The Effect of Season of Fire on Post-fire Legacies in Northwestern Ontario Red Pine (*Pinus resinosa*) Mixedwoods

by

Brett D. Woodman

A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Planning

Waterloo, Ontario, Canada, 2005

ABSTRACT

Prescribed burns are employed in the southern boreal forest of northwest Ontario, Canada, as a method of re-instating fire in this fire-dependent landscape. They are also used to manage fuel loads associated with tree mortality from defoliating insects and from blow-downs, as well as in-site preparation following harvest. The natural fire season in boreal Canada typically runs from April through September and is most often characterized by stand replacing fires. However, prescribed burns in northwestern Ontario are mostly scheduled for October when fire crews and equipment are available and fire hazard is reduced. In this study, three recent fires: a spring prescribed natural fire, a summer wildfire, and a fall prescribed burn were examined to assess the effect of season on post-fire legacies in red-pine mixedwood stands in Quetico Provincial Park, northwestern Ontario. Legacies were assessed by tree, shrub and herb species composition, and by measurements of structure such as litter depth, basal areas of live trees and coarse woody debris. Tree species diversity was nearly identical. Post-fire stand structure varied widely between the different sites. The spring treatment experienced the least mortality of trees (10% of basal area dead); the summer treatment had the highest mortality (100%); and the fall prescribed burn was intermediate with 49% dead. The effect of the fall burn on the forest was probably more intense than that of a comparable natural fall fire because of the way in which it was managed, thus partly compensating for the late season.

This research suggests that all fires are not equal. Different post-fire structure will have lasting ecological implications such as varying edge to interior ratios, and forest habitats. From a policy perspective this is important because maintaining ecological processes including fire is mandated for some provincial parks. In addition, the new Fire Policy for Ontario has established targets to limit wildfires, and permit ecologically renewing fires, without recognition of the variability of the effects of fire or fire legacies.

ACKNOWLEDGEMENTS

I would like to first thank Dr. Roger Suffling, my advisor. His endless support and encouragement has been very much appreciated. In the years I have worked and studied under his supervision, he has shown himself to be insightful, thoughtful and considerate. Also, I want thank my committee member, Dr. Stephen Murphy for sharing his wisdom and statistical savvy. To Larry Lamb, I want to say a special thank-you for your generosity with the Ecology Lab and supplies, but mostly for your appreciation of nature; it has been a source of inspiration to me for many years now. To Edie Cardwell I owe many thanks for making ease of all things administrative.

To everyone I met in Quetico and Atikokan I want to say thank-you for a summer I will never forget. Special thanks go out to Robin Reilly, Park Superintendent, Quetico Provincial Park, Andrea Allison, Park Librarian, and John Munroe, District Planner, MNR Atikokan. I also appreciate the support I received from the staff of the MNR Fire Management Headquarters in Fort Frances, especially Matt Meyers, Acting Fire Services Co-ordinator, and Harold Boven.

For financial support I am grateful to the Quetico Foundation.

To Sean Barfoot, my field research assistant and personal fishing guide, thank-you for your continuous hard work and friendship.

I want to say a special thank-you to my whole family. To my Mom and Dad, your unwavering support and encouragement is remarkable. Thank-you.

To Amaryah, my fiancé, I will never be able to say thank-you enough. After meeting in a voyageur canoe in Quetico, you have changed my life forever. I can’t wait to marry you.

TABLE OF CONTENTS

ABSTRACT .... **iii**
LIST OF TABLES .... **vi**
LIST OF FIGURES .... **vii**
1.0 Introduction **1**
2.0 Literature Review **10**
  2.2 Fire Models **15**
  2.3 Weather **18**
  2.4 Fire Intensity **20**
  2.5 Plant Phenologies **22**
  2.6 Nutrient and Carbon Cycles **23**
  2.7 Other Disturbance Agents **24**
3.0 Methods and Study Sites **26**
  3.1 Site Selection Process **27**
  3.2 Study Sites **31**
    3.2.1 Stanton Bay (Fire 137) 31
    3.2.2 Pulling Lake (PNF-1) 32
    3.2.3 Emerald Lake Prescribed Burn (FOR-01-00) 33
  3.3 Field Methods **35**
    3.3.1 Initial fire inspections 35
    3.3.2 Establishing a Plot 37
  3.4 Laboratory Methods **39**
    3.4.1 Soil Analysis 39
    3.4.2 Tree Core Analysis 40
    3.4.3 Statistical Methods 40
4.0 Results **41**
  4.1 Soils, Tree Cores, and Basal Areas **42**
    4.1.1 Soils 43
    4.1.2 Tree Cores 45
    4.1.3 Structure 47
  4.2 Groundcover **48**
  4.3 Shrub / Seedling / Sapling **52**
5.0 Discussion **57**
  5.1 Legacies **61**
  5.2 Structure **62**
  5.3 Species Composition **64**
  5.4 Fire Management Policy Framework for Quetico Provincial Park **66**
  5.5 Recommendations **70**
APPENDIX A **72**
APPENDIX B **78**
APPENDIX C **85**
REFERENCES **90**

LIST OF TABLES

Table 1. Ontario forest fire statistics by month between 1984 and 1989............14
Table 2. Quetico Provincial Park fire summary 1930 – 1989 27
Table 3. Modified Braun- Blanquet abundance scale scoring system................38
Table 4. Tree cores extracted from red pines at each fire revealed some differences. 46
Table 5. Pine regeneration recorded in the groundcover quadrats 49
Table 6. Results of ANOVA analysis on the average litter depths recorded in groundcover quadrats at each fire with raw and modified data. 50
Table 7. Results of ANOVA analysis on all seedlings, conifer seedlings, deciduous seedlings, shrub species, herbaceous species, and moss species recorded in the groundcover quadrats at each fire site.......................................51
Table 8. Pine regeneration recorded in the shrub / seedling quadrats...............53
Table 9. Total conifer and deciduous seedling regeneration and shrub species diversity recorded in the shrub / seedling quadrats..54
Table 10. Comparison of site similarities based on pre-fire tree ages................59
Table 11. Range of soil textures found at each site. 60
Table 12. Summary of results. 70

LIST OF FIGURES

Figure 1. Number of Forest Fires in Canada, 1995 – 2002 11
Figure 2. . Area of lands burned by forest fires in Canada per month in 2000 and 2001..13
Figure 3. Average number of forest fires per month in the Intensive Protection Zone in Ontario (1990 – 2001)...13
Figure 4. Description of V13 red pine mixedwood..30
Figure 5. General locations of the selected study sites within Quetico Provincial Park. 32
Figure 6. Plot configuration showing sub-plots 36
Figure 7. Summer Fire 1995. Stanton Bay Plot 4 41
Figure 8. Spring Fire 1999. Pulling Lake Plot 2...42
Figure 9. Fall Fire (prescribed burn) 2000. Emerald Lake Plot 4......................43
Figure 10. The average of five soil depth measurements taken at each plot show similarity between study sites. 44
Figure 11. Soil texture triangle 45
Figure 12. Tree cores from each plot 46
Figure 13. Relative proportions of dead and live basal areas (cm^2)..................48
Figure 14. Total number of red, white and jack pine saplings recorded in the groundcover quadrats in each plot...49
Figure 15. Total, conifer, and deciduous seedling regeneration in the groundcover quadrats at each fire. 51
Figure 16. The number of pine seedlings per species recorded in the shrub / seedling quadrats in each plot at the different treatments..................................53
Figure 17. The total number of seedlings recorded in the shrub / seedling quadrats per plot. 54
Figure 18. Total number of shrub species (diversity) recorded in each plot.......55

Figure 19. The total number of tree seedlings per species recorded in the shrub / seedling quadrats for each treatment..56
Figure 20. Percent ratios of dead versus live basal areas for each treatment…63

1.0 Introduction

Fires are one of the primary natural disturbance agents in the boreal forest (Flanningan 2000; Flemming et al. 2004). Quetico Provincial Park (QPP), located 160 km west of Thunder Bay, is situated along the southern edge of the boreal forest in northwestern Ontario (Walshe 1998; OMNR 1977). Within the park, fire has played a significant role in determining the spatial, structural and functional characteristics that make up the forest mosaic (Heinselman 1996, Woods and Day 1977). Fire has many specific effects, but at a landscape scale in northwestern Ontario, it serves a number of general ecological roles including nutrient cycling and maintaining a complex mosaic of forest patches (Heinselman 1996; Lynham and Curran 1998). The effectiveness of fire suppression since the end of the Second World War has increased the average interval between fires in QPP from 78 years to 870 years (Woods and Day 1977). As a result, there is a shift in the distribution of forest age classes within the park's landscape (OMNR 1997). This same pattern has been occurring elsewhere in North America and other parts of the world; in general, as forests age fuels accumulate and the likelihood of fire increases. In recent decades, there have been numerous initiatives to re-introduce fire in the landscape. These initiatives have focused on re-establishing fire as a natural ecological process and minimizing hazards to people and infrastructure. Since the ratification of the Quetico Provincial Park Fire Management Plan in 1997, park managers are better equipped to make consistent and informed planning decisions regarding fire.

Reconciling the hazardous nature of fire with its important ecological function is problematic for parks planners. As a Wilderness Park, Quetico is mandated to maintain natural ecological processes such as fire, while at the same time minimizing the fire hazard to other park, and adjacent land-uses (OMNR 1997). In QPP, this situation has led to a measured and cautionary approach to the re-introduction of fire in the landscape. QPP's fire plan has a prescribed fire zone in the interior (roughly 63% of the total park lands) with a buffer around the perimeter known as the measured fire zone.

Since the park is situated on the international border north of Minnesota, United States, and adjacent to Forest Management Agreement areas (FMAs) and the town of Atikokan, it is imperative that fire does not escape from within the park boundaries. The planning process plays an integral role in ensuring that fire does not jeopardize these values. According to the fire plan, certain natural fires can be prescribed if they fall within specific hazard parameters. As of 2002, only one natural fire had been prescribed: PNF-1. As a coincidence, this fire was selected as one of the treatments (spring / Pulling Lake) for this study.

QPP is authorized through the fire plan to conduct prescribed burns. To date, several prescribed burns have been successfully coordinated for specific purposes. Developing knowledge of the proposed burn site prior to ignition helps planners to remove some of the uncertainty. For example, measurements of fuel types and load along with topography and other site characteristics can be inputted into a fire model to develop a range of possible fire scenarios. Technical expertise in fire modeling and design can be applied in the planning of fire breaks and ignition patterns to help achieve the desired fire. As well it is an important component in the planning process helping fire crews to achieve a desired fire, which may be measured in terms of size and intensity.

Prescribed burns are more desirable than naturally occurring fires from a land-use planning perspective as they can be co-ordinated to better ensure human safety, have fire personnel and equipment on-hand, and select the ideal weather conditions. During the natural fire season in Canada, typically May through September, fire personnel and equipment are often unavailable for prescribed burns as they are fighting undesired fires elsewhere. At the same time, the weather is less suited to a controlled fire. For these two main reasons, many prescribed burns in forested areas in Ontario occur in October. This discrepancy between the dates of natural fires and prescribed burns in Ontario and Canada is central to this research.

In other ecosystems including savannas, prairies and grasslands, the time of year or date has been shown to have specific effects on post-fire vegetation composition and community structure. The sum of post-fire conditions can be conceptualized as the fire legacy. The goal of this study is to examine the effect of season of fire, in terms of time of year or date, on red pine (*Pinus resinosa*) mixedwood forests in QPP.

Prescribed burns that I have worked on in southwestern Ontario prairies and oak (*Quercus spp.*) savannas are typically conducted in late April and early May. The timing of these burns is set to eradicate non-native cold season grasses and forbes which emerge earlier than the desired warm season flora. The fires kill off the weedy vegetation and at the same time provide a nutrient input for the native plants, thus the timing explicitly effects the species composition. In northwestern Ontario, forest fires typically occur between April and September, although fires can and have occurred in all months. In this study the spring and summer fires are in essence pseudo-controls.

1.1 Research Objectives: ***The general objective of this research is to provide science-based research findings which spell out the effect of season (time of year, date) on post-fire legacies in red pine mixedwood forests of QPP***. Specific post-fire variables, including species composition and structure, are compared to assess different fire legacies. ***This research will examine the post-fire legacies of 3 fires, one of which was a prescribed burn conducted outside the natural fire season in QPP***. The effects of season on prescribed and natural fires have been documented in other ecosystems (Jacqmain et al. 1999; Williams et al. 1998; Drewa 2003; Sparks 2003, 1998; Brockway et al. 2002; Owens et al. 2002; Howe 1994). The persistent legacies of fire are expressed in the species composition of the succeeding communities (Howe 1994; Bond and van Wilgen 1996). Post-fire surviving and regenerating plant composition may relate to species specific strategies, or be the result of broader susceptibilities like conifers versus deciduous. Little work has been done to test the effect of seasonally different fires in the forest communities in northwestern Ontario. Elsewhere, the effects of fire have varied; in prairie ecosystems of the mid-west United States post-fire species composition is related to plant flowering times (Howe 1994). In mixed mesquite acacia savannas, prescribed burn experiments yielded no significant differences between growing and late season fires (Owens et al. 2002). In pine grasslands in south eastern United States, growing season versus dormant season fires had no effect on the distribution and abundance of more than 90% of the vascular plant species (Sparks et al. 1998).

QPP is an ideal study area from a land-use planning and management perspective because it typifies the challenges of managing natural areas. Designated as a Wilderness Park located on the Canada-United States border, the planning equation for park management is complicated by surrounding communities and land-uses. In Canada, the adjacent communities are the town of Atikokan, located roughly 2 km north, and Lac la Croix First Nations community and reserve, found along the west side of the park perimeter. Much of the remaining adjacent lands are part of Forest Management Agreements (FMAs) which dedicate the timber to local forestry companies. On these same lands are numerous private cabins and lodges. South of QPP in the United States is the Boundary Waters Canoe Area (BWCA), a similarly large wilderness area. According to a Memorandum of Understanding between Ontario and Minnesota, any fire within 3 km of the international border will be suppressed (OMNR 1997). As a result of these neighbouring communities, infra-structure, land-uses, and multiple jurisdictions it is unacceptable for forest fires to escape from within QPP's boundaries.

A major windstorm on July 4, 1999 "The Independence Day Blowdown" blew down trees and entire forest stands across more than 291,000 ha in northern Minnesota and adjacent parts of Ontario; 11,000 ha were affected in the southeast corner of QPP, just north of the border and the adjacent BWCA. The majority of the affected areas were within the BWCA and the Superior National Forest, U.S. This event created a nearly continuous belt of fire fuels from the U.S. into QPP, with only the narrow width of Knife Lake as a buffer along the international border.

Quetico was the first Provincial Park in Ontario to issue a Fire Management Plan (OMNR 1997), and since its ratification, it has conducted three prescribed burns. Each burn was carried out to reduce fuel loads associated with the July 1999 blowdown, and create a fuelbreak to prevent fire from south of the border escaping into the park. These burns are also achieving desirable ecological objectives associated with the maintenance of a fire regime within a fire-shaped and dependent ecosystem (OMNR unpublished fire reports). The first of these prescribed burns was conducted on October 12, 2000 to reduce fine fuels associated with the blowdown and create a fuelbreak along the Canada, U.S. border. This fire is known as the Emerald Lake Prescribed Burn and is used in this study as the fall treatment.

Ideally, to isolate the effects of season with respect to post-fire legacies, one would conduct a series of controlled experimental fires in identical forest stands. In this way, the effects of season are isolated and the confounding effects of other variables such as date, year, and pre-fire composition could be minimized. Due to time and funding constraints, few researchers have been able to achieve such experimental objectives. Scaling back from this ideal research design, to choosing recent fire sites within QPP, the general objective of this research is to explore the effect of season on post-fire legacies. QPP is well-suited for this research as it is a large Wilderness Park with recent fires in unlogged forests. The three fires examined in this study, reflect the limited number of comparable study sites, and the constraints of time and budget associated with 2 field researchers and a single field season. Using three pre-existing fire sites, the goal is to demonstrate that post fire legacies, measured by structure and species composition, may vary. More extensive research in this field will go a long way to help fire planning and protected areas management. Better understanding of how season affects fire legacies will facilitate fire planning for a wide range of objectives such as species at risk habitat, as well as maintaining a range of size and age class stands within forest mosaics.

Season or time of burning is the key area of focus within this research; to that end four specific objectives were established:

1. To characterize the fire season in Canada, and scaling down, the fire season in QPP
2. Measure the effects of season on post-fire legacies
3. Discuss the fire plan and other relevant documents that outline how fire is managed with QPP

4. Discuss the findings with respect to other season-based fire research, what are the next steps, what is warranted

The first objective is to broadly characterize the fire season in Canada and then more specifically in northwestern Ontario and in Quetico Provincial Park. The natural fire cycle in Canada ranges from 50 -200 years (Bonan and Shugart 1989) which results in a mix of stand ages across the landscape. In fire-adapted forests of QPP, which is situated in a transitional area between the Great Lakes and boreal regions, fire is the primary disturbance agent and is integral to the development and perpetuation of complex landscape mosaics (Heinselman 1996; Beverley 1998; and Suffling 1995). The majority of forest fires in Canada occur between the months of April and September (NFDP 2004). Similarly, the majority of lands affected by fire are burned during these same months.

The second objective is to measure the effect of season or timing of fire on post–fire legacies at recent forest fire sites in QPP. Surveys of species composition and structure were conducted at Pulling Lake, burned in June 1999, Stanton Bay (August 1995), and Emerald Lake (October 2000). These sites were chosen for being located within QPP, having red pine mixedwood forests prior to burning, and a final fire size of more than 10 hectares.

The third objective is to outline the framework in which fire is managed in QPP. Specifically, there is the Park Master Plan and the Fire Management Plan. These two documents define the context for specific fire management decisions. These documents recognize that the Quetico landscape is fire driven and that effective suppression since the 1940s has increased the proportion of older-aged stands and thereby changed fuel complexes and loads. In conjunction with other natural disturbance agents, such as outbreaks of spruce budworm, and large blowdown events, the landscape of QPP is increasingly fire prone. Additionally, the broader implications of the new fire policy for Ontario will be discussed.

The fourth objective is to identify the implications of this research for fire management in QPP, and to identify future research topics.

Study Area Description

Quetico Provincial Park in north western Ontario is located approximately 160 km west of Thunder Bay. It is a designated Wilderness Park spanning 4758 km^2 of forests, wetlands and lakes in the Quetico section of the Great Lakes St. Lawrence Forest Region (Rowe1959). The park region is recognized as a major ecotone between boreal, Great Lakes forests, and tall grass prairie ecosystems (Kronberg et al. 1998; Walshe 1994; OMNR 1977).

Quetico is situated in the southern portion of the Canadian Shield. The park straddles the Wawa Greenstone Belt and the Quetico Gneissic Belt, two sub-provinces in the Canadian Shield. The majority of the park is underlain by altered sedimentary rocks of the Quetico Gneissic Belt (OMNR 1977). Surficial deposits are predominantly fine glacial till, resulting from the Wisconsin glacial period (OMNR1977).

Quetico was established in 1913 and officially designated as a Wilderness Park in 1977 (OMNR 1977). Logging has not occurred in the park since 1971. The park consists of a complex mosaic of forest types with Great Lakes mixed forests integrating with boreal species. The forests of Quetico are typically of either fire or logging origin (Beverly and Martell 2003; Heinselman 1996; Woods and Day 1977); some stands were possibly established after wind or insect disturbances. Historically the natural fire cycle or mean interval between fires within the park was 78 years; the effect of suppression on the fire regime has been to extend this interval from 78 years to 870 years (Woods and Day 1977).

2.0 Literature Review

2.1 Introduction

The natural fire cycle in Canadian boreal forests ranges between 20 and 250 years (OMNR 2004; Bonan and Shugart 1989) and results in a mix of stand ages that are maintained across the landscape. Maintaining multiple seral stages allows for a greater diversity of species that thrive at different periods of forest succession (Heinselman 1999). This ecological role of forest fire is unfortunately not readily compatible with human safety or economic considerations.

Due to this incompatibility, much time and energies have focused on means to eliminate fire from the landscape. In northwestern Ontario, fire suppression has been largely effective since the 1940s (Woods and Day 1977). While technology has helped to advance our ability to suppress fire, scientific research has helped develop our understanding of it.

Fires are one of the primary disturbance agents in the boreal forest (Flanningan 2000; Flemming et al. 2002). Since 1970 Canada has experienced between 5,300 and 11,000 fires a year. In that same time the annual area burned has fluctuated between 600,000 and 6,000,000 hectares (National Forestry Database Program 2004).

