Trends in large fires in Canada, 1959-2007

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PREFACE

The Canadian Councils of Resource Ministers developed a Biodiversity Outcomes Framework[1] in 2006 to focus conservation and restoration actions under the *Canadian Biodiversity Strategy*.[2] *Canadian Biodiversity: Ecosystem Status and Trends 2010*[3] was a first report under this framework. It assesses progress towards the framework's goal of "Healthy and Diverse Ecosystems" and the two desired conservation outcomes: i) productive, resilient, diverse ecosystems with the capacity to recover and adapt; and ii) damaged ecosystems restored.

The 22 recurring key findings that are presented in *Canadian Biodiversity: Ecosystem Status and Trends 2010* emerged from synthesis and analysis of technical reports prepared as part of this project. Over 500 experts participated in the writing and review of these foundation documents. This report, *Trends in large fires in Canada, 1959-2007*, is one of several reports prepared on the status and trends of national cross-cutting themes. It has been prepared and reviewed by experts in the field of study and reflects the views of its authors. Since the analysis for this report was completed in 2009, trends for total area burned in Canada by decade were calculated including data up to 2010. Results can be found on page 96 of *Canadian Biodiversity: Ecosystem Status and Trends 2010* at www.biodivcanada.ca/ecosystems (Federal, Provincial and Territorial Governments of Canada, 2010).

Acknowledgements

We thank the reviewers of this report.

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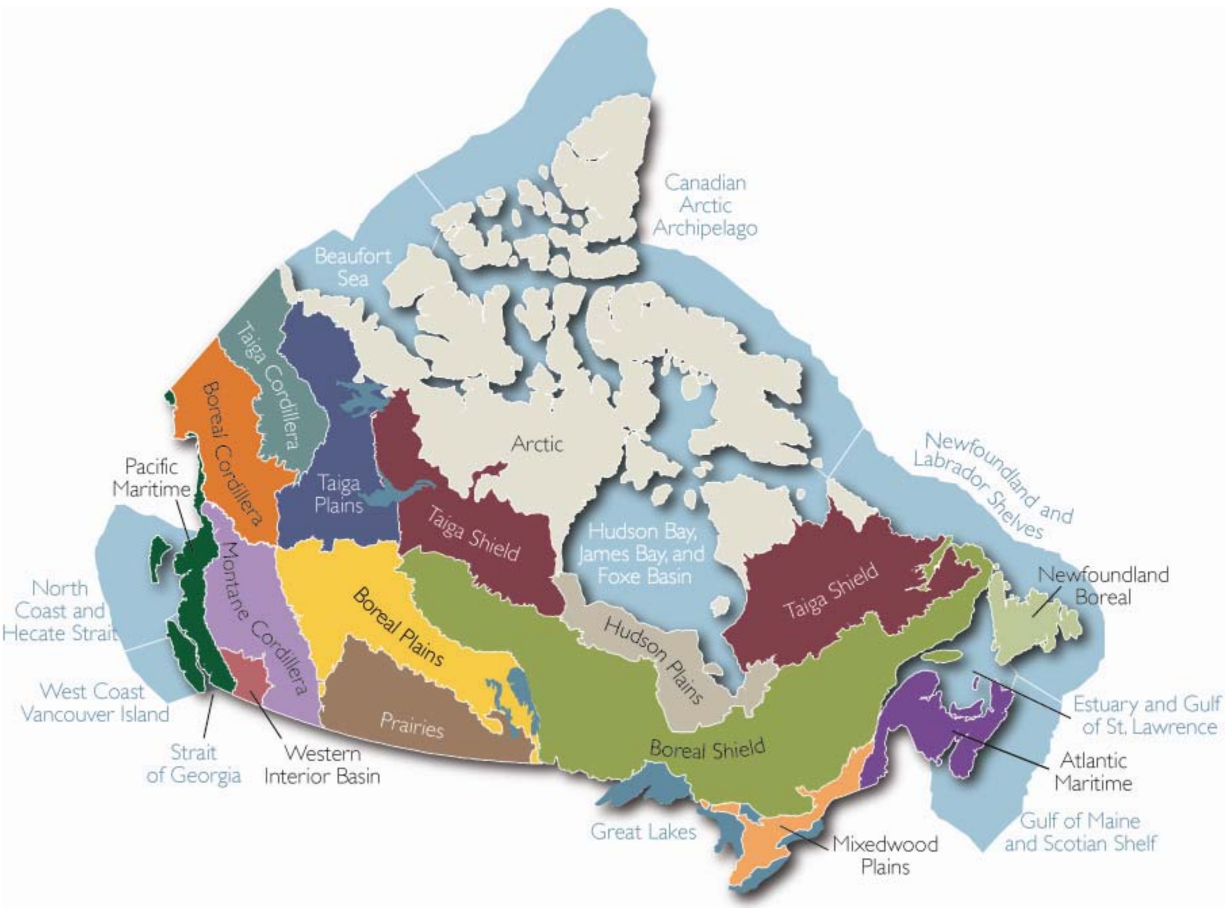
[1] Environment Canada. 2006. Biodiversity outcomes framework for Canada. Canadian Councils of Resource Ministers. Ottawa, ON. 8 p. http://www.biodivcanada.ca/default.asp?lang=En&n=F14D37B9-1

