983).

VARIABLE FIRE REGIMES

Aspen-Birch, Aspen-Birch-Conifer

Stand and Soil Characteristics

Aspen and white birch occur in hardwood mixedwood and mixedwood stands with black spruce, white spruce, jack pine, balsam fir, and white cedar associates. Shrubs may include mountain maple, bunchberry, twinflower, dwarf raspberry, and bush honeysuckle. The understorey commonly consists of a medium number of shrubs and herbs and a ground cover of abundant deciduous litter with feathermosses and conifer litter. Soils vary from dry to moist and typically range from fine to coarse loamy (Taylor et al. 2000).

Natural Fire Regime Characteristics

Prior to human intervention, seral aspen and birch stands likely experienced a variable fire regime of low intensity surface fires and higher intensity fires, depending on the amount of fuel on the forest floor (Duchesne and Hawkes 2000). In the Clay Belt region of Québec, the mean fire return interval for hardwood mixedwood stands ranged from approximately 55 to 120 years (Bergeron 1991). In Temagami District, Day and Carter (1991) estimated the mean fire interval between fires causing regeneration to have ranged from 66 years in stands dominated by aspen to 104 years in stands dominated by white birch. A fire cycle ranging from 70 to 210 years has been suggested for these communities in the Great Lakes forest region (Cwynar 1977; Heinselman 1981; Zhang et al. 1999). In Boundary Waters Canoe Area, aspen-birch stands experienced a fire regime similar to those of adjacent conifer stands, with severe surface fires or even crown fires (in aspen-birch-conifer stands) with fire cycles of perhaps 80 years (Heinselman 1981). Fires likely occurred most frequently during spring and fall when fuels were dry and leaf litter was deep (Duchesne and Hawkes 2000).

Vegetation Responses to Fire

Aspen and white birch are generally considered to be short lived, shade intolerant, pioneer species (Safford et al. 1990; Laidly 1990; Perala 1990). Since neither aspen nor white birch is capable of reproducing under its own shade, a major stand disturbance is required to maintain these early-successional communities on the landscape (Rouse 1986a; Day and Carter 1991). Fire is considered to be the primary natural disturbance responsible for regeneration in both species as it creates suitable seedbeds and reduces competition (Day and Carter 1991). Both aspen and white birch rapidly colonize open sites created by fire, but usually persist for only one generation before being replaced by more shade-tolerant species (Safford et al. 1990; Laidly 1990; Perala 1990).

Aspen and birch-dominated stands burn only under specific site and climatic conditions, such as in early spring before flushing, following an unusually severe drought, or late in stand history when the proportion of conifers has increased. Fires in young stands are typically low intensity, while those in older stands with abundant fuels burn with greater intensity. Due to the high moisture content and lush understorey, crown fires in adjacent conifer stands often stop at the boundary of large aspen or white birch stands, or become slow-moving ground fires. The presence of conifers, whether in the understorey or the canopy, generally increases the flammability of aspen-birch stands (Foster and King 1986; Duchesne and Hawkes 2000).

Although aspen-white birch forests do not readily burn, aspen and white birch trees are particularly susceptible to fire because their thin bark is highly flammable and has little heat resistance (Duchesne and Hawkes 2000). Even low intensity surface fires can ignite bark, girdle and kill sufficient trees to open the stand to light and warming thereby stimulating root suckering (Ahlgren and Ahlgren 1960; Day and Carter 1991). Moderate intensity fires easily top-kill most mature aspen and white birch and high-intensity fires may kill roots near the soil surface or damage meristematic tissues thus reducing sucker regeneration.

Deeper roots, however, are not damaged by severe fire and remain capable of re-sprouting. On surviving trees, basal wounds caused by fire serve as entrance points for wood-rotting fungi (Rouse 1986a; Laidly 1990).

Succession After Fire

Regeneration of both aspen and white birch is rapid and results in the formation of an even-aged overstorey (Day and Carter 1991). Both species are capable of re-establishing by means of root suckers and seed blown in from adjacent stands, though aspen tends to recolonize primarily through extensive suckering from lateral roots and white birch tends to seed in on fire-prepared seedbeds (Laidly 1990; Perala 1990; Safford et al. 1990; Day and Carter 1991). Sprouts, and seedlings if a seed source is nearby, will appear within the first year following fire. Sucker densities peak in either the first or second postburn year and then decline rapidly thereafter. Even-aged aspen stands can develop within a decade (Brown and DeByle 1989). In the absence of recurring fire or other disturbance, aspen and white birch reach maturity and are replaced by more shade-tolerant species such as red maple, black spruce, and balsam fir (Woods and Day 1977).

Management Considerations

In the past, fire played an important role in maintaining aspen and white birch communities in a mosaic pattern and increasing regional vegetation diversity (Day and Carter 1991). Today, however, the presence of seral aspen and white birch on the landscape is threatened by the lack of fire due to suppression. In protected areas where the perpetuation of early successional communities may be desired, prescribed burning and prescribed fire offer an economical and ecologically sensitive means of regenerating aspen and white birch in a manner that closely mimics the natural disturbance and regeneration process (Brown and DeByle 1989; Duchesne and Hawkes 2000). The timing and intensity of burning will be important to regeneration success for two reasons:

- the vigour of a sucker stand will be greater if the parent stand is killed in early spring before the root system has expended its reserves on new growth (Van Wagner 1993); and
- fires of moderate to high intensity are required to ensure adequate spread and sufficient mortality to the overstorey (Brown and DeByle 1989).

In some cases managers can increase their chances of success by cutting trees (especially conifers) to increase the surface fuel loading and continuity (Brown and DeByle 1989).

Lowland black spruce

Stand and Soil Characteristics

Black spruce occurs on lowland sites in pure stands or in association with balsam fir, jack pine, tamarack, white cedar, white spruce, white birch, aspen, and black ash. Shrubs typically include Labrador tea, creeping snowberry, blueberry spp., dwarf raspberry, bunchberry, and small cranberry. The understorey generally consists of a medium number of shrubs (often ericaceous), a low number of herbs, and a ground cover of abundant feathermosses and S*phagnum*, sparse patches of conifer litter, low hummocks, and small water-filled depressions. Soils are moist, sandy to clayey mineral soils or shallow to deep organic soils (Taylor et al. 2000).

Natural Fire Regime Characteristics

Lowland black spruce stands often occur as pockets surrounded by upland vegetation. As a result, the fire regime is generally driven by the return interval of the adjacent upland vegetation and by interactions of insect and disease, large-scale blowdowns, and periods of drought. Lowlands embedded within or adjacent to relatively fire-resistant landscapes experience fire less frequently than those embedded within or adjacent to fire-prone landscapes (Cleland et al. 2004a). Fire cycle and maximum longevity are probably longer on lowland sites than nearby upland sites (Heinselman 1973).

Bergeron (1991) estimated the average time since fire to be 171 years in conifer bogs near Lake Duparquet, Québec. Heinselman (1981) estimated the fire cycle to be 150 years in a large black spruce peatland in northern Minnesota. Zhang et al. (1999) estimated the fire cycle to be 194 years in stands dominated by tamarack, and 893 years in stands dominated by black spruce, and 1741 years in stands dominated by white cedar. Whitney (1986) estimated a fire cycle of 3000-6000 years in swamp conifers.

Most fires in lowlands would have occurred in July, August, or September of severe drought years when the water tables were low enough that moss layers became thoroughly desiccated. Under these circumstances, given sufficient wind, the spruce, tamarack, and cedar forests of lowlands can carry major crown fires (Heinselman 1981).

Vegetation Responses to Fire

Lowland black spruce stands are generally not as prone to fire as other forest types because of their wetter conditions. Their high water table in the spring, dense green understorey, and more humid environment make them less susceptible to fire, except in severe drought years. Another characteristic of lowland forest types that reduces their susceptibility to fire is the convex nature of the depressions they occupy. Fire tends to avoid convex depressions and seeks concave landforms such as hilltops and slopes. As a result, lowlands are often spared from even large, high-intensity forest fires, leaving unburned pockets of forest that become important seed sources for adjacent uplands (Duchesne and Hawkes 2000).

Despite their relative resistance to fire, lowlands undoubtedly burned periodically during presettlement times and wetland fires during drought in Upper Michigan and in other parts of the eastern U. S. are well documented (Loope 1991). Black spruce, tamarack, and white cedar are susceptible to fire due to their thin bark and shallow roots and can be killed by even low severity fire (Viereck and Johnston 1990; Johnston 1990a; Johnston 1990b). Crown fires are common in black spruce stands because the layering habit of black spruce and the frequent occurrence of abundant lichens on its lower branches often form a continuous fuel that is easily ignited by surface fires. Crown fires typically result in extensive mortality in black spruce stands (Viereck 1983).

Lowland hardwood species are also sensitive to fire due to their thin bark and shallow roots and even large individuals can be killed by moderate intensity fires (Safford et al. 1990; Perala 1990). Low-intensity fires can damage the cambium causing decay, even though the bark remains intact for several years after fire (Wade et al. 2000).

Succession After Fire

There is very little information on succession after fire in lowland stands. Successional sequence after fire is complex and depends on a number of factors such as time of year, parent material, severity of burn, climate, stand age, pre-burn vegetation type, weather and presence or absence of permafrost (Viereck, 1983). Lowland conifers establish well on burned organic soils provided a seed source is available and the humus layer is not consumed (Sullivan 1994). Black spruce-*Sphagnum* stands that have been consumed by fire are often replaced by white birch and other pioneer species. These stands then succeed to a stage where both black spruce and white birch are present and then finally to a black spruce stage at which paludification begins. Recurrent fire, however, prevents many sites from reaching late-successional stages (Duchesne and Hawkes 2000).

Management Considerations

Lowland black spruce communities are capable of reproducing and perpetuating in the absence of fire. Generally, as the lowland stands develop and gradually open up there is an influx of seedlings and a release of the suppressed layerings which, together, form an uneven-aged understorey that eventually develops into the main canopy of the stand (Woods and Day 1977). As a result, prescribed burning is not necessary for management of lowland black spruce but prescribed fire may be considered since these stands are known to burn following drought cycles or due to fires in adjacent upland vegetation (Cleland et al. 2004a).

Tolerant hardwoods and hardwood mixedwoods

Stand and Soil Characteristics

Sugar maple, red maple, or yellow birch occur as canopy dominants in association with white birch, aspen, balsam fir, white spruce, and white cedar. Shrubs may include mountain maple, beaked hazel, bush honeysuckle, blueberry spp., and bunchberry. The understorey consists of a low to moderate number of shrubs, a moderate number of herbs, and abundant deciduous litter. Some conifer litter and feathermoss may also be present. Soils vary from dry to moist, sandy to coarse loamy and silty (Taylor et al. 2000).

Natural Fire Regime Characteristics

Tolerant hardwood and mixed-hardwood stands historically experienced very long interval stand-replacement or understorey fires. Mean fire intervals reported in the literature range from 800 years in northeastern Maine (Lorimer 1977) to 1200 years in northern lower Michigan (Whitney 1986). Fire cycles of many centuries, ranging from 300 years to more than 2700 years, have been suggested by surveyor notes (Lorimer 1977; Whitney 1986; Zhang et al. 1999) and canopy accession dates (Frelich and Lorimer 1991). These ecosystems seem to have erratic fire cycles; the majority of fires likely occurred only after prolonged drought, and then mostly in stands that were already breaking up due to wind or icestorm damage, insect attack, and other events that generate ground fuels (Heinselman 1981).

Vegetation Responses to Fire

Shade-tolerant hardwoods and hardwood mixedwoods are generally considered to be late seral. Grimm (1984) suggests these forests are typically not very flammable for several reasons including: 1) potential fuels decompose rapidly, 2) little fuel exists at ground level due to dense shade, 3) tree trunks are not very flammable, and 4) open tree crowns do not carry fire very well. Additionally, low solar radiation, high humidity, and low wind speeds within the stands tend to prolong the moisture retention of ground-level fuels, thereby inhibiting the ignition and spread of fire (Grimm 1984). Windthrow and other treefall gaps are the dominant disturbance types in these ecosystems (Lorimer 1977; Canham and Loucks 1984; Whitney 1986).

Many of the species associated with these ecosystems, including sugar maple, yellow birch, white birch, trembling aspen, balsam fir, and white cedar are considered sensitive to fire due to their thin bark and shallow roots (Daubenmire 1936; Erdmann 1990; Safford et al. 1990; Perala 1990; Frank 1990; Johnston 1990). Seedlings and saplings of many species are readily killed by even low intensity fire (e.g., sugar maple, yellow birch), and some larger trees can also be killed (Safford et al. 1990; Erdman 1990). Following top-kill by fire, several species-specific responses have been noted:

- sugar maple saplings occasionally sucker, but post-fire establishment occurs primarily through seedling sprouts and seedlings (Daubenmire 1936);
- red maple, aspen, and white birch sprout vigorously from the root collar or stump (Walters and Yawney 1990; Perala 1990; Safford et al. 1990);
- yellow birch is a poor sprouter, but seed germination and seedling establishment are enhanced by fire disturbance (Maissurow 1941);
- balsam fir is generally slow to recover from fire and relies on survivors or trees from adjacent stands to provide seed for re-establishment (Uchytil 1991); and
- white cedar re-establishes a burned site if a seed source is nearby and if exposed soil is moist (Carey 1993).

Succession After Fire

Low intensity surface fires appear to favour maple, which quickly re-establishes post-fire through stump sprouting, seedling sprouts, and seedlings (Maissurow 1941; Walters and Yawney 1990). However, high-intensity fires often consume the existing reproduction of maple and create openings in the forest resulting in greater percentage of yellow birch. Yellow birch is unable to reproduce on the forest floor and enters the composition of hardwood stands together with white birch on the bare mineral soils present following fire (Maissurow 1941). In the absence of stand-replacing disturbance, shade-tolerant, slow growing, and very long-lived species such as sugar maple and yellow birch will be favoured (Cleland et al. 2005).

Management Considerations

In spite of low rates of stand-replacing fire disturbance, disturbances of moderate severity were much more common and probably provided suitable habitat for some early successional or fire-dependent species (Lorimer and White 2003). Fire plays a significant role in the perpetuation of a number of species, such as red maple, yellow birch, white birch, and aspen, thus shaping and determining the form and composition of the hardwood forest. Due to periodic fire disturbance, tolerant hardwood and mixed-hardwood stands consist of (1) uneven-aged groups developed during periods of uninterrupted growth made up of tolerant hardwoods, and (2) one or more even-aged groups of fire-origin species which are unable to reproduce readily on the forest floor. In the absence of fire, monotonous stands of sugar maple would spread over the entire range of hardwood soils (Maissurow 1941).

In Ontario, prescribed burns have been used to create suitable seedbed conditions for yellow birch regeneration. Low intensity surface burns are conducted in late fall following sugar maple leaf and seedfall and prior to yellow birch seedfall. The fire consumes litter and kills advanced regeneration of sugar maple, resulting in higher stocking of yellow birch (Van Wagner 1993).

Jack pine-White pine-Red pine

Stand and Soil Characteristics

Jack pine, white pine, and/or red pine occur as canopy dominants in association with black spruce, white birch, and trembling aspen. Shrubs may include blueberry spp., bush honeysuckle, bunchberry, willow spp., and twinflower. The understorey generally consists of a moderate number of shrubs, low number of herbs, and a groundcover of conifer litter, feathermoss, and scattered patches of lichen. Soils are deep, dry to fresh, sandy to coarse loamy (Taylor et al. 2000).

Natural Fire Regime Characteristics

Prior to settlement and fire protection, mixed jack-white-red pine forests likely experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. There is little to no information on the natural fire regime in mixed pine in the Clay Belt region of Ontario, but in the Clay Belt region of Québec Bergeron and Brisson (1990) suggest a return interval of 30 years for low-intensity fires and 70 years for stand-replacing fires on islands, and Bergeron (1991) reports a fire return interval of approximately 100 years on islands and 160 years on lakeshores. In the Great Lakes-St. Lawrence forest region of Ontario, Burgess and Methven (1977) reported an average return interval of 33 years for low to moderate intensity fires in mixed pine stands at the Petawawa Forest Experiment Station at Chalk River and Dominy (1981) reported an average fire return interval of 13 years and a fire cycle of 36 years near Sault Ste. Marie. Researchers in the Great Lakes states have reported similar regimes for mixed pine, with average fire return intervals for low to moderate intensity surface fires of 22 years in Pictured Rocks National Lakeshore in Upper Michigan (Loope 1991) and high-intensity, stand-replacing fires ranging from 27 years at Mack Lake in northern lower Michigan (Simard and Blank 1982) to 35 years in Itasca State Park in northern Minnesota (Spurr 1954). Fire cycles have been reported to range from 129 to 258 years in upper and lower Michigan (Whitney 1986; Zhang et al. 1999).

Vegetation Responses to Fire

Mixed jack-white-red pine stands are typically fire-maintained seral types. Each of these pine species has regeneration requirements that are generated by fire, however jack pine is most restrictive in its requirements (due to its cone serotiny) and white pine is least restrictive (due to its greater tolerance to shade) (Wright and Bailey 1982). Fire is necessary for regeneration in pine because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species to provide light (Maissurow 1935; Van Wagner 1970; Wright and Bailey 1982).

Neither white pine nor red pine individuals can tolerate fire until they are 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant because their bark is still thin and their limbs are too close to the understorey vegetation and can easily ignite (Wright and Bailey 1982; Rouse 1988). High-intensity surface fires and crown fires can kill mature white and red pine trees. Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature trees need to survive to reseed the burned area (Heinselman 1981).

Though well-adapted to fire, fire can easily girdle or kill established jack pine. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger trees tend to be more susceptible to crown fires than older ones whose crowns are often thinner and higher from the ground and understorey vegetation (Rouse 1986c; Rowe 1983; Stocks 1989). Despite its low tolerance to fire, jack pine is ideally suited to regenerate following fire as a result of adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993).

Succession After Fire

The surface fires typical of mixed jack-white-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species and shrubs, to mid-seral mixed jack pine/red pine/white pine/early-mid-tolerant hardwood stands and finally, after approximately 50 years, to mature white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998; Cleland et al. 2004a). In the absence of fire, boreal sites will continue to succeed to white spruce, balsam fir, white birch, white cedar, and black spruce (Heinselman 1973). Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of pine on fire for regeneration, fire is an ideal tool for promoting regeneration and the removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be (1) sufficient duff for pine germination is removed when its moisture content is about 60% or less, (2) competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire, (3) good 10-year-growth of red pine seedlings occurred only in open conditions, and (4) the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, the following observations reported in the literature on prescribed burning in pine should be considered:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time) (McRae et al. 1994);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control (McRae et al. 1994);
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production (McRae et al. 1994);
- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970); and
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988).

White pine-Red pine, White pine-Conifer

Stand and Soil Characteristics

White pine and red pine occur in mixedwood and hardwood mixedwood stands with white spruce, black spruce, white cedar, balsam fir, jack pine, white birch, yellow birch, aspen, red maple and black ash associates. Shrubs may include mountain maple, dwarf raspberry, beaked hazel, blueberry spp., and bunchberry. The understorey consists of a medium number of shrubs and a low to moderate number of herbs a ground cover of conifer and deciduous litter and scattered patches of feathermoss. Soils are dry to moist, sandy to coarse loamy or silty (Taylor et al. 2000).

Natural Fire Regime Characteristics

Before fire management, white and red pine stands experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. There is little to no information on the natural fire regime in white and red pine in the Clay Belt region of Ontario, however in the Clay belt of Québec the presettlement regime was characterized by low intensity fires at 30 year intervals and higher intensity, stand-replacing fires at approximately 70 year intervals (Bergeron and Brisson 1990). In the Great Lakes-St. Lawrence forest region of Ontario, low to moderate intensity surface fires occurred at mean intervals ranging from 12 to 37 years (Howe 1915; Burgess and Methven 1977; Cwynar 1977, 1978; Alexander et al. 1979; Guyette and Dey 1995b, Dey and Guyette 1996a), while high-intensity, stand-replacing fires occurred at mean intervals of 46 to 85 years (Day and Carter 1991; Guyette and Dey 1995b). Studies in the Great Lakes states found similar fires regimes for white pine-red pine, with average return intervals for surface fires ranging from 22 to 36 years, and 160 years for stand-replacing fires (Frissel 1973; Heinselman 1981; Clark 1990; Loope 1991; Engstrom and Mann 1991). White pine stands with a significant shade-tolerant component growing on mesic sites or fire resistant physiographic sites (e.g., islands, valleys, lower slopes of high ridges) likely had a history of only one severe fire every 150 to 300 years (Heinselman 1973; 1981).

Vegetation Responses to Fire

White and red pine stands are typically fire-maintained seral types that occasionally survive as self-perpetuating climax under mixed fire regimes (Methven 1973; Duchesne and Hawkes 2000). Both species require fire for optimal germination and establishment, though white pine is less restrictive in its requirements (Heinselman 1981; Wright and Bailey 1982). Fire is necessary for regeneration because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species to provide light (Maissurow 1935; Van Wagner 1970). Neither white pine nor red pine grows well in heavy shade and both seed-in best on mineral soil and with little or no competition from shrubs and shade-tolerant trees (Heinselman 1973).