Of these fires, there are significant seasonal differences in the total numbers and the total area burned. Bond and van Wilgen (1996) listed the three key components of a fire regime: fire intensity (including fire type), burn area, and season. In Canada, fires have been documented in every month but most occur between April and September. Figure 1 shows the number of fires per month in Canada for each year between 1995 and

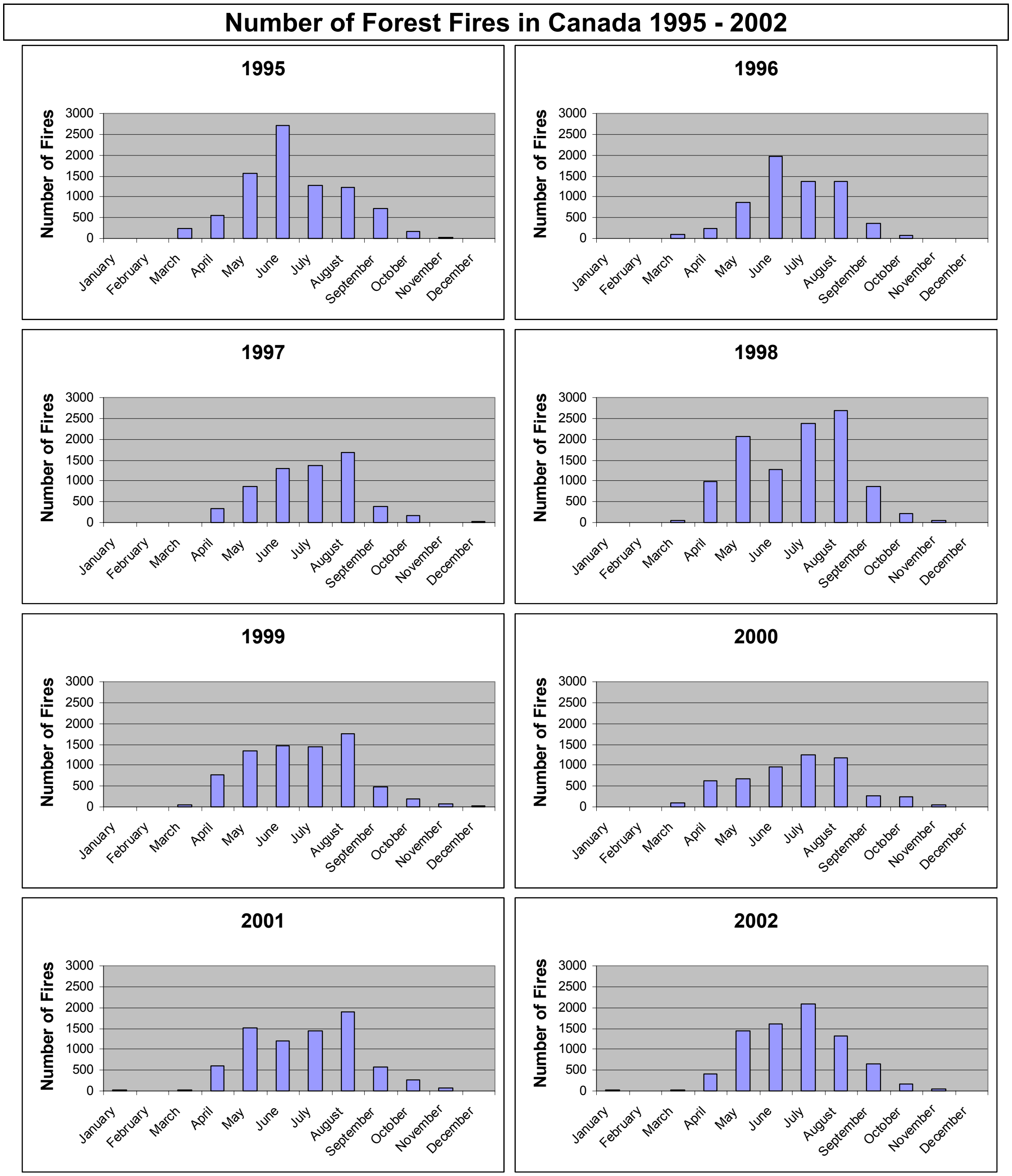


Figure 1. Number of Forest Fires in Canada, 1995 – 2002 (National Forestry Database Program 2004).

2002. Figure 2 shows the area burned in hectares per month during the 2000 and 2001 fire seasons. Figure 1 illustrates that although there is variability in the number of fires per month in a given year, there are definite trends that suggest what is typical.

Comparisons between Figures 1 and 2 shows that the number of fires per month strongly correlates with the area of lands burned.

1,905 fires, roughly 25% of all fires in Canada in 2001, burned during the month of August. In 2000, July saw the greatest number of fires in Canada with 1,249, more than 23% of all fires that year. Conversely during the winter months, fire activity is greatly reduced. In 2001, less than 2% of the total number of fires occurred during the months of January through March, and November and December of the same year. In 2000, just over 3% of the fires occurred during that same time frame. This same pattern of seasonal fire activity has been reported in Ontario (see Figure 3 and Table 1).

Protecting forest resources for economic benefit is an important rationale for forest fire suppression. In Ontario, much of the forested crown land south of the 50^{o} parallel is dedicated for harvest through Forest Management Agreements (FMAs). This base for current logging operations within the province is called the *Area of Undertaking* (AOU) (OMNR 2004). Forest harvesting provides significant contributions to local communities. Therefore, protecting forest resources is a necessary management objective. However, in a fire-adapted landscape such as northwestern Ontario, resource managers are obliged to accept that some fire is not only inevitable but also desirable in terms of maintaining ecosystem processes. Understanding the potential results of specific fires can help managers prioritize which fires need to be suppressed and which may be allowed to burn.

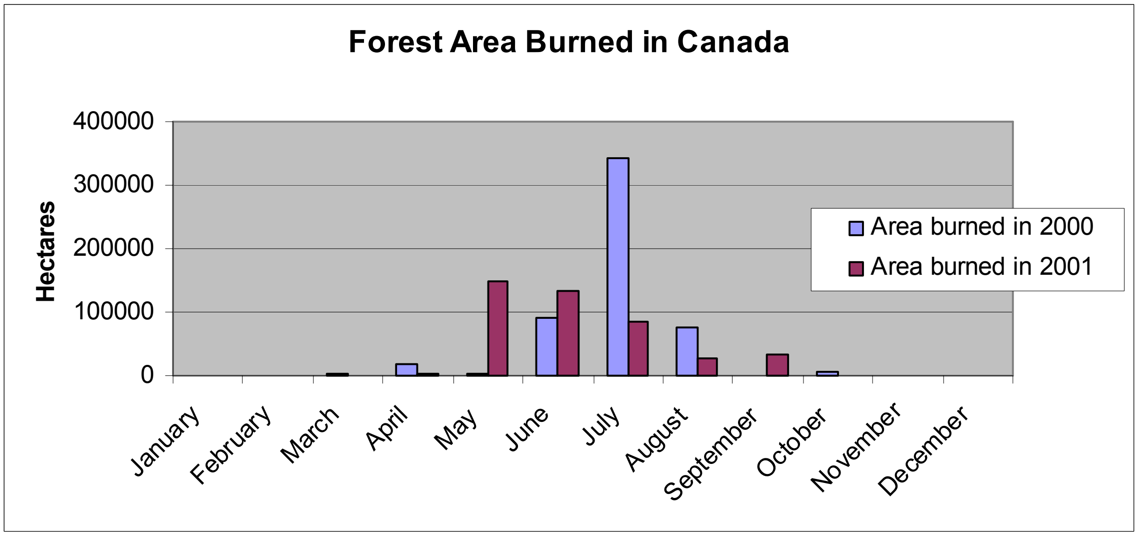


Figure 2. . Area of lands burned by forest fires in Canada per month in 2000 and 2001 (National Forestry Database Program 2004).

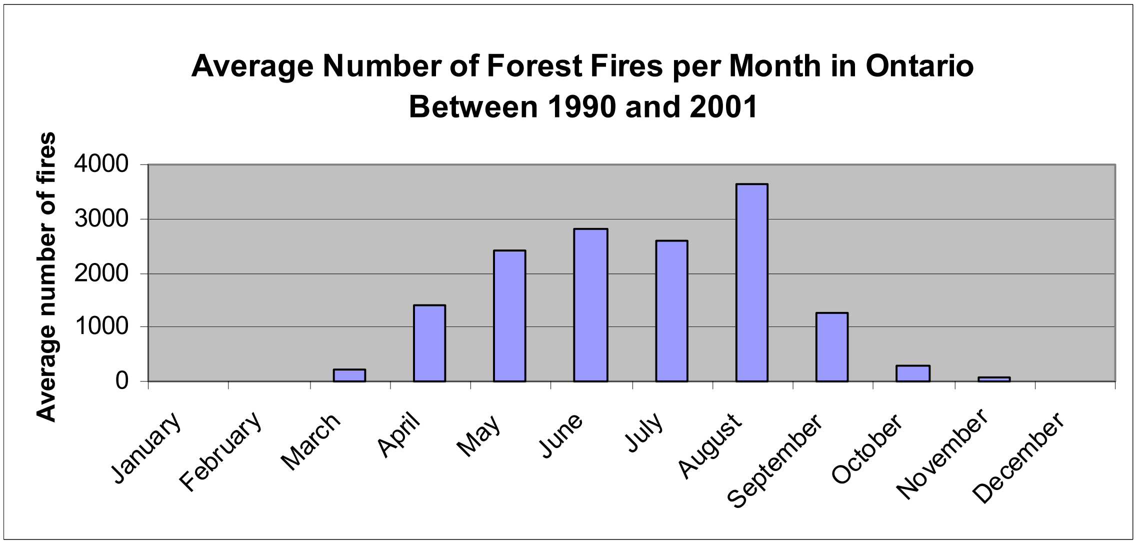


Figure 3. Average number of forest fires per month in the Intensive Protection Zone in Ontario (1990 – 2001). Based on National Forestry Database Program statistics for Ontario.

The original concept of the fire triangle stipulates that fuel, air and heat, determine the start and spread of a fire (Parks Canada 1978). Essentially, fire is dependent on a source of ignition (heat), weather (air), and fuels. Each of these variables has seasonal fluctuations; for example, lightning and human-caused ignitions predominantly occur between May and August (Wierzchowski et al. 2002; Flanningan and Wotton 1991). Similarly, spring and fall weather is generally cooler and has greater moisture availability than during summer. Fuel hazard, which is a product of weather and species composition, will fluctuate according to the weather. These main fire variables - ignition, weather and fuels - are key inputs in computer-based fire models.

Table 1. Ontario forest fire statistics by month between 1984 and 1989 (OMNR 1985, 1986, 1987, 1988, 1989, 1990, 1991).

Month	Number of Fires	Hectares Burned	Calculated Average Fire Size / Month
January	0	0	0
February	0	0	0
March	55	148.8	2.7
April	1467	35040.7	23.9
May	1817	348127.6	191.6
June	2305	240708.8	104.4
July	2816	412062.1	146.3
August	1568	96406.3	61.5
September	565	2723.3	4.8
October	325	1866.0	5.7
November	25	75.2	3.0
December	2	0.3	0.2

2.2 Fire Models

Fire models are used for most elements of forest fire prediction, including frequency, size, intensity, and rate of spread. The Canadian Forest Fire Danger Rating System (CFFDRS) is used to project forest fire danger and provide quantitative measurements of fire behaviour characteristics. The CFFFDRS is made up of several independent index systems: the Canadian Forest Fire Weather Index (FWI), the Canadian Forest Fire Behaviour Prediction System (FBP), and the Canadian Forest Fire Occurrence Prediction System (FOP).

FWI is a relative index of a fire's potential and is determined by three moisture codes: the Fine Fuel Moisture Code (FFMC), the Duff Moisture Code (DMC), and the Drought Code (DC). The FFMC is a measure of the moisture content in fine fuels (ie. needles and twigs) in weight per cubic metre. The DMC is similarly a measure in weight per cubic metre of the moisture content in organic debris in the upper seven centimeters of the forest floor. These measures are a direct function of rainfall, relative humidity, and temperature. The final component, the DC, is calculated using temperature and rainfall to characterize the flammability of coarse woody debris; the moisture content of larger fuels fluctuates more slowly than that of finer fuels. The Initial Spread Index (ISI) is an indicator of the potential for fire to spread. The Build-up Index (BUI) is a combination of the DMC and the DC. Together, these indices provide a qualitative description of potential fire risk. The results can be classed according to a scale from 0 to 30+, or very low to extreme.

The second index in the Canadian Forest Fire Danger Rating System is the FBP. The FBP is a quantitative measurement of forest fire behaviour across a range of fuel types in a variety of topographic conditions. Fourteen variables are entered under the headings of fuel, weather, topography, foliar moisture content, and type of prediction. Fuel and weather are considered the most important variables in this model (Doran 2004). Fuels are classified as one of sixteen different types (covering most of the major fuel types found in Canada). Weather data includes FFMC, ISI, BUI, wind speed and direction. Rate of spread, fuel consumption, head fire intensity, and fire description along with eleven secondary output variables provide detailed behaviour characteristics that can be used to calculate the spatial extent of a fire. From these indices, it is apparent that fuels and weather are important variables in determining fire legacies.

The third index in the Canadian Forest Fire Danger Rating System is the Fire Occurrence Prediction (FOP) System. The FOP is still in the early development stages, but is being designed to include models for both lightning and human-caused fires (Natural Resources Canada 2004).

Hely et al. (2001) ran seasonal simulations using the FBP to study the role of vegetation and weather on fire behaviour in mixedwood boreal forest in Quebec. They found the FBP to be quantitatively accurate. Their assessment was based on a comparison of the model's predictions versus observed results.

Fire models have also been used to test the effects of fire suppression and fire re-introduction. Using a GIS based spatial model, Baker (1994) analyzed vegetation changes resulting from fire suppression in the BWCA and recommended spatially-explicit prescribed burning programs to restore landscape mosaics.

The weather input data used in the different CFFDRS component systems show seasonal trends which suggest that season alone will affect fire danger ratings and behaviour characteristics. Fire research focusing on the effects of season of burning have explored many specific aspects such as spring fires (Quintio et al. 1991); cool season fires (Tacqmain et al. 1999); early versus late fires in the dry seaon (Williams *et al.* 1998); and dormant and growing season fires (Drewa 2003; Sparks et al. 2002; Brockway et al. 2002; Kirkman et al. 1998; Owens *et al.* 2002; Engle and Bidwell 2001; & Howe et al. 2002). In addition, some have looked at historical records of fires by date and compared that to the timing of prescribed burns in a specific region (McLoughlin 1998).

Currently, research in prairie and xeric landscapes pertaining to the effects of fire in different seasons is more abundant than for forested ecosystems in particular boreal and near boreal forests. Howe (1994) explored the effect season as a determinant of species composition in prairie ecosystems; Drewa (2003) measured shrub re-sprouting responses to fire season in Chihuahuan desert grasslands; Owens et al. (2002) conducted growing season and dormant season prescribed burns to determine any changes in species composition as a result of fire season. Little is known of the different post-fire legacies of spring, summer, or fall fires for mixedwood and boreal forests.

Prescribed burns are used to achieve ecological, silvicultural, and management objectives such as creating a fuel break (Franklin et al. 2003). In forests of northwestern Ontario, such fires are often conducted in October when fire hazards are reduced and fire crews and equipment are not busy with active wildfires. By burning late in the fire season, it is expected that the weather will create less hazardous fire conditions and that natural fuel breaks will be most effective. From a precautionary perspective this expectation is ideal, however little is known of how post-fire legacies may differ according to season in terms of stand composition and structure.

The effect of season or timing of burn on post-fire legacies is not clear. It is advantageous to include knowledge from a number of disciplines to get a better picture. Weather and atmospheric data are important as they can define the fire hazard and probability for natural ignition (lightning). They are also directly related to the total areas burned. Fire intensity, which is the product of fuels and weather, is also significant as it determines mortality rates and modes of regeneration such as sprouts versus seeds. Specific plant phenologies will determine when different species are most susceptible to fire (Bond and van Wilgen 1996). Carbon and nutrient cycles fluctuate before and after fire and can determine which species will survive and which will germinate in the post-fire environment (Heinselman 1996; Driscoll et al. 1999). Exploring the findings of different fire disciplines demonstrates that season is an important variable and can potentially be used to forecast different post-fire environments. The ability to estimate how season might affect intensity or rate of spread, or forecast different post-fire environments would be extremely useful. This knowledge would aid in planning silvicultural and other prescribed burns to achieve different post-fire environments.

2.3 Weather

Considerations of weather and climate are crucial to fire management (Baker 1984). Specific weather variables have been examined to determine the extent to which they control fire behaviour or total area burned (Baker 1984; Flanningan and Harrington 1987; Skinner et al. 1999). Baker (1984) found that precipitation, barometric pressure, temperature, and wind speed are all important fire weather variables on the days preceding and during fire events in Banff National Park, Alberta. At a seasonal scale, deviations from the average precipitation levels were linked to extreme fire behaviour. Less than 60% of winter or spring precipitation or less than 70% summer precipitation levels resulted in extreme fire behaviour during a given fire season (Baker 1984).

Skinner et al. (1999) compared anomalous mid-tropospheric circulation over forest regions of Canada to monthly and seasonal burned areas between 1953 and 1995. Monthly averages of the hemispheric 500 hPa height records revealed detectable increases in wildland fire activity since mid-1970s. In northwestern and west-central regions of Canada, and to a lesser extent in the east-central region, fire activity was associated with increases in the 500 hPa height anomalies over the past two decades (Skinner et al. 1999). This study suggests that seasonal trends in atmospheric activity are helpful to forecast the extent and severity of fire by season.

In exploring the extent to which area burned on a provincial scale and a monthly temporal scale, Flannigan and Harrington (1987) determined that the weighted sequence of dry days and the product of wind speed and weighted dry days to best explain the area burned. They found these two meteorological variables – wind speed and the number of sequential dry days - to be as accurate for forecasting area burned as the FWI.

The literature indicates that seasonal weather or atmospheric variables play a significant role in determining fire severity and total area burned in the forested regions of Canada. What is still not clear is whether fluctuations in these weather and atmospheric conditions will result in different post-fire environments.

In Ontario, roughly 35% of fires are lightning caused and burn up to 85% of total annual area burned (National Forestry Database Program 2004; Flanningan and Wotton 1991). Detection time, the time between ignition and when fire managers become aware of the fire/ignition, is a key factor in lightning fires burning more land than human caused ignitions is detection time. People at the scene of human-caused fires can readily notify managers, often before they spread out of control.

Lightning and lightning fires in northwestern Ontario have demonstrated a strong seasonal trend beginning in May, at a maximum in June with a decline during July and August, and abruptly falling off in September (Flanningan and Wotton 1991). In the central Cordillera of western Canada, lightning fire follows the same seasonal trends, with 93% of all strikes occurring in June, July or August (Wierzchowski et al. 2002).

Even human caused ignitions have been shown to have strong seasonal trends. The location and the number of people-caused fires vary throughout the season with respect to fuel type conditions, the timing of deciduous tree and groundcover green-up, and the seasonal variation in people’s use of forests (Todd and Kourtz 1991).

2.4 Fire Intensity

Fire intensity is used to characterize the effects of fire. By definition, fire intensity is the rate of heat energy released from a fire per unit time per unit length of fire front (Alexander 1982; Beverly and Martell 2003). This concept serves to quantitatively describe fire and is useful in evaluating the impact of fire on forest ecosystems (Alexander 1982). In the field, fire intensity can be estimated by the height of scorch on trees. As the intensity of a fire increases, there becomes a greater potential for consumption of crown fuels due to flare-ups, torching of individual trees, or scorching (Beverly and Martell 2003). Fires in Canadian boreal forests are often high-intensity crown fires (Bergeron and Dansereau 1993).

Variation in fire intensity will affect the mode of regeneration i.e. from sprouts, seedling banks, seed banks, or dispersed seeds, and may determine the success or dominance of a species (Kennard et al. 2002). Bond and Wilgen (1996) found that variation in fire intensity in conifer forests can alter recruitment conditions for canopy trees by altering soil surface conditions.

Fire intensity has been shown to vary significantly according to season in tropical savannas in northern Australia. This variation results from fluctuating moisture levels in the fuel bed and seasonal weather differences (Williams et al. 1998). Experimental burning of *Prosopis glandulosa* in Chihuahuan grasslands in southwestern United States, revealed that seasonal timing had no effect on intensity, but that the responses of resprouting woody vegetation vary according to fire season and intensity (Drewa 2003). In shortleaf pine (*Pinus echinata*) stands in southeastern United States fireline intensity, heat per unit area, reaction intensity, and rate of spread were greater in dormant season fires (March 2-4) than in growing season fires (September 10 – October 15) (Sparks et al. 2002). In Canadian forests, similar seasonal fluctuations occur (Wotton & Flannigan 1993). Spring and fall are cooler and have greater moisture availability suggesting that fires may not burn with the same intensity as they would during the drier and hotter summer months (Glitzenstein et al. 1995), and will possibly leave different legacies in response to the phenologies of different forest species (Bond and van Wilgen 1996; Drewa 2002).

The Ambient Temperature hypothesis is based on the relationship between height of crown scorch and wind speed, fireline intensity, and ambient air temperature. Assuming constant wind speed and fireline intensity, height of scorch increases in a curvilinear fashion with increasing air temperature (Glitzenstein et al. 1995). Plant tissue can survive only within a specific range of temperatures, and so seasonal variation in air temperatures dictates that hot summer temperatures are closer to the upper tolerances of most plants than cooler spring or fall temperatures. It can then be expected that during the summer months, less of a rise in temperature (from fire) will be necessary to raise the plant tissue temperature to a lethal level.

2.5 Plant Phenologies

All trees experience heightened susceptibilities to fire at different times of the year. For example, deciduous hardwoods are most susceptible to spring fires occurring after leaf expansion, whereas pines and other evergreens are most vulnerable to fires in late summer and early fall (Glitzenstein et al. 1995). At a stand scale, these variable susceptibilities suggest that forests with higher conifer content will be more vulnerable to fire mortality later in the year and deciduous forests more vulnerable in the spring. Part of this phenomenon is attributed to seasonal differences in foliar moisture content (Van Wagner, 1983) and also the changes associated with spring leaf-out (Hely et al. 2000). Before leaf-out, sunlight penetrates the deciduous component of the canopy and warms and dries the forest floor and fuelbeds. During summer months, the deciduous canopy shades and cools the ground. These facts are important considerations for modeling fire hazard (Hely et al. 2000).

Season of burning will influence tree species composition in upland habitats according to the tree physiology hypothesis (Glitzenstein et al. 1995). Seasonal variation in tree physiology and phenology is important in determining susceptibility of trees to fire. This hypothesis put forward by Wade and Johnson (1986) suggests that fires in different seasons will result in different post-fire forest species composition. This unique seasonal fire legacy is due to the fact that each species is at its peak sensitivity to burning at varying times of the year (Glitzenstein et al. 1995).