[2] Federal-Provincial-Territorial Biodiversity Working Group. 1995. Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity. Environment Canada, Biodiversity Convention Office. Ottawa, ON. 86 p. http://www.biodivcanada.ca/default.asp?lang=En&n=560ED58E-1

[3] Federal, Provincial and Territorial Governments of Canada. 2010. Canadian biodiversity: ecosystem status and trends 2010. Canadian Councils of Resource Ministers. Ottawa, ON. vi + 142 p. http://www.biodivcanada.ca/default.asp?lang=En&n=83A35E06-1

Ecological Classification System – Ecozones+

A slightly modified version of the Terrestrial Ecozones of Canada, described in the *National Ecological Framework for Canada*,[4] provided the ecosystem-based units for all reports related to this project. Modifications from the original framework include: adjustments to terrestrial boundaries to reflect improvements from ground-truthing exercises; the combination of three Arctic ecozones into one; the use of two ecoprovinces – Western Interior Basin and Newfoundland Boreal; the addition of nine marine ecosystem-based units; and, the addition of the Great Lakes as a unit. This modified classification system is referred to as "ecozones+" throughout these reports to avoid confusion with the more familiar "ecozones" of the original framework.[5]



[4] Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa/Hull, ON. 125 p. Report and national map at 1:7 500 000 scale.

[5] Rankin, R., Austin, M. and Rice, J. 2011. Ecological classification system for the ecosystem status and trends report. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 1. Canadian Councils of Resource Ministers. Ottawa, ON. http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-0

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INTRODUCTION

Fire is an important disturbance in the forest ecosystems of Canada. On average, 18,471 km^2 of forest burn annually, 92% of which burns within the boreal forest. Due to the long history of fire in the boreal forest, many boreal tree species have evolved to rely on fire to perform important ecological functions including: nutrient cycling, influencing species composition and age structure, maintaining productivity and diversity of habitats, and regulating insects and disease (Weber and Flannigan, 1997; McCullough et al., 1998; Volney and Hirsch, 2005; Parker et al., 2006; Soja et al., 2007). The boreal forests of Canada are primarily contained within the Taiga Plains, Taiga Shield, Taiga Cordillera, Boreal Plains, Boreal Shield, Newfoundland Boreal, Boreal Cordillera, and Hudson Plains ecozones$^+$. From an ecological standpoint fires can be an essential driver of ecosystem processes in these and other ecozones$^+$.

Characteristics of the fire regime (fire frequency, size, intensity, type, seasonality, and severity) have been shown to influence forest ecology and species composition (Vaillancourt et al., 2009). Areas that experience frequent fires select for species that take advantage of shorter life cycles, for example trembling aspen (*Populus tremuloides* Michx) (de Groot et al., 2003), compared to species like balsam fir (*Abies balsamea* (L.) Mill.), which are found in areas with less frequent fire occurrence, such as the Atlantic Maritime (Weber and Flannigan, 1997).

Fire size affects landscape patchiness by influencing regeneration distances. Areas where larger fires typically occur, such as the Boreal Shield, typically contain species that can spread their seeds over large distances, for example birch (*Betula papyrifera* Marsh) (de Groot et al., 2003) or that have an aerial seedbank, such as *Pinus banksiana* or *Picea mariana* (Chabot et al., 2009).

Fire intensity is a measure of the energy released during a fire. Intensity depends on fuel loads, topography, and weather, and can also be affected by previous disturbances. Some tree species are strongly affected by fire intensity, for example red pine (*Pinus resinosa* Aiton) (Flannigan and Bergeron, 1998). Although red pines are dependent on fire to promote regeneration by opening the canopy and reducing competition; they are limited by intense crown fires that cause mortality. Mature pines can survive moderately intense surface fires allowing them to persist after fire and act as a seed source for the next generation (Flannigan and Bergeron, 1998). Another example of the ecological effects of intensity is from species such as Jack pine (*Pinus banksiana* Lamb) and lodgepole pine (*Pinus contorta* Dougl.), which store seeds in their canopy requiring moderately intense crown fires to occur at an intermediate cycle (reproductive age is 20 to 25 years) (Amiro et al., 2004; Burton et al., 2008) to disperse seeds (Weber and Flannigan, 1997; Flannigan et al., 2000; Gauthier et al., 2009). The seeds of these species are stored in serotinous cones that require high temperatures to open and release the seeds for dispersal (Beaufait, 1960; Gauthier et al., 1996).

Fire intensity can also be related to fire type. There are three types of forest fires: ground, surface, and crown (Brown and Davis, 1973). Ground fires are fires that burn in the organic material below the litter layer, mostly by smouldering combustion. Surface fires burn in the litter, in other live and dead debris on the forest floor, and/or in small vegetation at or near the surface of the ground. Surface fires burn by flaming combustion. Crown fires also burn by flaming combustion but are located in the canopy of the trees. Crown fires remain connected to the surface fire from which they began or, rarely, they can become independent of the surface fire running ahead of it through the tree crowns. Crown fires are more intense than ground or surface fires. Most large fires that occur in the boreal forests of Canada are a mix of active crown fires, intermittent crown fires, and surface fires that create a mosaic of degrees of burning throughout the forest. The season during which fires occur also has ecological significance. Seasonality of fires determines succession trajectories post fire, and can affect regeneration capacity and fire intensity. For example, low intensity spring fires prior to leaf out can cause tree mortality in trembling aspen and birch (de Groot et al., 2003). If fires occur at this time they have been shown to girdle stems and prevent resprouting, but fires occurring after leaf flush can scorch leaves and promote aspen root suckering (Weber, 1990).