Neither white pine nor red pine individuals can tolerate fire until they are 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant because their bark is still thin and their limbs are too close to the understorey vegetation and can easily ignite (Wright and Bailey 1982; Rouse 1988).

High-intensity surface fires and crown fires can kill mature white and red pine trees. The main cause of their mortality following fire is crown scorch (Pinto 1993), with trees sustaining more than 75 percent crown damage most likely to die within the first year post-fire (Van Wagner 1970). Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature individuals must survive these severe fires to reseed the burn, unless the fire happened to occur in a good seed year (Heinselman 1981).

Succession After Fire

The surface fires typical of white pine-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species and shrubs, to mid-seral mixed jack pine/red pine/white pine/early-mid-tolerant hardwood stands and finally, after 50 years, to mature white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998; Cleland et al. 2004a). In the absence of fire, boreal sites will continue to succeed to white spruce, balsam fir, white birch, white cedar, and black spruce (Heinselman 1973). Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of white pine and red pine on fire for regeneration, fire is an ideal tool for regeneration and removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be (1) sufficient duff for pine germination is removed when its moisture content is about 60% or less, (2) competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire, (3) good 10-year-growth of red pine seedlings occurred only in open conditions, and (4) the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, McRae et al. (1994) suggest the following with regard to understorey prescribed burning in white and red pine:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control; and
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production.

GREAT LAKES-ST. LAWRENCE FOREST REGION

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GREAT LAKES-ST. LAWRENCE FOREST REGION

Fire plays an important but complex role in the Great Lakes-St. Lawrence forest region (Uhlig et al. 2001). The region represents a broad transition between the transcontinental Boreal Forest to the north and the Deciduous Forest to the south. It includes many fire-adapted and fire-tolerant species from each of the adjacent forest regions (Carleton 2003).

A variable regime with low intensity surface fires occurring at relatively short intervals and higher intensity, stand-replacing fires occurring at long intervals is most common in the region and is thought to have played an important role in the establishment and maintenance of pine and oak dominated forests. Surface fires do not generate enough heat to consume most large trees and rarely flare up into the canopy. As a result, these fires create small openings in the forest and kill young, shade-tolerant trees and shrubs, and occasionally individual mature trees, thereby altering succession to maintain early and mid-seral tree species on the landscape (Thompson 2000; Carleton 2003). High-intensity, stand-replacing fires are less common than in the boreal but have been known to affect large areas and appear to be associated with high levels of ground fuels following prolonged drought, wind, ice storm, or repeated insect damage (Kershaw 1993; Thompson 2000). The enclaves of boreal forest in the region appear to have fire regimes similar to the full boreal forest (Heinselman 1981). Aboriginal use of fire may have been a significant factor in this region but its extent and impact are not well understood (Uhlig et al. 2001).

The ELC for southern Ontario (Lee et al. 1998) is currently the only classification that provides descriptions for non-forested ecosites such as prairie, savanna, woodland, alvar, and barrens. As a result, fact sheets have only been prepared for these ecosites in the context of the Deciduous Forest region. However, other forest regions have similar non-forested ecosites, and planners and managers may wish to refer to these fact sheets in the context of the northern forests as well.

Table 5. Mean fire interval (MFI) and fire cycle (FC), in years, by homogeneous fire group for ecosites in the Great Lakes-St. Lawrence Forest Region (Ecoregions 4E and 5E). See Appendices 4 and 5 for descriptions of fire history studies and Chambers et al. (1997) for descriptions of ecosites.

Homogeneous Fire Group	**Corresponding Ecosites (Central FEC)**	**Fire Regime (years)**		
		Maintenance	**Stand Replacement**	**Variable**
White pine-Red pine	11.1, 11.2, 12.1, 12.2			MFI:12-300
Jack pine-White pine-Red pine	13.1, 13.2			MFI:13-35, FC:36-258
Jack pine	15.1, 15.2		MFI:15-71, FC: 50-187	
Black spruce	16.1, 16.2		MFI: 64, FC:50-893	
Aspen-Birch, Aspen-Birch-Conifer	17.1, 17.2, 18.1, 18.2, 19.1, 19.2, 20.1, 20.2, 21.1, 21.2, 22			MFI:66-104, FC:70-210
Oak-hardwood, Oak-pine	14.1, 14.2, 23.1, 23.2			MFI:6-200
Tolerant hardwoods and mixed hardwoods	24.1, 24.2, 25.1, 25.2, 26.1, 26.2, 27.1, 27.2, 28.1, 28.2, 29.1, 29.2, 30.1, 30.2			MFI:800-1200, FC:300-2700
Conifer and hardwood lowlands	31, 32, 33, 34, 35			MFI:171-183, FC:150-6000

STAND-REPLACEMENT FIRE REGIMES

Jack pine

Stand and Soil Characteristics

Jack pine occurs in pure stands or as a main canopy dominant in association with black spruce. Shrubs commonly include blueberry spp., creeping snowberry, twinflower, and bush honeysuckle. The understorey consists of moderate to high levels of conifer regeneration, moderate levels of ericaceous shrubs, low numbers of herbs, and high levels of feathermosses. Soils are typically dry to moist and sandy to silty (Chambers et al. 1997).

Natural Fire Regime Characteristics

Prior to settlement, jack pine stands usually experienced a fire regime of short-interval, high-intensity surface or crown fires that caused stand replacement. In Temagami, Day and Carter (1991) found that stand-replacing fires occurred at mean fire intervals of approximately 71 years, while fire history studies in the Great Lakes states found that jack pine stands burned at mean intervals of approximately 28 years (Heinselman 1973; Simard and Blank 1982), and with fire cycles ranging from 50 to 187 years (Heinselman 1980; Whitney 1986; Zhang et al. 1999). Major stand-replacing fires in the Boundary Waters Canoe Area occurred in years with summer drought (Heinselman 1973). Heinselman (1981) also suggested that, on the xeric glacial outwash sand plains of central Wisconsin and lower Michigan and in other dry sites, many jack pine areas apparently had regimes of short interval, moderate intensity surface fires that killed only portions of stands in the range of every 15 to 35 years.

Vegetation Responses to Fire

Jack pine is an early to mid-successional species that almost exclusively originates after fire (Cayford 1970). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). These stands normally become mature and decadent at 70 to 80 years of age and produce a large amount of fuel as stand vigour declines, thus predisposing them to another fire (Day and Carter 1991).

Though well-adapted to fire, fire can easily girdle or kill an established jack pine stand. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger stands tend to be more susceptible to crown fires than older stands whose crowns are often thinner and higher from the ground and understorey vegetation (though the presence of a black spruce understorey of varying heights can aid in the crown fire propagation process in mature stands)(Rouse 1986c; Stocks 1989). Young jack pine stands are also especially susceptible to early spring fires (Rudolph and Laidly 1990). Mature jack pine stands can survive low severity fires (Rowe 1983).

Succession After Fire

The high-intensity, stand-replacing fires typical of jack pine communities completely reset succession and promote jack pine establishment by temporarily eliminating competing vegetation and creating a mineral soil seedbed (Ahlgren and Ahlgren 1960; Cayford and McRae 1983). Although jack pine seed usually germinates following fire, most of the seedlings will die unless the organic matter on the site has been reduced to a depth less than 1.3 cm thick. Therefore, the probability of successful jack pine establishment increases with greater fire severity (Rudolph and Laidly 1990).

Most germination of jack pine occurs the first and second season following fire, with most seedling mortality occurring between the first and second growing season (Rudolph and Laidly 1990). After 15 years post-fire, a dense, vigorous, even-aged jack pine-aspen community often dominates the burn site, with black spruce establishing in the understorey. As jack pine matures, it continues to dominate the spruce and shade-tolerant hardwood understorey, but is unable to regenerate due to low light levels, severe root competition, and increasing accumulation of organic matter. At approximately 75 years, jack pine begins to decline thus creating openings in the canopy that release suppressed black spruce, balsam fir, and shade-tolerant hardwoods (Day and Woods 1977). In the absence of fire or other disturbance, the original jack pine community is replaced by longer lived and more shade-tolerant species, except on the poorest, driest sites where jack pine may persist and form an edaphic climax (Heinselman 1973; Rudolph and Laidly 1990; Johnson 1992).

Management Considerations

Prescribed burns and prescribed fire can be undertaken in jack pine communities to meet one or more objectives, including seedbed preparation, opening serotinous cones, and reducing fire hazard (McRae 1979). Though there is modest literature on prescribed burning done in conjunction with seed tree systems for natural regeneration of jack pine following harvesting, the practice has never become seriously operational in Canada or the United States (Van Wagner 1993). The largest obstacle to the widespread use of prescribed burning in jack pine appears to be the limited number of days when the weather is appropriate to conduct a burn and the widespread acceptance of other chemical, mechanical and silvicultural methods of jack pine regeneration (Rouse 1986c).

There is very little information on prescribed burning or fire to meet regeneration objectives in an established stand of jack pine. However, the following observations that have been reported in the literature on prescribed burning in jack pine slash should be considered:

- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970);
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988);
- if seed trees are being used, the prescribed fire should be timed early enough in the season so that seedlings become well-established before winter, or late enough in the season so that seeds overwinter before germinating (Carey 1993);
- successful establishment of jack pine is limited primarily by the depth of organic matter and, therefore, progressively increases with greater fire severity (Rudolph and Laidly 1990); and
- mature and immature jack pine forests have very different stand and fuel characteristics (e.g., density and vertical continuity) and, therefore, exhibit different fire behaviour (Stocks 1987; Stocks 1989).

Black spruce

Stand and Soil Characteristics

Black spruce grows as a canopy dominant in association with white pine, red pine, jack pine, aspen and white birch. Shrubs commonly include blueberry spp., creeping snowberry, twinflower, bush honeysuckle, and sheep laurel. The understorey consists of moderate to high levels of conifer regeneration and ericaceous shrubs, low levels of hardwoods shrubs, low number of herbs, and high levels of feathermosses. Soils vary from dry to moist and sandy to coarse loamy (Chambers et al. 1997).

Natural Fire Regime Characteristics

Black spruce stands typically experience a natural fire regime characterized by large, frequent, high-intensity crown or surface fires that usually kill the canopy trees and prevent the development of uneven-aged stands (Viereck 1983; Viereck and Johnston 1990). In Temagami, the mean interval between stand-replacing fires was approximately 64 years (Day and Carter 1991). Heinselman (1981) estimated a fire cycle ranging from 50 to 150 years for black spruce stands throughout much of Canada's boreal region, while Zhang et al. (1999) estimated a fire cycle of 893 years for black spruce stands on the Upper Peninsula of Michigan.

Vegetation Responses to Fire

Black spruce is a shade-tolerant, fire-initiated species (Viereck and Johnston 1990; Day and Carter 1991). It is well adapted to regeneration following fire due to early and frequent seed production, and persistent semi-serotinous cones that retain viable seed for up to three years and open when exposed to the heat of fire (Ahlgren and Ahlgren 1960). After fire, a large seed supply is released onto burned-over seedbeds, allowing rapid seedling establishment and development of an even-aged stand (Day and Carter 1991). Delayed seedfall and delayed germination are additional adaptations that ensure seed availability and allow black spruce to establish during post-fire years with favourable growing conditions (Thomas and Wein 1985). Despite these adaptations, black spruce is easily killed by both surface and crown fires because of its thin bark and shallow roots (Ahlgren and Ahlgren 1960; Viereck and Johnston 1990).

Succession After Fire

The amount of organic material on the forest floor that is removed by fire may determine the successional sequence following fire (Viereck 1983). Low severity surface burns, such as those that occur in early spring when the subsurface humus is wet, do not provide adequate conditions for spruce seedling survival. However, severe fires which consume the humus layer, or nearly so, are much more effective in eliminating competition and preparing a seedbed suitable for spruce germination and seedling survival (Rowe 1970).

The frequent, high-intensity, stand-replacing fire typical of upland black spruce sites tends to reset succession, thus permitting seral hardwoods such as white birch and aspen to rapidly invade the burn site (Viereck 1975). After fire, black spruce quickly re-establishes on relatively dry upland sites where it occurs with jack pine, white pine, and red pine. The pines also seed in vigorously and quickly overtop the slower-growing black spruce. However, black spruce is very shade-tolerant and can survive in this suppressed condition for more than 100 years (Heinselman 1973; Viereck and Johnston 1990). In the absence of fire, these stands will slowly convert to hardwoods with some fir and black spruce (Woods and Day 1977).

Management Considerations

Fire plays a critical role in the perpetuation and maintenance of healthy and vigorous black spruce stands on upland sites. With continued fire suppression, black spruce uplands will become increasingly susceptible to fire as they age, become decadent, and the thinning process becomes more rapid and severe. Prescribed burning is a viable resource management tool for regenerating these upland black spruce sites and for reducing fire hazard (Archibald and Baker 1989; Woods and Day 1977). Based on their study of the ecological effects of fire in black spruce communities in Quetico Provincial Park, Woods and Day (1977) reported the following management considerations:

- fire should be excluded from young stands since there is a high probability that black spruce will not regenerate adequately before 40 years of age (young stands produce only sporadic amounts of seed and if crown fire occurs, it may be intense enough to destroy large amounts of an already limited seed supply); and
- fire may be permitted in stands older than 40 years, but ideally would be excluded until stands reach 90 to 120 years (thus permitting adequate black spruce regeneration without an unnecessary increase in fire frequency and maintaining the aesthetic quality of the black spruce stands).

The following observations regarding fire in black spruce have also been reported in the literature:

- fires that completely remove the surface organic layer exposing mineral soils usually provide good seedbeds for black spruce (Viereck and Johnston 1990);
- good seedling growth occurs after burns where the fire has not been sufficiently intense to destroy the cones in the tallest trees (Ahlgren 1959); and
- prescribed fire should not be used in black spruce stands with shallow soil profiles where soil conservation is a major concern (Archibald and Baker 1989).

White pine-Red pine

Stand and Soil Characteristics

White pine and red pine occur in pure stands or as co-dominants in the main canopy with jack pine, aspen, white spruce, white birch, balsam fir, and red oak associates. Shrubs commonly include beaked hazel, blueberry spp., bush honeysuckle, fly honeysuckle, serviceberry spp., wintergreen and twinflower. The understorey may consist of a low to moderate number of herbs and a ground cover of feathermosses. Soils are typically dry to fresh, sandy to coarse loamy (Chambers et al. 1997).

Natural Fire Regime Characteristics

Prior to modern intervention, white and red pine stands experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. In the Great Lakes forest region of Ontario, low to moderate intensity surface fires occurred at mean intervals ranging from 12 to 37 years (Howe 1915; Burgess and Methven 1977; Cwynar 1977, 1978; Alexander et al. 1979; Guyette and Dey 1995b, Dey and Guyette 1996a), while high-intensity stand-replacing fires occurred at mean intervals of 46 to 85 years (Day and Carter 1991; Guyette and Dey 1995b). Studies in the Great Lakes states found similar fires regimes for white pine-red pine, with average return intervals for surface fires ranging from 22 to 36 years, and 160 years for stand-replacing fires (Frissel 1973; Heinselman 1981; Clark 1990; Loope 1991; Engstrom and Mann 1991). White pine stands with a significant shade-tolerant component growing on mesic sites or fire resistant physiographic sites (e.g., islands, valleys, lower slopes of high ridges) likely had a history of only one severe fire every 150 to 300 years (Heinselman 1973; 1981).

Vegetation Responses to Fire

White and red pine stands are typically fire-maintained seral types that occasionally survive as self-perpetuating climax under mixed fire regimes (Methven 1973; Duchesne and Hawkes 2000). Both species require fire for optimal germination and establishment, though white pine is less restrictive in its requirements (Heinselman 1981; Wright and Bailey 1982). Fire is necessary for regeneration because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species which in turn increases light penetration to the ground (Maissurow 1935; Van Wagner 1970). Neither white pine nor red pine grows well in heavy shade and optimal germination for both species occurs on mineral soil with little or no competition from shrubs and shade-tolerant trees (Heinselman 1973).

Neither white pine nor red pine individuals can tolerate fire until roughly 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant due to thin bark and the close proximity of tree branches to the ground and understorey vegetation. These low branches can easily ignite during low intensity surface fires. (Wright and Bailey 1982; Rouse 1988).

High-intensity surface fires and crown fires can kill mature white and red pine trees. The main cause of their mortality following fire is crown scorch (Pinto 1993). Research indicates that red or white pine trees that sustain more than 75 percent crown damage most likely to die within the first year post-fire (Van Wagner 1970). Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature individuals must survive these severe fires to reseed the burn, unless the fire happened to occur in a good seed year (Heinselman 1981).

Succession After Fire

The surface fires typical of white pine-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species to shrub and hardwood, and finally, after 50 years, to white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998). In the absence of fire, stands will continue to succeed to spruce-fir on the northern boundaries of the region and to various combinations of tolerant hardwoods throughout most of the remaining range within 200 to 300 years. Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of white pine and red pine on fire for regeneration, fire is an ideal tool for regeneration and removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be:

- sufficient duff for pine germination is removed when its moisture content is about 60% or less;
- competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire;
- good 10-year-growth of red pine seedlings occurred only in open conditions; and
- the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, McRae et al. (1994) suggest the following with regard to understorey prescribed burning in white and red pine:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control; and
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production.

Jack pine-White pine-Red pine

Stand and Soil Characteristics

Jack pine, white pine, and red pine occur as canopy dominants in association with white spruce, aspen, black spruce, and white birch associates in the main and sub-canopies. Shrubs commonly include blueberry spp., wintergreen, bush honeysuckle, beaked hazel and twinflower. The understorey consists of ericaceous and low hardwood shrubs, a low numbers of herbs, feathermosses, and lichens. Soils are dry to moist, sandy to coarse loamy (Chambers et al. 1997).

Natural Fire Regime Characteristics

Prior to settlement and fire protection, mixed jack-white-red pine forests likely experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. In Ontario, Burgess and Methven (1977) reported an average return interval of 33 years for low to moderate intensity fires in mixed pine stands at the Petawawa Forest Experiment Station at Chalk River and Dominy (1981) reported an average fire return interval of 13 years and a fire cycle of 36 years near Sault Ste. Marie. Researchers in the Great Lakes states have reported similar regimes for mixed pine, with average fire return intervals for low to moderate intensity surface fires of 22 years in Pictured Rocks National Lakeshore in Upper Michigan (Loope 1991) and high-intensity, stand-replacing fires ranging from 27 years at Mack Lake in northern lower Michigan (Simard and Blank 1982) to 35 years in Itasca State Park in northern Minnesota (Spurr 1954). Fire cycles have been reported to range from 129 to 258 years in upper and lower Michigan (Whitney 1986; Zhang et al. 1999).

Vegetation Responses to Fire

Mixed jack-white-red pine stands are typically fire-maintained seral types. Each of these pine species has regeneration requirements that are generated by fire, however jack pine is most restrictive in its requirements (due to its cone serotiny) and white pine is least restrictive (due to its greater tolerance to shade) (Wright and Bailey 1982). Fire is necessary for regeneration in pine because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species to provide light (Maissurow 1935; Van Wagner 1970; Wright and Bailey 1982).

Neither white pine nor red pine individuals can tolerate fire until they are 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant because their bark is still thin and their limbs are too close to the understorey vegetation and can easily ignite (Wright and Bailey 1982; Rouse 1988). High-intensity surface fires and crown fires can kill mature white and red pine trees. Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature trees need to survive in order to reseed the burned area (Heinselman 1981).

Though well-adapted to fire, fire can easily girdle or kill established jack pine. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger trees tend to be more susceptible to crown fires than older ones whose crowns are often thinner and higher from the ground and understorey vegetation (Rouse 1986c; Rowe 1983; Stocks 1989). Despite its low tolerance to fire, jack pine is ideally suited to regenerate following fire as a result of adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993).

Succession After Fire

The surface fires typical of mixed jack-white-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species and shrubs, to mid-seral mixed jack pine/red pine/white pine/early-mid-tolerant hardwood stands and finally, after 50 years, to mature white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998; Cleland et al. 2004a). In the absence of fire, boreal sites will continue to succeed to white spruce, balsam fir, white birch, white cedar, and black spruce (Heinselman 1973). Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of pine on fire for regeneration, fire is an ideal tool for regeneration and removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be (1) sufficient duff for pine germination is removed when its moisture content is about 60% or less, (2) competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire, (3) good 10-year-growth of red pine seedlings occurred only in open conditions, and (4) the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, the following observations reported in the literature on prescribed burning in pine should be considered:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time) (McRae et al. 1994);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control (McRae et al. 1994);
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production (McRae et al. 1994);
- jack pine regeneration is typically better after summer fires than spring fires (because the drier conditions result in greater duff removal)(Chrosciewicz 1970); and
- favourable weather conditions, especially adequate precipitation, during the growing seasons following seed dispersal from parent trees has a profound effect on the quality of seedbed for pine regeneration (Chrosciewicz 1988).

Aspen-Birch, Aspen-Birch-Conifer

Stand and Soil Characteristics

Aspen and white birch often occur in pure stands or as co-dominants in mixed woods stands that also include white pine, red pine, jack pine, white spruce, white cedar, and balsam fir. Shrubs include beaked hazel, bush honeysuckle, fly honeysuckle, mountain maple, blueberry spp., and twinflower. The understorey usually consists of moderate amounts of hardwood and conifer regeneration, a moderate number of herbs, and a ground cover of feathermosses and lichens. Soils vary from dry to moist and are typically sandy to coarse loamy (Chambers et al. 1997).