2.6 Nutrient and Carbon Cycles

Forest fires create mineral soil seedbeds that are necessary for the germination and establishment of some tree seedlings by consuming forest floor organics (Methven et al. 1975; Beverly and Martell, 2003). In addition, fire reduces canopy coverage, allowing sunlight to reach the forest floor. In nutrient poor soils, such as those found in the Quetico or the Laurentian Shield, much of the nutrient capital in the system can be tied up in undecomposed plant material over the life of a forest stand. Releasing nutrients is a key role of fire in nutrient cycling in northern forests (Heinselman 1996). In cool, moist regions of Canada where biological decomposition is slower than accumulation of dead organic matter, fire is essential in maintaining ecosystem productivity. Carbon compounds are converted back to carbon dioxide and water, which are released into the atmosphere as gases. Mineral nutrients including phosphorous, potassium, magnesium, calcium and iron are tied-up in leaves, needles, bark, and the surface soil litter and hummus layers. These mineral nutrients are largely deposited in the ash layers after fire. Some mineral nutrients such as nitrogen are volatized and released into the atmosphere (Driscoll et al. 1999). The extent of nutrient volatization compared to deposition is related to fire temperature; nitrogen starts to volatize at 200°C (Neary et al. 1999). Vaporization of other nutrients requires higher temperatures: potassium > 760°C, phosphorus >774 °C, sulphur > 800 °C, sodium > 880 °C, magnesium 1107 °C, and calcium > 1240 °C (Neary et al. 1999). In spite of losses through volatization, available nitrogen is often higher shortly after fire, because environmental conditions are more favourable for micro-organisms which fix atmospheric nitrogen, making it more available to plants (Parks Canada 1978).

The carbon economy is also thought to play a significant role in fire mortality as it relates to season. Measurements of total non-structural carbohydrate (TNC) in roots have been compared to sprouting responses after fire. Seasonal variation in plant responses may be related to carbohydrate availability in underground organs at the time of a fire (Drewa 2003). Roots switch from carbon source to carbon sink in late spring and after new shoot growth (Bond and van Wilgen 1996). This translates into a higher springtime susceptibility to fire mortality when plants lack the carbon needed for replacing damaged tissue.

2.7 Other Disturbance Agents

From a landscape ecology perspective, fire is one of the greatest disturbances in the boreal forest; however, operating at different scales of space and time, are other disturbance agents including wind, defoliating insects, flooding, and ice. On their own, each disturbance agent has unique impacts; for example, fire will most affect the smaller size classes of trees and may spare the older more fire-resistant individuals, depending on intensity. Wind, on the other hand, will remove a greater proportion of the larger size classes of trees and opens up the canopy (Dyer and Baird 1997). It does not change the seedbed conditions significantly or the shrub-sapling layer with the exception of some individuals being crushed or damaged by canopy trees or wind sheared treetops coming down. Each disturbance agent leaves a signature on the landscape that is unique in terms of how it affects the structure and composition of stands within an area. At the same time, these disturbance agents interact to increase or diminish each other's effects (Suffling and Perera 2003). These interactions are classified as either synergisms or antagonisms. Synergism occurs where one disturbance driver interacts with one or more other drivers (insects, wind, ice, fire, etc.) to compound the overall effect (Picket and White 1985). Conversely, antagonism occurs when one disturbance driver reduces the effect of another. Essentially, synergistic and antagonistic interactions between disturbance agents are multiplier effects with the first increasing and the second decreasing the net effects of a given disturbance. These relationships between disturbance agents and ecosystem processes only serve to complicate our efforts to understand fire.

Thus fire prediction models, experimental burning, weather data, and phenological responses of plants to fire indicate that strong seasonal variations should be expected in the effects of fire at the stand and landscape level.

3.0 Methods and Study Sites

This study was conducted in Quetico Provincial Park (QPP), located approximately 140 km west of Thunder Bay, Ontario (48°49 N, 091° 43 W). QPP has a long history of forest fires. From the 1930's until early 1990's, the park experienced between 90 to 260 fires per decade (see Table 2). Three recent fires were selected to investigate the effect of burn season on post-fire legacy measured by species regeneration and forest structure, and to compare the effects of a prescribed fall burn with a summer and a spring fire. Implicit in the study design is the notion that fires of different seasons will have variable or different intensities, but will also have different interactions with plants based on their phenologies (e.g. seed set, regeneration, etc.).

This park was chosen because it is a designated Wilderness Park with a Fire Management Plan that strives to accommodate ecologically beneficial fires. It is also sufficiently large to accommodate other landscape level disturbances such as defoliating insect outbreaks, and wind. Under the Fire Management Plan, three different types of fires can occur within the park: prescribed natural fires, prescribed burns, and modified response fires. Unwanted fires are classified as wildfires (OMNR1997). Of the three fires selected in this study, one is a prescribed natural fire, one is a prescribed burn, and one is a wildfire. Pulling Lake (PNF-1) was the first prescribed natural fire in northwestern Ontario, occurring in QPP in June of 1999. Emerald Lake was a prescribed burn conducted by the Ontario Ministry of Natural Resources Staff in October 2000 to reduce fine fuel build-up resulting from a large wind disturbance along the Canada United States border. Stanton Bay was a human-caused wildfire which occurred in August 1995.

Table 2. Quetico Provincial Park fire summary 1930 – 1989.

Decade	# of Lightning Fires	# of Human Fires	Total Fires / Decade	Total ha. Burned
1930's	111	54	165	49,276.2
1940's	61	29	90	673.6
1950's	39	66	105	25.0
1960's	57	80*	137	2,176.8
1970's	155	105*	260	2,885.0
1980's	138	91*	229	351.1

* These numbers were derived by subtracting the number of lightning fires from the total number of fires per decade.

3.1 Site Selection Process

To examine the effects of season, it was necessary to select at least one spring, summer, and fall fire (three treatments). For this study, it was decided that fire size, and pre-fire forest stand type were the most important variables to be controlled; each of the fires chosen needed to have at least one common forest stand type prior to burning and need to be a minimum size. Other variables that play a role in either fire legacies or regeneration include pre-fire fuel loads, fuel types, stand age, composition, soils, topography, and aspect. Due to lack of available data and funding and time constraints it was not possible to account for these variables in the site selection process.

The success of fire suppression has cut down the total number of fire sites available for research. The 2002 fire season in Quetico saw 15 fires between June 2 and August 2 the largest of which burned 0.5 hectares. In total, these 15 fires burned only 3.9

hectares. Between 1995 and 2001 there were only 15 fires greater than 10 ha in size (unpublished park data 2002; see Appendix A). The question of scale is important in the study design process. To understand the effect of fire at the stand and landscape scales, larger fire sites are needed to spatially accommodate appropriately scaled measurements (plot distribution within the burn). In addition, larger fires behave differently than small ones, often generating localized weather, including thunderclouds and lightning (Vonnegut et al. 1995), as well as some creating vortices of up to 400m in diameter (McRae and Flannigan 1990). Ideally for research interests, all the study sites would have burned in the same year but due to the limited number of fires that satisfied the other site selection criteria, it was necessary to consider all fires within QPP going back to 1995.

Of course, to examine the effect of season or timing of burn it is also necessary to have a pool of recent fire sites representing spring, summer, and fall. The collective pool of suitable fires sites within Quetico is further diminished when they are sorted according to season or time of burn. Of the 15 fires in QPP greater than 10 ha between 1995 and 2001, 4 were in June, 7 in July, 2 in August, 1 in September, and 1 in October.

Another important design consideration for this study is that fires needed to be similar in terms of pre-fire composition and structure. Pre-fire composition was estimated using 1965 Forest Resource Inventory (FRI) maps. Although this FRI data was almost 40 years old, there had been no fires at either of the study sites in the interim. Facts on expected life spans of the different tree species in conjunction with the FRI data, permitted some general inferences to be made about what forest types would have existed at the time of the fires.

Using the FRI data, seasonal timing, and size, a short list of potential study sites was generated. Background information was collected for each of these potential sites from the Ridley Library at the park office and the MNR Fire Management Headquarters in Fort Frances. Multiple series of aerial photographs were used to assess sites pre and post fire, and archival fire reports were collected from the Fort Frances Fire Management Headquarters office. These reports contained information on fire duration, intensity, behaviour (crowning, if any), and spotting. The final selections of study sites were made after reviewing this information and speaking with numerous people who had knowledge of the pre or post fire conditions of the different sites. Particularly helpful information was obtained from John Munroe, District Planner, MNR Atikokan area office, Robin Reilly, Park Superintendent, Andrea Allison, Park Librarian, Matt Meyers, Acting Fire Service Co-ordinator, Fort Frances MNR Fire Management Headquaters, and Tim Lynham, Research Officer, Fire Research Group, Canadian Forest Service, Great Lakes Forest Centre (Sault Ste Marie).

Initially, it was anticipated that the common forest type would be jack pine (*Pinus banksiana*) mixedwoods, V17 or V18 using the Field Guide to the Forest Ecosystem Classification for northwestern Ontario (Sims et al. 1990). Although jack pine mixedwood stands had been widely documented on 2 of the 3 fires, none were known to have existed at the Pulling Lake fire. Based on further research, stands of red pine mixedwoods (V13) were determined to have existed at each of the fires. Although this stand-type was not dominant across the two larger fire areas, it is known to have existed at each of the fires (see Figure 4). The rationale behind choosing these 3 fires, and ultimately determining where plots would be established was based on this common stand type pre-existing at each of the fire sites.

V13 Red Pine Mixedwood

General Description
This forest type is most common in the Quetico / Rainy River / Dryden area of northwestern Ontario. V13 can be hardwood or conifer dominated in the overstorey, however the latter is most common. The conifer component of the overstorey is typically dominated by red pine. The understorey ranges from dense to open and sparse herb and shrub cover. These are usually dry to fresh sites on rapidly drained, non-calcereous, coarse textured mineral soils.

Tree Species
red pine, trembling aspen (*Populus tremuloides*), white pine (*Pinus strobus*) jack pine (*Pinus banksiana*), balsam fir (*Abies balsamifera*), large-toothed aspen (*Populus grandidentata*), black spruce (*Picea mariana*), and white spruce (*Picea glauca*).

Shrub Species
bush honeysuckle (*Diervilla lonicera*) low sweet blueberry (*Vacinium angustifolium*), twinflower (*Linnaea borealis*), beaked hazel (*Corylus cornuta*), serviceberry species (*Amelanchier spp.*), velvett leaf blueberry (*Vaccinium myrtilloides*), mountain maple (*Acer spicatum*), Canada fly honeysuckle (*Lonicera canadensis*), and bunchberry (*Cornus canadensis*).

Herbaceous Species
Canada mayflower (*Maianthemum canadense*), wild sarsaparilla (*Aralia nudicaulis*), blue bead lily (*Clintonia borealis*), and large -leaved aster (*Aster macrophyllus*).

Moss Species
Schreber's moss (*Pleurozium schreberi*), and broom mosses (*Dicranum spp.*).

Figure 4. Description of V13 red pine mixedwood (Sims et al. 1990).

3.2 Study Sites

3.2.1 Stanton Bay (Fire 137)

Stanton Bay, a part of Pickerel Lake is located in the Measured Fire Management Zone near the northern park boundary (see Figure 5). It is an access point to the park, making points of the fire site accessible in less than half an hour by canoe. The Stanton Bay fire was started by campers at 6:00pm on August 9, 1995 in a stone fire ring on a small island in Pickerel Lake. Escaping the fire ring and spreading quickly on the island, high winds carried embers to the north shore where fire spread to both the east and west sides of Stanton Bay and burned a total of 598 hectares. It was an intense, largely stand-replacing fire characteristic of many boreal forest fires (FWI 74.5, DC 453, BUI 96.7). First reported on August 10, at 11:50am by the Organized Aerial Detection (OAD), the attack began at 12:08pm, and was classified as “Not Under Control” until August 15. Between the 15th to the 19th it was “Being Held” with no further spread anticipated under normal burning conditions. On the 19th, it was not quite out but “Under Control”. It was declared out on September 28, 1995.

The 1965 FRI maps indicate that the areas affected ranged in composition from almost pure jack pine (Pj7Sb2Po1) to jack pine mixedwoods (Pj5Po2Sb1Bw1Sw1) to red pine mixedwoods (Pr4Po3Sb2Bw1). Discussions with fire experts confirmed that red and white pine (*Pinus strobus*) mixedwood areas could be found along the north limit of the fire. Field estimates of pre-fire tree composition by basal area within the plots indicated that red pine had accounted for 30%, white pine fluctuated between 0-30%, and jack pine up to 30%, mixed with white birch (*Betula papyrifera*), large-leaved aspen (*Populus grandidentata*), red maple (*Acer rubrum*), and trembling aspen (*Populus tremuloides*) . It was noted that the northeast fire corner of the fire had been populated by pockets of red and white pine mixedwoods, interspersed between jack pine and poplar stands.

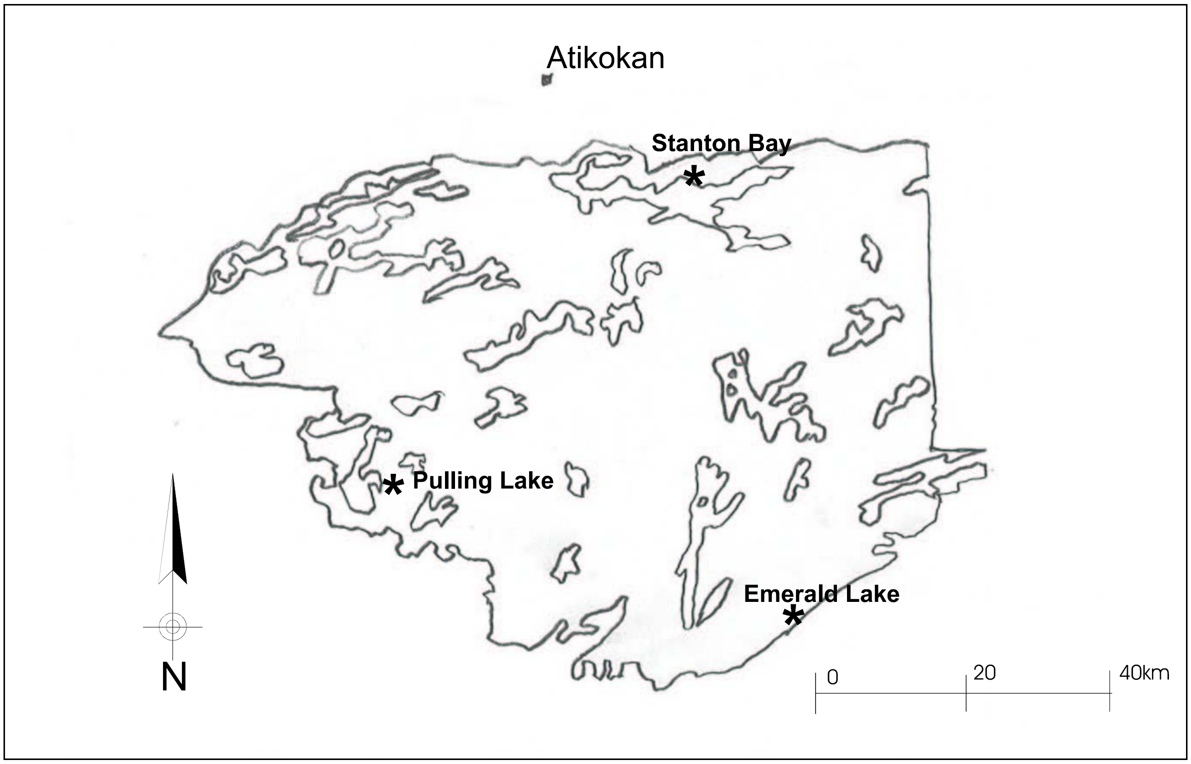


Figure 5. General locations of the selected study sites within Quetico Provincial Park.

3.2.2 Pulling Lake (PNF-1)

The Pulling Lake fire site is located in the southwest corner of the park roughly a one-day paddle from the Lac la Croix First Nations community and entry point (see Figure 5). The fire site is located in the south western portion of the park. Started by lightning on June 12, 1999, the fire was declared an excellent candidate for a prescribed natural fire because it was surrounded by ideal fire breaks including a chain of small unnamed lakes and marshes to the east and north, Pulling Lake to the south, and a creek and lakes to the west. To qualify, a prescribed natural fire must occur in the Prescribed Natural Fire

Management Zone, roughly 63% of the core park area, and satisfy a number of prescription criteria such as having less than a certain Build-up Index or Drought Code score under the Canadian Forest Fire Weather Index (OMNR 1997). In the case of Pulling Lake, the FWI was scored 2, BUI 20, and the DC 118. On the first day, June 12, the fire grew to 0.7 hectares. The following day, it reached 8.0 ha; by June 17 it was 15.0 ha, and on June 18 it reached its final size of 20.0 hectares. It was not declared out until August 8, 1999.

Field exploration of the fire-affected area confirmed that only one forest stand was burned. The 1965 FRI maps classified the affected stand as red pine mixedwoods (Bw4Po2Pr2Pw1Sb1). The pre-fire dominant species were readily identifiable as the canopy was largely intact; red pine and white pine were associated with jack pine, black spruce (*Picea mariana*), large-leaved aspen, red maple, red oak (*Quercus rubra*), and white birch. At the time of sampling, fire scars were not seen more than two meters above ground indicating that it had been a low intensity surface fire. Many of the pre-existing woody species had been fire-girdled, and were rapidly suckering back, including red oak and red maple.

3.2.3 Emerald Lake Prescribed Burn (FOR-01-00)

Emerald Lake prescribed burn was conducted on October 12, 2000 to reduce fire hazards along the Canada United States border (see Figure 5). On July 4, 1999 gale force winds (The Independence Day Blowdown) sheared and blew down trees across more than 291,000 hectares in northern Minnesota and Ontario. In QPP, 11,000 hectares were blown down along the north shore of Knife Lake extending north to Emerald Lake. Blowdown was 100% on the hilltops and 20 – 30% in lower lying areas

(Summary Report 2000). The conifer component was reported to be snapped at an average height of 3m, while the hardwood deciduous species were bent over with many root systems intact (Summary Report 2000). The ground level and aerial fuels produced by the storm were of serious concern to the Aviation and Forest Fire Management Branch of the OMNR, especially as there was little separation between the extensive affected areas in the United States and those in Canada. It was theorized that any fire in the blow down areas of the United States could have carried easily into Canada.

In the post-burn report (OMNR 2001), there were three burning objectives and five desired results:

Burning Objectives

1. To remove fine fuels in 100% blow down areas, to reduce wild fire hazard in the area, and to create a fuel break between blow down fuels south of the border and in Quetico Provincial Park.
2. To document fire behaviour in blow down fuels.
3. To compare succession between burned and unburned areas of blow down.

Desired Results

1. Reduction of Slash – reduction of fine fuels (woody material with a diameter of 0.0 – 6.99 cm) by 70 – 100% in areas of 100% blowdown. Moderate reduction of medium and coarse fuels (woody material with a diameter greater than 7.0 cm) is desirable, as is the removal of understory fuels (litter and needles) in areas within the treatable area that have a low percentage of blowdown.

2. To promote regeneration of this fire-driven ecosystem through application of low intensity surface fire under residual standing white and red pine on the site.
3. Reduction of the Duff Layer – reduction of duff by 1 – 3 cm is desirable.
4. Mineral Soil Exposure – some mineral soil exposure over the site is desirable.
5. Reduction in Vegetation – reduction of competing shrubs and balsam fir in the understory in residual white and red pine is desired.

Ignited at 11:45am and finished at 5:30pm, the fire burned 1,620 hectares of the proposed 1,789 hectares Project Area (FWI 9.2, BUI 23, DC 238). In the postburn evaluation it was judged a complete success. Within the five plots established on this fire site, pre-fire composition determined by basal area was predominantly red pine (30 – 60%) and white pine (20 -30%) mixed with jack pine, white birch, black spruce, and red maple.

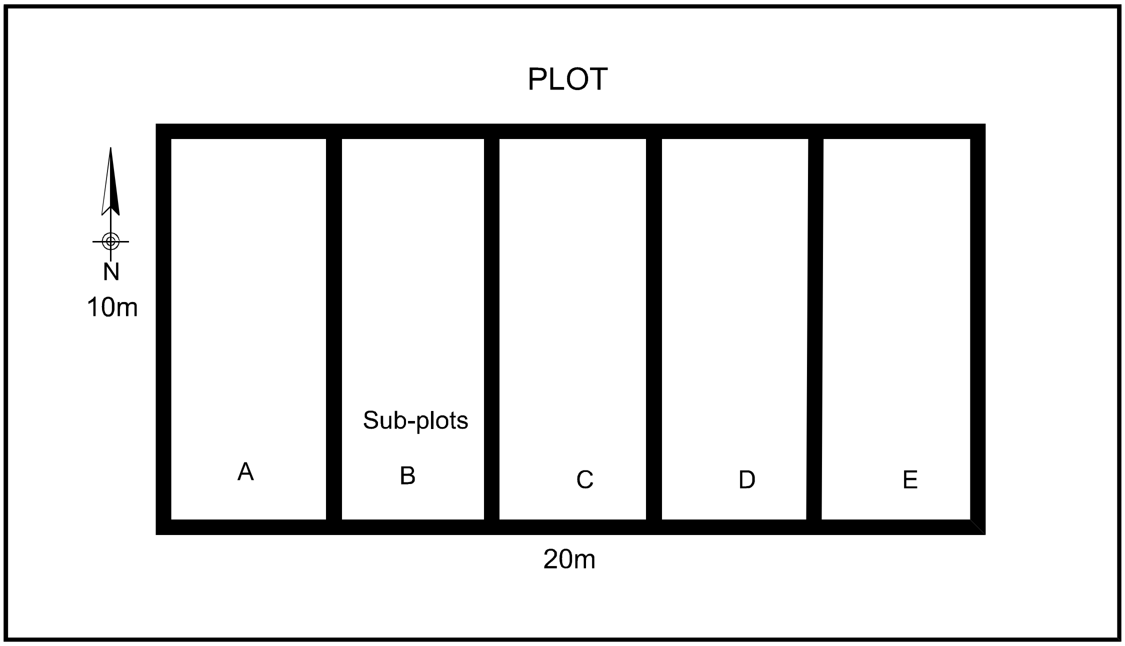
3.3 Field Methods

3.3.1 Initial fire inspections

Accessing each of the fire sites was achieved using pre-planned routes from nearby lakeshores. Routes were plotted from a shoreline feature visible on air photos to a pre-determined area within the fire. Once within the fire scar several hours were spent becoming familiar with the general site conditions. This site reconnaissance was to ensure that the plots established were representative of the larger fire area, and also to ensure that the plots reflected common values such as pre-fire canopy composition and age, between each of the fires.