Lastly, the severity of fires, which relates to fuel consumption and is measured by depth of burn, influences post fire ecosystem structure and function. Fire severity impacts roots, underground reproductive tissues, and seed banks (McLean, 1969; Greene et al., 2007). For example, depth of burn of surface organic layers in black spruce (*Picea Mariana* (Mill.)) affects tree recruitment and vegetation recovery post fire (Landhaeusser and Wein, 1993; Gauthier et al., 1996). Greene et al. (2007) found that greater fire severity, due to prolonged smouldering around tree boles, resulted in thinner organic layers post burn. This was conducive to greater plant recruitment of small-seeded tree species (such as aspen) around the boles post-burn.

Due to the ecological influences of fire, patterns in the natural fire regime of the last few hundred years have shaped the forests we know today in Canada (Weber and Flannigan, 1997; Lertzman et al., 2002; Girardin et al., 2006a; Girardin et al., 2006b). Fire records prior to the past 40 to 50 years have been derived using proxy data from analysis of charcoal sediments, tree rings, and post-fire stand age distribution maps. These data can be used to put the current fire regime into a longer term context. Girardin et al. (2006a) showed that for Ontario (primarily the Boreal Shield Ecozone+), the fire regime in the 1940s to 1970s was the lowest fire activity in the past 200 years. They also showed that increases in the 1980s were still below levels recorded in the 1920s, around the time of increased human settlement, and much lower than levels recorded in the 1850s, the end of the Little Ice Age. These results concur with other findings for boreal Canada (Girardin et al., 2006b) and the eastern Canadian boreal (Bergeron et al., 2004; Bergeron et al., 2006; Gauthier et al., 2009). The frequency of large areas burned, especially in eastern Canada has declined since the 1850s. For areas outside the boreal forest, Lertzman et al. (2002) showed that very few fires have occurred in the temperate rainforest of British Columbia (Pacific Maritime Ecozone+) over the last 6,000 years, resulting in very large old-growth tree species like Sitka spruce (*Picea sitchensis* Bong. Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.).

More recently, humans have become an important factor in the fire regime, primarily over the last century. In the beginning of the 20th century, large fires, primarily caused by human activities, destroyed communities and caused significant loss of human life (Podur et al., 2002; Flannigan et al., 2009). These events led to fire management programs that were designed to detect and protect against unwanted fires. Fire suppression, especially since the 1970s with the advent of water bombers (Bergeron et al., 2001) and the use of helicopters for primary attack, has been very successful in some areas at reducing area burned by fires. Fire suppression techniques, particularly those directed at the initial stages of the fire, have been shown in Alberta and Ontario to reduce the proportion of large fires that occur, therefore reducing area burned in these boreal forest regions (Cumming, 2005; Martell and Sun, 2008). On the other hand, it has also been shown that when weather conditions are extreme suppression is less effective (Gauthier et al., 2005) and large fires occur regardless of suppression efforts. Nevertheless, as mentioned above, fire is a necessary disturbance in some of Canada's forests. In order to balance the positive ecological benefits with the negative social and economic impacts, fire suppression has become a balancing act between maintenance of the ecological functions of fire and protecting human life and property (Flannigan et al., 2009).

The occurrence of fire from one year to the next is influenced by a complex set of factors which can be simplified into four categories: weather/climate, fuels, topography, and human influence (Flannigan and Wotton, 2001; Flannigan et al., 2005; Parisien et al., 2006). Weather influences fuel moisture and the occurrence of lightning ignitions. Severe fire weather, weather conditions that are most conducive to fire spread, is characterized by infrequent precipitation, warm temperatures, and high winds. Weather is a short term process having influence at the scale of the fire season or shorter, compared to climate which influences the atmosphere over longer periods (years to decades) (Flannigan and Wotton, 2001). Fuel structure, amount, moisture, and type all influence the propensity of the forest to burn. Topography influences the continuity of fuels, patterns of fuel moisture, and rate of spread. Humans act as both a source of ignition and of fire management through fire prevention education, suppression policies, and actions.

Regional variations in the factors that influence fire occurrence, as well as changes to the drivers themselves (such as climate change), have resulted in changes to the long-term fire regime across the country. This report provides a national synopsis highlighting changes and trends in the national fire regime and establishing patterns in the fire regime between different ecozones+ areas. More detailed information, including more information on long-term trends, is then provided for each ecozone+.

METHODOLOGY

An analysis of long-term forest fire characteristics was performed using a combination of data from the large fire database and data derived from remote sensing methods. The primary national source of historic fire occurrence is the large fire database (Stocks et al., 2003). The database spans from 1959 to 1999 and includes all documented fires larger than 2 km^2. Although these large fires only make up approximately 3% of the total number of fires that occur, they represent 97% of the total area burned. Documentation of fires in the database is from aerial mapping and/or remote sensing gathered from the provinces, territories, and Parks Canada. A limitation of the large fire database is missing data in northern parts of the country prior to the 1970s (Stocks et al., 2003). Caution should therefore be exercised in interpretation of the results for these early years in the northern ecozones+. These omissions were corrected with the advent of satellites in the 1970s. Also, complete mapping of large fire polygons did not start to occur until the 1980s, preventing spatial analysis of large fires prior to this date.