Natural Fire Regime Characteristics

Prior to settlement, aspen-birch stands likely experienced a variable fire regime of low intensity surface fires and higher intensity fires, depending on the amount of fuel on the forest floor (Duchesne and Hawkes 2000). In Temagami District, Day and Carter (1991) estimated the mean fire interval between fires causing regeneration to have ranged from 66 years in stands dominated by aspen to 104 years in stands dominated by white birch. A fire cycle ranging from 70 to 210 years has been suggested for these communities in the Great Lakes forest region (Cwynar 1977; Heinselman 1981; Zhang et al. 1999). In Boundary Waters Canoe Area, aspen-birch stands experienced a fire regime similar to those of adjacent conifer stands, with severe surface fires or even crown fires (in aspen-birch-conifer stands) with fire cycles of perhaps 80 years (Heinselman 1981). Fires likely occurred most frequently during spring and fall when fuels were dry and leaf litter was deep (Duchesne and Hawkes 2000).

Vegetation Responses to Fire

Aspen and white birch are generally considered to be short lived, shade intolerant, pioneer species (Safford et al. 1990; Laidly 1990; Perala 1990). Since neither aspen nor white birch is capable of reproducing under its own shade, a major stand disturbance is required to maintain these early-successional communities on the landscape (Rouse 1986a; Day and Carter 1991). Fire is considered to be the primary natural disturbance responsible for regeneration in both species as it creates suitable seedbeds and reduces competition (Day and Carter 1991). Both aspen and white birch rapidly colonize open sites created by fire, but usually persist for only one generation before being replaced by more shade-tolerant species (Safford et al. 1990; Laidly 1990; Perala 1990).

Aspen and birch-dominated stands burn only under specific site and climatic conditions, such as in early spring before leaf flush, following an unusually severe drought, or late in stand history when the proportion of conifers has increased. Fires in young stands are typically low intensity, while those in older stands with abundant fuels may burn with greater intensity. Due to the high moisture content and lush understorey, crown fires in adjacent conifer stands often stop at the boundary of large aspen or white birch stands, or become slow-moving ground fires. The presence of conifers, whether in the understorey or the canopy, generally increases the flammability of aspen-birch stands (Foster and King 1986; Duchesne and Hawkes 2000).

Although aspen-white birch forests do not readily burn, aspen and white birch trees are particularly susceptible to fire because their thin bark is highly flammable and provides little or no heat resistance to the cambium layer immediately beneath the bark (Duchesne and Hawkes 2000). Even low intensity surface fires can ignite bark, girdle and kill sufficient trees to open the stand to improved or increased light penetration to through the canopy and increased warming thereby stimulating root suckering (Ahlgren and Ahlgren 1960; Day and Carter 1991). Moderate intensity fires easily top-kill most mature aspen and white birch and high-intensity fires may kill roots near the soil surface or damage meristematic tissues thus reducing sucker regeneration. Deeper roots, however, are not damaged by severe fire and remain capable of re-sprouting. On surviving trees, basal wounds caused by fire serve as entrance points for wood-rotting fungi (Rouse 1986a; Laidly 1990).

Succession After Fire

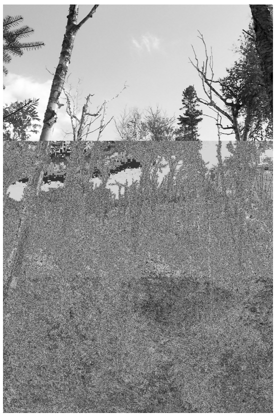
Regeneration of both aspen and white birch is rapid and results in the formation of an even-aged overstorey (Day and Carter 1991). Both species are capable of re-establishing by means of root suckering and seed blown in from adjacent stands, though aspen tends to recolonize primarily through extensive suckering from lateral roots and white birch tends to seed in on fire-prepared seedbeds (Laidly 1990; Perala 1990; Safford et al. 1990; Day and Carter 1991). Sprouts, and seedlings if a seed source is nearby, will appear within the first year following fire. Sucker densities peak in the first or second postburn year and then decline rapidly thereafter. Even-aged aspen stands can develop within a decade (Brown and DeByle 1989). In the absence of recurring fire or other disturbance, aspen and white birch reach maturity and are replaced by red pine, red oak, and red maple on dry sites; white pine on intermediate sites; and by tolerant hardwoods, spruce spp., and balsam fir on mesic sites (Palik and Pregitzer 1992).

Management Considerations

Concurrent with the maturation of second-growth stands, the abundance of early successional habitats has declined in much of northeastern North America. The effects of habitat loss on wildlife species that require early-successional habitat have received relatively little attention, possibly because of the notion, even among conservation groups, that these species are generalists that thrive in human-dominated landscapes and therefore require no special conservation measures. However, significant population declines have occurred among early successional obligates (Lorimer and White 2003). In the past, fire played an important role in maintaining early-successional aspen and white birch forests in a mosaic pattern and in increasing regional vegetation diversity (Day and Carter 1991). Today, however, the presence of seral aspen and white birch on the landscape is threatened by the lack of fire due to suppression. Prescribed burning and prescribed fire offer an economical and ecologically sensitive means of regenerating aspen and white birch in a manner that closely mimics the natural disturbance and regeneration process (Brown and DeByle 1989; Duchesne and Hawkes 2000). The timing and intensity of burning will be important to regeneration success for two reasons:

- the vigour of a sucker stand will be greater if the parent stand is killed in early spring before the root system has expended its reserves on new growth (Van Wagner 1993); and
- fires of moderate to high intensity are required to ensure adequate spread and sufficient mortality to the overstorey (Brown and DeByle 1989).

In some cases managers can increase their chances of success by cutting trees (especially conifers) to increase the surface fuel loading and continuity (Brown and DeByle 1989).



VARIABLE FIRE REGIMES

Oak-Hardwood, Oak-Pine

Stand and Soil Characteristics

Red oak grows as a canopy dominant in many communities, including (1) mixed stands with sugar maple, aspen, white pine, white birch, hemlock, red maple, beech, and white ash associates; and (2) oak-pine communities with white pine, red pine, aspen, and white birch associates. Shrubs commonly include striped maple, fly honeysuckle, serviceberry spp., wintergreen, partridgeberry, and beaked hazel. The understorey consists of moderate to high levels of hardwood and conifer regeneration, a moderate number of herbs, and a ground cover of feathermosses and lichens. Soils vary from dry to moist with a wide range of textures (Chambers et al. 1997).

Natural Fire Regime Characteristics

Prior to settlement, oak communities experienced a regime characterized by frequent, low intensity burns (Van Lear 2004). Based on several fire history studies in oak communities, Dey and Guyette (2000) concluded that fire regimes have varied spatially and temporally at studies sites across central Ontario. They found the mean fire intervals for low intensity surface fires ranged from 6 to 29 years among sites (Guyette et al. 1995; Guyette and Dey 1995a, 1995c; Dey and Guyette 1996b, 1996c), and from 5 to more than 76 years between historic periods at some sites (Dey and Guyette 2000). Moderate intensity surface fires occurred at intervals of 47 years, and high-intensity, stand-replacing fires occurred at intervals of 200 years (Guyette and Dey 1995a). Lorimer and White (2003) suggest that most natural fires in oak stands occur in early spring and late fall after the leaves have dropped when herbaceous vegetation is largely in a cured stage and the bare tree crowns allow direct sunlight to dry out the ground fuels on dry, windy days. However, lightning fires are uncommon in many regions because lightning strikes occur primarily during the growing season and are often accompanied by rain (Wade et al. 2000; Lorimer and White 2003). Other research indicates that most fires resulted from Aboriginal land-use activities or the logging and farming practices of early European settlers (Guyette et al. 1995).

Vegetation Responses to Fire

Red oak is generally considered a midseral species with intermediate to low shade tolerance; and as such, its seedlings are incapable of establishing and growing in environments characterized by low light levels (Dey and Guyette 2000; Abrams 1992). This requirement for light restricts red oak establishment to open sites where competition can be intense (Crow 1988). Fire is necessary because it opens up the canopy and thins out the understorey, thereby reducing competition from shade-tolerant species, and releasing suppressed oak seedlings for recruitment into the canopy (Guyette and Dey 2000; Wolf 2004).

Red oak is considered well adapted to recurrent fire (Crow 1988; Abrams 1992; Dey and Guyette 2000). Compared to other hardwoods, fire typically favours oaks because of their thick bark, sprouting ability, resistance to rotting, suitability of fire-created seedbeds for acorn germination, deep roots, xeromorphic leaves, and high photosynthetic rates during drought (Crow 1988; Abrams 1992).

Depending on severity, fire can injure, kill, stimulate, or have no effect on individuals of established red oak communities. Older, larger trees are better able to survive fires than smaller trees because they have thicker bark and a larger area of cambium that can continue to function if a portion is killed (though such wounds provide a threshold for insects and diseases)(Rouse 1986b). Seedlings, saplings, and pole-sized individuals are more susceptible to fire, but commonly resprout vigorously from the stumps or root collar following the death of aboveground parts by fire (Crow 1988, Van Wagner 1993).

Succession After Fire

Periodic fire should check succession in oak forests and maintain open conditions by inhibiting shade-tolerant species such as sugar maple, beech, and ironwood, and shade intolerant species such as aspen and white birch (Abrams 1992; Dey and Guyette 2000). Light surface fires trigger oak regeneration and establishment, often increasing stem density by promoting sprouting and reducing competition. Post-fire seedling establishment may also occur since dying trees often produce a massive seed crop and acorns germinate well on mineral soil (Rouse 1986b). Higher intensity fires occasionally top-kill pole and sawtimber-sized trees, but many of these sprout and create new even-aged stands (Sander 1990).

Oak seedling sprouts that survive recurrent fires develop a large root system and the carbohydrate reserves needed for accelerated shoot growth. Under a disturbance regime of short return intervals (e.g., 5 to 10 years), oaks remain in a “grub” or seedling-sprout stage, continuing to accumulate biomass. However, given a sufficiently long interval, larger oak grubs, or seedling sprouts, are capable of growing rapidly enough to have a good chance of surviving another fire, and then of growing into the canopy (Dey and Guyette 2000). In the absence of fire, these forests will be transformed by gap dynamic processes that favour shade-tolerant species over oaks within 20 to 40 years (Crow 1988; Dey and Guyette 2000).

Management Considerations

Current distribution of red oak in Ontario, and other regions in northeastern North America, appears to be closely related to intense anthropogenic disturbance (Crow 1988; Nowacki and Abrams 1991; Abrams 1992; Dey and Guyette 2000). Though oak species were an important component in presettlement forests, it seems likely that their dominance has been maintained or even promoted by recurring disturbances (i.e., fire and logging), due to their resistance to fire and competitiveness in post-disturbance environments. However, decreased disturbance in the past 100 years has led to conditions favouring shade-tolerant species, and oak species will most likely decline on all but the most xeric sites (Nowacki and Abrams 1991).

Prescribed burns can be an important tool for regenerating oak stands, removing competition, slowing successional transition, and enhancing wildlife habitat (Rouse 1986b; Crow 1988; Van Wagner 1993; Ruffner and Groninger 2004). The intensity and frequency of burns are important in promoting effective advance regeneration. Low-intensity prescribed fires have not always favoured oak regeneration and a single burn often has little lasting impact on reducing competition (Crow 1988; Kruger and Reich 1997). Crow (1988) suggests a commitment to frequent burning is required to compensate for decades of fire exclusion. The number of fires required will depend on the degree of low-level competition from species such as maple and beech. Two or more successive fires might be needed to give red oak the required boost and open the canopy enough to permit fast oak growth. Prescribed burns should be conducted in spring before flushing, when root reserves are highest, in order to achieve the strongest resprouting (Van Wagner 1993). In addition, vigorous competitors of oak should be harvested at the beginning of the burning program (Van Lear 2004).

Tolerant hardwoods and mixed-hardwoods

Stand and Soil Characteristics

On mesic sites, sugar maple, beech, and basswood are the predominant hardwood species while hemlock and white cedar are the main conifer species (Maycock 1979). Sugar maple often dominates the main canopy, with red oak, beech, basswood, white birch, hemlock, and yellow birch subdominants and red maple, white ash, aspen, white cedar, white pine and white spruce associates. Hemlock can also occur as a canopy dominant or codominant in association with yellow birch and sugar maple. Shrubs include striped maple, beaked hazel, fly honeysuckle, mountain maple, leatherwood and hobblebush. The understorey typically consists of a moderate number of herbs, and a ground cover mosses, liverworts and lichens. Soils vary from dry to moist with a wide range of soil textures (Chambers et al. 1997).

Natural Fire Regime Characteristics

Tolerant hardwood and mixed-hardwood stands historically experienced very long interval stand-replacement or understorey fires. Mean fire intervals reported in the literature range from 800 years in northeastern Maine (Lorimer 1977) to 1200 years in northern lower Michigan (Whitney 1986). Fire cycles of many centuries, ranging from 300 years to more than 2700 years, have been suggested by surveyor notes (Lorimer 1977; Whitney 1986; Zhang et al. 1999) and canopy accession dates (Frelich and Lorimer 1991). These ecosystems seem to have erratic fire cycles; the majority of fires likely occurred only after prolonged drought, and then mostly in stands that were already breaking up due to wind or icestorm damage, insect attack, and other events that generate ground fuels (Heinselman 1981). On sites where oak or conifers such as pine and hemlock were a substantial component of the hardwood forest, stand-replacing fires probably occurred more frequently (Abrams 1992; Wade 2000).

Vegetation Responses to Fire

Shade-tolerant hardwoods and mixed-hardwoods dominated by sugar maple or hemlock are generally considered to be late seral. Grimm (1984) suggests these forests are typically not very flammable for several reasons including: 1) potential fuels decompose rapidly, 2) little fuel exists at ground level due to dense shade, 3) tree trunks are not very flammable, and 4) open tree crowns do not carry fire very well. Additionally, low solar radiation, high humidity, and low wind speeds within the stands tend to prolong the moisture retention of ground-level fuels, thereby inhibiting the ignition and spread of fire (Grimm 1984). Windthrow and other treefall gaps are the dominant disturbance types in these ecosystems (Lorimer 1977; Canham and Loucks 1984; Whitney 1986).

Many of the species associated with these ecosystems, including sugar maple, beech, basswood, yellow birch, and hemlock, are considered sensitive to fire due to their thin bark and shallow roots (Daubenmire 1936; Swan 1970; Crow 1990; Erdmann 1990; Godman and Lancaster 1990; Tubbs and Houston 1990). Hemlock, in particular, is further susceptible because of its low-branching habit and heavy litter deposits (Rogers 1978).

Seedlings and saplings of many species are readily killed by even low intensity fire (e.g., sugar maple, beech, yellow birch, hemlock), and some larger trees can also be killed (Swan 1970; Erdman 1990). Following top-kill by fire, several species-specific responses have been noted:

- sugar maple saplings occasionally sucker, but post-fire establishment occurs primarily through seedling sprouts and seedlings (Daubenmire 1936);
- beech re-establishes by root suckering or stump sprouting (Tubbs and Houston 1990);
- basswood will sprout vigorously from the root crown (Crow 1990);

- yellow birch is a poor sprouter, but seed germination and seedling establishment are enhanced by fire disturbance (Maissurow 1941); and
- hemlock does not sprout and appears to reinvade a burn over time (Swan 1970; Henry and Swan 1974).

Succession After Fire

Low intensity surface fires appear to favour maple, which quickly re-establishes post-fire through seedling sprouts and seedlings. High-intensity fires often consume the existing reproduction of maple and create openings in the forest, resulting in greater percentage of yellow birch, basswood, elm, white pine, and hemlock. Both yellow birch and hemlock are unable to reproduce on the forest floor, and enter the composition of hardwood stands together with white birch and white pine on the bare mineral soils present following fire (Maissurow 1941).

Management Considerations

In spite of low rates of stand-replacing fire disturbance, disturbances of moderate severity were much more common and probably provided suitable habitat for some early successional or fire-dependent species (Lorimer and White 2003). Fire plays a significant role in the perpetuation of a number of species (e.g., yellow birch, hemlock, pines, and intolerant hardwoods) thus shaping and determining the form and composition of the hardwood and mixed-hardwood forest. Due to periodic fire disturbance, tolerant hardwood and mixed-hardwood stands consist of (1) uneven-aged groups developed during periods of uninterrupted growth made up of tolerant hardwoods, maple and basswood, and (2) one or more even-aged groups of fire-origin species which are unable to reproduce readily on the forest floor. In the absence of fire, monotonous stands of sugar maple, mixed with basswood in moist locations, would spread over the entire range of hardwood soils and a good portion of white pine sites (Maissurow 1941).

In Ontario, prescribed burns have been used to create suitable seedbed conditions for yellow birch regeneration. Low intensity surface burns are conducted in late fall following sugar maple leaf and seedfall and prior to yellow birch seedfall. The fire consumes litter and kills advanced regeneration of sugar maple, resulting in higher stocking of yellow birch (Van Wagner 1993). Prescribed burns can also be used to help obtain natural regeneration in hemlock (Godman and Lancaster 1990).

Conifer and hardwood lowlands

Stand and Soil Characteristics

Conifer lowlands are generally dominated by pure stands or mixtures of black spruce, tamarack, and white cedar and may include balsam fir, white spruce, white birch, or red maple associates. Shrubs commonly include Labrador tea, blueberry spp., creeping snowberry, northern wild raisin and showy mountain ash. The understorey may consist of moderate levels of conifer regeneration, tall hardwood shrubs, low to moderate number of herbs, and high levels of *Sphagnum* and feathermosses. Soils are typically wet organic and very moist, sometimes fresh, mineral soils (Chambers et al. 1997).

Hardwood lowlands are very diverse. Overstorey species may include black ash, aspen, sugar maple, red maple, yellow birch, white birch, basswood, white spruce and cedar. Shrubs commonly include dwarf raspberry, mountain maple, fly honeysuckle, beaked hazel and choke cherry. The understorey often consists of high levels of tall hardwood shrubs and is herb rich. Soils are typically fresh to very moist, sometimes wet, and often calcareous (Chambers et al. 1997).

Natural Fire Regime Characteristics

Conifer and hardwood lowlands historically experienced relatively infrequent to very infrequent stand-replacement or understorey fires. Fire regimes in these lowlands were strongly influenced by fires intruding from adjacent ecosystems and by interactions of insect and disease, large-scale blowdowns, and periods of drought. Lowlands embedded within or adjacent to relatively fire-resistant landscapes experience fire less frequently than those embedded within or adjacent to fire-prone landscapes (Cleland et al. 2004a). Fire cycle and maximum longevity are probably longer on lowland sites than nearby upland sites (Heinselman 1973).

Bergeron (1991) estimated the average time since fire to be 171 years in conifer bogs near Lake Duparquet, Québec. Heinselman (1981) estimated the fire cycle to be 150 years in a large black spruce peatland in northern Minnesota. Zhang et al. (1999) estimated the fire cycle to be 194 years in stands dominated by tamarack, and 893 years in stands dominated by black spruce, and 1741 years in stands dominated by white cedar. Whitney (1986) estimated a fire cycle of 3000-6000 years in swamp conifers. There is very little information in the literature on fire cycle in hardwood lowlands, but Bergeron (1991) estimated an average time since fire of 183 years in black ash, white elm lowland forests, and Zhang et al. (1999) estimated a fire cycle of 1067 years for mixed lowland conifers and hardwoods.

Most fires in lowlands would have occurred in July, August, or September of severe drought years when the water tables were low enough that moss layers became thoroughly desiccated. Under these circumstances, given sufficient wind, the spruce, tamarack, and cedar forests of lowlands can carry major crown fires (Heinselman 1981).

Vegetation Responses to Fire

Conifer and hardwood lowlands are generally not as prone to fire as other forest types because of their wetter conditions. Their high water table in the spring, dense green understorey, and more humid environment make them less susceptible to fire, except in severe drought years. Another characteristic of lowland forest types that reduces their susceptibility to fire is the convex nature of the depressions they occupy. Fire tends to avoid convex depressions and seeks concave landforms such as hilltops and slopes. As a result, lowlands are often spared from even large, high-intensity forest fires, leaving unburned pockets of forest that become important seed sources for adjacent uplands (Duchesne and Hawkes 2000).

Despite their relative resistance to fire, lowlands undoubtedly burned periodically during presettlement times and wetland fires during drought in Upper Michigan and in other parts of the eastern U. S. are well documented (Loope 1991). Black spruce, tamarack, and white cedar are susceptible to fire due to their thin bark and shallow roots and can be killed by even low severity fire (Viereck and Johnston 1990; Johnston 1990a; Johnston 1990b). Crown fires are common in black spruce stands because the layering habit of black spruce and the frequent occurrence of abundant lichens on its lower branches often form a continuous fuel that is easily ignited by surface fires. Crown fires typically result in extensive mortality in black spruce stands (Viereck 1983).

Lowland hardwood species are also sensitive to fire due to their thin bark and shallow roots (Daubenmire 1936; Crow 1990; Erdmann 1990); even large individuals can be killed by moderate intensity fires (Erdmann 1990; Walters and Yawney 1990). Low-intensity fires can damage the cambium causing decay, even though the bark remains intact for several years after fire (Wade et al. 2000).