Species composition and structure were measured in five plots at each treatment. The number of plots per fire was an empirical decision based on total time available for field work. Each 10m x 20m plot was sub-divided into five sub-plots (4m x 10m)(see Figure 6). In each of the sub-plots, two randomly placed 0.5m^2 groundcover quadrats and one 4.0m^2 shrub and seedling quadrat were established. The number of groundcover and srub / seedling quadrats used in this study is comparable in intensity with other boreal forest studies and was determined in consultation with my advisor Dr. Roger Suffling and Dr. Geoff Lipsett-Moore, MNR Zone Ecologist for northwestern Ontario. Within the plot, all trees and coarse woody debris were also measured.

Figure 6. Plot configuration showing sub-plots



3.3.2 Establishing a Plot

1. Using a compass to determine cardinal points, the plots were established 10m north x 20m east from the tie-in point. The plot corners were staked with metal survey pins and connected along the perimeter using two 30m measuring tapes. Five equal sub-plots were established at 4m intervals along the x-axis (measuring tape) and marked using flagging tape.

2. The field data sheets included records of date, air photo numbers, UTM, elevation, and site description including the percentage of canopy killed by fire, estimates of pre-fire canopy composition, evidence of wildlife especially birds, and general woody debris characterization.

3. In each plot, ten 0.5m x 1.0m randomly placed ground cover quadrats were completed (2 per sub-plot). They were aligned 0.5m wide (east-west) x 1.0 m tall (north-south). Five litter depth measurements were taken in each of the groundcover quadrats starting in the southwest corner and progressing diagonally to the northeast corner at regular intervals (0, ¼, ½, ¾, and 1). Next all visible plant species within the quadrat were identified and scored according to a modified Braun-Blanquet abundance scale of 0-7; the total number of tree seedlings per species within each quadrat was also recorded. Each species was recorded and was coded as a herb, shrub, tree, fern, moss, or grass.

Table 3. Modified Braun- Blanquet abundance scale scoring system.

Code Recorded	Abundance
7	More than 75% cover
6	50 – 75% cover
5	25 – 75% cover
4	5 – 25% cover
3	Less than 5% cover – many plants
2	Less than 5% cover – several (<10) plants
1	Less than 5% cover – single plant
0	absent

4. Next, five 2m x 2m shrub plots (one per sub-plot) were completed documenting all woody plants. Each species was scored using the modified Braun-Blanquet abundance scale, and tree seedlings and saplings were counted and the maximum height per species recorded.

5. Surviving trees in each plot were each identified to species, diameter-at-breast-height (dbh)(1.4m) was recorded, and heights were estimated to the nearest meter. The position of each tree within the plot was recorded by (x, y) coordinates. Health was recorded as normal by no record, and unhealthy or vigorous by plus and minus signs. Additional comments allowed noted fire scars, and multi-stem trees of which only the largest stem was measured (dbh).

6. Coarse woody debris (CWD) was divided into stumps (<1.5m in height), snags (>1.5m), and logs. All CWD was measured within each plot for comparison across plots and treatments. Snag dbh and heights were measured. Stumps were measured using a dbh tape at 1.4m or their highest point if less than 1.4m.

Logs were measured by their total length, and by diameters at each end. Stumps and snags were also assigned x, y coordinates within each plot.

7. Soil samples were collected in each sub-plot using a soil auger to determine soil depth, depth of organics, and presence of mottles or gleys. Parent soil samples were bagged for laboratory analysis.

8. Tree cores were extracted using a Swedish Increment Borer from the two largest pines within each plot. Most often samples were of one white pine and one red pine; however, on one occasion, jack pine was also sampled. Each tree cored was also measured using a Suunoto clinometer to determine heights.

9. Finally, three colour photographs were taken of each plot. One to capture the whole plot from the southwest corner and two more of general site conditions or fire scars.

3.4 Laboratory Methods

3.4.1 Soil Analysis

Sand, silt, and clay content of soil samples were determined using the standard method for particle-size analysis of soils (Annual Book of ASTM Standards 1982).

3.4.2 Tree Core Analysis

In the lab, each tree core was glued into slotted wooden core trays. The cores were sanded to enhance the rings. Using a Wild M5A Leitz microscope with a 6x objective lens and a Leica illuminator (light), all growth rings were counted. In addition to the total number of visible rings an estimate was made of the number that were not visible due to rotten sections of the core or if the centre had been missed.

3.4.3 Statistical Methods

Statistical analyses of the data were completed using the general linear model procedure in the SAS System. Statistical consultation was provided by Erin Harvey of the University of Waterloo Statistical Consulting Service. The groundcover and shrub/sapling data were generated from quadrats randomly located within the sub-plots and the tree and coarse woody debris data were collected for the whole plot. Each of these databases (groundcover, shrub/sapling, trees, and coarse woody debris) were analysed separately using a one-way analysis of variance (ANOVA) for each of the dependent variables. In consultations with Ms. Harvey and Dr. Stephen Murphy, our consensus was that the groundcover and shrub/sapling data are not spatially independent because the sub-plots are situated adjacent to one another (see Figure 6). The residual assumptions were checked via visual inspection and found to be normally distributed and hence satisfactory. Other methods such as the Bartlett test were deemed to be to be too sensitive to check residual assumptions in this application. The least significant differences were determined post-hoc. Because there were several values of “zero” for the dependent variables (red, white, and jack pine), a non-parametric test (Kruskal-Wallis) was used for the ANOVA.

4.0 Results

Species composition and stand structure and conditions were measured in five plots for each fire treatment. Sampling began on July 18, 2002 and was completed on August 26, 2002.

Photographs taken at each of the study areas characterize the variability of post-fire structural conditions. Many fire-killed trees at Stanton Bay had blown down in the interim and are obscured from view by the dense regeneration (see Figure 7).

Figure 7. Summer Fire 1995. Stanton Bay Plot 4 no trees survived in the plot and only a scattered few throughout the fire site. Regeneration is being dominated by jack pine seeding in from pre-fire stands immediately to the south.

Figure 8. Spring Fire 1999. Pulling Lake Plot 2 shows surviving trees with scorch marks < 2 meters up the trunk. Many of the deciduous trees and shrubs have suckered back aggressively since the fire.

4.1 Soils, Tree Cores, and Basal Areas

The purpose of collecting soil samples, tree cores, and measuring the dbh of trees and snags and stumps was to demonstrate the similarities and differences between the sites beyond what was observed at the time of plot selection. Soils play a role in determining the plant species matrix (Lee et al. 1998). The tree cores provide insight into the stand history. The basal areas indicate much about the pre-fire stocking in terms of the size, composition, and structure of the stand.

Figure 9. Fall Fire (prescribed burn) 2000. Emerald Lake Plot 4 shows many surviving canopy trees and a thinned out understorey. Several fire killed deciduous saplings and shrubs are visible in the foreground.

4.1.1 Soils

Soil depths were taken at 5 random points within each plot; one per sub-plot. These depths were averaged per plot. These averages can be seen on Figure 10 with the exception of Pulling Lake plot 4 for which soil data were not recorded. ANOVA analysis of these averaged depths showed no significant difference (DF=2; F=0.17; and P=0.84).

Soil texture was analyzed for each plot. The clay content was low and showed little difference between the samples; most of the variability was found in the percentage of sand versus silt content. The sand content fluctuated between 20 – 70% between the plots.

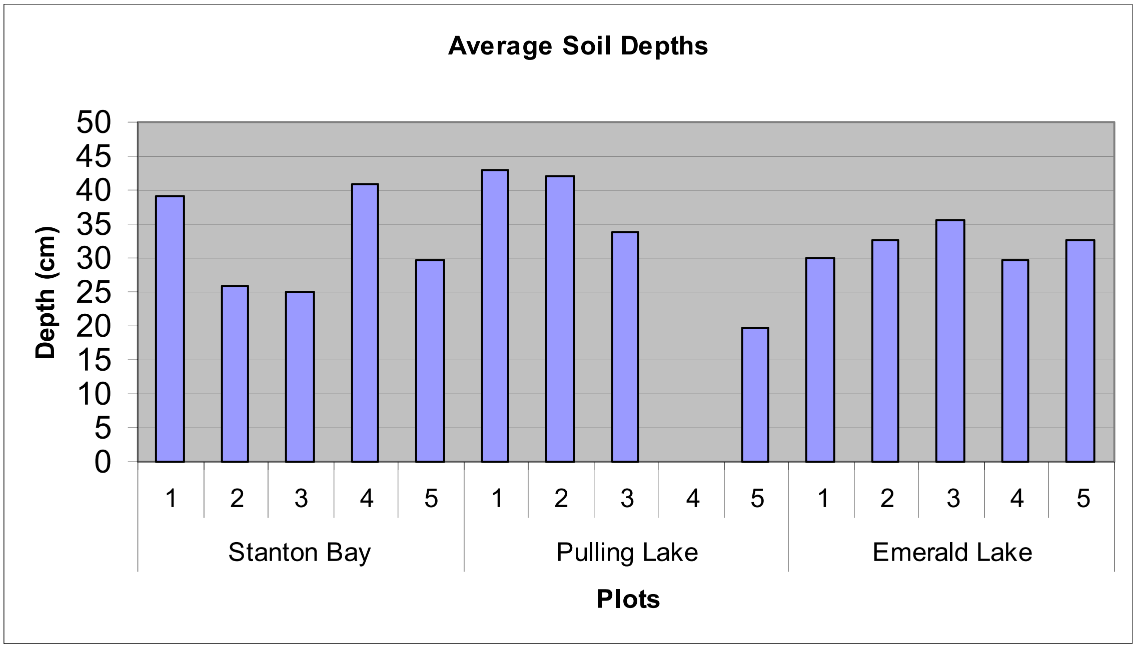


Figure 10. The average of five soil depth measurements taken at each plot show similarity between study sites.

Over the course of the 2000 – 2003 field seasons, researchers sponsored by the Quetico Foundation surveyed a selection of sites representing the various forest types within the park. A component of that research was soil sampling. The soils results from this study are plotted against the Quetico Foundation results in Figure 11.

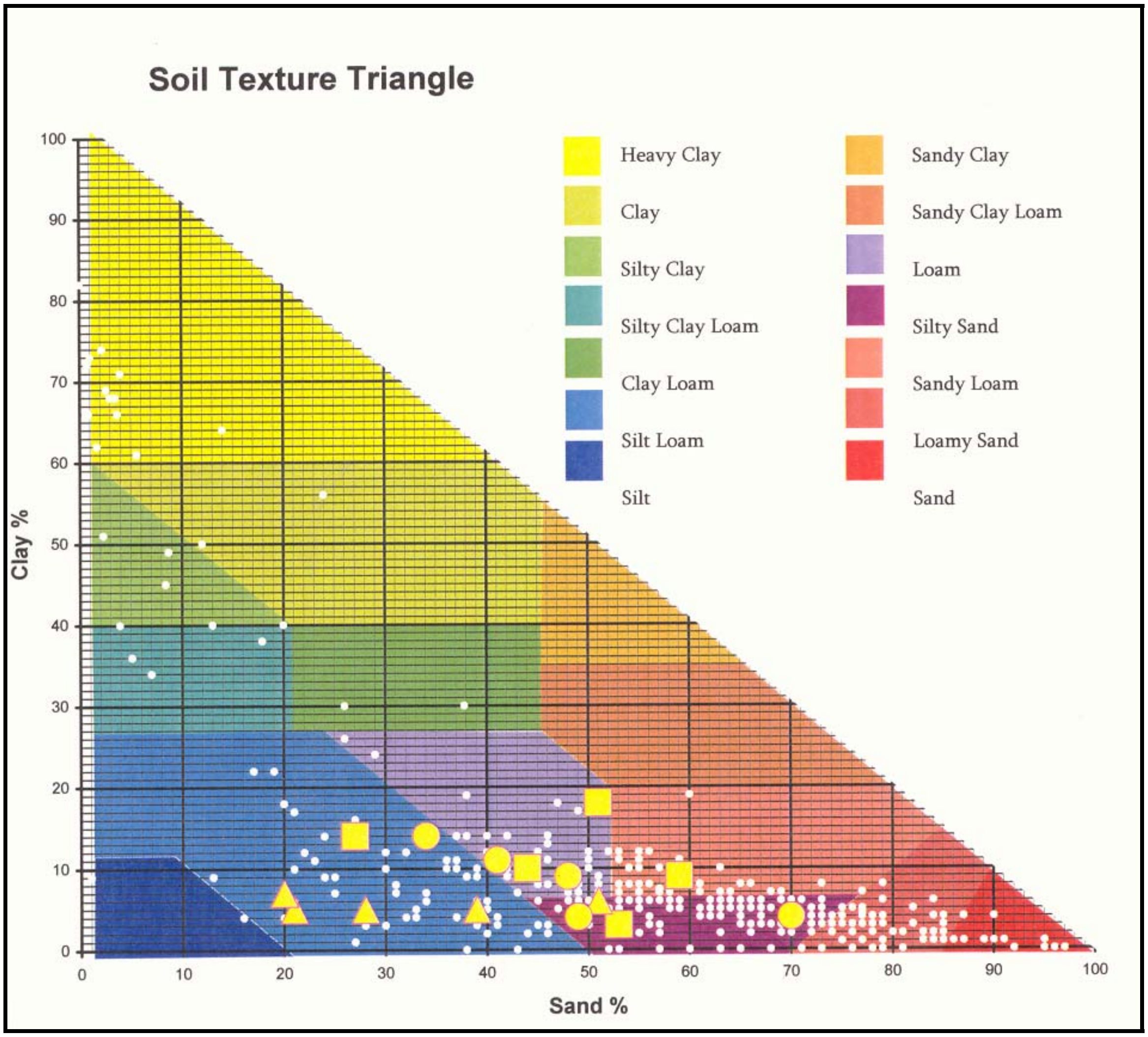


Figure 11. Soil texture triangle showing soils throughout the park in fine points, Stanton Bay in triangles, Pulling Lake in circles, and Emerald Lake in squares.

4.1.2 Tree Cores

A single tree core was extracted for the largest red and white pines in each plot. The one exception was at Stanton Bay Plot 2 where a jack pine was substituted because there where no white pines. The ages of these cored trees was determined and graphed (See Figure 12).

ANOVA analysis of the age variability between sites was completed for red pine and white pines separately due to their different regeneration strategies after fire. Red pine ages are the same between Stanton Bay and Pulling Lake and Pulling Lake and Emerald Lake, but are not the same between Emerald Lake and Stanton Bay.

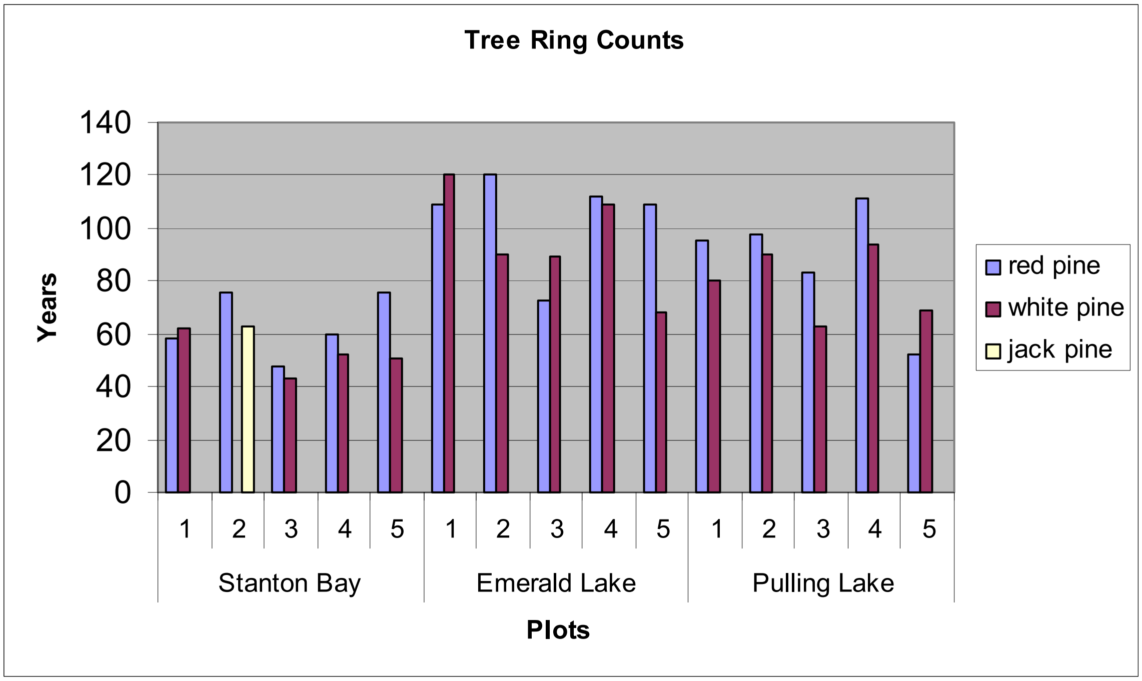


Figure 12. Tree cores from each plot were used to estimate stand ages between study areas.

Table 4. Tree cores extracted from red pines at each fire revealed some differences.

				Stanton Bay	Pulling Lake	Emerald Lake
F	**Pr > F**	**DF**	**LSD**	**Mean**		
6.5	0.012	2	24.9	104.6	87.8	63.6

Data on the ages of white pine showed some variation between the fires (DF = 2; F=9.21; Pr > F 0.005). Emerald Lake and Pulling Lake were the same with a difference between the means of +/- 16.0; Emerald Lake and Stanton Bay were different with a difference between the means of +/- 43.2; and that Stanton Bay and Pulling Lake were different with a difference between the means of +/- 27.2.

4.1.3 Structure

Basal areas were calculated for all live trees, snags, and stumps. Totals of live and dead basal areas were used to compare the likeness of structure between the different sites. Live trees, snags, and stumps characterize the post-fire conditions, while total basal area, the combination of live and dead wood, is used to get a sense of pre-fire structure. ANOVA analyses of live trees, snags and stumps, and total basal areas were performed to complete this analysis. The analysis of live trees showed Stanton Bay and Emerald Lake to be the same, Emerald Lake and Pulling Lake to be the same, but Stanton Bay and Pulling Lake to be different (P=0.0294). The analysis of snags and stumps (dead wood) showed Stanton Bay and Emerald Lake to be the same, and Pulling Lake to be different from both (P=0.0044). The analysis of total basal area (pre-fire structure) showed Stanton Bay, Pulling Lake, and Emerald Lake to be the same (P=0.3048).

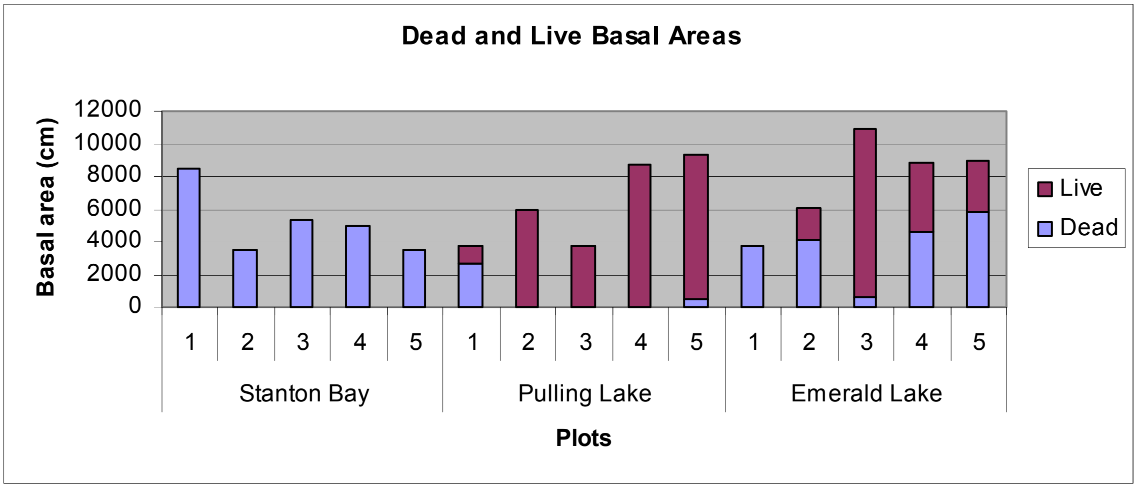


Figure 13. Relative proportions of dead and live basal areas (cm^2) per plot per fire.

4.2 Groundcover

Ten randomly placed rectangular 0.5m^2 groundcover quadrats in each plot (2 per sub-plot) generated herbaceous and woody plant data. The variables included litter depth, number of tree species, number of shrub species, number of non-woody vascular plant species, and the number of individuals of each tree species. Litter depth was measured at five points in each quadrat and averaged. ANOVA analysis was conducted on the numbers of red pine, white pine, jack pine, total number of seedling / saplings, total number of conifers, total number of deciduous seedling / saplings, total number of shrubs, total number of herbaceous plant species, and total number of moss species. In cases where zero values were recorded for either of the treatments i.e. numbers of white, red, and jack pine, it was necessary to perform Kruskal-Wallis nonparametric one-way procedures for analysis of variance.

No jack pine seedlings or saplings were documented at either Emerald Lake or Pulling Lake. At Stanton Bay jack pine was the dominant regenerating species; in the groundcover quadrats alone 117 were counted (in $25.0m^2$), equivalent to 46,800 seedlings per hectare. This abundance of these seedlings at Stanton Bay are the result of neighbouring pre-fire stands of jack pine located immediately to the south within the fire boundaries. Jack pine regeneration at Stanton Bay (mean = 22.0) showed significant difference form Pulling Lake (mean = 0.0) and Emerald Lake (mean = 1.4) when using Kruskal-Wallis nonparametric one-way analysis of variances.

Red and white pine regeneration in the groundcover quadrats showed no difference.