More recently remote sensing methods have become more widely used to detect and map burned areas. For the analysis for this report, remote sensing of burned areas was completed for 1995 to 2007 using the HANDS (Hotspot and NDVI – Normalized Difference Vegetation Index – Differencing Synergy (Fraser et al., 2000)) processing method that uses AVHRR (Advanced Very High Resolution Radiometer) or SPOT-VGT (Système Probatoire d'Observation Terrestre – VEGETATION) satellite images obtained from the Canadian Centre for Remote Sensing. Fires detected from these methods have been shown to be as good as conventional large fire mapping methods (Fraser et al., 2000; Fraser et al., 2004). The caveat to coarse remote sensing methods is that areas burned are often over-estimated because they include large unburned islands within the fire polygon. Also, remote sensing data do not include metadata from the fire protection agencies (provinces, territories, and Parks Canada) that identifies the cause of fires. Lastly, because burned area maps are calculated at the end of the fire season, the start and end dates of the fires are not provided through this data source.

To make the best use of available data a combination of the large fire database and remote sensing data were used. For the analysis of area burned, data from the large fire database was used from 1959 to 1994, and remote sensing data was used to complete the record from 1995 to 2007. Based on a comparison of fire polygons during the period of overlap (1995 to 1999) there was a 1.7% difference in burned area between the large fire database and remote sensing methods.

Average annual area burned was calculated as the total area burned from 1959 to 2007 divided by the number of years (49). Percent annual forested area burned was calculated as the annual area burned divided by the forested area of the region of concern, multiplied by 100. Forested areas were defined as those areas that contained forest fuels, that is conifer and deciduous forests, shrubland, grasslands, previous burned areas, and woodlands interspersed within croplands. These forested areas were calculated by subtracting water bodies and other non-fuel areas (croplands, urban and built-up areas, snow and ice, and barren land) from the total ecozone$^+$ area. Land cover areas were determined by averaging data from land cover matrices developed by Ahern (2011) for 1985 to 2005. Land cover maps were not available for this study prior to 1985, so an assumption was made that there were minimal changes in forest cover from 1959 to 1985.

Long-term trends in annual area burned were calculated by summing the area burned by decade. Totals for the 2000s decade were pro-rated over 10 years based on the average from 2000 to 2007. The seasonality and cause of large fires (those > 2 km^2) was derived from data in the large fire database for 1959 to 1999 inclusive.

NATIONAL TRENDS

Fire frequency is commonly represented by the percent of the total area that is burned annually. On average from 1959 to 2007, 18,471 km² burned in Canada each year. This is about 0.35% of the forested area in Canada (Table 1). This number is quite variable from one year to the next (Figure 1), ranging from a low of 1,524 km² in 1963 to a high of 75,377 km² in 1989.

Table 1. Average annual area burned by large fires, the percent of the forest land base that burns each year, and the contribution to the total area burned annually in Canada by ecozone⁺, 1959-2007.

Ecozone⁺	Average annual area burned (km^2)	Annual forested area burned (%)	Relative contribution of the ecozone⁺ to the total area burned in Canada (%)
Boreal Shield	6,468	0.49	36.9
Newfoundland Boreal	124	0.13	0.8
Boreal Plains	2,214	0.15	11.4
Taiga Plains	2,858	0.71	13.8
Taiga Shield	3,789	0.77	17.7
Hudson Plains	547	0.17	3.3
Taiga Cordillera	857	0.47	4.5
Boreal Cordillera	1,206	0.38	7.8
Montane Cordillera	316	0.10	2.6
Western Interior Basin	54	0.11	0.4
Pacific Maritime	20	0.02	0.3
Atlantic Maritime	38	0.02	0.5
CANADA	**18,471**	**0.35**	**100.0**

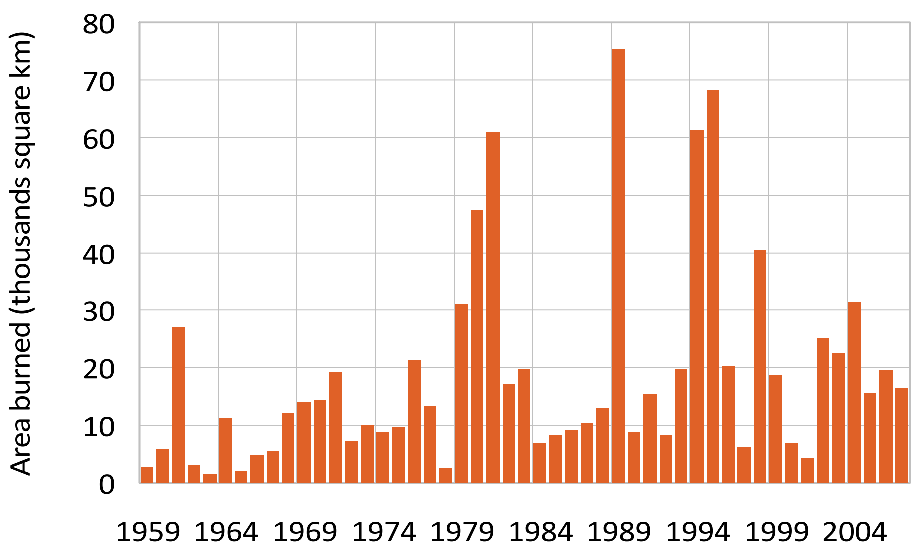

Figure 1. Annual area burned by large fires in Canada, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