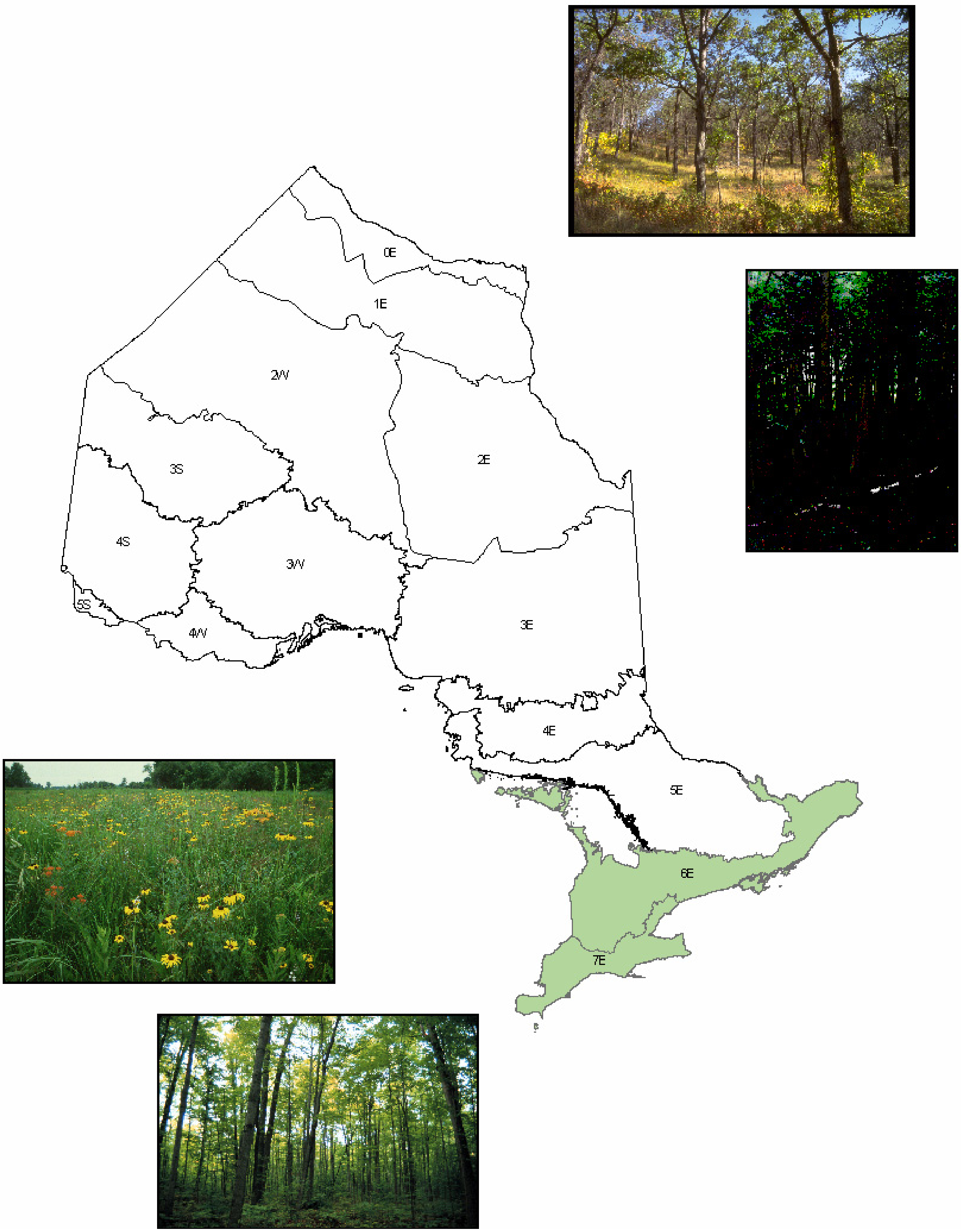
Succession After Fire

There is very little information on succession after fire in lowland stands. Lowland conifers establish well on burned organic soils provided a seed source is available and the humus layer is not consumed. Some lowland hardwood species sprout readily after damage or top-kill, including black ash, aspen, and red maple (Wright and Rausher 1990; Perala 1990; Walters and Yawney 1990). Others, including sugar maple, white birch, and yellow birch tend to seed in following fire (Daubenmire 1936; Maissurow 1941; Safford et al. 1990). Sprouting of understorey species depends on fire severity and the depth of perennating tissues (Sullivan 1994).

Management Considerations

Lowland conifer and hardwood communities are capable of reproducing and perpetuating in the absence of fire. As a result, prescribed burning is not necessary for management of lowland communities but prescribed fire may be considered since these sites are known to burn following drought cycles or due to fires in adjacent upland vegetation (Cleland et al. 2004a).

DECIDUOUS FOREST REGION



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DECIDUOUS FOREST REGION

The Deciduous Forest region is the most diverse and productive forest landscape in Ontario (Uhlig et al. 2001). Unfortunately, studies of the historical role of fire in this region are limited. Though fire did occur occasionally, it was much less common than in the Great Lakes-St. Lawrence forest region. Aboriginal use of fire may also have been a significant factor in this region but its extent and impact are not well understood (Uhlig et al. 2001). Estimates of fire frequency and cycle are primarily based on literature from central Ontario, Québec, and adjacent Great Lakes and northeastern states. These references may not be entirely adequate for comparison; however the extensive loss and fragmentation of natural cover for agriculture and urban development, combined with a high population density, likely prevent the restoration of fire at the landscape scale and may justify the use of general estimates of fire regime characteristics on a fragment by fragment basis. It is assumed that the natural fire regimes for homogenous fire groups in the Deciduous Forest region will generally be similar to those in the Great Lakes-St. Lawrence Forest region, though perhaps fire will occur at longer return intervals given the deeper, more nutrient rich soils and warmer, more humid climate in the Deciduous Forest region.

The Ecological Land Classification for southern Ontario (Lee et al. 1998) is currently the only Ontario classification that provides descriptions for non-forested ecosites such as prairie, savanna, woodland, alvar, and barrens. As a result, fact sheets have only been prepared for these ecosites in the context of the Deciduous Forest region. However, other forest regions have similar non-forested ecosites, and planners and managers may wish to refer to these fact sheets in the context of Ontario’s other forest regions as well.

Table 6. Mean fire interval (MFI) and fire cycle (FC), in years, by homogeneous fire group for ecosites in the Deciduous Forest Region (Ecoregions 6E and 7E). See Appendices 4 and 5 for descriptions of fire history studies and Lee et al. (1998) for descriptions of ecosites or community series.

Homogeneous Fire Group	**Corresponding Ecosites or Community Series (Southern ELC)**	**Fire Regime (years)**		
		Maintenance	**Stand Replacement**	**Variable**
White pine-Red pine	FOC1-2			MFI:12-300
Jack pine	FOC1-1			MFI:15-35
Poplar-White birch, White birch-Poplar-Conifer	FOC2, FOD3, FOM4, FOM5, FOM8			MFI:66-104, FC:70-210
Oak deciduous, White pine-Maple-Oak Mixed	FOD1, FOM1-2, FOM2			MFI:6-200
Pitch pine-oak mixed	FOM1-1			MFI:20-40
Tolerant hardwoods and mixed hardwoods	FOC3, FOC4, FOM3, FOM6, FOM7, FOD4, FOD5, FOD6,			MFI:800-1200, FC:300-2700
Conifer, deciduous, and mixed lowlands	FOC4, FOD7, FOD8, FOD9, SWC1, SWC2, SWC3, SWC4, SWC5, SWM1, SWM2, SWM3, SWM4, SWM5, SWM6, SWD1, SWD2, SWD3, SWD4, SWD5, SWD6, SWD7			MFI:171-183, FC:150-6000
Oak-Maple-Hickory	FOD2	MFI:3-30		
Prairie	TPO	MFI:1-25		
Savanna	TPS	MFI:3-17		
Woodland	TPW	MFI:5-15		
Alvar	ALO, ALS, ALT	MFI:200-500?		
Rock barren	RBO, RBS, RBT	?		
Sand barren	SBO, SBS, SBT	?		

MAINTENANCE FIRE REGIMES

Tallgrass prairie

Stand and Soil Characteristics

Prairies are areas of native grassland controlled by a combination of moisture deficiency and fire. They are open communities dominated by grasses such as big bluestem, little bluestem, and Indian-grass. Other associated species include side-oats grama, sand dropseed, rough dropseed, northern dropseed, needle grass, Canada wild-rye, and switchgrass (Bakowsky 1993). Prairies typically support a rich herb flora, and shrubs and trees may also be present, but canopy cover is less than 25 percent. Soils are typically deep sands or sandy loams that vary from dry to wet-mesic (Lee et al. 1998).

Natural Fire Regime Characteristics

Fire plays a major role in maintaining prairie habitat, but without trees to carry fire scar records, it is difficult to estimate presettlement fire return intervals (Madden et al. 1999). Very little scientific information exists on the fire regimes in tallgrass prairie in Ontario, but information is available for prairie ecosystems of the Great Lakes states. Presettlement tallgrass prairie is thought to have developed and flourished in an environment that was exposed to large, low to moderate intensity surface fire recurring at one- to ten-year intervals (Wright and Bailey 1982; Leitner et al. 1991; Abrams 1992; Snyder 1994), though intervals may have been as long as 25 years on dry sites (Madden et al. 1999). A distinction between dry and mesic prairie is important because fire effects vary with moisture conditions; those prairie communities receiving more moisture have higher productivity and therefore are more fire-dependent (Madden et al. 1999).

Vegetation Responses to Fire

Periodic fire is necessary for the development and maintenance of tallgrass prairie ecosystems. It affects many of the key characteristics of tallgrass prairie, including plant species composition, productivity, and ecosystem nutrient cycles (Blair 1997) by controlling the invasion of woody species, removing the annual accumulation of plant detritus, and recycling the heavy nutrients making them available for instant uptake by new growth (Van Wagner 1993; Madden et al. 1999).

Prairie species are well adapted to annual or biennial fire (Uchytil 1988; Van Wagner 1993; Steinberg 2002). Seed production, germination, and seedling establishment of annual and perennial prairie species are typically promoted by fire. Vegetative reproduction, which is stimulated by fire and aided allelopathically, gives prairie species a competitive advantage and increased survivorship (Vogl 1979). Fire injures or kills most woody plant tops while generally leaving the living portions of prairie species undamaged (Vogl 1979). Annual burns do not seem to harm the native warm-season species if burned in late spring before the emergence of new growth. Late spring burning also tends to reduce competition from undesirable cool season plants such as Kentucky bluegrass and smooth bromegrass (Wright and Bailey 1980; Uchytil 1988; Steinberg 2002).

Succession After Fire

Prairie environments are dynamic in nature and are characterized by constant change. Periodic fire prevents vegetational decadence or change so that succession is a cyclic phenomenon (Vogl 1979). In tallgrass prairie, repeated fires usually promote grasses at the expense of forbs and shrubs, although a number of woody plants are extremely fire tolerant and even fire dependent (Vogl 1979; Collins 2000). Woody plants often have difficulty invading established prairie, particularly if it is subject to recurring fire since fire maintains vigorous herbaceous growth which successfully competes with the woody species for space, moisture, and light (Vogl 1979).

Generally, repeated burning in prairie communities does not reduce species diversity and may even increase it by promoting the growth of additional grasses, legumes, and other species. Since the effects of fire are not long lasting, recurring fires are often necessary to maintain vigorous growth of prairie species (Vogl 1979). In the absence of fire for long periods of time, litter accumulates, woody species invade, moisture and nutrient availability increase, and prairie eventually develops into shrubland and woodland vegetation. However, these changes occur relatively slowly (Van Wagner 1993; Collins 2000).

Management Considerations

It has been suggested that the extent and abundance of tallgrass prairie, oak and pine savanna, and barrens prior to European settlement were largely the result of Aboriginal burning practices (Wade et al. 2000). Periodic fires of low to moderate intensity were ignited in spring or fall to promote the production of grasses and forbs that provided habitat and forage for large game and fowl (Dey and Guyette 2000). During the initial period of European settlement, pioneers adopted Aboriginal burning practices, which became instrumental in clearing land for agricultural development. However, the settlers eventually altered the disturbance regime directly by fire suppression and indirectly by habitat fragmentation and land-use conversion. This alteration of the fire regime led to the conversion of savanna remnants into closed oak forest, and the invasion of prairie remnants by trees and shrubs (Leitner et al. 1991).

The use of fire is advocated in the management of tallgrass prairie where woody plant invasion and heavy growth accumulations are a problem (Vogl 1974). Late spring prescribed burning is the most beneficial to big bluestem prairie. The later in the spring burning occurs, just prior to the emergence of warm-season grasses, the greater the regeneration post-fire. Late spring burning can also be used to favour big bluestem and other warm season prairie grasses in prairie infested with undesirable cool season grasses such as Kentucky bluegrass. Late spring burning favours warm season grasses because they are dormant at the time of ignition, and resume growth as normal from stored food reserves held in underground organs, but often harms cool season grasses because they begin spring growth earlier and are actively growing at the time of ignition (Uchytil 1988).

In remnant prairies, heterogeneity within remnants and regionally between remnants is an important management objective. Managers generally should try to incorporate some element of randomness in the fire management plan. For example, some remnants may be burned every 1 to 2 years, some every 4 to 5 years, and some areas every 10 years, and at different times of year. Attempts should also be made to burn only portions of remnants at a given time in order to allow refugia and to protect cover for animals in unburned areas (Madden et al. 1999; Wade et al. 2000).

Tallgrass savanna

Stand and Soil Characteristics

Tallgrass savanna represents part of the continuum between true prairie and the eastern hardwood forest (Van Wagner 1993). Savannas are widely spaced, open-grown treed communities with an understorey of prairie graminoids and forbs (Bakowsky 1993). Tree cover ranges from 25 to 35 percent. Black, bur, white, red, pin and chinquapin oaks may be present, as well as white and red pine and red cedar. Shagbark, pignut and big shellbark hickories may also be present. Soils are well-drained sands, loams, and sometimes clay, and vary from dry to moist (Bakowsky 1993; Lee et al. 1998).

Natural Fire Regime Characteristics

Historically, fire played an important role in producing and maintaining successional habitats such as savanna in central and eastern North America (Abrams 1992). A recent reconstruction of the fire history of oak savanna at Pinery Provincial Park found that over the past 150 years low intensity surface fires occurred at a mean fire interval of 17 years (Bravo 2004). However, the mean fire interval may have been underestimated since fires have been suppressed for most of the period of study. Similar studies in southeastern Wisconsin found that the mean fire interval for oak savanna ranged from approximately 4 years to 16 years (Leitner et al. 1991; Wolf 2004).

Aboriginal burning practices contributed to the creation and maintenance of prairie and savanna ecosystems through frequent burning of these ecosystems to control woody vegetation and to maintain dominance by herbaceous plants. In the eastern tall grass prairie and savanna, Aboriginals were likely a far more important source of ignition than lightning since grasses are green through late summer and there is a low incidence of dry lightning storms (Wade et al. 2000).

Vegetation Responses to Fire

Like prairie ecosystems, periodic fire is also necessary for the development and maintenance of savanna communities. In savanna, frequent fires tend to be of low intensity, do not kill canopy trees, do little damage to grasses and sedges, and create an open understorey. Infrequent fires tend to be more intense due to litter accumulation, can kill canopy trees, and promote vigorous sprouting of woody species, often resulting in a thicket (Wade et al. 2000). In general, short fire return intervals reduce tree canopy while longer fire return intervals increase tree canopy (Wade et al. 2000).

Prairie species are well adapted to frequent fire (Uchytil 1988; Van Wagner 1993; Steinberg 2002). Vegetative reproduction, which is stimulated by fire and aided allelopathically, gives prairie species a competitive advantage and increased survivorship (Vogl 1979). Oak species are adapted to fire by having thick corky bark (especially bur oak), the ability to resprout after topkill and tolerance of low precipitation and nutrient levels (Crow 1988; Abrams 1992). Similarly, mature pine can tolerate light to moderate surface fires due to their branch-free trunks and moderately deep rooting habit (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990).

Succession After Fire

Frequent fire should check succession in savanna communities by reducing overstorey tree density and basal area, favouring savanna tree species, eliminating or suppressing understorey shrubs and trees (including invasive exotic species), and promoting development of a continuous herbaceous layer dominated by grasses (Peterson and Reich 2001). Prior to European settlement, oak trees grew in a continuum of fire-adapted communities within the grassland biome where tree densities varied from open prairie with less than 25 percent cover to oak forests with greater than 60 percent cover (Kline and McClintock 1992; Lee et al. 1998). Savannas, along with oak woodlands, are considered intermediate communities along the continuum, but the boundaries are neither discreet nor stationary. Instead, the boundaries shift in time in response to long and short term climate fluctuations and the frequency and intensity of fires (Kline and McClintock 1992). In the absence of fire for long periods of time, savannas can succeed to woodland and forest. However, if fires occur too frequently, savannas can be converted to prairie (Wade et al. 2000).

Management Considerations

Prescribed burning is a management tool that is commonly used for savanna restoration and maintenance on sites that once supported savanna vegetation, but have since grown into woodland or forest (Peterson and Reich 2001). The uses of prescribed fire for restoration and maintenance should be considered separately since the type of fire (e.g., frequency, intensity, season) needed for restoration of savanna community may be quite different from the type of fire needed to maintain the savanna community once it is achieved (White 1986).

For sites where the primary goal is restoration of savanna that has developed into woodland or forest, mechanical thinning of stands should be considered as a management tool complementary to prescribed burning to rapidly reduce overstorey density and suppress growth of understorey shrubs and saplings while a healthy, productive herbaceous layer develops (White 1986; Peterson and Reich 2001). Annual to biennial fires are needed to produce the most rapid reductions in tree canopy density. Low-frequency fire is often ineffective for maintaining savannas on sites with high densities of established woody plants, but might be effective on sites where woody plant establishment and survival is more severely limited by droughts or competition from grasses (Peterson and Reich 2001).

The ideal fire return interval for maintaining oak savanna is more subtle than for treeless prairie because even oak seedlings cannot withstand repeated annual or biennial fire. Presumably the ideal regime will be one where fire is frequent enough to eliminate almost all woody species yet not quite frequent enough to prevent the establishment of occasional oak seedlings. Still, occasional fire-free intervals long enough to permit young oaks to break free of repeated resprouting and to become mature, fire-resistant trees will likely be required. If there is too much fire then the oaks will gradually disappear, but if there is too little fire then a closed oak forest will emerge. Regardless of the interval, once burning has seriously begun the commitment is effectively permanent; otherwise the ecosystems will be lost (Van Wagner 1993).

MAINTENANCE FIRE REGIMES

Tallgrass woodland

Stand and Soil Characteristics

Tallgrass woodland communities represent part of the continuum from true prairie to hardwood forest. They are considered to be mid-seral, fire-maintained communities with open grown trees and an understorey dominated by prairie graminoids and forbs (Lee et al. 1998; Nowacki et al. 2004). Tree cover ranges from 35 to 60 percent. Black, bur, white, and pin oak and shagbark hickory may dominate the main canopy. Soils are dry to moist, sands and coarse loams and occasionally clay (Lee et al. 1998).

Natural Fire Regime Characteristics

Historically fire has played an important role in producing and maintaining successional oak habitat in central and eastern North America (Abrams 1992). There is little to no information on the natural fire regime in tallgrass woodland communities in Ontario and the presettlement fire frequencies in tallgrass woodland in the United States are not well known either. Woodlands are characterized by low severity surface fires with a fire return interval of 5 to 15 years (Nowacki et al. 2004). The burning practices of Native Americans played a critical role in keeping woodlands open as natural, lightning-strike ignitions were limited (Olson 1998; Nowacki et al. 2004).

Vegetation Responses to Fire

Oak and hickory are generally considered midseral, moderate in tolerance to shade, and well adapted to periodic fire (Smith 1990; Graney 1990; Abrams 1992). Most oaks are resistant to fire to some extent and fire resistance generally increases with stem diameter. Most oaks sprout from basal buds after top-kill (Sullivan 1995). Like oak, young hickory is most susceptible to damage by fire but even older hickory stems are at risk due to the low insulating capacity of their bark. Light fires commonly top-kill hickory sprouts and seedlings but leave underground portions undamaged. Hot fires often kill or damage even large trees (Tirmenstein 1991). Mature hickories often sprout from the stump, root crown or roots following top-kill by fire. Some seedling establishment may also occur (Tirmenstein 1991; Coladonato 1992).