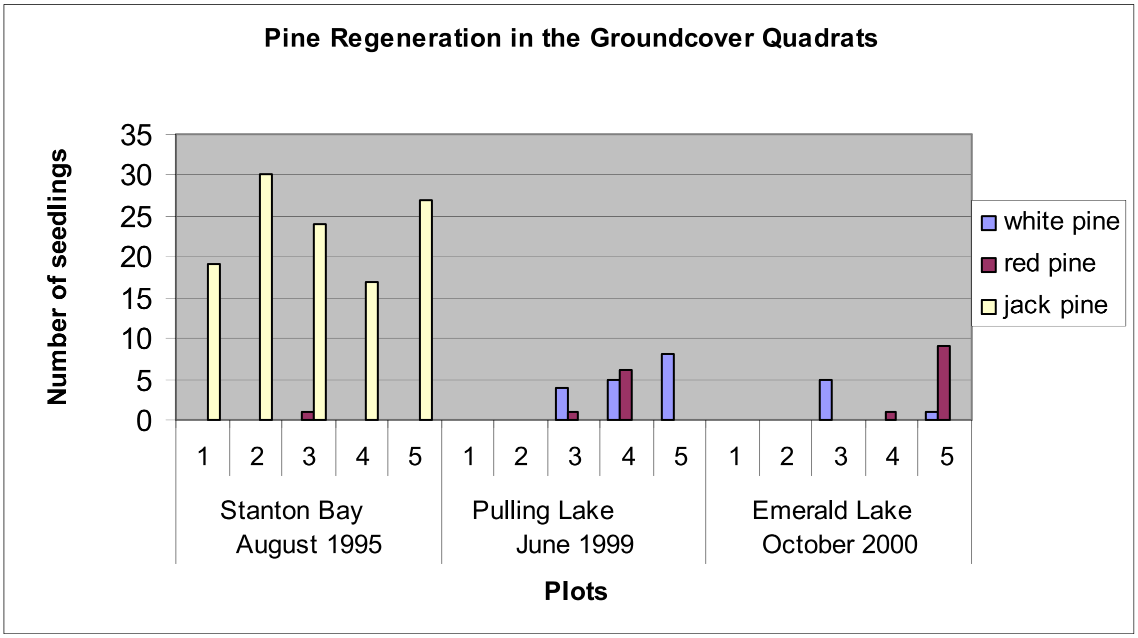


Figure 14. Total number of red, white and jack pine saplings recorded in the groundcover quadrats in each plot.

Table 5. Pine regeneration recorded in the groundcover quadrats.

				Stanton Bay	Pulling Lake	Emerald Lake
	F	**Pr > F**	**DF**	**Mean**		
Jack pine	26.07	<0.0001	2	22.0	0.0	1.4
White pine	2.55	0.12	2	0.0	3.2	1.2
Red pine	0.56	0.59	2	0.2	1.4	2.0

Average litter depth in centimetres was tested for least significant differences between the three treatments. It was necessary to log transform this variable. Anomalous average measurements were recorded in two ground cover quadrats in Stanton Bay Plot 3. Blowdown debris in this plot resulted in exceptionally deep organic litter (average: 30cm and 66cm) in two quadrats. Since this debris had accumulated after the fire, it was not a reflection of the post-fire legacy but of a more recent wind event. To eliminate this point of confusion, average litter depth was statistically tested with raw field data, and then again with the anomalous data replaced by the plot average. In the first case, the results were not statistically different; however, using the modified data for Stanton Bay Plot 3 resulted in some differences. Stanton Bay and Pulling Lake showed no difference and Stanton Bay and Emerald Lake neither, but results from Emerald Lake and Pulling Lake varied.

Table 6. Results of ANOVA analysis on the average litter depths recorded in groundcover quadrats at each fire with raw and modified data.

					Stanton Bay	Pulling Lk.	Emerald Lk.
	F	**Pr > F**	**DF**	**LSD**	**Mean**		
Raw data	1.12	0.36	2	0.52	1.62	1.66	1.33
Modified data	3.35	0.07	2	0.30	1.37	1.66	1.33

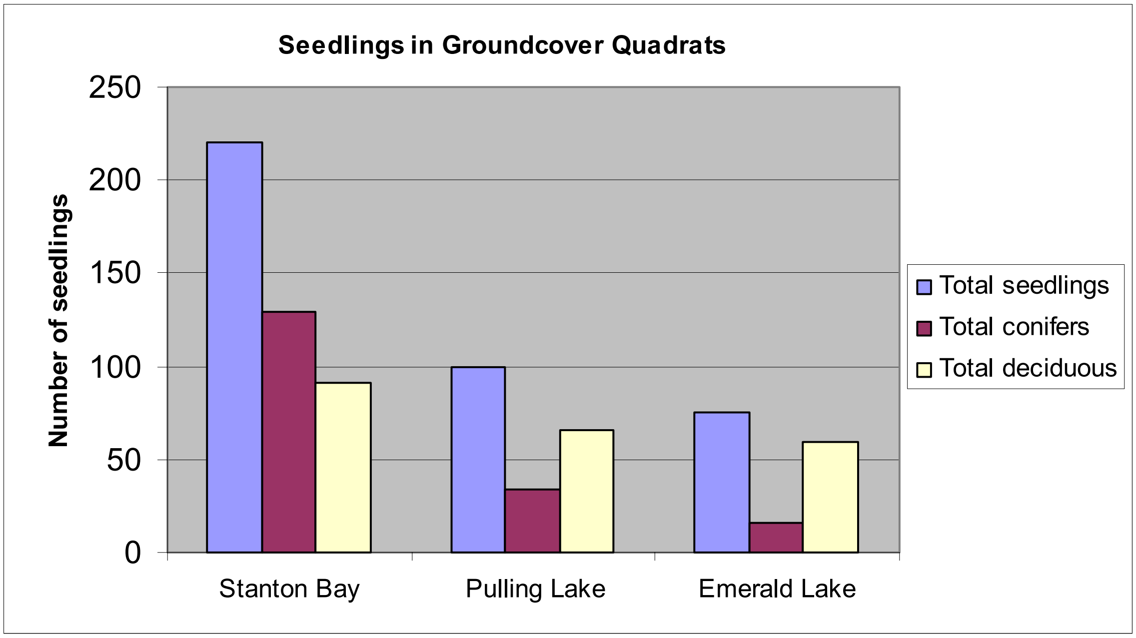


Figure 15. Total, conifer, and deciduous seedling regeneration in the groundcover quadrats at each fire.

The total seedlings / saplings data needed to be log-transformed. Stanton Bay (mean =3.73) results were different from both Pulling Lake (mean =2.93) and from Emerald Lake (mean =2.72), however, results from Emerald Lake and Pulling Lake were similar. Differences in the fire sites were more pronounced when only looking at the total number of conifer seedlings.

Table 7. Results of ANOVA analysis on all seedlings, conifer seedlings, deciduous seedlings, shrub species, herbaceous species, and moss species recorded in the groundcover quadrats at each fire site.

					Stanton Bay	Pulling Lk.	Emerald Lk.
	F	**Pr > F**	**DF**	**LSD**	**Mean**		
seedlings	10.51	0.002	2	0.51	3.73	2.93	2.72
conifers	13.29	0.001	2	9.06	24.20	6.60	4.80
deciduous	0.93	0.423	2	10.16	18.00	13.20	12.00
shrubs	2.99	0.089	2	6.63	12.40	17.60	19.60
herbaceous	5.92	0.016	2	9.89	16.00	21.40	31.40
mosses	2.45	0.136	2				

Deciduous seedling regeneration was the consistent among the different fire sites.

The variable “shrubs” is a measure of shrub species diversity that was recorded in the groundcover quadrats. Since many shrubs species are either multi-stemmed or clonal, only their diversity was analysed. Results showed a significant difference between the treatments. While Stanton Bay was the same as Pulling Lake and Pulling Lake was the same as Emerald Lake, Emerald Lake and Stanton Bay were significantly different from each other.

There was also a significant difference between treatments in the number of herbaceous (non-woody vascular plant) species recorded (P = 0.0162). Emerald Lake results were different from both Stanton Bay and from Pulling Lake; however, Stanton Bay and Pulling Lake were similar.

The final variable examined from the groundcover database was the total number of moss species. It was necessary to log-transform this variable. There was no significant difference between the sites (P = 0.1359).

4.3 Shrub / Seedling / Sapling

Five randomly placed square $4.0m^2$ shrub / sapling quadrats in each plot (one per sub-plot) generated data that further described woody plant regeneration. ANOVA analysis was completed for each variable: numbers of red pine, white pine, jack pine, total number of conifer seedlings, total number of deciduous seedlings, and shrub species diversity.

The following regeneration results are based on counts of individuals occurring within the shrub / seedling quadrats (i.e. density). Red pine regeneration between the three sites was the same (P=0.18). White pine regeneration between the three sites the same (P=0.41). Jack pine regeneration between the three sites was very different (P=0.001), strengthening the findings of the groundcover dataset. The results from jack pine regeneration in the shrub / seedling quadrats showed that Stanton Bay was significantly different from both Pulling Lake and from Emerald Lake, while Pulling Lake and Emerald Lake were similar.

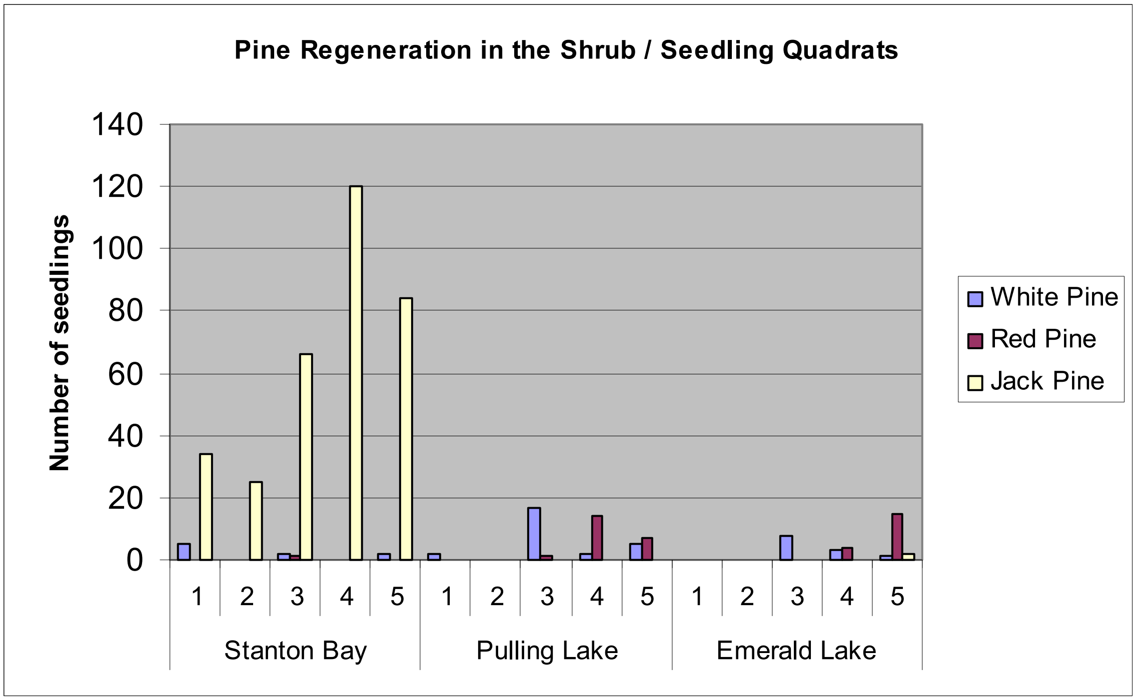


Figure 16. The number of pine seedlings per species recorded in the shrub / seedling quadrats in each plot at the different treatments.

Table 8. Pine regeneration recorded in the shrub / seedling quadrats.

				Stanton Bay	Pulling Lake	Emerald Lake
	F	**Pr > F**	**DF**	**Mean**		
Jack pine	12.41	0.001	2	63.80	0.40	2.00
White pine	0.95	0.41	2	1.80	5.20	2.40
Red pine	2.02	0.18	2	0.20	5.40	2.8

Due to the limited regeneration of other conifer tree species, the analysis of total number of conifers between plots was largely the same as the results for pine regeneration. Stanton Bay (mean=69.20) was significantly different from both Pulling Lake (mean=11.40) and from Emerald Lake (mean=7.40), and Pulling Lake and Emerald Lake were similar. The total number of regenerating deciduous trees was the same (P=0.7956) between treatments.

Table 9. Total conifer and deciduous seedling regeneration and shrub species diversity recorded in the shrub / seedling quadrats.

					Stanton Bay	Pulling Lk.	Emerald Lk.
	F	**Pr > F**	**DF**	**LSD**	**mean**		
Conifer	9.56	0.003	2	34.47	69.20	11.40	7.40
Deciduous	0.23	0.796	2	17.93	32.00	26.40	29.60
Shrubs	15.93	0.0004	2	5.23	12.00	15.20	25.00

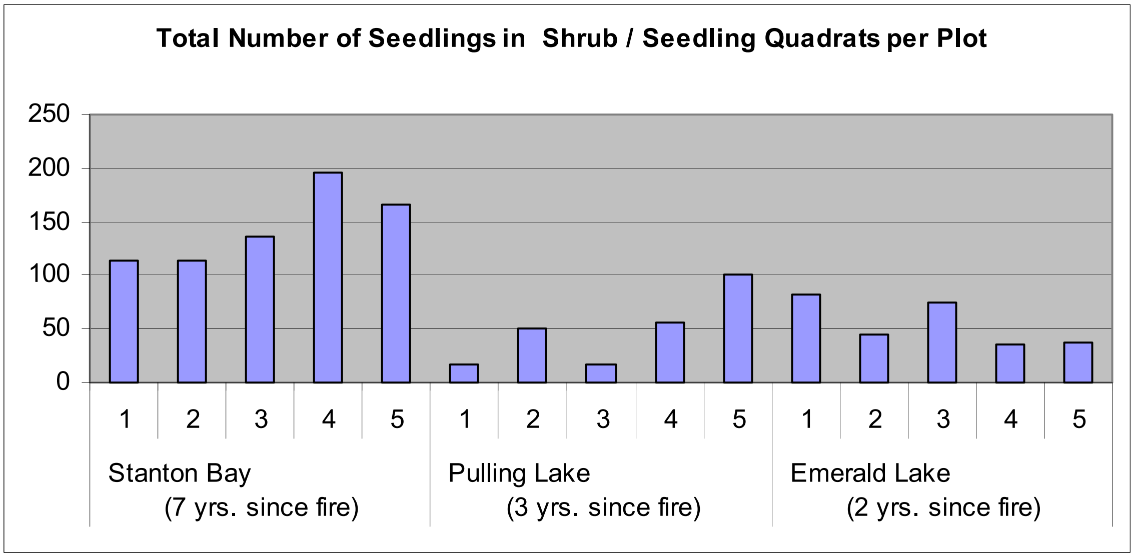


Figure 17. The total number of seedlings recorded in the shrub / seedling quadrats per plot.

Shrub species diversity varied between treatments. Emerald Lake (mean=25) and Pulling Lake (mean=15) were the same, and Stanton Bay (mean=12) was different from both. The shrub species diversity showed an inverse relationship to the time since fire. In this case, Stanton Bay which burned in 1995 has the lowest species diversity. Pulling Lake, which burned in 1999, is higher; and Emerald Lake, which burned in 2000, is slightly higher still. Field observations show that as the tree seedlings become established, they are out-competing many of the shrubs.

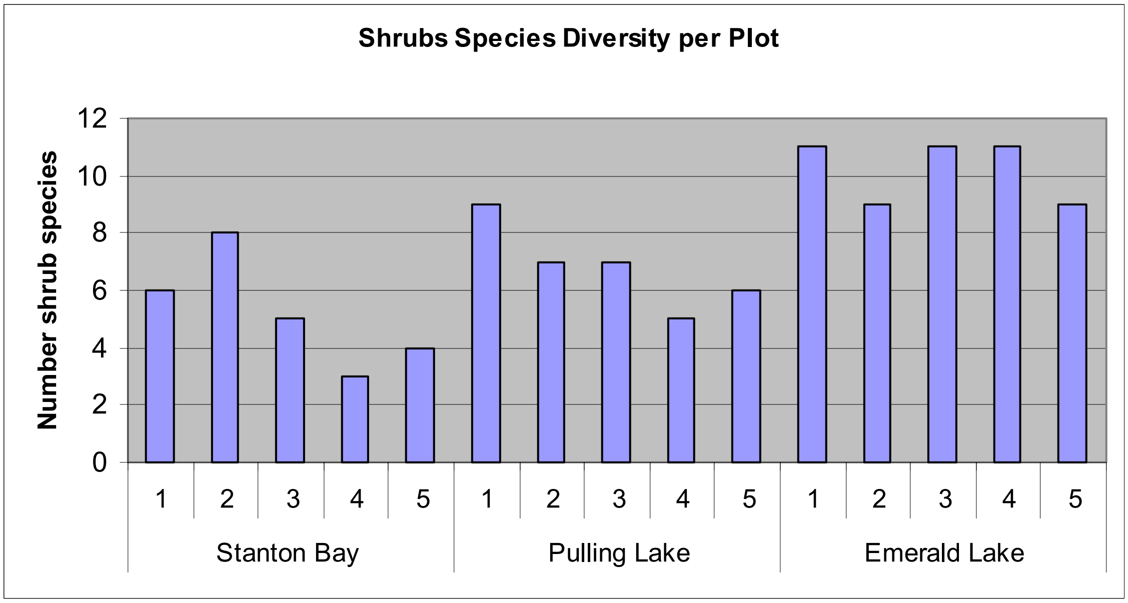


Figure 18. Total number of shrub species (diversity) recorded in each plot.

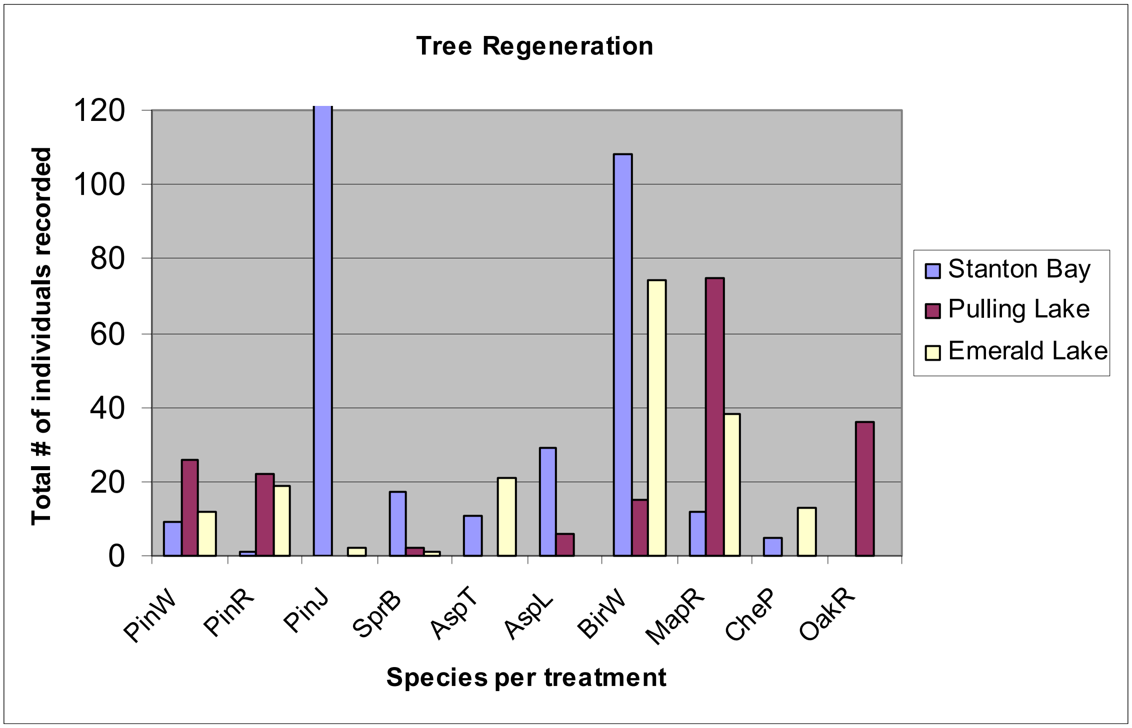


Figure 19. The total number of tree seedlings per species recorded in the shrub / seedling quadrats for each treatment.

Code	**Scientific Name**	**Common Name**
PinW	*Pinus strobus*	white pine
PinR	*Pinus resinosa*	red pine
PinJ	*Pinus banksiana*	jack pine
SprB	*Picea mariana*	black spruce
AspT	*Populus tremuloides*	trembling aspen
AspL	*Populus grandidentata*	large-toothed aspen
BirW	*Betula papyrifera*	white birch
MapR	*Acer rubrum*	red maple
CheP	*Prunus pensylvanica*	pin cherry
OakR	*Quercus rubra*	red oak

5.0 Discussion

Forest fires typically occur between April and September in Canada. A variety of factors explain why fires burn at different times of the year and so create different post-fire legacies. Legacy, which is the suite of conditions that exist after a disturbance, was measured in this study by structure (coarse woody debris, live trees, and litter depth), and plant species composition. Quantitative data describing stand regeneration after fires of different seasons is important for understanding the potential effects of the current practice of conducting prescribed burns in the fall in northwestern Ontario.

Climate, which can be thought of as weather averaged over a period of time i.e. season, and weather as a daily variable, create different fire hazard conditions at different times of the year. The expectation that fall weather will create less hazardous fire conditions coupled with fire crew and equipment availability, dictate that most prescribed burns in northwestern Ontario forests occur during the fall months, particularly October.

Plants are more vulnerable or resistant to fire depending on age, foliar moisture content, and nutrient cycling, especially carbon availability (Drewa 2003; Bond and van Wilgen 1996). Post-fire regeneration is dictated in part by which species were best advantaged or least negatively affected. Date of fire compared to seeding times of plants is important in determining post-fire species matrix in prairies and xeric ecosystems (Howe 1994). Similar patterns may exist for tree replacement within forest areas affected by fire.

The specific challenge for this study is to determine the effects of season or date of burn on post-fire legacies in red pine mixedwood forests in northwestern Ontario. In an ideal world, this problem would be tackled by conducting experimental burns in uniform forests at different times of the year over a period of a number of years, and comparing quantitative measurements of pre-fire conditions and post-fire legacies.