Area burned also varies spatially across the country (Figure 2). The largest areas burned are ecozones+ with the least human influences and most severe fire weather (Stocks et al., 2003; Gillett et al., 2004; Parisien et al., 2006). This includes the Boreal Shield, which makes up 37% of the area burned in Canada annually, followed by the Taiga Shield and Taiga Plains which make up 32% of the area burned in Canada collectively (Table 1). One should be aware that the fire regime is not consistent across the Boreal Shield or the Taiga Shield. There is large variability from east to west, with the west side of each having significantly higher fire frequency. Therefore these ecozones+ are commonly treated as two separate regions within the fire literature (Amiro et al., 2001; Stocks et al., 2003; Parisien et al., 2006; Burton et al., 2008; Amiro et al., 2009). Fire is also frequent in the Boreal Plains and Boreal Cordillera as a result of severe fire weather. Fire is less common in the wetter coastal climates of the Pacific Maritime, Atlantic Maritime, and Newfoundland Boreal. Lastly, large forest fires seldom occur in the Arctic, Prairies, and Mixedwood Plains due to a lack of fire prone fuels and/or discontinuity of fuels.

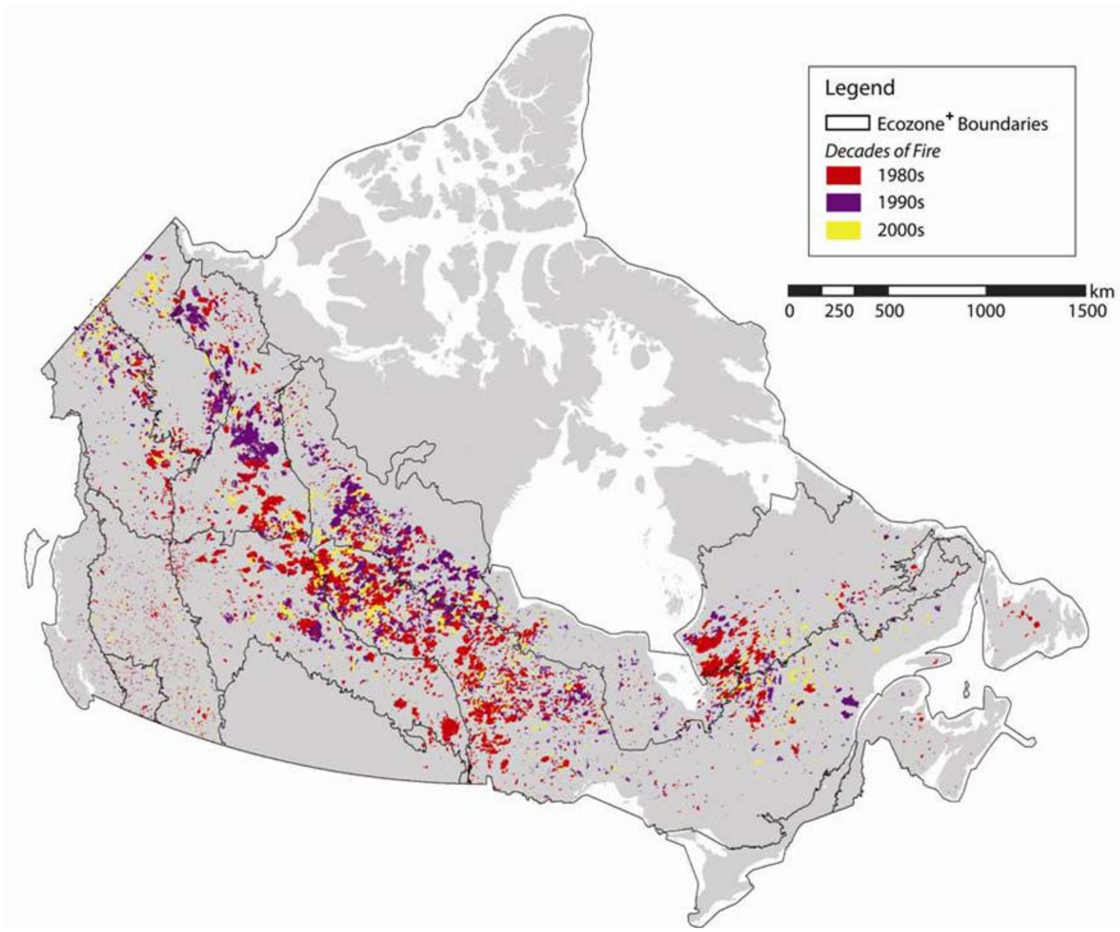

Figure 2. Distribution of large fires across Canada, 1980s-2000s.
Each colour represents the total area burned in the corresponding decade (1980s, 1990s, and 2000s). The 2000 decade includes only data from 2000-2007.
Since the analysis for this report was completed, trends for total area burned in Canada by decade were calculated including data up to 2010. Results can be found on page 96 of Canadian Biodiversity: Ecosystem Status and Trends 2010 at www.biodivcanada.ca/ecosystems (Federal, Provincial and Territorial Governments of Canada, 2010).