Succession After Fire

Periodic low intensity fire maintains woodland communities by preparing suitable seedbeds and by favouring sprouting species over fire-sensitive hardwoods that shade the forest floor (Sullivan 1995; Wade et al. 2000). In the absence of fire, however, oak-hickory woodlands readily succeed to late successional, closed canopy oak-hickory forest (Nowacki et al. 2004). Tallgrass woodland and associated seral stages (e.g., prairie, oak-hickory grubs, savanna, oak-hickory forest) are fire-maintained and their presence on the landscape is contingent on fire frequency and intensity. Grassland prairies burn often, usually annually or biennially, and are probably associated with flat-to-gently rolling topography that effectively carries fire. Oak-hickory grub communities likely occur in areas that burn a little less frequently (e.g., 3-9 year intervals) or arise following high-severity fire which top-kills tree-dominated communities. Savannas and woodlands develop under a moderate fire regime with fire return intervals averaging 5 to 15 years. If short-return interval fires are interrupted for several years (e.g., 15 to 30 years), closed canopy oak-hickory forests develop. If fire is excluded over several decades, shade-tolerant, fire-sensitive maples and other associated late-successional species establish in the understorey beneath oak-hickory canopies (Nowacki et al. 2004). With continued fire exclusion, stem densities increase significantly and the dense shade from these fire sensitive species reduces the abundance of forbs and grasses and inhibits the regeneration of oak and hickory. Consequently, when a canopy oak or hickory dies, its regeneration will not be capable of sufficient growth and the gap will be filled by maple and other late-successional hardwood species (Wade et al. 2002; Nowacki et al. 2004). However, long periods of time (e.g., 100 to 150 years) would be needed for maple dominance to manifest (Nowacki et al. 2004).

Management Considerations

Due to European settlement and fire suppression, sites that once supported successional oak habitat such as savanna and woodland are growing into closed canopy oak forest. Prescribed burning is a management tool that is commonly used for prairie and savanna restoration and maintenance (Vogl 1974; Peterson and Reich 2001) but can also be used to maintain woodland habitat on the landscape (Sullivan 1995). Understorey burning of mature hardwood stands can help establish oak and hickory regeneration by preparing a seedbed and top-killing many of the shrubs and small trees that shade the forest floor. In a less shaded environment, acorns and hickory nuts can germinate and new seedlings can establish their root systems and eventually replace the canopy trees. To achieve this, prescribed burns are initially applied at a frequent interval (either annually or biennially) depending on the season of burn and the severity of shade. Once the oak seedlings have established, sites should not be burned for a few years and then periodically exposed to fire once or twice a decade. This increases chances of successful oak regeneration by allowing time for root systems to develop. If oak and hickory regeneration is already present in the understorey, a two-step shelterwood harvest combined with a prescribed fire can be used to release oak and hickory regeneration (Wade et al. 2000).

MAINTENANCE FIRE REGIMES

Oak-Maple-Hickory

Stand and Soil Characteristics

Oak-hickory communities are part of a continuum from true prairie to hardwood forest. They are considered to be late-seral, fire-maintained communities where prairie and forest species overlap (Olson 1998; Nowacki et al. 2004). In Ontario, red and white oak dominate the main canopy in association with red maple, hickory spp., sugar maple, white ash, beech, basswood, ironwood and black cherry. Understorey species include *Trillium* spp., *Hepatica* spp., bellwort, jack-in-the-pulpit, and zigzag goldenrod. These stands represent a transition from dry to fresher sites. Soils are moderately dry to fresh, sands and coarse loams with silt and clay components (Lee et al. 1998).

Natural Fire Regime Characteristics

Historically fire has played an important role in producing and maintaining successional oak habitat in central and eastern North America (Abrams 1992). There is little to no information on the natural fire regime in oak-maple-hickory communities in Ontario and the presettlement fire frequencies in oak-hickory forests in the United States are not well known either. Indigenous fires are believed to account for over 95% of the ignitions in oak-hickory forest resulting in a mosaic of oak-hickory vegetation types across the landscape dependent on fire history, which is believed to have varied considerably depending on proximity to Native American habitation (Cutter and Guyette 1994; Wade et al. 2000; Nowacki et al. 2004). The fire regime of oak hickory forests is characterized by low severity surface fires (Nowacki et al. 2004). A presettlement fire return interval of 7 to 14 years has been suggested for the mid-Atlantic and Ozark regions of the United States (Wade et al. 2000), while a fire return interval of approximately 3 years has been reported in the Mark Twain National Forest for the period 1740- 1850 (Cutter and Guyette 1994). Nowacki et al. (2004) suggest that closed-canopy oak forests would develop under a fire return interval of 15 to 30 years.

Vegetation Responses to Fire

Oak and hickory are generally considered midseral, moderate in tolerance to shade, and well adapted to periodic fire (Smith 1990; Graney 1990; Abrams 1992). Most oaks are resistant to fire to some extent and fire resistance generally increases with stem diameter. Most oaks sprout from basal buds after top-kill (Sullivan 1995). Like oak, young hickory is most susceptible to damage by fire but even older hickory stems are at risk due to the low insulating capacity of their bark. Light fires commonly top-kill hickory sprouts and seedlings but leave underground portions undamaged. Hot fires often kill or damage even large trees (Tirmenstein 1991). Mature hickories often sprout from the stump, root crown or roots following top-kill by fire. Some seedling establishment may also occur (Tirmenstein 1991; Coladonato 1992).

Succession After Fire

Periodic low intensity fire maintains oak-hickory communities by preparing suitable seedbeds and by favouring sprouting species over fire-sensitive hardwoods that shade the forest floor (Sullivan 1995; Wade et al. 2000). Beech and sugar maple lack the adaptations of oak and hickory, making them more susceptible to damage by fire (Olson 1998; Wade et al. 2000). In the absence of fire, however, oak-hickory forests readily succeed to more mesophytic beech and sugar maple (Tirmenstein 1991; Olson 1998; Nowacki et al. 2004). Oak-hickory forests and associated seral stages (e.g., prairie, oak-hickory grubs, savanna, woodland) are fire-maintained and their presence on the landscape is contingent on fire frequency and intensity. Grassland prairies burn often, usually annually or biennially, and are probably associated with flat-to-gently rolling topography that effectively carries fire. Oak-hickory grub communities likely occur in areas that burn a little less frequently (e.g., 3-9 year intervals) or arise following high-severity fire which top-kills tree-dominated communities. Savannas and woodlands develope under a moderate fire regime with fire return intervals averaging 5 to 15 years. If short-return interval fires are interrupted for several years (e.g., 15 to 30 years), closed canopy oak-hickory forests develop. If fire is excluded over several decades, shade-tolerant, fire-sensitive maples and other associated late-successional species establish in the understorey beneath oak-hickory canopies (Nowacki et al. 2004). With continued fire exclusion, stem densities increase significantly and the dense shade from these fire sensitive species reduces the abundance of forbs and grasses and inhibits the regeneration of oak and hickory. Consequently, when a canopy oak or hickory dies, its regeneration will not be capable of sufficient growth and the gap will be filled by maple and other late-successional hardwood species (Wade et al. 2002; Nowacki et al. 2004). However, long periods of time (e.g., 100 to 150 years) would be needed for maple dominance to manifest (Nowacki et al. 2004).

Management Considerations

Due to European settlement and fire suppression, oaks are being successionally replaced as shade-tolerant and fire-sensitive species increase in number and cover in many oak-hickory forests (Abrams 1992; Sullivan 1995). In the Great Lakes region, canopy oaks are already declining and regeneration is poor in the dense shade of beech, maple, and cherry (Abrams 1992; Olson 1998). Prescribed burning can be a useful tool for maintaining the diversity of oak-hickory forests across the landscape and has been applied with good results (Sullivan 1995). Understorey burning of mature hardwood stands can help establish oak and hickory regeneration by preparing a seedbed and top-killing many of the shrubs and small trees that shade the forest floor. In a less shaded environment, acorns and hickory nuts can germinate and new seedlings can establish their root systems and eventually replace the canopy trees. To achieve this, prescribed burns are initially applied at a frequent interval (either annually or biennially) depending on the season of burn and the severity of shade. Once the oak seedlings have established, sites should not be burned for a few years and then periodically exposed to fire once or twice a decade. This increases chances of successful oak regeneration by allowing time for root systems to develop. If oak and hickory regeneration is already present in the understorey, a two-step shelterwood harvest combined with a prescribed fire can be used to release oak and hickory regeneration (Wade et al. 2000).

MAINTENANCE FIRE REGIMES

Alvar

Stand and Soil Characteristics

Alvars are naturally open ecosystems which occur on shallow (less than 15 cm) soils over flat limestone or marble bedrock, and which have a dominant cover of grasses and sedges or low shrubs and with less than 60 percent tree cover (Lee et al. 1998; Catling and Brownell 1995; Jones and Reschke 2005). Bur and chinquapin oak; shagbark hickory; aspen; white and red cedar; white, red and jack pine; balsam fir and white spruce may be present. Shrubs commonly include common juniper, creeping juniper, prickly ash and shrubby cinquefoil; herbs and grasses include nodding onion, dwarf lake iris, early buttercup, little bluestem, poverty grass, and tufted hairgrass. Vegetation cover varies from patchy and barren to more closed and treed (Lee et al. 1998; Catling and Brownell 1998).

Natural Fire Regime Characteristics

Very little information exists on the historical role of fire in alvars in Ontario. There is debate in the literature surrounding the importance of fire in the maintenance of alvar communities (Catling and Brownell 1998; Schaefer and Larsen 1997). The characteristic openness, or lack of tree cover, in alvar communities might be maintained by any one of a number of factors, or combination of factors, including seasonal and periodic drought, extremes of soil moisture, cold onshore winds, shallow soils, grazing and fire. The relative importance of each of these factors in maintaining alvar vegetation will vary from site to site. Plant communities and habitats maintained by drought, or other factors, may be very similar to those maintained by fire (Catling and Brownell 1998).

Certain alvar community types show more evidence of burning than others. Savannas and woodlands, structural types often maintained by fire in non-alvar habitats, show the strongest correlation with burning (Jones 2000; Jones and Reschke 2005). On the other hand, evidence of the role of fire for other alvar types is either lacking or shows a fairly even split between presence and absence of evidence, perhaps indicating that fire has been an incidental or stochastic event rather than an essential occurrence for development or maintenance of the alvar type (Reschke et al. 1999; Jones and Reschke 2005).

Jones and Reschke (2005) suggest that there are several fire regimes for Great Lakes alvars: 1) there is no fire at all; 2) fire is incidental, with small local fires that do little to alter the community; 3) fire removes biomass creating (and possibly maintaining) savanna alvar types and probably juniper alvar shrubland; and 4) fire clearly removes woody biomass, but does so with long fire return intervals and occasionally stand-replacing results, sometimes even creating new alvars.

Vegetation Responses to Fire

Information on the vegetation responses to fire in alvar communities is very limited. In their study of the vascular plant community 100 days after a severe fire in alvar woodland, Catling et al. (2001) found the development of post-fire flora was related to growth form:

- roots as in the case of root suckers (e.g., trembling aspen, balsam poplar);
- rhizomes and root crowns (e.g., wild sarsaparilla, large-leaved aster, bracken fern, thin-leaved snowberry); and
- soil seed bank (e.g., golden corydalis, American dragonhead, Bicknell’s cranesbill).

Succession After Fire

Information on the successional sequence following fire in alvar community types is also limited. Observations at the Burnt Lands alvar 37 years following cutting and burning of wooded areas suggests that shrubs appear to colonize before trees and that white spruce and poplar are the most frequent early colonizers (Catling and Brownell 1998). At the same site, the post-fire flora was diverse and consisted of mostly native species, including rare early successional species (e.g., Cooper's milkvetch, low bindweed, Richardson sedge, golden corydalis, marsh muhly, wiry witch grass, Philadelphia panic grass, sweet coltsfoot, small skullcap, and northern bog violet) 100 days after a severe fire (Catling et al. 2001).

Management Considerations

Researchers disagree on the relevance of historic fires or prescribed burns to alvar communities. Catling and Brownell (1998) concluded that the burning of alvar habitat, regardless of the presence or absence of evidence of past fire, is an appropriate consideration because many alvars have burned in the past, even though some may not have burned for 500 years based on the presence of ancient white cedar trees. However, Schaefer and Larson (1997) propose that maintenance of alvars is site-specific and that fire at burned alvars is only incidental and maintenance of alvar by drought actually prevails. Jones and Reschke (2005) suggest that fire is infrequent in alvar landscapes and that some communities experience fire at a return interval of at least 200 to 500 years while others may not burn at all.

Careful further study is required before prescribed burning can be recommended for most alvar communities. Recommendations will almost certainly need to be developed on a site-by-site basis rather than on the basis of alvar community types as a whole (Reschke et al. 1999). Managers will need to consider whether fire was likely an important process in maintaining the alvar landscape or whether it will only reset the successional clock back to zero and create a new alvar from the beginning (Brownell and Riley 2000; Jones and Reschke 2005). Given the long history of alvar communities from presettlement times, natural fires appear always to have been at least an incidental part of their history, and probably instrumental in maintaining some alvar types. This suggests that aggressive fire suppression is not needed on alvar habitats, although no alvar should be allowed to burn entirely in one fire event in order to ensure the survival of invertebrate fauna. If fires do occur within alvars, researchers should use these occurrences as opportunities to gather much-needed data on vegetation response and ecological changes (Reschke et al. 1999).

If prescribed burning or prescribed fire is considered appropriate, Catling and Brownell (1998) suggest the following with regard to fire in alvar habitat:

- it may be appropriate to protect old growth trees from burning, as would occur under natural conditions due to isolation within limestone pavements, onshore winds, chance etc.;
- burning is best done in patches simulating the way natural fire frequently operates; and
- it may be appropriate to burn only 20 to 30 per cent of a community at a time.

To achieve the 'patchy' character of natural burns, prescribed burns should be sequential, small, and low complexity (Wilkinson pers. comm.).

Rock barren

Stand and Soil Characteristics

Rock barrens are naturally open ecosystems consisting of exposed bedrock with rolling rock knobs and hollows and grassy areas, shrubs, and scattered trees (less than 60 percent tree cover). These habitats are never entirely barren however, but openness and bare rock, or rock with only lichen and moss cover, are considered characteristic features. Red cedar, hackberry, oak sp., red maple, white birch, aspen, pitch pine, white pine and jack pine may be present. Shrubs commonly include common juniper, round-leaved dogwood, chokecherry, and blueberry spp.; herbs, grasses, and sedges include harebell, early saxifrage, cow-wheat, prairie cinquefoil, pale corydalis, poverty grass, and bristle-leaved sedge. Soil development is patchy and varies with substrate; where soils have developed depth is less than 15 cm (Brownell 1994; Lee et al. 1998; Catling and Brownell 1999).

Natural Fire Regime Characteristics

Very little information is available on the incidence of fire in rock barrens. Burned stumps and fire scars throughout the barrens region in Ontario suggest that fire has been a major factor in limiting tree establishment and growth. Several severe fires are known to have burned on the eastern Kaladar barrens in the late 1880s and the most recent severe and extensive fire occurred between 1931 and 1936 (Catling and Brownell 1999).

At the Kaladar Jack Pine Barrens Area of Natural and Scientific Interest fires were probably frequent in the past, possibly even occurring yearly due to lightning and ignition by local individuals to promote blueberry production (Brownell 1994).

Vegetation Responses to Fire

In rock barren types where the fuel loading is sparse, a mosaic of burned and unburned areas may result given the patchy character of low-fuel fires, changes in wind direction, and differential rates in advance (Brownell and Riley 2000).

Management Considerations

Many of the tree species which are characteristic of rock barrens are well adapted to periodic fire (Rogers 1990; Sander 1990; Walters and Yawney 1990; Wendel and Smith 1990; Little and Garrett 1990; Rudolph and Laidly 1990) and may benefit from occasional, low-intensity prescribed burning or prescribed fire. Like alvar landscapes, aggressive fire suppression may not be needed in rock barren habitat; although no rock barren should be allowed to burn entirely in one fire event. Fire may be ecologically deleterious, depending on severity, frequency, and area burned relative to the amount given in an area (Wilkinson pers. comm.). If fires do occur on rock barrens, researchers should use these occurrences as opportunities to gather much-needed data on vegetation response and ecological changes.

Sand barren

Stand and Soil Characteristics

Sand barrens are naturally open communities occurring on open, bare sand substrates that are not associated with distinct topographic features (i.e., sand dune). Tree cover varies from patchy and barren to more closed and does not exceed 60 percent. Vegetation is dominated by drought tolerant graminoids, forbs, mosses, and lichens. Soils are extremely droughty and disturbed sands (Lee et al. 1998; Lee et al. in prep).

Natural Fire Regime Characteristics

There is little to no information on the incidence of fire on sand barrens (also known as dry sand savanna). They are, however, ecologically and floristically related to other communities on sandy soils or other extreme sites, including tallgrass prairie, sand dunes, shorelines, and alvars (Lee et al. in prep). A combination of drought and frequent fires were probably important in maintaining sand barrens (Catling and Catling 1993).

Succession After Fire

Frequent or intense fire may result in scrub oak or brush prairie in clumps alternating with open patches of prairie species. In the absence of fire, oak woodland develops, often with the same tree species, but with a more uniform, tall canopy. Consequently, the proportion of shade-intolerant herbaceous species decreases as canopy closure increases. On less extreme sites, fire suppression permits the invasion of red maple and other moderately shade-tolerant, dry-site species (Will-Wolf and Stearns 1999).

Management Considerations

Many sand barren sites continue to support prairie and savanna vegetation because the poor soil conditions make agriculture unprofitable. However, the quality of sand barren remnants has declined as vegetation has grown too dense for maintenance of savanna structure, oak reproduction, or for persistence of relatively shade-intolerant understorey plant species. Fragmentation has also probably led to loss of species. Recent management and recovery plans for sand barrens in the Great Lakes states recommend thorough inventories of existing sites followed by prescribed burning to expand and/or improve the site. However, the interval between burns is important as burning too frequently and/or too thoroughly can be harmful to arthropods and possibly cryptogams. The most successful approaches to sand barrens management have included burns at irregular intervals and then on only portions of the community at one time. Managers should also be aware that aggressively restoring pine barrens on xeric or nutrient impoverished sites may reduce the area of oak-dominated sand barrens. Differences between oak-dominated sand barrens and jack pine barrens reflect differences in disturbance regime and these sites may be best managed as oak-jack pine complexes (Will-Wolf and Stearns 1999).

White Pine-Red Pine

Stand and Soil Characteristics

White pine and red pine dominate separately or occur in variable mixtures with oak species, white cedar, white birch, and to a lesser extent hemlock, balsam fir, and red maple associates. Shrubs commonly include low sweet blueberry, common juniper, wintergreen, buffalo berry, and serviceberry. The understorey may consist of bracken fern, gaywings, bristle-leaved sedge, large-leaved aster, and hairy goldenrod. Soils are typically dry to fresh, sandy to coarse loamy (Lee et al. 1998).

Natural Fire Regime Characteristics

Prior to modern intervention, white and red pine stands experienced a variable fire regime of low intensity fires at short intervals punctuated by stand-replacement fires at longer intervals. In Ontario, low to moderate intensity surface fires occurred at mean intervals ranging from 12 to 37 years (Howe 1915; Burgess and Methven 1977; Cwynar 1977, 1978; Alexander et al. 1979; Guyette and Dey 1995b, Dey and Guyette 1996a), while high-intensity stand-replacing fires occurred at mean intervals of 46 to 85 years (Day and Carter 1991; Guyette and Dey 1995b). Studies in the Great Lakes states found similar fires regimes for white pine-red pine, with average return intervals for surface fires ranging from 22 to 36 years, and 160 years for stand-replacing fires (Frissel 1973; Heinselman 1981; Clark 1990; Loope 1991; Engstrom and Mann 1991). White pine stands with a significant shade-tolerant component growing on mesic sites or fire resistant physiographic sites (e.g., islands, valleys, lower slopes of high ridges) likely had a history of only one severe fire every 150 to 300 years (Heinselman 1973; 1981).

Vegetation Responses to Fire

White and red pine stands are typically fire-maintained seral types that occasionally survive as self-perpetuating climax under mixed fire regimes (Methven 1973; Duchesne and Hawkes 2000). Both species require fire for optimal germination and establishment, though white pine is less restrictive in its requirements (Heinselman 1981; Wright and Bailey 1982). Fire is necessary for regeneration because it removes duff to provide a seedbed, controls brush to reduce low-level competition, and kills overstorey species which in turn increases light penetration to the ground (Maissurow 1935; Van Wagner 1970). Neither white pine nor red pine grows well in heavy shade and optimal germination for both species occurs on mineral soil with little or no competition from shrubs and shade-tolerant trees (Heinselman 1973).

Neither white pine nor red pine individuals can tolerate fire until roughly 18 metres tall, or approximately 50 years old (Wright and Bailey 1982; Rouse 1988). At this point their thick bark, branch-free trunks, and moderately deep rooting habit serve as an effective protection against light to moderate surface fires that usually consume the litter layer and kill shrubs and shade-tolerant competitors (Heinselman 1973, 1983; Alexander et al. 1979; Bergeron and Brisson 1990). Younger pines are not as fire resistant due to thin bark and the close proximity of tree branches to the ground and understorey vegetation. These low branches can easily ignite during low intensity surface fires. (Wright and Bailey 1982; Rouse 1988).

High-intensity surface fires and crown fires can kill mature white and red pine trees. The main cause of their mortality following fire is crown scorch (Pinto 1993). Research indicates that red or white pine trees that sustain more than 75 percent crown damage most likely to die within the first year post-fire (Van Wagner 1970). Since red and white pine do not have persistent or serotinous cones, and only infrequent good seed years, at least some mature individuals must survive these severe fires to reseed the burn, unless the fire happened to occur in a good seed year (Heinselman 1981).