In reality, a single research assistant and 12 weeks over one field season required that this study focus on three recent fires in QPP. Without having quantitative pre-fire data of species composition and structure, it is necessary to otherwise demonstrate that each site was comparable before fire. To verify similarities, all relevant background information for each site was reviewed and a number of post-fire measurements were made.

Background information collected for each of the study sites included aerial photographs and archival Forest Resource Inventory data from the 1960s. Additionally, interviews were conducted with fire experts who had knowledge of the different fire site conditions were conducted to develop a strong knowledge base of each fire site. Before fieldwork began, it was determined that each fire site had stands of red pine mixedwood forest, classified as v-13 (FEC)(Sims et al. 1990), and each fire had been greater than 10 hectares.

On-the-ground reconnaissance of each fire site allowed plot placement to be determined using estimates of pre-fire similarities between all sites. Over the course of the field season, differences between the study sites were noted. These differences can be divided into those that are the result of the different treatments, those that are likely the result of pre-fire differences of the respective study areas, and those that existed for other reasons. Most of these differences were the likely the result of the different treatments. One pre-fire difference was that red oak likely existed only at Pulling Lake; some stems survived the fire and others were suckering back. No evidence of red oak was found at either of the other study sites. Another observed difference that cannot necessarily be attributed to treatment, was that regeneration at Stanton Bay was dominated by jack pine. This change from pre-fire composition is likely the result of seeding from jack pine stands that were also burned south of the study sites. The serotinous cones of jack pine require fire to open and readily rain seed into immediate and downwind areas. Given that the prevailing winds blow typically from southwest, it is intuitively apparent that the Stanton Bay plots would be colonised by jack pine from adjacent stands.

Tree cores, soil samples, and measurements of coarse woody debris and live trees were taken to generate quantitative descriptors of the pre-fire conditions. Tree cores typically showed red pines to be older than white pines at each of the sites (10 out of 14 times). Inferences about the disturbance history of the site or the time of the last catastrophic fire can be made by comparing the age of the oldest tree from each site and the average age of the pines on each site.

Table 10. Comparison of site similarities based on pre-fire tree ages.

	Stanton Bay	Pulling Lake	Emerald Lake
Age of oldest pine at each site	76	111	120
Average age of all pines cored per site	59	84	100

Measurements of the dbh of live trees, snags, and stumps characterize the existing and pre-fire structure. Pre-fire structure is estimated to be the sum of the basal areas of live tree, snags, and stumps. Comparisons showed no significant differences in pre-fire structure of the different sites based on basal area calculations.

Soil depth measurements showed no significant difference between the sites. Comparison of soil textures indicated that the clay content was low across each site and that variability in soil texture was mostly in the ratio of sand versus silt content. All but one of the soil samples had between 20% and 60% sand content. The one outlier from Pulling Lake Plot 2 had 70% sand. This variability still represents a fair degree of consistency when compared to soil texture ranges for the whole park. Sand content in soil samples from throughout the park range from 0% to 98%.

Table 11. Range of soil textures found at each site.

	Stanton Bay	Pulling Lake	Emerald Lake
Sand	20-51	34-70	27-59
Silt	43-73	26-52	31-59
Clay	5-7	4-14	3-18

These measurements indicate that efforts to select plots that were nearly uniform within and between sites prior to fire were successful in a number of ways. Plots were located only where estimates of pre-fire stand composition were similar and where stands could be classified as red pine mixedwoods – V 13 according to the Forest Ecosystem Classification system for northwestern Ontario (Simms et al. 1990). The soil depths were the same; the soil textures had roughly the same clay content but varied according to sand versus silt content. Only the stand ages appear to have been different prior to fire, with Emerald Lake being roughly 15 years older than Pulling Lake which in turn was roughly 25 years older than Stanton Bay.

Additionally, each of the selected fires burned most recently in different years. Ideally, they would have burned in the same year but the available pool of recent fires in QPP of a minimum size during different seasons with nearly identical pre-fire stands did not afford this opportunity. Therefore, conclusions about post-fire legacies must be weighed against the fact that Stanton Bay burned in August 1995, Pulling Lake in June 1999, and Emerald Lake in October 2000. At the time of field work these burns were in their 2nd, 3rd, and 7th growing season respectively. Certain differences, especially in species composition but also structure, can be attributed to the fact that the regenerating fire sites are different ages.

5.1 Legacies

Comparing the legacies of the spring, summer, and fall fires in this study was completed using structure, and post-fire species composition. Measurements of structure included litter depth, and basal areas of live tree and coarse woody debris. Since there were no significant differences in pre-fire structure based on the sum of stump, snag, and live tree basal areas, ratios of live versus dead basal areas make a simple tool for comparing between treatments.

5.2 Structure

Litter depth after fire is a product of fire intensity, dryness of the organic matter (litter) and underlying soil, and thickness of the organic layer (Neary et al. 1999). Post-fire litter depth was different between the spring and fall fires in this study. This result would probably not hold true for all spring versus fall fires. Typically, the greatest differences in post-fire litter depth would be associated with either summer versus spring or summer versus fall fires. Summer fires, in response to hot dry conditions are often more intense and therefore consume more of the organic litter. In this case, too many variables cannot be accounted for, specifically not knowing the pre-fire litter depths. As a result, the post-fire litter depths are not a particularly meaningful indicator of the intensity of each of the fires. However, the observed litter depths at each of these sites will play a role in determining seed germination and species composition. For example, red pine regeneration is most successful on exposed mineral soils and associated thin moss; whereas white pine is less particular, regenerating on a range of litter depths and seedbed conditions (Ahlgren 1976).

Differences in the basal areas of stumps, snags and live trees indicate significant structural differences resulting from the spring, summer, and fall treatments of this study. Stanton Bay, the summer fire site, had no live trees, whereas the spring fire site at Pulling Lake had predominantly live trees, and the fall fire site at Emerald Lake had a mix of live and dead trees. This exemplifies the stark differences that can result from fires in different seasons. To generalize and suggest that spring and fall conditions are on average similar in terms of fire hazards, it would follow that the post-fire legacies of fires in these seasons would be similar or at the least have a similar range of variability. In this case, the spring fire resulted in an understorey burn with few of the canopy trees killed; whereas the fall burn had a range of effects from one plot with no surviving trees and another with very few fire-killed trees.

Conversely, fires during the summer, when conditions are more hazardous, will more likely be severe and result in stand-replacing fires. This study documented 100% tree mortality at the summer fire.

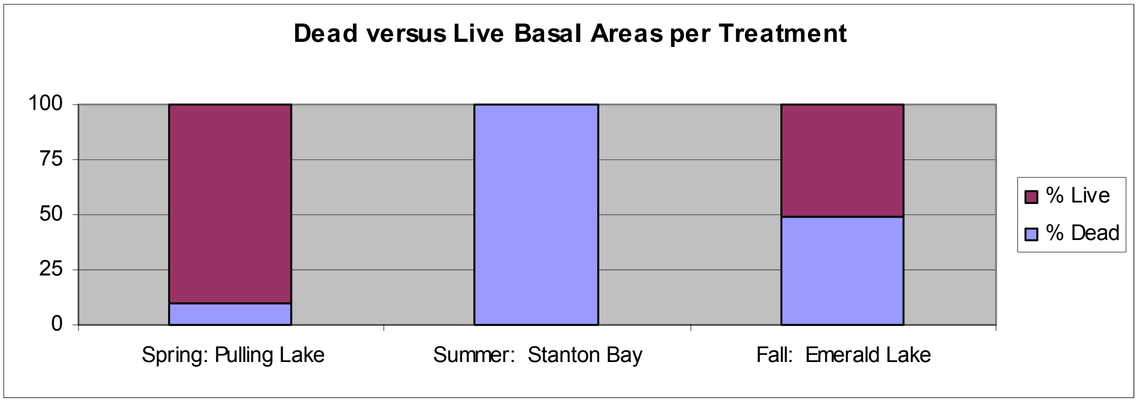


Figure 20. Percent ratios of dead versus live basal areas for each treatment.

Understanding the effects of the fall fire in this study is challenging. This prescribed burn was conducted to create a fuel break along the Canada U.S. border in an area heavily impacted by a major windstorm in July 1999. Once the fire was ignited in the blown down areas, it was monitored as it spread, ultimately reaching natural barriers, such as lakes (Beverly and Martell 2003). The fire spread into healthy red and white pine stands that had not been affected by the blowdown. The study plots for Emerald Lake were established in these stands which had not been affected by blowdown but had been subjected to naturally spreading fire. Some of these areas were immediately adjacent to the north shore of Knife Lake. In the case Emerald Lake Plot 3, the shoreline was 30 meters south of the plot, with a small cliff face to the northeast. The topography may have made it difficult for naturally spreading fire to back down areas with steeper topography. In addition, the topography may have created a lee or sheltered area so that fire was not intensified by wind. This plot showed the least fire mortality (dead basal area = 605cm^2 and live basal area = 10351cm^2). It is not possible to comment on whether the proximity of the lake or the immediate topography resulted in reduced fire intensity in this area.

Forest structure resulting from fire is important for a number of reasons. Large stand-replacing fires will create large even-aged forests. As they mature, such stands or forest areas provide important habitat conditions for wildlife such as woodland caribou, pine martin, and forest-interior birds (OMNR 1986; Dobbyn 1994; Banfield 1981). Conversely, smaller fires create smaller forest blocks that will have a higher edge to interior ratio and therefore provide habitat for different species. Similarly, fires that leave parts of the canopy intact may also result in forests with higher edge to interior ratios. This question of what forest structure may result from different fires is central to this study, as significant differences in post-fire structure have been documented for each of the different seasonal treatments. Specifically, the results of this study indicate that more work is needed to fully discern the effect of season on post-fire structure. With respect to prescribed burning objectives in the province as a method to restore the ecologically beneficial impacts of fire for forest renewal, it is important to fully understand the potential long-term implications in terms of forest structure of burning in the fall.

5.3 Species Composition

Vascular plant species diversity showed differences between treatments. These differences were predominantly documented for herbaceous plant and shrub species.

The diversity of tree species was nearly identical between the different fire treatments. Essentially, all the pre-fire tree species were found in each of the regenerating sites. The fall fire had both the highest shrub species diversity and the highest herbaceous species diversity. These differences are most likely the result in the differences in time since fire between the selected fires. Many herbaceous species (i.e. *Epilobium angustifolium*) are only able to occupy forested areas immediately after a fire or a similar disturbance makes light and nutrients sufficiently available. As trees and shrubs re-colonize the area, these adventitious herbaceous species are squeezed out. The spring fire in this study did not sufficiently open the canopy to allow for much influx of herbaceous species. The summer fire, with the lowest herbaceous species diversity, was well stocked with regenerating conifers to a height of 2m which were effectively squeezing out any herbaceous species that may have initially invaded the burn site.

It is apparent that species diversity and stand structure after fire are variable. Species diversity will fluctuate according to fire intensity and time since fire. In post-fire environments, the greatest species diversity will occur at the outset when numerous shrub and herbaceous plant species take advantage of increased nutrient and light availability. Many of these adventitious species are shade intolerant and will disappear as tree seedlings re-stock the area.

Deciduous tree species regeneration was the same between the different treatments. The deciduous regeneration was dominated by white birch and red maple. Conifer regeneration between sites was not as straightforward; no readily discernable patterns were observed between treatments. The spring fire at Pulling Lake had the greatest number of red and white pine and no jack pine seedlings. The fall fire at Emerald Lake had slightly fewer red pines and roughly half as many white pine and only a few jack pine seedlings. The summer fire at Stanton Bay was almost entirely regenerating as jack pine along with a few scattered white pines but almost no red pine seedlings. Black spruce seedlings were documented at all of the treatments, however in limited numbers (1 at Emerald Lake; 2 at Pulling Lake; and 17 at Stanton Bay). Good seed years for red and white pines are on average about seven years apart (Ahlgren 1976). Given that these fire sites are only in their second, third, and seventh growing seasons since the most recent fire, it may be too soon to project the eventual species matrix for each of the sites. Ultimately, time will determine which species will fill canopy gaps and regenerate forest stands at each of the different treatment areas.

Together post-fire forest structure and surviving trees will in part determine seedling regeneration. Forest structure will dictate light availability and seedbed conditions, while surviving trees may be important sources of seed. In the case of red pine, if seed trees are more than 35 to 70 meters apart, pollination and seed set will be limited (Ahlgren 1976).

5.4 Fire Management Policy Framework for Quetico Provincial Park

Fire management policy for parks and conservation reserves has grown out of increasing awareness of the importance of fire to ecosystems. One key issue is the accumulation of fuels as successive fire suppression creates an older aged stand mosaic on the landscape. This in turn results in a higher proportion of shade tolerant species including balsam fir. As the density of balsam fir has increased in regions across Ontario, so too have outbreaks of spruce budworm. Stands that have been affected by budworm, and are dead or dying, would naturally be renewed by fire. Currently, they are accumulating in the landscape. Interspersed with valuable stands of productive forests, managers are stuck between a rock and hard place. Allowing fire will restore forest productivity in affected areas but possibly at the expense of neighbouring stands; suppressing fire allows scheduled forest harvesting but further jeopardizes current productive forests, infrastructure and other human values in situations of catastrophic fire.

The new provincial fire policy has set targets for up to 160,100 hectares of ecological fire (renewing) per year, as well as goals for limiting unwanted fire to less than 75,100 hectares each year (OMNR 2004). This balancing act is a wise move towards re-integrating fire on the landscape of northwestern Ontario.

QPP is designated as a Wilderness Park under the Provincial Parks Act (1990) and therefore intended to be an "…area where the forces of nature are permitted to function freely," provided they do not threaten human safety or values inside the park, or land outside the park. Wilderness parks are the ideal place to achieve provincial objectives for ecological fire for many reasons. For one, fire is an ecological process and so should not be suppressed in a wilderness park. Secondly, fire can help ensure the full suit of ecological diversity in the specific regions that parks are representing. According to the new fire management strategy, "parks and other protected areas containing examples of …fire–dependent ecosystems will not continue to represent the natural heritage they were designed to protect unless exposed to fire in the coming decades"(OMNR 2004, p.12). Additionally, parks can serve as training grounds for developing technical and planning strategies for re-introducing fire cycles on the landscape and for promoting public understanding of fire's ecological role. These experiences may prove beneficial and widely applicable as the forest fire situation in Canada changes in response to climate change and other factors affecting fire cycles.

Quetico Provincial Park Fire Management Plan (1997)

The fire management goal for QPP is:

"To approximate the natural role of fire in perpetuation of Quetico's ecological processes, within the constraints of personal injury, value loss, economic and social disruption" (OMNR 1997).

Under the Regional Fire Management Strategy (Ontario West Fire Region), QPP is treated as a Measured Fire Management Zone; the area surrounding QPP is zoned Intensive. Fires within a Measured zone will be actioned commensurate with values threatened according to regional Measured zone direction and strategy (OMNR 1997). Within the Intensive zone, fires receive immediate and sustained suppression action to protect the allocated wood supply and the high number of human values (OMNR 1997). Balancing the park's desired fire objectives with fire suppression mandates that exist immediately beyond its boundaries, the Quetico Park Fire Management Plan delineates two zones: a Measured Zone and a Prescribed Natural Fire Zone. The Prescribed Natural Fire Zone makes up 63% of the park's core area; the measured zone is a buffer along the east, west, and north limits of the park boundary. Within the park's measured zone, regional directives and strategies for a measured zone will be followed. The southern boundary of the park abuts the BWCA in northern Minnesota, U.S. which has similar fire management objectives. However, under a Memorandum of Understanding between Ontario and Minnesota, all fires within in 3 km of the international border will be suppressed (OMNR 1997).

The Prescribed Natural Fire zone allows for natural fire and prescribed burns to meet management objectives. Human-caused fires will only be permitted in areas identified for renewal. Such areas include over-mature stands or areas affected by blowdown, insect outbreak or disease. Accepted prescription fires in QPP include Prescribed Natural Fire (PNF), Prescribed Burns (PBs), and Modified Response Fire. Using decision key, natural fires will be assessed to ensure that they fall within specific prescription parameters. Specifically, the Drought Code must be less than 300 and the Buildup Index less than 50, according to the Canadian Forest Fire Weather Index; these levels characterize mid-range high fire hazard. Prescribed burns must adhere to the guidelines in the Prescribed Burn Planning Manual. Modified Response Fires include human-caused fires in areas slated for renewal. Each Modified Response Fire requires an action plan and must satisfy prescription criteria.

A Vegetation Management Plan is to be developed for QPP. Through this plan the park will "strive to maintain the forest structure (e.g. age class distribution, patch size, shape) and forest composition (e.g. species, snags) of a natural fire driven ecosystem (OMNR 1997). This study provides preliminary evidence of how current fire management within the park is affecting forest structure and species composition. A summary of the results from this study (Table 12) indicate that forest structure may be readily influenced by fires of different season and that species diversity will be similar. What is not clear is how pre-fire forest stands will regenerate; specifically, if they will return to pre-fire stand composition or if new forest types will establish. This data could be established through ongoing post-fire monitoring over a period of many years. Quantitative pre-fire vegetation data in conjunction with post-fire vegetation data for time periods over several decades will best determine how forest stands may change as a result of fires in different seasons.

Table 12. Summary of results.

	Spring Fire: Pulling Lake June 1999. Prescribed Natural Fire	Summer Fire: Stanton Bay August 1995. Human-caused Fire	Fall Fire: Emerald Lake 2000. Prescribed Burn
Structure			
Basal area	90% alive : 10%dead	0% alive : 100% dead	51% alive : 49% dead
Species Richness			
Herbaceous	13	11	23
Shrubs	12	11	14
Trees	7	9	8
Total	35	30	46

5.5 Recommendations

Based on the findings of this research, recommendations are divided between those directed at park managers and those for future research.

Recommendations for park management:

- Allow as many fires as possible that satisfy the criteria to be a Prescribed Natural Fire;
- Monitor forests throughout the park for suitable sites to conduct renewing prescribed burns (i.e. areas of blowdown, spruce budworm outbreak, over-mature stands, etc.);

- Continue to educate the public on the ecological role of fire and link this back to the park's mandate to maintain ecological processes;
- Promote forest and fire research in Quetico and other Wilderness Parks;
- Establish or adopt a standard monitoring methodology to compile comparable data of post-fire conditions on recent fires and prescribed burns, and document trends;
- Explore connections between fire ecology and habitat requirements for species at risk, and fire–dependent species to ensure that opportunities to achieve multiple park objectives are not missed;
- Modify the Fire Management Plan as new science-based findings become available.

Recommendations for future research:

- One of the questions that arose out of this research is whether prescribed burns can be designed or engineered to emulate intense summer-like fire conditions during the fall or outside the natural fire season. As engineering variable prescribed burn intensities is possible, then further research should explore how the post-fire conditions of an intense fall prescribed burn compare to typical summer fires in terms of structure and species composition
- In fire-adapted ecosystems, such as the forests of Quetico Provincial Park, the findings of this study suggest that species composition after fire is dependent on multiple factors (e.g. the percentage of intact canopy), but that structure after fire is mostly a product of fire intensity, and fire intensity might be correlated to the season of fire. Further research to clarify the relationship between fire intensity, fire season, and post-fire structure is required.