Over the last 50 years the contribution to annual area burned by ecozone+ is variable, with the exception of Pacific Maritime, Western Interior Basin, and Atlantic Maritime, which are consistently small contributors (Figure 3). The trends reflect the averages shown in Table 1. The Boreal Shield is regularly the dominant contributor to area burned, followed by the Taiga Shield for all decades except the 1960s (Figure 3). The low number for the 1960s may be due to poor monitoring in northern parts of the country (Stocks et al., 2003). Some trends not evident in Table 1 include an increasing contribution by the Hudson Plains ecozone+ over time. In the 1960s, this ecozone+ contributed 1.9% to the total area burned rising to 4.8% in the 2000s, but again this could be related to insufficient monitoring in the early period. Another trend is the decreased significance of burned area in the Newfoundland Boreal Ecozone+ since the 1960s. The high value in this decade is attributed to a number of large human caused fires that occurred in 1961, which have not occurred since (see Newfoundland Boreal section on page 15 for more details).

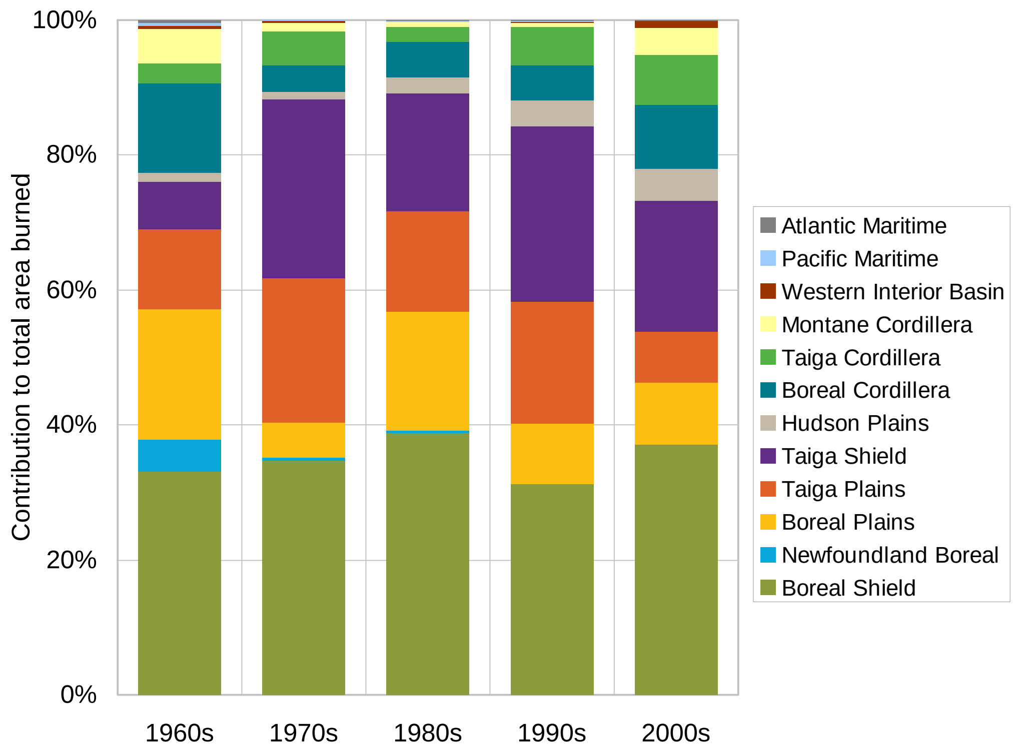

Figure 3. Canadian area burned statistics by ecozone+, 1960s-2000s.
The 2000 decade includes only data from 2000-2007.

Changes to long-term area burned over the last five decades are shown in Figure 4. There is an increasing trend in annual area burned from the 1960s to 1980s, follow by a levelling off in the 1990s, and a decline in the 2000s (Figure 4). Stocks et al. (2003) attribute the increase up to the 1980s to the expanded use of forests by humans combined with advances in fire detection methods and monitoring. Other studies have shown that the increase is not just an artefact of changes to fire detection methods, but is linked to increased temperatures over the last 40 years (Podur et al., 2002; Gillett et al., 2004; Skinner et al., 2006; Girardin, 2007). At first glance the recent decline does not appear to be in line with the preceding increase and with predictions that area burned is expected to continue to increase with warmer global temperatures (Weber and Flannigan, 1997; Gillett et al., 2004; Flannigan et al., 2005; Flannigan et al., 2009). Further investigation of these predictions shows increases in area burned with global warming are not expected to be linear, nor are they anticipated to be consistent across the country. One of the potential reasons for the decline in area burned in the 2000s may be other climatic influences that affect fire occurrence. These include large scale ocean circulation patterns such as the El Niño - Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (Flannigan and Wotton, 2001; Skinner et al., 2002; Girardin et al., 2006b). The rise in area burned from the 1970s through to the 1980s corresponds to a warm (positive) phase of the PDO. Skinner et al. (2006) showed a positive relationship between the warm phases of ENSO and PDO and higher Seasonal Severity Rating (SSR – part of the Canadian Forest Fire Danger Rating System) in western, northwestern, and northeastern Canada. The SSRs are calculated to estimate the control difficulty of fires by predicting their potential intensity based on fire weather (Van Wagner, 1987; Flannigan et al., 2000). Starting in the mid-1990s there was a shift to a cool phase PDO that has subsequently been flipping between warm and cool phases until recently. Based on historic data, Skinner et al. (2006) found a cold phase PDO led to wetter summers and lower SSRs in western Canada. Changes to these large scale atmospheric oscillations may result in variability within the expected increase in area burned attributed to warming global temperatures. Further research is required to determine if this is the reason behind the recent decline in area burned (for more information on large scale climatic oscillations, see Bonsal and Shabbar, 2011).