Succession After Fire

The surface fires typical of white pine-red pine communities do not completely reset succession, but rather, thin the understorey and promote pine establishment. The severity of the fire has a distinct impact on early successional development (Sidhu 1973; Kershaw 1993). Light to moderate fires stimulate sprouting in shrubs, limiting pine recruitment. High-intensity surface fires, in contrast, can eliminate aggressive deciduous competitors (e.g., beaked hazel and striped maple) by killing their roots (Kershaw 1993).

Following a high-intensity stand-replacing fire, succession proceeds from herbaceous species to shrub and hardwood, and finally, after 50 years, to white and red pine stages (Kershaw 1993; Wright and Bailey 1982; Lynham and Curran 1998). In the absence of fire, stands will continue to succeed to spruce-fir on the northern boundaries of the region and to various combinations of tolerant hardwoods throughout most of the remaining range within 200 to 300 years. Conversely, if crown fires occur more often than every 50 years, jack pine, aspen, and white birch will be the dominant species (Wright and Bailey 1982).

Management Considerations

Given the dependence of white pine and red pine on fire for regeneration, fire is an ideal tool for regeneration and removal of competing vegetation (McRae et al. 1998). Based on several series of prescribed burns in white and red pine stands at the Petawawa Forest Research Station, Van Wagner (1970) reported the key findings to be:

- sufficient duff for pine germination is removed when its moisture content is about 60% or less;
- competing hardwoods require two consecutive annual fires to be successfully controlled while balsam fir, another undesirable competitor in the understorey, is readily killed by one gentle fire;
- good 10-year-growth of red pine seedlings occurred only in open conditions; and
- the higher the fire intensity, the better the site preparation, and consequently the pine regeneration.

Further, McRae et al. (1994) suggest the following with regard to understorey prescribed burning in white and red pine:

- understorey prescribed burns should be scheduled for spring, before leaves have emerged and ground level moisture has increased, to ensure that the fire will spread throughout the understorey (which is especially important on sites that are being burned for the first time);
- litter fall is heavy enough that sites can be burned again the following year to ensure hardwood control; and
- the final understorey burn should be conducted in the spring of a good seed year to take advantage of seed production.

Jack pine

Stand and Soil Characteristics

Jack pine occurs in pure stands or as a main canopy dominant in association with white pine, red pine, oak spp., and red maple. Shrubs commonly include blueberry spp., common juniper, wintergreen, buffalo berry, and serviceberry. Soils are typically xeric to moderately dry, shallow sands and coarse loams over bedrock (Lee et al. 1998).

Natural Fire Regime Characteristics

Prior to settlement, jack pine stands on dry, nutrient impoverished sites usually experienced a variable fire regime of short interval, moderate and high-intensity surface or crown fires. Heinselman (1981) reported that, on the xeric glacial outwash sand plains of central Wisconsin and lower Michigan and in other dry sites, many jack pine areas apparently had regimes of short interval, moderate intensity surface fires that killed only portions of stands in the range of every 15 to 35 years. Vogl (1970) reported a mean fire return interval of 24 years (range 8-41) for high-intensity, stand-replacing fire in red pine, jack pine, and oak barrens in northern Wisconsin. At the Mack Lake area of northern lower Michigan, the mean fire interval was 27 years (Simard and Blank 1982).

Vegetation Responses to Fire

Jack pine is an early to mid-successional species that almost exclusively originates after fire (Cayford 1970). Adaptations such as extreme cone serotiny, vigorous growth rates, intolerance of shade, early cone development, and preference for mineral soil seedbeds make it ideally suited to regeneration following fire, where it typically develops as an even-aged stand (Cayford and McRae 1983; Rouse 1986c; Van Wagner 1993). These stands normally become mature and decadent at 70 to 80 years of age and produce a large amount of fuel as stand vigour declines, thus predisposing them to another fire (Day and Carter 1991).

Though well-adapted to fire, fire can easily girdle or kill an established jack pine stand. Jack pine needles are highly flammable and readily burn if crowns are too close to the ground. Few trees survive crown fires, and younger stands tend to be more susceptible to crown fires than older stands whose crowns are often thinner and higher from the ground and understorey vegetation (Rouse 1986c; Stocks 1989; Pregitzer and Saunders 1999). Young jack pine stands are also especially susceptible to early spring fires (Rudolph and Laidly 1990). Mature jack pine stands can survive low severity fires (Rowe 1983).

Succession After Fire

Frequent fire in xeric jack pine stands likely maintains a mixture of grasses and sedges by permitting herbaceous plants to exploit resources such as light, space, and nutrients which are released after burning, and promotes pine establishment. However, fires with a return time of less than 20 to 40 years may reduce the establishment and recruitment of jack pine and increase the vigour of understorey shrubs. A fire interval of less than 50 years will promote areas with jack pine, while a fire interval of 50 to 200 years will favour dominance by red pine, white pine, and hardwoods. In Minnesota, jack pine is typically replaced by red pine, followed by white pine, and finally a mixed hardwood forest composed of sugar maple, basswood, and red oak. Occasionally the red and white pine stages are absent and white birch and trembling aspen succeed jack pine and the final stage is mixed hardwood forest (Pregitzer and Saunders 1999).

Management Considerations

Periodic fires are necessary to maintain and perpetuate xeric areas dominated by jack pine. Species composition and structure in these communities often changes if fire is suppressed. Recent initiatives in the northern Great Lakes states suggest that prescribed burning can be used successfully to restore the diversity of composition and structure historically found in jack pine barrens (Pregitzer and Saunders 1999). Based on his study of fire in the northern Wisconsin pine barrens, Vogl (1970) concludes:

- barrens occur on sandy plains or sites with low fertility that lend themselves to droughts and frequent fires;
- fire is a critical and controlling factor in determining the conifer composition of pine barrens;
- fires at return intervals of 20 to 40 years would help maintain the jack pine and the open nature of the barrens; and
- fires at return intervals of less than 10 years promote vigorous understorey growth and benefit wildlife by promoting maximum berry production and vegetative reproduction for browse.

Poplar-White Birch, White Birch-Poplar-Conifer

Stand and Soil Characteristics

Trembling aspen, largetooth aspen and white birch dominate separately or in variable mixtures in hardwood stands or occur as co-dominants in mixed woods stands that also include balsam fir, white pine, white cedar, and white spruce. Stands typically represent early successional stages with high shrub and herb cover and species richness. Soils vary from dry to moist and are typically sandy to coarse loamy (Lee et al. 1998).

Natural Fire Regime Characteristics

Prior to settlement and human intervention, seral aspen and birch stands likely experienced a variable fire regime of low intensity surface fires and higher intensity fires, depending on the amount of fuel on the forest floor (Duchesne and Hawkes 2000). There is little to no information on their historical fire regimes in the Deciduous forest region, but in Temagami District the mean fire interval between fires causing regeneration is estimated to have ranged from 66 years in stands dominated by poplar to 104 years in stands dominated by white birch (Day and Carter 1991). A fire cycle ranging from 70 to 210 years has been suggested for seral aspen and birch communities in the Great Lakes forest region (Cwynar 1977; Heinselman 1981; Zhang et al. 1999). In Boundary Waters Canoe Area, poplar-birch stands experienced a fire regime similar to those of adjacent conifer stands, with severe surface fires or even crown fires (in poplar-birch-conifer stands) with fire cycles of perhaps 80 years (Heinselman 1981). Fires likely occurred most frequently during spring and fall when fuels were dry and leaf litter was deep (Duchesne and Hawkes 2000).

Vegetation Responses to Fire

Poplar and white birch are generally considered to be short lived, shade intolerant, pioneer species (Safford et al. 1990; Laidly 1990; Perala 1990). Since neither poplar nor white birch is capable of reproducing under its own shade, a major stand disturbance is required to maintain these early-successional communities on the landscape (Rouse 1986a; Day and Carter 1991). Fire is considered to be the primary natural disturbance responsible for regeneration in both species as it creates suitable seedbeds and reduces competition (Day and Carter 1991). Both poplar and white birch rapidly colonize open sites created by fire, but usually persist for only one generation before being replaced by more shade-tolerant species (Safford et al. 1990; Laidly 1990; Perala 1990).

Poplar and birch-dominated stands burn only under specific site and climatic conditions, such as in early spring before leaf flush, following an unusually severe drought, or late in stand history when the proportion of conifers has increased. Fires in young stands are typically low intensity, while those in older stands with abundant fuels may burn with greater intensity. Due to the high moisture content and lush understorey, crown fires in adjacent conifer stands often stop at the boundary of large aspen or white birch stands, or become slow-moving ground fires. The presence of conifers, whether in the understorey or the canopy, generally increases the flammability of poplar-birch stands (Foster and King 1986; Duchesne and Hawkes 2000).

Although poplar-white birch forests do not readily burn, poplar and white birch trees are particularly susceptible to fire because their thin bark is highly flammable and provides little or no heat resistance to the cambium layer immediately beneath the bark (Duchesne and Hawkes 2000). Even low intensity surface fires can ignite bark, girdle and kill sufficient trees to open the stand to improved or increased light penetration to through the canopy and increased warming thereby stimulating root suckering (Ahlgren and Ahlgren 1960; Day and Carter 1991). Moderate intensity fires easily top-kill most mature poplar and white birch and high-intensity fires may kill roots near the soil surface or damage meristematic tissues thus reducing sucker regeneration. Deeper roots, however, are not damaged by severe fire and remain capable of re-sprouting. On surviving trees, basal wounds caused by fire serve as entrance points for wood-rotting fungi (Rouse 1986a; Laidly 1990).

Succession After Fire

Regeneration of both poplar and white birch is rapid and results in the formation of an even-aged overstorey (Day and Carter 1991). Both species are capable of re-establishing by means of root suckering and seed blown in from adjacent stands, though poplar tends to recolonize primarily through extensive suckering from lateral roots and white birch tends to seed in on fire-prepared seedbeds (Laidly 1990; Perala 1990; Safford et al. 1990; Day and Carter 1991). Sprouts, and seedlings if a seed source is nearby, will appear within the first year following fire. Sucker densities peak in the first or second postburn year and then decline rapidly thereafter. Even-aged poplar stands can develop within a decade (Brown and DeByle 1989). In the absence of recurring fire or other disturbance, poplar and white birch reach maturity and are replaced by red pine, red oak, and red maple on dry sites; white pine on intermediate sites; and by tolerant hardwoods, spruce spp., and balsam fir on mesic sites (Palik and Pregitzer 1992).

Management Considerations

Concurrent with the maturation of second-growth stands, the abundance of early successional habitats has declined in much of northeastern North America. The effects of habitat loss on wildlife species that require early-successional habitat have received relatively little attention, possibly because of the notion, even among conservation groups, that these species are generalists that thrive in human-dominated landscapes and therefore require no special conservation measures. However, significant population declines have occurred among early successional obligates (Lorimer and White 2003). In the past, fire played an important role in maintaining early-successional aspen and white birch forests in a mosaic pattern and in increasing regional vegetation diversity (Day and Carter 1991). Today, however, the presence of seral aspen and white birch on the landscape is threatened by the lack of fire due to suppression. Prescribed burning and prescribed fire offer an economical and ecologically sensitive means of regenerating aspen and white birch in a manner that closely mimics the natural disturbance and regeneration process (Brown and DeByle 1989; Duchesne and Hawkes 2000). The timing and intensity of burning will be important to regeneration success for two reasons:

- the vigour of a sucker stand will be greater if the parent stand is killed in early spring before the root system has expended its reserves on new growth (Van Wagner 1993); and
- fires of moderate to high intensity are required to ensure adequate spread and sufficient mortality to the overstorey (Brown and DeByle 1989).

In some cases managers can increase their chances of success by cutting trees (especially conifers) to increase the surface fuel loading and continuity (Brown and DeByle 1989).

Oak Deciduous, White pine-Maple-Oak mixedwoods

Stand and Soil Characteristics

Oaks grow as a canopy dominant in many communities, including (1) deciduous stands where red, white, and black oak dominate the canopy separately or in variable mixtures with red maple, white pine, and black cherry associates and the canopy cover is variable but is typically relatively open (60 to 80 percent canopy closure); and (2) mixed stands where white pine occurs with red oak, sugar maple and, to a lesser extent, white oak and shrubs commonly include serviceberry, wintergreen, downy arrow-wood, low sweet blueberry, and partridgeberry. Soils are typically dry to fresh, shallow sands and coarse loams over bedrock (Lee et al. 1998).

Natural Fire Regime Characteristics

Prior to settlement, oak communities experienced a regime characterized by frequent, low intensity burns (Van Lear 2004). Based on several fire history studies in oak communities, Dey and Guyette (2000) concluded that fire regimes have varied spatially and temporally at studies sites across central Ontario. They found the mean fire intervals for low intensity surface fires ranged from 6 to 29 years among sites (Guyette et al. 1995; Guyette and Dey 1995a, 1995c; Dey and Guyette 1996b, 1996c), and from 5 to more than 76 years between historic periods at some sites (Dey and Guyette 2000). Moderate intensity surface fires occurred at intervals of 47 years, and high-intensity, stand-replacing fires occurred at intervals of 200 years (Guyette and Dey 1995a). Lorimer and White (2003) suggest that most natural fires in oak stands occur in early spring and late fall after the leaves have dropped when herbaceous vegetation is largely in a cured stage and the bare tree crowns allow direct sunlight to dry out the ground fuels on dry, windy days. However, lightning fires are uncommon in many regions because lightning strikes occur primarily during the growing season and are often accompanied by rain (Wade et al. 2000; Lorimer and White 2003). Other research indicates that most fires resulted from Aboriginal land-use activities or the logging and farming practices of early European settlers (Guyette et al. 1995).

Vegetation Responses to Fire

Oak species are generally considered midseral with intermediate shade tolerance, though white oak is more shade-tolerant than red oak and black oak. As a result, seedlings are incapable of establishing and growing in environments characterized by low light levels, with the exception of white oak, which is able to persist under a forest canopy for more than 90 years (Dey and Guyette 2000; Abrams 1992; Rogers 1990). This requirement for light restricts red oak establishment to open sites where competition can be intense (Crow 1988). Fire is necessary because it opens up the canopy and thins out the understorey, thereby reducing competition from shade-tolerant species, and releasing suppressed oak seedlings for recruitment into the canopy (Guyette and Dey 2000; Wolf 2004).

Oak species are considered well adapted to recurrent fire (Crow 1988; Tirmenstein 1991; Abrams 1992; Carey 1992; Dey and Guyette 2000). Compared to other hardwoods, fire typically favours oaks because of their thick bark, sprouting ability, resistance to rotting, suitability of fire-created seedbeds for acorn germination, deep roots, xeromorphic leaves, and high photosynthetic rates during drought (Crow 1988; Tirmenstein 1991; Abrams 1992).

Depending on severity, fire can injure, kill, stimulate, or have no effect on individuals of established oak communities. Older, larger trees are better able to survive fires than smaller trees because they have thicker bark and a larger area of cambium that can continue to function if a portion is killed (though such wounds provide a threshold for insects and diseases)(Rouse 1986b). Seedlings, saplings, and pole-sized individuals are more susceptible to fire, but commonly resprout vigorously from the stumps or root collar following the death of aboveground parts by fire (Crow 1988, Van Wagner 1993).

Succession After Fire

Periodic fire should check succession in oak forests and maintain open conditions by inhibiting shade-tolerant species such as sugar maple, beech, and ironwood, and shade intolerant species such as aspen and white birch (Abrams 1992; Dey and Guyette 2000). Light surface fires trigger oak regeneration and establishment, often increasing stem density by promoting sprouting and reducing competition. Post-fire seedling establishment may also occur since dying trees often produce a massive seed crop and acorns germinate well on mineral soil (Rouse 1986b). Higher intensity fires occasionally top-kill pole and sawtimber-sized trees, but many of these sprout and create new even-aged stands (Sander 1990).

Oak seedling sprouts that survive recurrent fires develop a large root system and the carbohydrate reserves needed for accelerated shoot growth. Under a disturbance regime of short return intervals (e.g., 5 to 10 years), oaks remain in a “grub” or seedling-sprout stage, continuing to accumulate biomass. However, given a sufficiently long interval, larger oak grubs, or seedling sprouts, are capable of growing rapidly enough to have a good chance of surviving another fire, and then of growing into the canopy (Dey and Guyette 2000). In the absence of fire, these forests will be transformed by gap dynamic processes that favour shade-tolerant species over oaks within 20 to 40 years (Crow 1988; Dey and Guyette 2000).

Management Considerations

Current distribution of red oak in Ontario, and other regions in northeastern North America, appears to be closely related to intense anthropogenic disturbance (Crow 1988; Nowacki and Abrams 1991; Abrams 1992; Dey and Guyette 2000). Though oak species were an important component in presettlement forests, it seems likely that their dominance has been maintained or even promoted by recurring disturbances (i.e., fire and logging), due to their resistance to fire and competitiveness in post-disturbance environments. However, decreased disturbance in the past 100 years has led to conditions favouring shade-tolerant species, and oak species will most likely decline on all but the most xeric sites (Nowacki and Abrams 1991).

Prescribed burns can be an important tool for regenerating oak stands, removing competition, slowing successional transition, and enhancing wildlife habitat (Rouse 1986b; Crow 1988; Van Wagner 1993; Ruffner and Groninger 2004). The intensity and frequency of burns are important in promoting effective advance regeneration. Low-intensity prescribed fires have not always favoured oak regeneration and a single burn often has little lasting impact on reducing competition (Crow 1988; Kruger and Reich 1997). Crow (1988) suggests a commitment to frequent burning is required to compensate for decades of fire exclusion. The number of fires required will depend on the degree of low-level competition from species such as maple and beech. Two or more successive fires might be needed to give red oak the required boost and open the canopy enough to permit fast oak growth. Prescribed burns should be conducted in spring before flushing, when root reserves are highest, in order to achieve the strongest resprouting (Van Wagner 1993). In addition, vigorous competitors of oak should be harvested at the beginning of the burning program (Van Lear 2004).

Pitch pine-Oak mixedwoods

Stand and Soil Characteristics

Pitch pine, red oak and, to a lesser extent, white oak occur in variable mixtures in communities with a canopy typically open in nature. Understorey species include common hairgrass, panic grass, and bracken fern. Soils are dry to moderately fresh, shallow sands and coarse loams over bedrock. These communities are restricted to the shallow substrates and bare rock surfaces associated with knobs and ridges on the Canadian Shield in Frontenac County (Lee et al. 1998).

Natural Fire Regime Characteristics

There is little to no information on the natural fire regime in pitch pine-oak communities in Ontario. The natural fire return interval for pitch pine habitat in the north-eastern United States has been studied for some sites, but regimes remain not well understood (Lorimer and White 2003). Where Native American burning was common, pitch pine existed as an understorey fire regime. Estimates of fire return interval in upland pine-oak stands range from approximately 20 years to 40 years for sites in New Jersey during the late 1800s and early 1900s (Little and Moore 1949; Forman and Boerner 1981). However, fire return intervals in other upland pine-oak stands will vary due to local variations in the distribution of natural fire breaks (e.g., swamps), community composition, and weather patterns (Lorimer and White 2003).

Most wildfires in the Long Island pine barrens have occurred in the spring prior to leaf flush when the winds are often high, humidity is low, and surface fuels are dry and readily combustible. Although spring fires may be of high-intensity, deep duff is usually moist and limits burning. Severe, duff-consuming fires typically occur following prolonged drought, often during the summer. Severe fires occur less frequently than high-intensity springtime fires, for once the duff is consumed it takes several years before enough duff has accumulated to support another severe fire (Jordan et al. 2003).

Vegetation Responses to Fire

Pitch pine is a shade intolerant, early successional species that regenerates well following disturbances. Characteristics such as thick bark, extensive root systems, the ability to resprout from basal or epicormal buds, early seed production, and variable levels of serotiny (though pitch pine trees growing in the Thousand Islands are not serotinous) allow it to regenerate quickly following fire (Witzke 1996; Landis et al. 2005). Though well-adapted to fire, pitch pine is flammable and easily top-killed by fire. Seedlings less than 1.5 meters in height will nearly always be killed and a hot fire during a dry season can even kill mature individuals (Carey 1992). The thick bark of older individuals generally makes them resistant to all surface and most crown fires. However, if the crown is consumed, the dormant buds along the bole in stems less than 40 years old will generally sprout vigorously following most fires. After stand-replacing fire, pitch pine re-establishes from the seed of survivors or from individuals outside the burn (Jordan et al. 2003).

Succession After Fire

The low to moderate intensity surface fire typical of pitch pine-oak communities does not completely reset succession, but rather, promotes pine establishment by thinning the understorey, eliminating competition from shade-tolerant species, and preparing seedbeds (Landis et al. 2005; Howard et al. 2005). In the absence of severe crown fires, but with frequent low intensity surface fires, duff accumulation is limited and pine establishment is promoted. However, if return intervals for crown scorching fires exceeds 30-50 years, tree oaks can establish, produce acorns and increase in abundance. After fire-free periods of 10-20 years, tree oak canopies close causing sunlight at the forest floor to decline. Large, old pitch pines may persist in these conditions until senescence, but are unable to reproduce due to accumulating leaf litter and duff, and the lack of sunlight. Pitch pine and scrub oaks will gradually disappear as pine-oak forests succeed to closed oak forest. Community transitions due to succession in the absence of fire occur gradually, but a single top-killing or crown scorching fire can quickly convert a forest or woodland into a shrubland (Jordan et al. 2003).