APPENDIX A

QUETICO PROVINCIAL PARK FIRES FROM 1995 TO 2001

APPENDIX A

Quetico Provicial Park Fire From 1995 through 2001

	Fire #	Date	Size (ha)	Cause
1995	45	June 24	36	lightning
	46	July 01	1	lightning
	68	July 05	15	lightning
	71	July 18	88	lightning
	72	July 15	39	unknown
	81	June 25	6	lightning
	82	July 06	10	lightning
	83	July 07	10	lightning
	94	July 04	2.5	lightning
	95	July 13	28	lightning
	96	July 07	24	lightning
	97	July 03	1.5	lightning
	107	July 07	1	lightning
	115	July 29	1	lightning
	117	July 02	0.8	lightning
	118	July 04	0.1	recreation
	123	July 29	0.1	recreation
	128	August 04	0.3	lightning
	131	August 07	0.1	recreation
	139	August 23	15	lightning
	141	August 09	25085	recreation
	143	August 11	0.1	recreation
	149	August 17	1	lightning
	152	August 21	1	lightning
	154	August 21	0.1	lightning
	155	August 20	0.1	lightning
	156	August 21	0.2	lightning
	157	August 24	0.1	lightning
	160	August 30	0.2	lightning
	161	August 30	0.1	lightning
	163	August 30	0.1	lightning
	164	August 30	0.1	lightning
	166	September 01	0.2	lightning
	169	September 02	0.3	lightning
	171	September 03	0.4	lightning
	172	September 04	0.2	lightning
	175	September 05	0.2	lightning
	178	September 06	0.1	lightning
	180	September 15	0.1	lightning
	39	**Fires burned a total of :**	**25369**	

	Fire #	Date	Size (ha)	Cause
1996	4	June 07	0.7	lightning
	6	June 16	0.1	unknown
	7	June 17	0.1	recreation
	8	June 24	0.2	recreation
	9	June 13	200-250	unknown
	13	June 13	0.5	lightning
	14	June 13	88	lightning
	16	Jun 19	0.1	recreation
	25	June 26	0.1	lightning
	26	July 06	0.1	lightning
	29	June 21	0.1	recreation
	36	September 27	0.4	recreation
	42	August 22	0.1	recreation
	13	**Fires burned a total of :**	**90.5**	
1997	7	May 03	0.3	miscellaneous
	15	May 20	0.1	lightning
	22	June 10	2	recreation
	23	June 13	0.2	lightning
	39	July 17	0.5	lightning
	41	July 19	0.1	recreation
	44	July 27	0.1	recreation
	46	July 30	0.1	recreation
	48	July 30	0.1	recreation
	49	July 30	0.2	recreation
	56	August 01	0.3	recreation
	63	August 04	0.1	lightning
	80	August 06	0.1	lightning
	93	August 08	0.1	unknown
	94	August 08	0.3	recreation
	95	August 08	0.1	lightning
	96	August 09	4	lightning
	109	September 03	0.1	lightning
	112	September 12	0.4	recreation
	114	September 15	0.7	lightning
	115	September 19	0.3	recreation
	119	September 24	0.3	recreation
	121	September 25	0.3	miscellaneous
	23	**Fires burned a total of :**	**10.8**	

	Fire #	Date	Size (ha)	Cause
1998	36	May 29	0.1	lightning
	42	June 20	0.3	recreation
	46	July 04	3	lightning
	49	July 08	0.4	recreation
	52	July 16	0.4	lightning
	53	July 16	0.5	lightning
	54	July 16	0.2	lightning
	55	July 16	0.1	lightning
	58	July 17	0.7	lightning
	60	July 19	0.1	lightning
	63	July 21	0.1	lightning
	64	July 23	0.1	recreation
	67	July 24	0.1	lightning
	69	July 24	0.7	unknown
	70	July 24	0.1	lightning
	71	July 24	0.1	recreation
	74	July 28	0.1	lightning
	79	August 06	1.2	lightning
	81	August 08	0.1	recreation
	82	August 08	0.2	lightning
	83	August 09	1.5	lightning
	84	August 12	0.1	recreation
	87	August 14	0.8	lightning
	88	August 14	3.3	lightning
	89	August 14	0.3	lightning
	93	August 14	0.1	lightning
	94	August 14	0.3	recreation
	98	August 15	0.1	lightning
	99	August 15	0.1	lightning
	104	August 17	0.1	lightning
	105	August 17	0.1	lightning
	106	August 17	0.1	lightning
	107	August 17	0.1	lightning
	108	August 17	0.1	lightning
	109	August 17	0.1	lightning
	113	August 17	0.1	lightning
	114	August 17	0.1	lightning
	117	August 18	0.1	lightning
	119	August 18	0.1	lightning
	123	August 18	0.1	lightning
	132	August 21	0.2	lightning

	Fire #	Date	Size (ha)	Cause
1998	141	August 30	0.3	lightning
	143	August 30	0.1	recreation
	146	September 01	4.7	lightning
	151	September 04	0.1	lightning
	152	September 04	1.5	lightning
	153	September 05	0.1	lightning
	155	September 05	14	lightning
	157	Septemebr 06	0.4	lightning
	158	Septemebr 06	0.5	recreation
	159	Septemebr 06	0.5	lightning
	160	September 08	0.1	lightning
	162	Septemebr 12	0.1	lightning
	163	Septemeber 12	0.1	lightning
	164	Septmeber 13	0.1	lightning
	167	September 16	0.2	recreation
	56	**Fires burned a total of :**	**39.3**	
1999	17	May 26	0.3	recreation
	20(PNF-1)	June 12	20	lightning
	21	June21	1	recreation
	22	June22	0.1	lightning
	24	June 26	0.3	recreation
	33	July 31	0.6	recreation
	34	July 31	0.3	lightning
	7	**Fires burned a total of :**	**22.6**	
2000	8	May 19	1.3	recreation
	18	September 18	0.1	lightning
	22	August 02	0.1	lightning
	25	August 27	0.1	recreation
	27	August 30	0.2	recreation
	29	October 02	0.2	recreation
	6	**Fires burned a total of :**	**2**	
2001	3	June 05	0.3	lightning
	7	June 09	0.2	lightning
	8	June 24	0.8	lightning
	14	June 29	0.1	lightning
	16	June 30	0.1	lightning
	17	June 30	0.2	lightning
	18	June 30	0.1	lightning

	Fire #	Date	Size (ha)	Cause
2001	20	July 07	3	lightning
	22	July 07	1.6	lightning
	24	July 08	0.2	lightning
	28	July 09	5	lightning
	31	July 12	0.1	recreation
	33	July 14	1.5	lightning
	34	July 12	0.2	lightning
	37	July 13	0.2	lightning
	50	September 04	0.2	recreation
	55	September 27	0.5	recreation
	17	**Fires burned a total of :**	**14.3**	

APPENDIX B

Synoptic Results of Groundcover Quadrats

Appendix B

Synoptic Results of Groundcover Quadrats

* see foot of table for legend

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Stanton Bay	1	A	1	5.8	2	1	1	1			1				4				
		A	2	2.6	0	1	1	0											
		B	3	4.6	1	1	2	1									1		
		B	4	5.6	2	1	3	1			2						4		
		C	5	8.8	0	1	2	0											
		C	6	3.4	3	3	1	1			4		1				1		
		D	7	5	3	1	7	2			3				1			1	
		D	8	3.8	2	2	4	2			5							1	
		E	9	1.8	4	1	1	0			4				1		2	1	
		E	10	3.8	0	2	5	1											
Stanton Bay	2	A	1	3.2	3	1	2	0			3				4		3		
		A	2	3.8	2	3	2	1			5						4		
		B	3	5.2	0	2	2	0											
		B	4	3.8	0	2	2	1											
		C	5	1.6	0	0	0	1											
		C	6	1.6	0	1	1	2											
		D	7	2.6	1	1	2	1							2				
		D	8	8.6	3	1	3	0			2				1		3		
		E	9	5.6	3	1	2	1			2		2		3				
		E	10	10	3	2	2	1			18				2		3		

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Stanton Bay	3	A	2	1.4	1	1	1	1			3								
		B	3	4	3	0	1	1		1			1					1	
		B	4	1.8	0	0	0	1											
		C	5	5.2	2	1	2	1			4							2	
		C	6	1.8	3	1	0	1			3			1				1	
		D	7	30.2	3	2	0	1			1			2			2		
		D	8	6.2	3	0	2	1			2		1				1		
		E	9	66	2	1	1	0			3						2		
		E	10	3.8	3	1	2	1			7		1					1	
Stanton Bay	4	A	1	3	1	2	2	0			1								
		A	2	2.8	1	1	1	1			3								
		B	3	10.2	0	2	1	0											
		B	4	4.8	2	0	2	0			3						2		
		C	5	3	2	2	2	1									6	1	
		C	6	0	0	1	0	2											
		D	7	2	2	1	2	1			3						2		
		D	8	1.4	3	1	3	1					2				3	2	
		E	9	2.8	2	2	1	1			1						1		
		E	10	3.2	2	1	0	1			6						1		
Stanton Bay	5	A	1	5	1	2	1	1			1								
		A	2	1.4	1	1	1	1			3								
		B	3	5.4	0	2	1	0											
		B	4	4.8	2	0	1	0			3						2		
		C	5	5.2	2	1	1	1			4							2	
		C	6	1.8	3	1	0	1			3			1				1	
		D	7	4	2	1	2	1			3						2		
		D	8	5	3	3	1	1					2				3	2	
		E	9	5.4	2	1	1	0			3						4		
		E	10	3.8	3	0	1	1			7		1					1	

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Emrald Lake	1	A	1	6.8	1	5	2	0									1		
		A	2	2.4	0	2	1	0											
		B	3	5.3	1	1	4	0									2		
		B	4	3	0	2	4	0											
		C	5	6.4	0	4	3	0											
		C	6	3.8	0	3	4	0											
		D	7	3.2	0	4	2	0											
		D	8	5	0	3	2	0											
		E	9	5	0	3	3	0											
		E	10	0.2	0	2	2	0											
Emrald Lake	2	A	1	2.6	1	1	1	0									1		
		A	2	3.2	0	2	3	0											
		B	3	7.6	2	0	6	0									2		1
		B	4	1.6	1	1	1	0									1		
		C	5	1.6	1	1	2	0									3		
		C	6	2.1	0	2	3	0											
		D	7	3.6	1	2	4	0									1		
		D	8	1.6	1	0	3	0						1					
		E	9	1.8	1	4	3	0									2		
		E	10	1.4	0	2	3	0											
Emrald Lake	3	A	1	4	1	3	3	0	1										
		A	2	5	2	3	4	0	1									3	
		B	3	4.2	1	2	4	0	1										
		B	4	3	0	3	4	0											
		C	5	1.8	2	3	2	0	1								5		
		C	6	3.6	0	1	6	0											
		D	7	1.8	0	3	5	0											
		D	8	5.8	1	2	4	1	1										
		E	9	3.6	0	3	4	0											
		E	10	3.4	0	2	4	0											

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Emrald Lake	4	A	1	7.8	1	1	3	0										2	
		A	2	2.6	1	1	3	0									1		
		B	3	5.8	0	2	3	0											
		B	4	5	3	1	3	0		1							2	1	
		C	5	2	1	3	1	0									1		
		C	6	5.4	0	2	4	0											
		D	7	4.8	1	1	2	0									2		
		D	8	1.6	1	0	3	0										1	
		E	9	3	1	0	3	0										1	
		E	10	3.2	0	0	3	0											
Emrald Lake	5	A	1	3	2	3	1	0		1							5		
		A	2	4.6	3	2	4	3	1								1	2	
		B	3	4.2	0	1	5	2											
		B	4	2.6	2	2	4	0						1				3	
		C	5	2.6	0	1	3	0											
		C	6	3.8	2	1	3	3		6							6		
		D	7	3.6	1	2	5	0										1	
		D	8	5.2	1	3	4	0						3					
		E	9	3.4	2	3	3	0		2								3	
		E	10	4.6	0	4	3	1											
Pulling Lake	1	A	1	3.2	2	2	3	0								1		3	
		A	2	2.4	1	2	3	0										4	
		B	3	6.2	2	2	4	0									1	1	
		B	4	4.2	1	3	5	1											2
		C	5	7	2	2	5	0									1	1	
		C	6	6.4	1	1	3	0										2	
		D	7	3.6	1	3	2	1										3	
		D	8	8.6	2	3	2	0								3		2	
		E	9	9.2	2	1	1	0					1					3	
		E	10	11.6	2	1	2	0					4					1	

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Pulling Lake	2	A	1	6.6	1	2	4	0										2	
		A	2	7.4	0	2	3	0											
		B	3	7.6	0	3	2	0											
		B	4	10.4	2	3	0	0									1	1	
		C	5	7.8	2	1	1	1				1						1	
		C	6	4	1	2	3	0										1	
		D	7	8	1	2	3	0										7	
		D	8	5.4	1	1	2	0								1			
		E	9	7.4	0	3	2	0											
		E	10	2.8	1	3	2	2										1	
Pulling Lake	3	A	1	4.2	2	3	3	1								1		1	
		A	2	8.2	0	2	2	1											
		B	3	5.6	3	1	1	0	1	1								3	
		B	4	8	2	1	2	0	1							4			
		C	5	2.8	1	1	1	2										3	
		C	6	4	1	3	1	0										1	
		D	7	3	1	1	2	2					1						
		D	8	2.4	2	3	1	1	1									1	
		E	9	4.8	1	2	3	0										2	
		E	10	7.8	2	3	4	3	1							1			
Pulling Lake	4	A	1	4	1	2	4	1	2										
		A	2	3	1	2	3	1	2										
		B	3	4.4	3	2	3	1		5			1					2	
		B	4	4.6	0	2	4	1											
		C	5	3	4	1	3	0	1	1			1		1				
		C	6	5.4	0	2	3	1											
		D	7	7.8	0	1	1	0											
		D	8	4.2	0	1	2	0											
		E	9	2.8	1	0	1	2					1						
		E	10	2	0	0	1	2											

Site ID	Plot	Sub-plot	Quadrat	Average LD*	# of tree spp.	# of shrub spp.	# of herb spp.	# of moss spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Pulling Lake	5	A	1	6.4	1	1	0	1	1										
		A	2	6.4	1	1	1	1								1			
		B	3	4.8	0	1	1	0											
		B	4	8.6	0	1	1	0											
		C	5	2.8	0	1	1	0											
		C	6	4.4	1	1	0	0	5										
		D	7	3	1	1	1	1									1		
		D	8	2	2	1	1	1	1							1			
		E	9	4	0	1	1	1											
		E	10	2.8	1	0	1	1	1										

Code	**Scientific Name**	**Common Name**
Pinu str	*Pinus strobus*	white pine
Pinu res	*Pinus resinosa*	red pine
Pinu ban	*Pinus banksiana*	jack pine
Pice gla	*Picea glauca*	white spruce
Pice mar	*Picea mariana*	black spruce
Popu tre	*Populus tremuloides*	trembling aspen
popu gra	*Populus grandidentata*	large-toothed aspen
Quer rub	*Quercus rubra*	red oak
Betu pap	*Betula papyrifera*	white birch
Acer rub	*Acer rubrum*	red maple
Prun pen	*Prunus pensylvanica*	pin cherry

* Average LD is Average Litter Depth

APPENDIX C

Synoptic Results of Shrub / Seedling Quadrats

Appendix C

Synoptic Results of Shrub / Sapling Quadrats

* see foot of table for a legend of codes

Site ID	Plot	Sub-plot	Quadrat	# of tree spp.	# of shrub spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Stanton Bay	1	A	1	4	3	2		9				12		4		
		B	2	3	3	1		5				1				
		C	3	3	2			10						3	1	
		D	4	4	3			10				4		2	2	
		E	5	4	3	2				1		1		7		
Stanton Bay	2	A	1	4	4			4			1	4		4		
		B	2	3	4			9				2		8		
		C	3	0	2											
		D	4	4	4			12				5		3		1
		E	5	3	3									2	2	4
Stanton Bay	3	A	1	1	3			3								
		B	2	4	1	1		22						7	1	
		C	3	6	1	1		16		1	1			5	1	
		D	4	3	3			10			2			1		
		E	5	4	2		1	15		1				7		
Stanton Bay	4	A	1	3	3			19			1			8		
		B	2	4	2			36		2				8	1	
		C	3	5	2			26		2	1			10	1	
		D	4	4	2			22		3				6		
		E	5	3	3			17		3					1	
Stanton Bay	5	A	1	5	0	1		16		1	1			5		
		B	2	3	3			17		3					1	
		C	3	4	1	1		22						7	1	
		D	4	3	3			19			2			8		
		E	5	3	3			10			2			3		

Site ID	Plot	Sub-plot	Quadrat	# of tree spp.	# of shrub spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Emrald Lake	1	A	1	0	5											
		B	2	1	7									7		
		C	3	0	7											
		D	4	0	7											
		E	5	3	6						1			1		5
Emrald Lake	2	A	1	1	3									5		
		B	2	2	4									4		2
		C	3	2	3									15		1
		D	4	1	4											2
		E	5	3	5						1			6		3
Emrald Lake	3	A	1	1	5	6										
		B	2	1	4	1										
		C	3	1	5	1										
		D	4	0	4											
		E	5	0	6											
Emrald Lake	4	A	1	4	5		1			1				4	12	
		B	2	5	10	2	1				1			13	1	
		C	3	4	7	1	2							4	4	
		D	4	1	3						3					
		E	5	1	3						3					
Emrald Lake	5	A	1	4	7		1				6			5	4	
		B	2	5	3	1	4				4			4	5	
		C	3	3	4		2							3	7	
		D	4	3	5		3				2				5	
		E	5	3	4		5	2						3		
Pulling Lake	1	A	1	2	4								8		2	
		B	2	2	4								5		1	
		C	3	3	4								1	4	7	
		D	4	3	3								1	2	6	
		E	5	3	4	2							3		9	

Site ID	Plot	Sub-plot	Quadrat	# of tree spp.	# of shrub spp.	Pinu str	Pinu res	Pinu ban	Pice gla	Pice mar	Popu tre	Popu gra	Quer rub	Betu pap	Acer rub	Prun pen
Pulling Lake	2	A	1	2	2									1	5	
		B	2	2	5								4		3	
		C	3	1	4										1	
		D	4	2	4									4	4	
		E	5	2	2								1		4	
Pulling Lake	3	A	1	3	2					2			1		4	
		B	2	3	3	10							1		5	
		C	3	2	3								2		4	
		D	4	2	4	6									2	
		E	5	4	2	1	1						5		9	
Pulling Lake	4	A	1	4	3	2	10					1			2	
		B	2	2	2							1	1			
		C	3	2	2									4	2	
		D	4	2	3		1						1			
		E	5	1	4		3									
Pulling Lake	5	A	1	0	4											
		B	2	1	1		3									
		C	3	4	1	4						3	1		2	
		D	4	3	2	1	4								2	
		E	5	3	2								1		1	

Code	**Scientific Name**	**Common Name**
Pinu str	*Pinus strobus*	white pine
Pinu res	*Pinus resinosa*	red pine
Pinu ban	*Pinus banksiana*	jack pine
Pice gla	*Picea glauca*	white spruce
Pice mar	*Picea mariana*	black spruce
Popu tre	*Populus tremuloides*	trembling aspen
popu gra	*Populus grandidentata*	large-toothed aspen
Quer rub	*Quercus rubra*	red oak
Betu pap	*Betula papyrifera*	white birch
Acer rub	*Acer rubrum*	red maple
Prun pen	*Prunus pensylvanica*	pin cherry

REFERENCES

A.D. Revill Associates. (1978). *Ecological effects of fire and its management in Canada's National Parks: A synthesis of the literature volume one, literature review*. pp.1-191. Parks Canada.

A.D. Revill Associates. (1978). *Ecological effects of fire and its management in Canada's National Parks: A synthesis of the literature volume two, annotated bibliography*. pp.193-328. Parks Canada.

A.D. Revill Associates. (1978). *Ecological effects of fire and its management in Canada's National Parks: A synthesis of the literature volume three, unannotated bibliography*. Parks Canada.

Agee J. K., Bahro, B., Finney, M. A., Omi, P. N., Sapsis, D. B., Skineer, C. N., et al. (2000). The use of shaded fuelbreaks in landscape fire management. *Forest Ecology and Management,* 127, 55-66.

Agee, J. K. (1998). The landscape ecology of western forest regimes. *Northwest Science*, 72, 24-34.

Ahlgren, C. E. (1976). Regeneration of red pine and white pine following wildfire and logging in northeastern Minnesota. *Journal of Forestry*, 74, 135-140.

Alexander, M. E. (1982). Calculating and interpreting fire intensities. *Canadian Journal of Botany - Revue Canadienne de Botanique*, 60, 349-357.

Anonymous. (1988). *Annotated bibliography of fire behaviour and effects research at Petawawa 1979 - 1987*. Canadian Forestry Service, Petawawa National Forestry Institute Chalk River, Ontario.

Baker, W. L. (1994). Restoration of landscape structure altered by fire suppression. *Conservation Biology,* 8, 763-769.

Baker, W. L., Flaherty, P. H., Lindemann, J. D., Veblen, T. T., Eisenhart, K. S., & Kulakowski, D. W. (2002). Effect of vegetation on the impact of a severe blowdown in the southern Rocky Mountains, USA. *Forest Ecology and Management,* 168, 63-75.

Batzer, H. O., and M. P. Popp. (1985). Forest succession following a spruce budworm Outbreak in Minnesota. *The Forestry Chronicle,* April 1985, 75-80.

Bebawi, F. F., & Campbell, S. D. (2002). Impact of early and late dry-season fires on plant mortality and seed banks within riparian and subriparian infestations of rubber vine (*Cryptostegia grandiflora*). *Australian Journal of Experimental Agriculture,* 42, 43-48.

Bergeron, Y., & Dansereau, P. (1993). Predicting the composition of Canadian southern boreal forest in different fire cycles. *Journal of Vegetation Science,* 4, 827-832.

Bergeron, Y., Gauthier, S., Kafka, V., Lefort, P. & Lesieur, D. (2001). Natural fire frequency for the eastern Canadian boreal forest: Consequences for sustainable forestry. *Canadian Journal of Forest Research*, 31, 384-391.

Beverly, J. L., & Martell, D. L. (2003). Modeling *Pinus strobus* mortality following prescribed fire in Quetico Provincial Park. *Canadian Journal of Forest Research*, 33, 740-751.

Beverly, J.L. (1998). *Management and history of fire in Wabakimi Provincial Park, northwestern Ontario*. Unpublished M.Sc.F. thesis, University of Toronto, Ontario, Canada.

Bonan, G. B., & Shugart, H. H. (1989). Environmental factors and ecological processes in boreal forests. *Annual Review of Ecology and Systematics*, 20, 1-28.

Bond W. J., & van Wilgen, B. W. (1996). *Fire and plants*. London: Chapman & Hall.

Boyce, R. L., Friedland, A. J., Vostral, C. B., & Perkins T. D. (2003). Effects of a major ice storm on the foliage of four New England conifers. *EcoScience*, 10, 342-350.

Brockway, D. G., Gatewood, R. G., & Paris, R. B. (2002). Restoring fire as an ecological process in shortgrass prairie ecosystems: Initial effects of prescribed burning during the dormant and growing seasons. *Journal of Environmental Management,* 65, 135-152.

Brown J. K., & Smith J. K. (Eds.). (2000). *Wildland Fire in Ecosystems. Effects of fire on flora*. U.S. Department of Agriculture.

Camp, A., Oliver, C., Hessburg, P., & Everett, R. (1997). Predicting late successional fire refugia pre-dating European settlement in the Wenatchee Mountains. *Forest Ecology and Management*, 95, 63-77.

Candau J. N., Fleming R. A., & Hopkin A. (1998). Spatiotemporal patterns of large-scale defoliation caused by the spruce budworm in Ontario since 1941. *Canadian Journal of Forest Research,* 28, 1733-1741.

Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., et al. (2001). Climate change and forest disturbances. *BioScience,* 51, 723-734.

DeGrandpre, L., Morissette, J., & Gauthier, S. (2000). Long-term post-fire changes in the northeastern boreal forest of Quebec. *Journal of Vegetation Science*, 11, 791-800.

Despain, D. G., Clark, D. L., & Reardon, J. J. (1996). Simulation of crown fire effects on canopy seed bank in lodgepole pine. *International Journal of Wildland Fire*, 6, 45-49.

Diaz-Avalos, C., Peterson, D. L., Alvarado E., Ferguson, S. A., & Besag, J. E. (2001). Space-time modelling of lightning caused ignitions in the Blue Mountains, Oregon. *Canadian Journal of Forest Research,* 31, 1579-1593.

Doran, H. (2004). *Using probability surfaces to assess forest fire risk in Algonquin Provincial Park*. Unpublished M.E.S. thesis, University of Waterloo, Ontario, Canada

Dovciak, M., Frelich, L. E., & Reich, P. B. (2001). Discordance in spatial patterns of white pine (*Pinus strobus*) size-classes in a patchy near-boreal forest. *Journal of Ecology,* 89, 280-291.