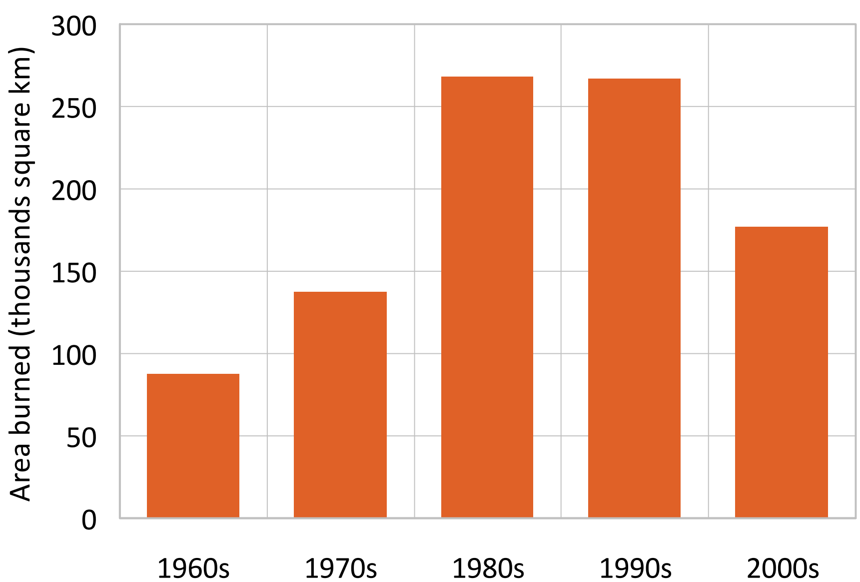

Figure 4. Total area burned by large fires per decade for Canada, 1960s-2000s.
The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007. Since the analysis for this report was completed, trends for total area burned in Canada by decade were calculated including data up to 2010. Results can be found on page 96 of Canadian Biodiversity: Ecosystem Status and Trends 2010 at www.biodivcanada.ca/ecosystems. The shape of the histogram remained the same (Federal, Provincial and Territorial Governments of Canada, 2010).

At a smaller scale, regional variations in weather control the seasonality of fires. The fire season generally starts in April in the southern parts of the country and lasts through mid-October, as seen in the duration of active fires in the Boreal Plains, Boreal Shield, and Montane Cordillera ecozones+ (Table 2). The peak month of the fire season is July. The duration of active fires is much shorter in more northern parts of the country, such as the Taiga Plains and Taiga Shield, and shorter still in some ecozones+ predominately affected by human caused fires, such as the Atlantic Maritime, Pacific Maritime, and Newfoundland Boreal. Based on statistics presented in Weber and Flannigan (1997) that included all fires (that is, those smaller than 2 km^2 in addition to those larger than 2 km^2), humans cause approximately 65% of the total number of fires in Canada, but are responsible for only 15% of the area burned (Stocks et al., 2003). Most of these fires are smaller than 2 km^2 and are therefore not included in the analysis for this report. Humans ignite fires either through recreational activities (for example, camping), arson, or industrial practices (for example, timber production and railways) (Wotton et al., 2003). These activities are generally close to human settlement resulting in early detection and quick response by fire crews limiting the size of most human caused fires. Human caused fires are also characterized by their seasonality as they occur predominately in the spring (Stocks et al., 2003; Kasischke and Turetsky, 2006; Burton et al., 2008). This is evident in the peak month of fire activity in the Atlantic Maritime and Newfoundland Boreal where the ratio of human to lightning caused fires is high (Table 2). Further details on trends and changes in fire seasonality and cause are presented in each ecozone+ section.

Table 2. Cause, duration, and seasonality of large fires by ecozone+, 1959-1999.

Ecozone+	**Ratio of number of human to lightning ignitions**	**Duration of the active fire season (days)**	**Month of peak fire activity**
Boreal Shield	0.26	143	June
Newfoundland Boreal	27.0	35	May
Boreal Plains	1.40	158	May
Taiga Plains	0.16	81	July
Taiga Shield	0.08	75	July
Hudson Plains	0.10	40	July
Taiga Cordillera	0.05	44	July
Boreal Cordillera	0.29	37	June
Montane Cordillera	1.00	101	August
Western Interior Basin	3.38	45	July
Pacific Maritime	1.85	54	July
Atlantic Maritime	4.06	32	May
CANADA	**0.36**	**199**	**July**

Fire cause is depicted as the ratio of human to lightning ignitions.
Seasonality is represented by the duration of active fires (average difference between fire start dates and end dates of each year), and the peak month of fire activity.
Source: data are from the large fire database

The other predominant cause of fires in Canada is lightning, which was responsible for the ignition of fires that resulted in 85% of the total area burned in Canada from 1959 to 1997, based on an analysis by Stocks et al. (2003). Lightning ignitions are most prevalent in northern parts of the country including the Taiga Plains, Taiga Shield, Boreal Shield, Boreal Cordillera, and Hudson Plains ecozones+ (Table 2). Fire suppression is limited to non-existent in some of these ecozones+ allowing lightning fires to burn naturally over large areas. Unlike human caused fires, lightning ignitions tend to occur later in the fire season in the summer months (Flannigan and Wotton, 2001; Stocks et al., 2003). These fires are often more severe than those that occur earlier in the spring as fuel moisture conditions are low enough to permit fires of greater severity and intensity (Amiro et al., 2001). Amiro et al. (2004) calculated the Head Fire Intensity (HFI) Index that is part of the Canadian Forest Fire Danger Rating System that estimates head fire intensity based on weather inputs. They found that the greatest HFIs were in the western boreal ecoregions. They also found a significant positive trend in HFI in the Taiga Shield only for data from 1959 to 1999.