Management Considerations

Pitch pine is rare in Canada and, in Ontario, occurs at the northwestern limit of its range. These northern pitch pine trees are believed to contain characteristics such as cold-hardiness and the ability to grow on dry rocky sites which are considered important to protect for the future gene pool. Unfortunately, without intervention, Ontario’s pitch pine is likely to disappear (Witzke 1996). Preserving pitch pine-oak communities and their full complement of plant and animal species will require frequent disturbance to (1) maintain the open-canopy, shrub dominated communities; (2) expose the mineral soil needed for pitch pine seedling establishment; and (3) prevent invasion of tree oaks and succession to hardwood forest (Jordan et al. 2003).

Jordan et al. (2003) suggest that wherever possible prescribed burning and prescribed fire, perhaps in combination with mechanical pre-treatment, is recommended to reduce fuel loads in an effort to protect human life and property and to perpetuate fire-dependent pitch pine-oak communities. They propose that an ideal fire regime would incorporate varied fire behaviours across the landscape and over many decades, including both low and high-intensity, and low and high-severity burns, in both dormant and growing seasons. However, it has been suggested that low-intensity winter prescribed burns may have little effect on hardwoods and could possibly increase hardwood growth (Wade et al. 2000). Boerner et al. (1988) recommend that the best way to control competing hardwoods is to prescribe a winter fire that reduces surface fuels followed by a summer fire. Similarly, Jordan et al. (2003) suggest a prescribed winter crown fires followed by growing season low-intensity backfires.

Tolerant hardwoods and mixed-hardwoods

Stand and Soil Characteristics

On mesic sites, sugar maple, beech, and basswood are the predominant hardwood species while hemlock and white cedar are the main conifer species (Maycock 1979). Sugar maple often dominates the main canopy with red oak, white oak, ironwood, beech, basswood, black cherry, hickory spp., white ash, white birch, and aspen subdominants and red maple, green ash, black ash, white elm, and yellow birch associates. Hemlock and white cedar can also occur as a canopy dominant or codominant in association with various hardwoods and conifers including yellow birch, red maple, sugar maple, white pine, white spruce, and balsam fir. Soils vary from dry to moist with a wide range of soil textures (Lee et al. 1998).

Natural Fire Regime Characteristics

Tolerant hardwood and mixed-hardwood stands historically experienced very long interval stand-replacement or understorey fires. Mean fire intervals reported in the literature range from 800 years in northeastern Maine (Lorimer 1977) to 1200 years in northern lower Michigan (Whitney 1986). Fire cycles of many centuries, ranging from 300 years to more than 2700 years, have been suggested by surveyor notes (Lorimer 1977; Whitney 1986; Zhang et al. 1999) and canopy accession dates (Frelich and Lorimer 1991). These ecosystems seem to have erratic fire cycles; the majority of fires likely occurred only after prolonged drought, and then mostly in stands that were already breaking up due to wind or icestorm damage, insect attack, and other events that generate ground fuels (Heinselman 1981). On sites where oak or conifers such as pine and hemlock were a substantial component of the hardwood forest, stand-replacing fires probably occurred more frequently (Abrams 1992; Wade 2000).

Vegetation Responses to Fire

Shade-tolerant hardwoods and mixed-hardwoods dominated by sugar maple or hemlock are generally considered to be late seral. Grimm (1984) suggests these forests are typically not very flammable for several reasons including: 1) potential fuels decompose rapidly, 2) little fuel exists at ground level due to dense shade, 3) tree trunks are not very flammable, and 4) open tree crowns do not carry fire very well. Additionally, low solar radiation, high humidity, and low wind speeds within the stands tend to prolong the moisture retention of ground-level fuels, thereby inhibiting the ignition and spread of fire (Grimm 1984). Windthrow and other treefall gaps are the dominant disturbance types in these ecosystems (Lorimer 1977; Canham and Loucks 1984; Whitney 1986).

Many of the species associated with these ecosystems, including sugar maple, beech, basswood, yellow birch, and hemlock, are considered sensitive to fire due to their thin bark and shallow roots (Daubenmire 1936; Swan 1970; Crow 1990; Erdmann 1990; Godman and Lancaster 1990; Tubbs and Houston 1990). Hemlock, in particular, is further susceptible because of its low-branching habit and heavy litter deposits (Rogers 1978).

Seedlings and saplings of many species are readily killed by even low intensity fire (e.g., sugar maple, beech, yellow birch, hemlock), and some larger trees can also be killed (Swan 1970; Erdman 1990). Following top-kill by fire, several species-specific responses have been noted:

- sugar maple saplings occasionally sucker, but post-fire establishment occurs primarily through seedling sprouts and seedlings (Daubenmire 1936);
- beech re-establishes by root suckering or stump sprouting (Tubbs and Houston 1990);
- basswood will sprout vigorously from the root crown (Crow 1990);
- yellow birch is a poor sprouter, but seed germination and seedling establishment are enhanced by fire disturbance (Maissurow 1941); and

- hemlock does not sprout and appears to reinvade a burn over time (Swan 1970; Henry and Swan 1974).

Succession After Fire

Low intensity surface fires appear to favour maple, which quickly re-establishes post-fire through seedling sprouts and seedlings. High-intensity fires often consume the existing reproduction of maple and create openings in the forest, resulting in greater percentage of yellow birch, basswood, elm, white pine, and hemlock. Both yellow birch and hemlock are unable to reproduce on the forest floor, and enter the composition of hardwood stands together with paper birch and white pine on the bare mineral soils present following fire (Maissurow 1941).

Management Considerations

Fire plays a significant role in the perpetuation of a number of species, such as yellow birch, hemlock, pines, and intolerant hardwoods, thus shaping and determining the form and composition of the hardwood forest. Due to periodic fire disturbance, tolerant hardwood and mixed-hardwood stands consist of (1) uneven-aged groups developed during periods of uninterrupted growth made up of tolerant hardwoods, maple and basswood, and (2) one or more even-aged groups of fire-origin species which are unable to reproduce readily on the forest floor. In the absence of fire, monotonous stands of sugar maple, mixed with basswood in moist locations, would spread over the entire range of hardwood soils and a good portion of white pine sites (Maissurow 1941).

In Ontario, prescribed burns have been used to create suitable seedbed conditions for yellow birch regeneration. Low intensity surface burns are conducted in late fall following sugar maple leaf and seedfall and prior to yellow birch seedfall. The fire consumes litter and kills advanced regeneration of sugar maple, resulting in higher stocking of yellow birch (Van Wagner 1993). Prescribed burns can also be used to help obtain natural regeneration in hemlock (Godman and Lancaster 1990).

Conifer, deciduous, and mixed lowlands

Stand and Soil Characteristics

Conifer lowlands are generally dominated by pure stands or mixtures of white cedar, tamarack, and black spruce and may include balsam fir, hemlock, white pine, white spruce, white birch, yellow birch, sugar maple, and green ash. Shrubs may include bunchberry, dwarf raspberry, wintergreen, fly honeysuckle, and swamp red currant. Soils are typically wet organic and very moist, sometimes fresh, mineral soils (Lee et al. 1998).

Deciduous lowlands are very diverse. Overstorey species may include white elm, willows, black walnut, maple spp., basswood, ash spp., aspen, sassafras, oak spp., and hickory spp. which dominate separately or in variable mixtures. The understorey often consists of high shrub, herb, fern and sedge cover and species richness. Soils are typically fresh to very moist, mineral and organic soils (Lee et al. 1998).

Mixed hardwood and conifer lowlands also occur and consist of variable mixtures of the species previously listed. Soils are typically wet organic and very moist, sometimes fresh, mineral soils (Lee et al. 1998)

Natural Fire Regime Characteristics

Conifer and deciduous lowlands historically experienced relatively infrequent to very infrequent stand-replacement or understorey fires. The fire regimes in these lowlands were strongly influenced by fires intruding from adjacent ecosystems and by interactions of insect and disease, large-scale blowdowns, and periods of drought. Lowlands embedded within or adjacent to relatively fire-resistant landscapes experience fire less frequently than those embedded within or adjacent to fire-prone landscapes (Cleland et al. 2004a). Fire cycle and maximum longevity are probably longer on lowland sites than nearby upland sites (Heinselman 1973).

Bergeron (1991) estimated the average time since fire to be 171 years in conifer bogs near Lake Duparquet, Québec. Heinselman (1981) estimated the fire cycle to be 150 years in a large black spruce peatland in northern Minnesota. Zhang et al. (1999) estimated the fire cycle to be 194 years in stands dominated by tamarack, and 893 years in stands dominated by black spruce, and 1741 years in stands dominated by white cedar. Whitney (1986) estimated a fire cycle of 3000-6000 years in swamp conifers. There is very little information in the literature on fire cycle in hardwood lowlands, but Bergeron (1991) estimated an average time since fire of 183 years in black ash, white elm lowland forests, and Zhang et al. (1999) estimated a fire cycle of 1067 years for mixed lowland conifers and hardwoods.

Most fires in lowlands would have occurred in July, August, or September of severe drought years when the water tables were low enough that moss layers became thoroughly desiccated. Under these circumstances, given sufficient wind, the spruce, tamarack, and cedar forests of lowlands can carry major crown fires (Heinselman 1981).

Vegetation Responses to Fire

Conifer and deciduous lowlands are generally not as prone to fire as other forest types because of their wetter conditions. Their high water table in the spring, dense green understorey, and more humid environment make them less susceptible to fire, except in severe drought years. Another characteristic of lowland forest types that reduces their susceptibility to fire is the convex nature of the depressions they occupy. Fire tends to avoid convex depressions and seeks concave landforms such as hilltops and slopes. As a result, lowlands are often spared from even large, high-intensity forest fires, leaving unburned pockets of forest that become important seed sources for adjacent uplands (Duchesne and Hawkes 2000).

Despite their relative resistance to fire, lowlands undoubtedly burned periodically during presettlement times and wetland fires during drought in Upper Michigan and in other parts of the eastern U. S. are well documented (Loope 1991). Black spruce, tamarack, and white cedar are susceptible to fire due to their thin bark and shallow roots and can be killed by even low severity fire (Viereck and Johnston 1990; Johnston 1990a; Johnston 1990b). Crown fires are common in black spruce stands because the layering habit of black spruce and the frequent occurrence of abundant lichens on its lower branches often form a continuous fuel that is easily ignited by surface fires. Crown fires typically result in extensive mortality in black spruce stands (Viereck 1983).

Lowland deciduous species are also sensitive to fire due to their thin bark and shallow roots (Daubenmire 1936; Crow 1990; Erdmann 1990); even large individuals can be killed by moderate intensity fires (Erdmann 1990; Walters and Yawney 1990). Low-intensity fires can damage the cambium causing decay, even though the bark remains intact for several years after fire (Wade et al. 2000).

Succession After Fire

There is very little information on succession after fire in lowland stands. Lowland conifers establish well on burned organic soils provided a seed source is available and the humus layer is not consumed. Some lowland deciduous species sprout readily after damage or top-kill, including black ash, aspen, and red maple (Wright and Rausher 1990; Perala 1990; Walters and Yawney 1990). Others, including sugar maple, white birch, and yellow birch tend to seed in following fire (Daubenmire 1936; Maissurow 1941; Safford et al. 1990). Sprouting of understorey species depends on fire severity and the depth of perennating tissues (Sullivan 1994).

Management Considerations

Lowland conifer and deciduous communities are capable of reproducing and perpetuating in the absence of fire. As a result, prescribed burning is not necessary for management of lowland communities but prescribed fire may be considered since these sites are known to burn following drought cycles or due to fires in adjacent upland vegetation (Cleland et al. 2004a).

SUMMARY AND RESEARCH NEEDS, REFERENCES, AND APPENDICES – TABLE OF CONTENTS

SUMMARY AND RESEARCH NEEDS

Fire was an important, recurring disturbance in many vegetation communities in Ontario, but over the past 150 years many factors have caused changes to the natural fire regimes and the vegetation associated with those regimes. Humans have played an important role in influencing fire on the landscape, whether providing a source of ignition or controlling its spread. For most of this century, fire has been regarded as a nuisance and as a destructive agent to be controlled. Recently, however, it has been recognized that when fire is eliminated from fire-dependent ecosystems it causes changes in succession and nutrient cycling, as well as build-ups in flammable fuels, which in turn threaten surrounding lands.

This report presents an overview of the current state of knowledge regarding how ecosystems interacted with fire in the past, under a minimum of human influence, and how fire processes can be used as a tool in resource management to restore ecological integrity to protected landscapes in the future. It answers critical restoration questions regarding where, when, how frequently, and how intense and is intended to help guide decisions regarding preliminary fire management goals, objectives and options for the maintaining and restoring fire-dependent ecosystems across Ontario.

Though this report will provide park planners, ecologists, and fire managers with critical information on the natural fire regime and scale of fire effects for a given ecosystem, there are many other issues to consider when managing fire on the landscape.

Reference conditions

The natural (or historical) range of variability is recognized as an important consideration in resource management and is characterized by the range of ecosystem conditions, such as the extent of particular seral stages of vegetation, and by the disturbance regime that produced such conditions (Sprugel 1991; Swanson et al. 1993). In order to determine how human activities have influenced disturbance regimes, and in turn vegetation composition and structure, there must be a reference condition to which current landscape vegetation and fire regimes can be compared and from which departure from can be measured. This departure from the natural range of variability can be used to guide management objectives and to identify areas having the greatest need for fire regime restoration (Hann et al. 2005). This report provides a general description of reference conditions for disturbance regimes in Ontario, but reference conditions based on the presettlement mix of vegetation classes remain to be established. These reference conditions can be determined through synthesis of expert knowledge, published literature, and historical information (e.g., surveyor notes) using standardized computer modeling tools and processes (Hann et al. 2005).

In the United States, several agencies including the Forest Service, The Nature Conservancy, and the U. S. Department of the Interior have collaborated to develop Fire Regime Condition Class (FRCC), a standardized tool for determining the degree of departure from reference condition vegetation, fuels, and disturbance regimes. An excellent interagency website provides guidance on FRCC methods and software, and related publications and can be accessed at: http://www.frcc.gov/index.html.

Time since last fire

Time since disturbance can strongly influence both succession and fire regime (Cleland et al. 2005). Fire probability often increases as the length of time that has elapsed since the last fire increases due to the accumulation of fuel along the forest floor and development of fuel ladders. As the amount of available fuel increases, the intensity of future surface and crown fires is affected and the outcomes of which become increasingly variable and difficult to predict. Fire probability also increases along a successional gradient due to the higher proportions of conifers (Thompson 2000; Cleland et al. 2005). Knowledge of the length of time since last fire is also important as it may be used as a surrogate for modern fire return interval and compared to the natural (presettlement) fire return interval to determine departure from the natural range of variability.

Effects of fire on ecosystem processes and biodiversity

Fire is a dynamic natural process that affects the composition, structure, and patterns of vegetation on the landscape. Fire and the habitat changes caused by fire in turn influence faunal populations and communities. Fire also affects the soil and water resources that are critical to overall ecosystem functions and processes. Therefore, park planners and ecologists must evaluate the fire effects on all these components, and balance the overall benefits and costs associated with the use of fire in resource management.

In the United States, a Joint Fire Sciences program produced a five-volume series on the effects of fire on air, soil and water, fauna, flora, and cultural resources. The five volumes, taken together, provide a wealth of information and examples regarding the effects of fire in the United States and Canada. With the exception of the volume on cultural resources, the fire effects reports are available on line on the Forest Service website at: http://www.fs.fed.us/database/feis/.

Species at risk

In the case of species at risk that are adapted to fire-prone habitats, any significant alteration of the fire regime may pose a serious threat. When establishing a burn program it must be remembered that options for suitable post-fire habitat have often been reduced, creating the potential for severe “bottlenecks” in space and time, particularly for species that have narrow habitat requirements, restricted distributions, or low mobility (McKenzie et al. 2004).

Exotic plants

Introduced exotic plants can seriously interfere with efforts to restore fire as an ecosystem process. Well-intentioned plans for prescribed burning and prescribed fire can be devastated if exotic plants are not anticipated and managed properly. Exotic invasions can occur more quickly after disturbances to ecosystems because disturbances remove competitive dominants and increase the rate of establishment of new individuals, exotic or not. Exotic species may also alter the disturbance rate (White and Jentsch 2001). Because exotic species invasions are one of the most important global environmental problems, research is required to determine how non-native plant species can be managed in combination with prescribed burning and prescribed fire to conserve biodiversity (Brown 2000; White and Jentsch 2001).

SUMMARY AND RESEARCH NEEDS

Interactions among disturbance agents

Many ecosystems experience multiple disturbances and these disturbances may act synergistically (Hobbs and Huenneke 1992; Li 2000). Knowledge of how disturbance agents such as insects, disease, blowdown, and fire interacted in the past, and how they characterized historical fire regimes and landscape patterns, will be important in setting appropriate management objectives and achieving desired results.

Climate change

Climate change is recognized as a major threat to the survival of species and integrity of ecosystems world-wide (Hulme 2005). Climate change will contribute to alterations in disturbance regimes by directly affecting the frequency and severity of weather favourable to fire spread, and by indirectly altering the physical and chemical properties of fuels (Ryan 2000; White and Jentsch 2001). The combination of a warmer climate with carbon dioxide fertilization may cause more frequent and more severe fires due to increases in the length of the fire season, frequency of lightning fires, and frequency of drought (Ryan 2000).

The interactions among climate, vegetation, and fire regime will also shift with global climatic change. Fire will be a catalyst for change in vegetation, especially if fire regimes change more rapidly than vegetation can respond to climate change alone. Thus fire may be more important than the direct effects of climate change on species fitness and migration (Weber and Flannigan 1997; McKenzie et al. 2004). Accordingly, fire management plans must be flexible to respond to rapid ecosystem alteration and should aim to enhance the adaptability of native species and ecosystem processes, and reduce environmental pressures that increase vulnerability to climate change.

Adaptive management

Fire, and its management, is extraordinarily complex. Since it is unlikely that a prescribed burning program will achieve desired outcomes based on natural fire regimes from the outset, the ability to monitor and test the plan and learn from experience within an adaptive management strategy is essential. Prescription conditions and firing techniques may need to be modified to achieve objectives such as a given level of fuel reduction or to meet constraints such as holding overstorey mortality to certain limits. Fire may not spread adequately under an initial prescription, thus requiring lower fuel moisture contents or higher wind speeds to be successful (Brown 2000).

Management alternatives

There are many protected areas on the landscape where prescribed burning and prescribed fire may not be permitted, or may not be permitted enough to restore even a semblance of natural conditions (Zasada et al. 2004). Reasons for this include being too small to contain a fire, location in areas where primary ignition points are outside protected area boundaries, location within matrices of high value lands where the risk of escape is too great, and location adjacent to areas particularly sensitive to air quality concerns. Additional constraints to prescribed burning and fire programs include inadequate funding and inadequate number of personnel (Parsons 2000). In those protected areas where it is unlikely that fire can be restored to presettlement fire return frequency, park planners and ecologists will have to decide whether to accept the consequences of continued fire suppression or to consider some alternative management option or surrogate for fire (e.g., mechanical manipulation of vegetation).

Public involvement

Given the challenge of managing or restoring fire in protected landscapes, protected area planners and fire managers need to engage the public and stakeholders in a collaborative process to develop appropriate and acceptable fire management plans for protected areas. Strong public and stakeholder involvement will be important when it comes to managing differences in opinion regarding the social and ecological risks and benefits of prescribed burning or prescribed fire and the social and ecological consequences of different management alternatives for fire (Parsons et al. 2003).

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APPENDIX 1

Fire management zones

APPENDIX 2

Summary of biotic and abiotic factors affecting fire behaviour *

Factor	Effect
Climate	Determines vegetation productivity and therefore rate of fuel accumulation. Seasonal drying and periodic droughts are important variables contributing to fire.
Weather	Local precipitation, temperature, relative humidity, and wind affect fuel moisture thus influencing likelihood of ignition, rate of combustion, and rate of spread. Dry weather conditions decrease fuel moisture and increase the probability of fire. Humid and/or wet weather conditions increase fuel moisture and decrease the probability of fire. Wind causes drying of fuel, increases oxygen available for combustion, and pre-heats and ignites fuel in advance of the front. Wind direction changes can increase fire front.
Frequency and seasonality of ignition sources	Fire will occur only if a source of ignition is present. Lightning strikes, the most significant natural source of fire, occur primarily between April and October but are more common midsummer than spring and fall. Lightning strikes during the growing season are often accompanied by rain which extinguishes most fires.
Firebreaks	Non-flammable vegetation types, lakes, rivers, streams, swamps, barren rock, and recently burned sites where fuels have been exhausted act as a barrier limiting fire spread.
Topography	Provides variation in local climate (i.e., fuel moisture, relative humidity, interaction with wind). Permits pre-heating and ignition for fires burning uphill. Can provide natural firebreaks. Creates back currents, eddies, turbulence, and erratic wind movements affecting fire spread. Partially determines distribution of plant communities of different flammabilities.
Soil texture	Rate of biomass drying is greater on coarse-textured soils, which hold less water, than fine-textured soils; fuels dry more quickly during drought periods contributing to a higher probability of fire. Intensity and severity of fire increases with increased soil dryness. Fuel load is typically lighter on coarse-textured soils.
Fuel load	Determines maximum energy available to fire. High fuel loads can increase probability of fire in drought conditions, and influence fire intensity, severity, and return intervals. Chemical composition of the foliage can increase flammability (i.e., resins and oils), or decrease it (i.e., mineral content). Seasonality can influence flammability of fuels (e.g., in spring and fall cured fuels are abundant while succulent green fuels are at a minimum). Size distribution of fuel can affect likelihood of initial ignition. Arrangement of fuel can affect aeration (tightly packed fuels), vertical spread (i.e., into canopy), and horizontal spread (patchy ground fuel). Breaks in fuel continuity can prevent or slow the spread of fire. Less-flammable plant communities interspersed with more-flammable ones can act as firebreaks in the spread of fire across the landscape.
Fuel accumulation	Rate of accumulation influences the frequency and intensity of fires because it determines the amount of fuel available for burning. The greater the accumulation of fuel since the last burn, the greater the fire intensity.