Drewa, P. B. (2003). Effects of fire season and intesity on *Prosopis glandulosa* Torr.var. *glandulosa*. *International Journal of Wildland Fire,* 12, 147-157.

Driscoll, K. G., Arocena, J. M., & Massicotte, H. B. (1999). Post-fire soil nitrogen content and vegetation composition in Sub-Boreal spruce forests of British Columbia's central interior, Canada. *Forest Ecology and Management,* 121, 227-237.

Dyer, J. M., & Baird, P. R. (1997). Wind disturbance in remnant forest stands along the prairie-forest ecotone, Minnesota, USA. *Plant Ecology,* 129, 121-134.

Engle, D. M., & Bidwell, T. G. (2001). The response of central North American prairies to seasonal fire. *Journal of Range Management*, 54, 2-10.

Flannigan, M. D., & Harrington, J. B. (1987). A study of the relationship of meteorological variables to monthly provincial area burned by wildfire in Canada 1953 - 80. pp. 229-234. American Meteorological Society, Boston, Mass.

Flannigan, M. D., & Wotton, B. M. (1991). Lightning-ignited forest fires in northwestern Ontario. *Canadian Journal of Forest Research,* 21, 277-287.

Flannigan, M. D., Bergeron, Y., Engelmark, O., & Wotton, B. M. (1998). Future wildfire in circumboreal forests in relation to global warming. *Journal of Vegetation Sciences*, 9, 469-476.

Flannigan, M. D., Stocks, B. J., & Wotton, B. M. (2000). Climate change and forest fire. *The Science of the Total Environment,* 262:221-229.

Flannigan, M. D., & Wotton, B. M. (2001). Climate, weather, and area burned. In: E. A. Johnson & K. Miyanishi (Eds.), *Forest fires: Behaviour and ecological effects*. (pp. 351-373). San Diego: Academic Press.

Fleming, R. A. (2000). Climate change and insect disturbance regimes in Canada's boreal forest. *World Resources Review,* 12, 521-555.

Fleming, R. A., Hopkin, A., & Candau, J. (2000). Insect and disease disturbance regimes in Ontario's forests. In A. Perara, D. Euler, and I. Thompson (Eds.), *Ecology of a managed terrestrial landscape: Patterns and processes of forest landscapes in Ontario*. (pp. 142-162). Vancouver: University of British Columbia Press.

Fleming, R. A., Barclay, H. J., & Candau, J. (2002). Scaling-up an autoregressive time-series model (of spruce budworm population dynamics) changes its qualitative behaviour. *Ecological Modelling,* 149, 127-142.

Fleming, R. A., Candau, J., & McAlpine, R. S. (2002). Landscape-scale analysis of interactions between insect defoliation and forest fires in central Canada. *Climatic Change*, 55, 251-272.

Fortin, M., Payette, S., & Marineau, K. (1999). Spatial vegetation diversity index along a postfire successional gradient in the northern boreal forest. *EcoScience,* 6, 204-213.

Foster, D. R., Knight, D. H., & Franklin, J. F. (1998). Landscape patterns and legacies resulting from large, infrequent, forest disturbances. *Ecosystems,* 1, 497-510.

Franklin J. F. & Agee J. K. (2003). Forging a science-based national forest fire policy. *Issues in Science and Technology,* 20, 59-66.

Franklin, S. B., Robertson, P. A., & Fralish, J. S. (2003). Prescribed burning effects on upland *Quercus* forest structure and function. *Forest Ecology and Management,* 184, 315-335.

Fraser, R. H., & Li, Z. (2002). Estimating fire-related parameters in boreal forest using SPOT VEGETATION. *Remote Sensing of Environment,* 82, 95-110.

Frelich, L. E., & Reich, P. B. (1995). Neighborhood effects, disturbance, and succession in forests of the western Great Lakes Region. *EcoScience,* 2, 148-158.

Gauthier, S., DeGrandpre, L., & Bergeron, Y. (2000). Differences in forest composition in two boreal forest ecoregions of Quebec. *Journal of Vegetation Science,* 11, 781-790.

Glenn-Lewin D. C., Peet, R. K., & Veblen, T. T. (Eds.). (1992). *Plant Succession: theory and prediction*. Cambridge: Chapman & Hall.

Glitzenstein, J. S., Platt, W. J., & Streng, D. R. (1995). Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. *Ecological Monographs*, 65, 441-476.

Grau, H. R. (2001). Regional-scale spatial patterns of fire in relation to rainfall gradients in sub-tropical mountains, NW Argentina. *Global Ecology & Biogeograpgy***,** 10, 133-146.

Hahn J. T. 1984. *Tree Volume and biomass equations for the Lake States*. (Research Paper NC-250). United States Department of Agriculture, Forest Service.

Harrington J. B., Flannigan M. D. & Van Wagner C. E. (1983). *A study of the relation of components of the Fire Weather Index to monthly provincial area burned by wildfire in Canada 1953 - 80*. (Information Report PI-X-25). Canadian Forestry Service, Petawawa National Forestry Institute.

Heinselman M. (1996). *The boundary waters wilderness ecosystem*. Minneapolis: University of Minnesota Press.

Hely, C., Bergeron, Y., & Flannigan, M. D. (2000). Effects of stand composition on fire hazard in mixed-wood Canadian boreal forest. *Journal of Vegetation Science,* 11, 813-824.

Hely, C., Flannigan, M. D., Bergeron, Y., & McRae, D. J. (2001). Role of vegetation and weather on fire behaviour in the Canadian mixedwood boreal forest using two fire behaviour prediction systems. *Canadian Journal of Forest Research*, 31, 430-441.

Hirsch, K. G. (1991). A chronological overview of the 1989 fire season in Manitoba. The *Forestry Chronicle,* 67, 358-365.

Hockings, M. (1998). Evaluating management of protected areas: Integrating planning and evaluation. *Environmental Management*, 22, 337-345.

Howe, H. F. (1994). Response of early-flowering and late-flowering plants to fire season in experimental prairies. *Ecological Applications,* 4, 121-133.

Howe, H. F. (1994). Managing species diversity in tallgrass prarie: Assumptions and implications. *Conservation Biology,* 8, 691-704.

Huston, M. A. (1999). Local processes and regional patterns: Appropriate scales for understanding variation in the diversity of plants and animals. *OIKOS,* 86, 393-401.

Jacqmain, E. I., Jones, R. H., & Mitchell, R. J. (1999). Influences of frequent cool-season burning across a soil moisture gradient an oak community strucuture in longleaf pine ecosystems. *The American Midland Naturalist,* 141, 85-100.

Jasinski, K., & Angelstam, P. (2002). Long-term differences in the dynamics within a natural forest landscape - consequences for management. *Forest Ecology and Management*, 161, 1-11.

Johnson D. R. & Agee J. K. (Eds.). (1988). *Ecosystem Management for Parks and Wilderness*. Seattle: University of Washington Press.

Johnson, E. A., Miyanishi, K., & O'brien, N. (1999). Long-term reconstruction of the fire season in the mixedwood boreal forest of Western Canada. *Canadian Journal of Botany - Revue Canadienne de Botanique*, 77, 1185-1188.

Keane, R. E., Burgan, R., & van Wagtendonk, J. (2001). Mapping wildland fuels for fire management across multiple scales: Integrating remote sensing, GIS, and biophysical modeling. *International Journal of Wildland Fire,* 10, 301-319.

Kennard, D. K., Gould, K., Putz, F. E., Fredericksen, T. S., & Morales, F. (2002). Effect of disturbance intensity on regeneration mechanisms in a tropical dry forest. *Forest Ecology and Management,* 162, 197-208.

King, A. W. (1993). Considerations of scale and hierarchy. In S. Woodley, J. Kay, and G. Francis (Eds.) *Ecological integrity and the management of ecosystems*. (pp.19-45). St. Lucie Press.

Kirkman, L. K., Drew, M. B., & Edwards, D. (1998). Effects of experimental fire regimes on the population dynamics of *Schwalbea americana* L. *Plant Ecology,* 137, 115-137.

Knight, D. H., & Wallace, L. L. (1989). The Yellowstone fires: Issues in landscape ecology. *BioScience*, 39, 700-706.

Kronberg, B. I., Watt, M. J., & Polischuk, S. C. (1998). Forest-climate interactions in the Quetico-Superior ecotone(northwest Ontario and northern Minnesota). *Environmental Monitoring and Assessment*, 50, 173-187.

Kulakowski D., & Veblen T. T. (2002). Influences of fire history and topography on the pattern of a severe wind blowdown in a Colorado subalpine forest. *Journal of Ecology*, 90, 806-819.

Kulakowski D., Veblen T. T., & Bebi P. (2003). Effects of fire and spruce beetle outbreak legacies on the disturbance regime of a subalpine forest in Colorado. *Journal of Biogeography* 30, 1445-1456.

Lassig, R., & Mocalov, S. A. (2000). Frequency and characteristics of severe storms in the Urals and their influence on the development, structure and management of the boreal forests. *Forest Ecology and Management,* 135, 179-194.

Leblon, B., Alexander, M., Chen, J., & White, S. (2002). Monitoring fire danger of northern boreal forests with NOAA_AVHRR ADVI images. *International Journal of Remote Sensing,* 22, 2839-2846.

Lorimer, C. G., Dahir, S. E., & Singer, M. T. (1999). Frequency of partial and missing rings in *Acer saccharum* in relation to canopy and growth rate. *Plant Ecology,* 143, 189-202.

Lynham, T. J., & Curan, T. R. (1998). Vegetation recovery after wildfire in old-growth red and white pine.(Technical Note no. 100) Canadian Forest Service. Great Lakes Forest Centre.

Lynham T. J., & Curan, T. R. (1998). Preliminary assessment of a 25,000 ha 1995 wildfire (FOR-141) in Quetico Provincial Park. Canadian Forest Service. Great Lakes Forest Centre.

Mack, M. C., & D'Antonio, C. M. (1998). Impacts of biological invasions on disturbance regimes. *TREE,* 13, 195-1998.

Martell, D. L. (1983). Fire impact management in the boreal forest region of Canada. In R. W. Wein, R. R. Riewe, and I. R. Methven (Eds.), *Proceedings – Resources and Dynamics of the Boreal Zone; August 1982; Thunder Bay, Ontario.* Association of Canadian Universities for Northern Studies, Ottawa, Ont. (pp. 526-533).

McLoughlin, L. C. (1998). Season of burning in the Sydney region: The historical records compared with recent prescribed burning. *Australian Journal of Ecology,* 23, 393-404.

McRae, D. J., & Stocks, B. J. (1987). Large-scale convection burning in Ontario. pp.23-30 *in* American Meteorological Society, Boston, Mass.

McRae, D. J., & Flannigan, M. D. (1990). Development of large vortices on prescribed fires. *Canadian Journal of Forest Research,* 20, 1878-1887.

McRae, D. J., Duschesne, L. C., Freedman, B., Lynham, T. J., & Woodley, S. (2001). Comparisons between wildfire and forest harvesting and their implications in forest management. *Environmental Review,* 9, 223-260.

Menge, B. A., Olson, A. M., & Dahlhoff, E. P. (2002). Environmental stress, bottom-up effects, and community dynamics: integrating molecular-physiological and ecological approaches. *Integrative and Comparitive Biology*, 42, 892-908.

Menges, E. S., & Deyrup, M. A. (2001). Postfire survival in south Florida slash pine: Interacting effects of fire intensity, fire season, vegetation, burn size, and bark beetles. *International Journal of Wildland Fire,* 10, 53-63.

Methven, I. R., Van Wagner C. E., & Stocks B. J. (1975). *The vegetation of four burned areas in northwestern Ontario*. (PS-X-60). Canadian Forest Service. Petawawa Forest Experiment Station.

Miller, C. & Urban, D. L. (2000). Connectivity of forest fuels and surface fire regimes. *Landscape Ecology*, 15, 145-154.

Morgan, P., Hardy, C. C., Swetnam, T. W., Rollins, M. G., & Long, D. G. (2001). Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. *International Journal of Wildland Fire,* 10, 329-342.

Mueller-Dombois, D, & Ellenberg, H. (1974). *Aims and methods of vegetation ecology*. Toronto: John Wiley & Sons.

Myers, M. (2000). *Summary of Emerald Lake Prescribed Burn Results*. Ontario Ministry of Natural Resources, Aviation and Forest Fire Management.

Neary, D. G., Klopatek, C. C., DeBanoa, L. F., & Ffolliott, P. F. (1999). Fire effects on belowground sustainability: A review and synthesis. *Forest Ecology and Management,* 122, 51-71.

Negron-Ortiz, V., & Gorchov, D. L. (2000). Effects of fire season and postfire herbivory on the cycad *Zamia pumila* (Zamiaceae) in slash pine savanna, Everglades National Park, Florida. *International Journal of Plant Sciences,* 161, 659-669.

Nelson, J. (1996). Fire ecology research in Quetico. *Man and Nature*, 77-85.

Niklasson, M., and A. Granstrom. (2000). Numbers and sizes of fires: Long-term spatially explicit fire history in a Swedish boreal landscape. *Ecology,* 81, 1484-1499.

Ontario Ministry of Natural Resources. (1977). *Quetico Provincial Park Master Plan*. Toronto: Queen's Printer for Ontario.

Ontario Ministry of Natural Resources. (1995). *Quetico Provincial Park revised park policy*. Toronto: Queen's Printer for Ontario.

Ontaroi Ministry of Natural Resources. (1997). *Quetico Provincial Park Fire Management Plan*. Toronto: Queen's Printer for Ontario.

Ontario Ministry of Natural Resources. (2004). *Background to the development of Ontario's forest fire management strategy*. Toronto: Queen's Printer for Ontario.

Ontario Ministry of Natural Resources. (2004). *Forest fire management strategy for Ontario*. Toronto: Queen's Printer for Ontario.

Owens, M. K., Mackley, J. W., & Caroll, C. J. (2002). Vegetation dynamics following seasonal fires in mixed mesquite / acacia savannas. *Journal of Range Management,* 55, 509-516.

Paine, R. T., Tegner, M. J., & Johnson, E. A. (1998). Compounded perturbations yield ecological surprises. *Ecosystems,* 1, 535-545.

Park, A. D. (2001). Environmental influences on post-harvest natural regeneration in Mexican pine-oak forests. *Forest Ecology and Management,* 144, 213-228.

Parks, B. (1999). *Post fire vegetaion dynamics in Quetico Park*. Unpublished B.E.S. thesis, University of Waterloo, Ontario, Canada.

Plonski, W. L. (1974). *Normal yield tables (metric) for major forest species of Ontario*. Toronto: Queen's Printer for Ontario.

Pollman, W. (2002). Effects of natural disturbance and selective logging on *Nothofagus* forests in south-central Chile. *Journal of Biogeography,* 29, 955-971.

Quintilio, D., Alexander, M. E., & Ponto, R. L. (1991). *Spring fires in a semimature trembling aspen stand in central Alberta*. (Information Report NOR-X-323). Forestry Canada, Northwest Region.

Radeloff, V. C., Mladenoff, D. J., & Boyce, M. S. (2000). A historical perspective and future outlook on landscape scale restoration in northwest Wisconsin pine barrens. *Restoration Ecology,* 8, 119-126.

Ramsey, G., & Higgins, D. (1986). *Canadian forest fire statistics / Statistiques sur les incendies de forest au Canada*. (Information Report PI-X-49 E/F). Canadian Forestry Service, Petawawa National Forestry Institute.

Rantis, P., & Johnson, J. E. (2002). Understorey development in canopy gaps of pine and pine-hardwood forests of the upper Coastal Plain of Virginia. *Plant Ecology,* 159, 103-115.

Reich, P. B., Carlson, D., Frelich, L. E., Friedman, S. K., & Grigal, D. F. (2001). Influence of logging, fire, and forest type on biodiversity and productivity in southern boreal forests. *Ecology,* 82, 2731-2748.

Rollins, M. G., Swetnam, T. W., & Morgan, P. (2001). Evaluating a century of fire patterns in two Rocky Mountain wilderness areas using digital fire atlases. *Canadian Journal of Forest Research,* 31, 2107-2123.

Romme, W. H., Everham, E. H., Frelich, L. E., Moritz, M. A., & Sparks, R. E. (1998). Are large, infrequent disturbances qualitatively different from small, frequent disturbances? *Ecosystems,* 1, 524-534.

Rowe, J. S. (1972). *Forest Regions of Canada*. Canadian Forest Service.

Ryan, K. C. (2002). Dynamic interactions between forest structure and fire behaviour in boreal ecosystems. *Silva Fennica,* 36, 13-39.

Schneider, D. C. (2001). The rise of the concept of scale in ecology. *BioScience,* 51, 545-553.

Simpson, M. (2002). Fire in the boreal forest. *Wildflower*, 18, 18-21.

Sims, R. A., Towill, W. D., Baldwin, K. A., & Wickware, G. M. (1990). *Field guide to the forest ecosystem classificantion for northwestern Ontario.* Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit.

Skinner, W. R., Stocks, B. J., Martell, D. L., Bonsal, B., & Shabbar, A. (1999). The association between circulation anomalies in the mid-troposphere and area burned by wildland fire in Canada. *Theoretical and Applied Climatology,* 63, 89-105.

Sparks J.C., Masters, R. E., Engle, D. M., Palmer, M. W., & Bukenhofer, G. A. (1998). Effects of late growing-season and late-dormant season prescribed fire on herbaceous vegetation in restored pine grassland communities. *Journal of Vegetation Science,* 9, 133-142.

Sparks, J.C., Masters, R. E., Engle, D. M., & Bukenhofer, G. A. (2002). Season of burn influences fire behaviour and fuel consumption in restored shortleaf pine-grassland communities*. Restoration Ecology*, 10, 714-722.

Stocks, B. J., Fosberg, M. A., Lynham, T. J., Mearns, L.B., Wotton, M., Yang, Q., et al. (1998). Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change*, 38, 1-13.

Suffling, R., Lihou, C., & Morand, Y. (1988). Control of Landscape Diversity by Catastrophic Disturbance: A Theory and a Case Study of Fire in a Canadian Boreal Forest. *Environmental Management,* 12, 73-78.

Suffling, R. & Perara, A. (2003). Concepts and approaches in characterising natural and anthropogenic forest disturbance. In *Proceedings – Emulating Natural Landscape Disturbances*.

Thonicke, K., Venevsky, S., Sitch, S., & Cramer, W. (2002). The role of fire disturbance for global vegetation dynamics: coupling fire into a Dynamic Global Vegetation Model. *Global Ecology and Biogeography,* 10, 661-677.

Todd, B., & Kourtz, P. H. (1991). *Predicting the daily occurrence of people-caused forest fires*. (Information Report PI-X-103). Forestry Canada, Petawawa National Forestry Institute, Chalk River, Ontario

Turner, M. G. (1989). Landscape ecology: The effect of pattern on process. *Annual Review of Ecology and Systematics* 20, 171-197.

Turner, M. G., & Romme, W. H. (1994). Landscape dynamics in crown fire ecosystems. *Landscape Ecology,* 9:59-77.

Turner, M. G., Baker, W. L., Peterson, C. J., & Peet, R. K. (1998). Factors influencing succession: Lessons from large, infrequent, natural disturbances. *Ecosystems,* 1, 511-523.

Turner, M. G., & Dale, V. (1998). Comparing large, infrequent disturbances: What have we learned? *Ecosystems,* 1, 493-496.

Tyhuis, R. J. (1999). *The effects of forest fire on the aquatic ecosystem: referenced to Quetico Provincial Park*. Unpublished report.

USDA. (2002). *After the storm: a progress report from the Superior National Forest*. United States Department of Agriculture, Forest Service.

Veblen, T. T. (1992). Regeneration Dynamics. In D.C. Glenn-Lewin, R.K. Peet, and T.T. Veblen (Eds.), *Plant succession: Theory and prediction*. (pp. 152-187). London: Chapman & Hall.

Vonnegut, B., Latham, D. J., Moore, C. B., & Hunyady, S. J. (1995). An explanation for anomalous lightning from forest fire clouds. *Journal of Geophysical Research,* 100, 5037-5050.

Vujnovic, K., Wein, R. W., & Dale, M. R. T. (2002). Predicting plant species diversity in response to disturbance magnitude in grassland remnants of central Alberta. *Canadian Journal of Botany - Revue Canadienne de Botanique,* 80, 504-511.

Walshe, S. (1980). *Plants of Quetico and the Ontario Shield*. Toronto: University of Toronto Press.

Ward, P.C., & Tithecott, A.G. (1993). *The impact of fire management on the boreal landscape of Ontario.* Aviation, flood and fire management; Ontario Ministry of Natural Resources.

Wierzchowski, J., Heathcott, M., & Flannigan, M. D. (2002). Lightning and lightning fire, central cordillera, Canada. *International Journal of Wildland Fire,* 11, 41-51.

Wikle, C. K. (2003). Hierarchical models in environmental science. *International Statistical Review,* 71, 181-199.

Williams, R. J., Gill, A. M., & Moore, P. H. R. (1998). Seasonal changes in fire behaviour in a tropical savanna in northern Australia. *International Journal of Wildland Fire*, 8, 227-239.

Winfield, M. (2000). *An evaluation of the feasibility of restoring woodland caribou (Rangifer tarandus caribou) into Quetico Provincial Park*. Unpublished B.E.S. thesis, University of Waterloo, Ontario, Canada.

Woods, G. T., & Day, R. J. (1976). *The present and past role of fire in Quetico Provincial Park*. Ontario Ministry of Natural Resources.

Woods, G. T., & Day, R. J. (1977). *A summary of the fire ecology study of Quetico Provincial Park*. Ontario Ministry of Natural Resources.

Woods, G. T., & Day, R. J. (1977). *A fire history study of Quetico Provincial Park*. 4, 1-16. Ontario Ministry of Natural Resources.

Wotton, B. M., & Flannigan, M. D. (1993). Length of the fire season in a changing climate. *The Forestry Chronicle,* 69, 187-1992.

Wotton, B. M., Martell, D. L., & Logan, K. A. (2003). Climate change and people-caused forest fire occurrence in Ontario. *Climatic Change,* 60, 275-295.