*From Heinselman 1973, Grimm 1984, Sousa 1984, Whelan 1995, Pyne et al. 1996, and Dwire et al. 2003

APPENDIX 3

Plant species list

List of plant species referred to in this report. List alphabetized by common name.

Common Name	Scientific Name
American dragonhead	*Dracocephalum parviflorum*
Balsam fir	*Abies balsamea*
Balsam poplar	*Populus balsamifera*
Basswood	*Tilia americana*
Beaked hazel	*Corylus cornuta*
Bearberry	*Arctostaphylus uva-ursi*
Beech	*Fagus grandifolia*
Bellwort	*Uvilaria grandiflora*
Bicknell's cranesbill	*Geranium bicknelli*
Big bluestem	*Andropogon gerardii*
Big shellbark hickory	*Carya laciniosa*
Black ash	*Fraxinus nigra*
Black cherry	*Prunus serotina*
Black oak	*Quercus velutina*
Black spruce	*Picea mariana*
Black walnut	*Juglans nigra*
Blueberry	*Vaccinium* spp.
Bracken fern	*Pteridium aquilinum*
Bristle-leaved sedge	*Carex eburnea*
Buffalo berry	*Shepherdia canadensis*
Bunchberry	*Cornus canadensis*
Bur oak	*Quercus macrocarpa*
Bush honeysuckle	*Diervilla lonicera*
Canada wild rye	*Elymus canadensis*
Cherry	*Prunus* spp.
Chinquapin oak	*Quercus muehlenbergii*
Choke cherry	*Prunus virginiana*
Common hair grass	*Deschampsia flexuousa*
Common juniper	*Juniperus communis*
Cooper's milkvetch	*Astragalus neglectus*
Cow-wheat	*Melampyrum lineare*
Creeping juniper	*Juniperus horizontalis*
Creeping snowberry	*Gaultheria hispidula*
Downy arrow-wood	*Viburnum rafinesquianum*
Dwarf lake iris	*Iris lacustris*
Dwarf raspberry	*Rubus pubescens*
Early buttercup	*Ranunculus fascicularis*
Early saxifrage	*Saxifraga virginiensis*
Fly honeysuckle (Canada)	*Lonicera canadensis*
Gaywings	*Polygala paucifolia*
Golden corydalis	*Corydalis aurea*
Gooseberry	*Ribes* spp.
Green ash	*Fraxinus pennsylvanica*
Hackberry	*Celtis occidentalis*

Hairy goldenrod	*Solidago hispida*
Harebell	*Campanula rotundifolia*
Hemlock	*Tsuga canadensis*
Hobblebush (Common)	*Viburnum alnifolium*
Indian grass	*Sorghastrum nutans*
Ironwood	*Ostrya virginiana*
Jack pine	*Pinus banksiana*
Jack-in-the-pulpit	*Arisaema triphyllum*
Kentucky bluegrass	*Poa pratensis*
Labrador tea	*Ledum groenlandicum*
Large-leaved aster	*Aster macrophyllus*
Largetooth aspen	*Populus grandidentata*
Leatherleaf	*Chamaedaphne calyculata*
Leatherwood	*Dirca palustris*
Little bluestem	*Schizachyrium scoparium*
Low bindweed	*Calystegia spithamaea*
Low sweet blueberry	*Vaccinium angustifolium*
Marsh muhly	*Muhlenbergia glomerata*
Mountain maple	*Acer spicatum*
Needlegrass	*Stipa* spp.
Nodding onion	*Allium cernuum*
Northern bog violet	*Viola nephrophylla*
Northern dropseed	*Sporobolus heterolepis*
Northern wild raisin	*Viburnum cassinoides*
Pale corydalis	*Corydalis sempervirens*
Partridgeberry	*Mitchella repens*
Philadelphia panic grass	*Panicum philadelphicum*
Pignut hickory	*Carya glabra*
Pin cherry	*Prunus pensylvanica*
Pin oak	*Quercus palustris*
Pitch pine	*Pinus rigida*
Poverty grass	*Danthonia spicata*
Prairie cinquefoil	*Potentilla arguta*
Prickly ash	*Zanthoxylum americanum*
Prickly wild rose	*Rosa acicularis*
Prince's pine	*Chimaphila umbellata* ssp. *cisatlantica*
Raspberry	*Rubus* spp.
Red cedar	*Juniperus virginiana*
Red maple	*Acer rubrum*
Red oak	*Quercus rubra*
Red osier dogwood	*Cornus stolonifera*
Red pine	*Pinus resinosa*
Richardson sedge	*Carex richardsonii*
Rough dropseed	*Sporobolus asper*
Round-leaved dogwood	*Cornus rugosa*
Sand dropseed	*Sporobolus cryptandrus*
Sassafras	*Sassafras albidum*
Serviceberry	*Amelanchier* spp.
Shagbark hickory	*Carya ovata*
Sheep laurel	*Kalmia angustifolia*
Showy mountain ash	*Sorbus decora*
Shrubby cinquefoil	*Potentilla fruticosa*

Side-oats grama	*Bouteloua curtipendula*
Silver maple	*Acer saccharinum*
Small cranberry	*Vaccinium oxycoccos*
Small skullcap	*Scutellaria parvula*
Smooth bromegrass	*Bromus inermis*
Speckled alder	*Alnus incana*
Striped maple	*Acer pensylvanicum*
Sugar maple	*Acer saccharum*
Swamp red currant	*Ribes triste*
Sweet coltsfoot	*Petasites frigidus*
Switchgrass	*Panicum virgatum*
Tamarack	*Larix laricina*
Thin-leaved snowberry	*Symphoricarpus albus*
Trailing arbutus	*Epigaea repens*
Trembling aspen	*Populus tremuloides*
Tufted hairgrass	*Deschampsia cespitosa*
Twinflower	*Linnaea borealis*
White ash	*Fraxinus americana*
White birch	*Betula papyrifera*
White cedar (Eastern)	*Thuja occidentalis*
White elm	*Ulmus americana*
White oak	*Quercus alba*
White pine (Eastern)	*Pinus strobus*
White spruce	*Picea glauca*
Wild sarsaparilla	*Aralia nudicaulis*
Willow spp.	*Salix* spp.
Wintergreen	*Gaultheria procumbens*
Wiry witch grass	*Panicum flexile*
Yellow birch	*Betula allegheniensis*
Zig-zag goldenrod	*Solidago flexicaulis*
	Sphagnum spp.
	Trillium spp.
	Hepatica spp.

APPENDIX 4

Fire return interval for natural (historic) fire regimes in Ontario and the Great Lakes region

Regime	Community Type	Fire Return Interval (years)	Location	Reference	Notes
Maintenance	Prairie	1 (annual)	Green county, southern Wisconsin	Leitner et al. 1991	Based on literature review
	Tallgrass prairie	1-10	Great Plains grasslands	Abrams 1992	Based on literature review
	Bluestem prairie	1-10 (several times per decade)	Great Plains grasslands	Snyder 1994	Based on literature review
	Oak savanna	17	Pinery Provincial Park, Ontario	Bravo 2004	Based on dated fire scars; 7 fires from 1889-1994
	Alvar	200-500?	Great Lakes region	Jones and Reschke 2005	Based on archives, burn evidence, and aerial photos
	Red pine/Jack pine/Oak barrens	24 (range 8-41)	Douglas County, northwestern Wisconsin	Vogl 1970	Anecdotal; based on 4 major fires since 1871
	Mixed-grass prairie	25	Great Plains grasslands	Madden et al. 1999	Based on literature review
	Prairie grassland	5-10	Great Plains grasslands	Wright and Bailey 1982	Estimated
	Oak/Hickory savannas and woodlands	5-15	east central United States	Nowacki et al. 2004	Based on literature review
	Savanna	6 (range 2-33)	Pleasant Prairie Township, Wisconsin	Wolf 2004	Based on dated fire scars; majority of fires of human origin
	Oak/Hickory forest	7-14	mid-Atlantic and Ozark regions	Wade et al. 2004	Based on literature review
Stand Replacing	Jack pine	20 (range 5-30)	Sachigo Hills, northwestern Ontario	Lynham and Stocks 1991	Based on dated fire scars; 10 major fires in previous 136 years (1848, 1860, 1870, 1882,1893,1923,1950, 1960, 1967)
	Jack pine/Boreal conifers and hardwoods	28	Boundary Waters Canoe Area, Minnesota	Heinselman 1973	Based on dated fire scars, stand origin dates, and archives
	Black spruce; Black spruce/Jack pine	30	northern clay belt, Ontario	MacLean and Bedell 1955	Based on age class distribution
	Jack pine/Black spruce	50	Boundary Waters Canoe Area, Minnesota	Heinselman 1981	Based on dated fire scars; revised from Heinselman 1973
	Black spruce	64	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure
	Jack pine	71	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure
Variable	White pine/Red pine	10-15	Okerson Heights, Itasca State Park, Upper Michigan	Clark 1990	Based on charcoal analysis (1640-1920)
	White birch	104	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure

Variable	Boreal mixedwood	117-170	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 37 fires from 1593-1987
	White pine/Red pine	12	Peterborough County, Ontario	Howe 1915	Based on dated fire scars and living trees; documented fires in 1880, 1890, 1895, 1897, 1899, 1905, 1907, and 1910
	Jack pine/Red pine/White pine	13	Parke Township, Sault Ste. Marie, Ontario	Dominy 1981	Based on dated fire scars and age-class data; 19 fires from 1700 to 1950
	Mid-tolerant hardwood/mixedwood	13 (range 5-76)	Bracebridge, Ontario	Guyette et al. 1995	Based on dated fire scarred stumps; 15 fires in 188 years (1664-1852)
	White pine/Red pine	14	Barron Township, Algonquin Park, Ontario	Cwynar 1977	Based on dated fire scars; 16 fires in 225 years (1696-1920)
	White pine/Red pine	14	Jocko River, Ontario	Dey and Guyette 1996a	Based on dated fire scarred stumps; 14 fires in 216 years (1721-1937)
	Red pine/White pine	150-300 (high intensity)	Great Lakes-St. Lawrence forest region from Maine to Minnesota	Heinselman 1981	Estimated
	Oak/Hickory	15-30	east central United States	Nowacki et al. 2004	Based on literature review
	Jack pine barrens	15-35	central Wisconsin and lower Michigan	Heinselman 1981	Estimated
	Pitch pine oak-forest	15-40	New Jersey	Little and Moore 1949	Based on literature review
	Spruce woodland	159	islands, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 56 fires from 1593-1987
	Oak savanna/woodlands	16	Green County, southern Wisconsin	Leitner et al. 1991	Anecdotal
	Pine woodland	162	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 37 fires from 1593-1987
	Spruce woodland	168	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 37 fires from 1593-1987
	Black spruce/White cedar/Tamarack bog	171	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 37 fires from 1593-1987
	Red pine	171	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure
	Black ash/American elm lowland	183	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 37 fires from 1593-1987
	White pine	185	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure
	Pitch pine-oak forest	20	New Jersey	Forman and Boerner 1981	Based on state fire records and literature review
	Red pine/White pine	22	Itasca State Park, Minnesota	Frissell 1973	Based on archives and dated fire scars; 32 fires from 1650-1922
	White pine/Red pine; Jack pine	22(± 12)	Pictured Rocks National Park, Munising, Upper Michigan	Loope 1991	Based on living trees and dated fire scarred stumps; 116 samples of fire interval
	Mid-tolerant hardwood/mixedwood	23 (range 10-70)	Seguin Falls, Parry Sound District, Ontario	Dey and Guyette 1996c	Based on dated fire scarred stumps; 9 fires in 205 years (1656-1861)

Variable	White pine/Red pine	26 (± 24)	Okerson Heights, Itasca State Park, Upper Michigan	Clark 1990	Based on dated fire scars; 82 fires in 220 years (1700-1920)
	Mid-tolerant hardwood/mixedwood	26 (low intensity); 47 (moderate intensity); 200 (high intensity)	Basin Lake, Algonquin Park, Ontario	Guyette and Dey 1995a	Based on dated fire scars; 10 fires in 191 years (1665-1856)
	Jack pine/Red pine	27	Mack Lake, northern lower Michigan	Simard and Blank 1982	Based on dated fire scars; 6 fires from 1830-1849
	White pine/Red pine	27 (low-moderate intensity); 46 (high intensity)	Lake Opeongo, Algonquin Park, Ontario	Guyette and Dey 1995b	Based on dated fire scarred stumps; 358 years (1636-1994), but no fires after 1940
	Balsam fir/Black spruce/White spruce/White birch	27 (range 4-47)	Lake Abitibi, northwestern Québec	Dansereau and Bergeron 1993	Based on forest age and dated fire scars; 7 fire years from 1760-1923
	Mid-tolerant hardwood/mixedwood	29 (range 10-60)	Papineau Lake, Bancroft District, Ontario	Dey and Guyette 1996b	Based on dated fire scarred stumps; 7 fires in 171 years (1643-1814)
	White pine/Red pine	29 (range 14-46)	Pointe aux Pins, Parke Township, Ontario	Alexander et al. 1979	Based on dated fire scars; 5 fires in 150 years (1727-1877)
	Oak/Hickory	3	Missouri Ozark Mountains	Cutter and Guyette 1994	Based on dated fire scars; time period 1740-1850
	Red pine/Jack pine	30 (low-moderate intensity); 68 (high intensity)	Lake Duparquet, Clay Belt region, Québec	Bergeron and Brisson 1990	Based on dated fire scars; 11 documented fires on two islands
	White pine/Red pine	34 (range 3-102)	Bolton, Vermont	Engstrom and Mann 1991	Based on dated fire scars; history from 1815-1987, but no fires after 1922
	Jack pine/Red pine/White pine	35	Itasca State Park, Minnesota	Spurr 1954	Based on 6 cohort-producing fires from 1714-1886
	White pine/Red pine	36 (low-moderate intensity); 160 (high intensity)	Boundary Waters Canoe Area, Minnesota	Heinselman 1981	Based on dated fire scars; revised from Heinselman 1973
	White pine/Red pine; Jack pine	37	Chalk River, Petawawa Forest Experiment Station, Ontario	Burgess and Methven 1977	Based on dated fire scars in living and remnant pines combined with historical records; 8 fires in 300 years (1678-1978)
	Boreal mixedwood	55-139	islands, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 56 fires from 1593-1987
	Mid-tolerant hardwood/mixedwood	6 (range 2->18)	Papineau Lake, Bancroft District, Ontario	Guyette and Dey 1995c	Based on dated fire scarred stumps; 13 fires in 119 years (1875-1994), but no fires after 1954
	White birch/Aspen	65	Hug Lake, Boundary Waters Canoe Area, Minnesota	Swain 1980	Based on pollen and charcoal analyses; 6 fires

Variable	Jack pine/spruce/White birch/aspen	65 (range 20-100)	Lake of the Clouds, northern Minnesota	Swain 1973	Based on charcoal and pollen analysis; time period of about 1,000 years
	Poplar	66	Temagami District, Ontario	Day and Carter 1991	Based on present age-class structure
	Poplar	70-80	Quetico Provincial Park, Ontario	Woods and Day 1977	Based on present age-class structure and mapping of old, unrecorded fires
	White pine/Red pine/Conifer and hardwood mix	80	Greenleaf Lake, Algonquin Park, Ontario	Cwynar 1978	Based on charcoal analysis; 6 fires in 500 years (770-1270)
	Pine woodland	97	islands, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dated fire scars; 56 fires from 1593-1987

APPENDIX 5

Fire cycle for natural (historic) fire regimes in Ontario and the Great Lakes region

Regime	Community Type	Fire cycle (years)	Location	Reference	Notes
Stand Replacing	Black spruce	893	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Black spruce	101 (79-129)	clay belt region, Québec	Bergeron et al. 2004	Based on aerial photographs, archives, and dendroecological data (to establish stand initiation)
	Black spruce/Jack pine	50	Boundary Waters Canoe Area, Minnesota	Heinselman 1981	Estimated; revised from Heinselman 1973
	Black spruce/Jack pine	60	Ontario	Chandler et al. 1983	Source unknown (from table 6.1)
	Black spruce/Jack pine	100	Québec	Chandler et al. 1983	Source unknown (from table 6.1)
	Black spruce/Jack pine	100	northern boreal, Québec	Payette et al. 1989	Based on dated fire scars and light-ring chronology
	Black spruce/Jack pine	115	James Bay region, northwestern Québec	Parisien and Sirois 2003	Based on spatial analysis of fire polygons from 1930-1998
	Black spruce/Jack pine	130	Laurentian Highlands, Québec	Cogbill 1985	Based on analyses of species composition and tree increment cores; widespread fires in at least three burning periods (1661-1663,1779-1791,1869-1871)
	Jack pine	134	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Jack pine	83-167	Crawford and Roscommon Counties, Lower Peninsula Michigan	Whitney 1986	Based on GLO surveyor notes; estimated cycle based on 15 and 30 year recording interval
Variable	Aspen/Birch/Fir	80	Boundary Waters Canoe Area, Minnesota	Heinselman 1981	Estimated; revised from Heinselman 1973
	Aspen-Birch	209	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Black spruce peatland	150	Lake Agassiz Peatlands, Minnesota	Heinselman 1981	Estimated
	Boreal conifers and mixedwoods	132	Lake Abitibi Model Forest, clay belt region, Ontario	Bergeron et al. 2001	Based on archives and dendroecological data
	Boreal conifers and mixedwoods	69 (47-102)	central Québec, clay belt region, Québec	Bergeron et al. 2001	Based on archives and dendroecological data
	Boreal conifers and mixedwoods	83 (65-105)	Abitibi west, clay belt region, Québec	Bergeron et al. 2001	Based on archives and dendroecological data

Variable	Fir-spruce mixedwood	83 (65-105)	clay belt region, Québec	Bergeron et al. 2004	Based on aerial photographs, archives, and dendroecological data (to establish stand initiation)
	Hardwood/Conifer mix	1067	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Hemlock/White pine/tolerant hardwoods	1389-2778	Crawford and Roscommon Counties, Michigan	Whitney 1986	Based on GLO surveyor notes; estimated cycle based on 15 and 30 year recording interval
	Intolerant hardwood/mixedwood	70	Barron Township, Algonquin Park, Ontario	Cwynar 1977	Five major fires each burned about half the township, these fires occurred about every 45 years
	Jack pine/Red pine/White pine	36	Parke Township, Sault Ste. Marie, Ontario	Dominy 1981	Based on dated fire scars and age-class data; 19 fires from 1700 to 1950
	Mixed conifer	578	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Mixed pine	163	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Mixed pine	129-258	Crawford and Roscommon Counties, Michigan	Whitney 1986	Based on GLO surveyor notes; estimated cycle based on 15-30 year recording interval
	Northern hardwoods	2624	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Pine and spruce woodland/boreal mixedwoods	63	lakeshore, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dendroecological data; time period from 1760-1870
	Pine and spruce woodland/boreal mixedwoods	74	islands, Lake Duparquet, Québec	Bergeron 1991	Based on archives and dendroecological data; time period from 1629-1870
	Pine-oak	172-344	Crawford and Roscommon Counties, Michigan	Whitney 1986	Based on GLO surveyor notes; estimated cycle based on 15 and 30 year recording interval
	Red pine/White pine	320	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Swamp conifers	2959-5917	Crawford and Roscommon Counties, Michigan	Whitney 1986	Based on GLO surveyor notes (1836-1839; 1849-1859)
	Tamarack	194	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	Tolerant hardwood/mixedwood	300	Huron Mountains, Upper Michigan	Frelich and Lorimer 1991	Based on canopy accession dates
	Tolerant hardwood/mixedwood	484	Porcupine Mountains Wilderness State Park, Upper Michigan	Frelich and Lorimer 1991	Based on canopy accession dates
	Tolerant hardwood/mixedwood	806	northern Maine	Lorimer 1977	Based on GLO surveyor notes and age-class structure (1793-1827)
	Tolerant hardwood/mixedwood	939	Sylvania Wilderness Area, Upper Michigan	Frelich and Lorimer 1991	Based on canopy accession dates

Variable	Tolerant hardwood/mixedwood	1000 ±	White Mountains, New Hampshire	Bormann and Likens 1979	Estimate based on the convergence of several lines of evidence
	Wetland	406	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)
	White cedar	1741	Luce District, Upper Peninsula, Michigan	Zhang et al. 1999	Based on GLO surveyor notes (1840-1856)