The fire season severity as measured by the SSR varies greatly across Canada. Parisien et al. (2006) calculated an average SSR for ecozones described in the National Ecological Classification System (Ecological Stratification Working Group, 1995) (slightly different than the ecozone+ framework used in this report -- see Preface on page i) based on fire weather from 1959 to 1997. SSR values range from 0 to 5 for long-term averages, with higher numbers indicating higher intensity potential. From these data, the Montane Cordillera had the highest SSR value at 4.7, followed by the Boreal Plains at 3.7. The lowest SSR, 0.7, was found in the eastern side of the Taiga Shield, compared to an SSR of 2.8 for the western side. Despite having the greatest potential for intense fires, the Montane Cordillera had the least area burned of all ecozones in the analysis due to its mountainous terrain that limits fire spread. Burton et al. (2008) also used the SSR values calculated by Parisien et al. (2006) as part of an analysis to look at burn severity across the country, which is also a limited topic covered at larger scales within the fire literature. They found the most severe fires occurred in the western Taiga Shield and Taiga Plains based on a comparison of pre- and post-fire net primary productivity. The lowest burn severities occurred in the Boreal Plains. Based on their analysis of individual large fires across the country they concluded that burn severity is a primary driver of the ecological diversity of these forests based on the mosaic of burned and unburned sites created.

Summary

An analysis was done using forest fire data from the large fire database (Stocks et al., 2003) and remote sensing to look at the status and trends in large fires (> 2 km^2) across the country. This analysis does not document all fires that occur in Canada each year, only large fires, which represent approximately 3% of the total number of fires, but account for approximately 97% of the area burned. Area burned varies greatly from one year to the next across the country. During low years as little as 1,500 km^2 has burned, compared to extremely high years where 75,000 km^2 of forest has burned. The majority of large fires occur in the boreal and taiga regions, in remote parts of the country, where suppression efforts are limited, and extreme fire weather conditions are common. The majority of fires in these areas are caused by lightning ignitions, compared to human ignitions. The predominance of lightning caused fires results in a large fire season that peaks in July nationally; while human caused ignitions are the predominate reason for the long duration of the fire season, which starts as early as April lasting into mid-October.

Despite limitations of the large fire database prior to the 1980s, the literature has shown that the increase in area burned from the 1960s to 1990s, has been linked to warmer temperatures across the country (Podur et al., 2002; Gillett et al., 2004; Skinner et al., 2006; Girardin, 2007). More recent data show a decline in area burned from 2000 to 2007. Although this may seem counterintuitive to the expectations of continued warmer temperatures due to climate change, further investigation of the literature demonstrates that the impacts of warmer temperatures are not expected to be consistent across the country, nor are they anticipated to be linear (Weber and Flannigan, 1997; Gillett et al., 2004; Flannigan et al., 2005; Flannigan et al., 2009). Further research and a complete dataset for 2000s are required to conclude that area burned has significantly declined[6] and to determine the causes.

Due to the large variability in annual fire statistics a longer time period is required to fully elucidate trends in the fire regime in all areas of Canada. Continued advancements in the monitoring and documentation of large and small (< 2 km^2) forest fires is therefore essential. Technologies like remote sensing that allow monitoring and detection in parts of the country that were previously limited, such as the North, are important assets to forest fire datasets. Ideally these data should continue to be supplemented and corroborated by qualitative and quantitative data collected by forest fire management agencies. Consistency in mapping methods and synthesis of both data types are required to provide a complete documentation of changes to the forest fire regime across Canada.

ECOZONE⁺ TRENDS

Boreal Shield

Fires within the Boreal Shield Ecozone⁺ are characterized as intense crown fires (Amiro et al., 2004; Beverly and Martell, 2005) that are moderate in severity compared to the other ecozones⁺ (Burton et al., 2008). These types of fires are important to many boreal tree species, such as like Jack pine (*Picea banksiana*) and black spruce (*Picea mariana* (Mill.) B.S.P.) that require fire to initiate seedling germination. These and other boreal species require periodic, intense stand replacing fires, which have historically resulted in large areas burned (Bergeron et al., 2001; de Groot et al., 2003). Even within an area where most fires are actively suppressed, the Boreal Shield is consistently the largest contributor to the total area burned in Canada. The long-term annual area burned for this ecozone⁺ is 6,467 km^{2}, which is 37% of the area burned in Canada (see Table 1 on page 5 and Figure 3 on page 7). Similar to trends at the national scale, there is large variability in area burned from year to year (Figure 5). The most extreme year was in 1989

[6] Analysis by decade including the full 2000s dataset was completed for *Canadian Biodiversity: Ecosystem Status and Trends 2010* (Federal, Provincial and Territorial Governments of Canada, 2010). Results confirm the decline.

when almost 28,000 km^2 burned, compared to low years when area burned was less than 1,000 km^2 (for example, 1982).

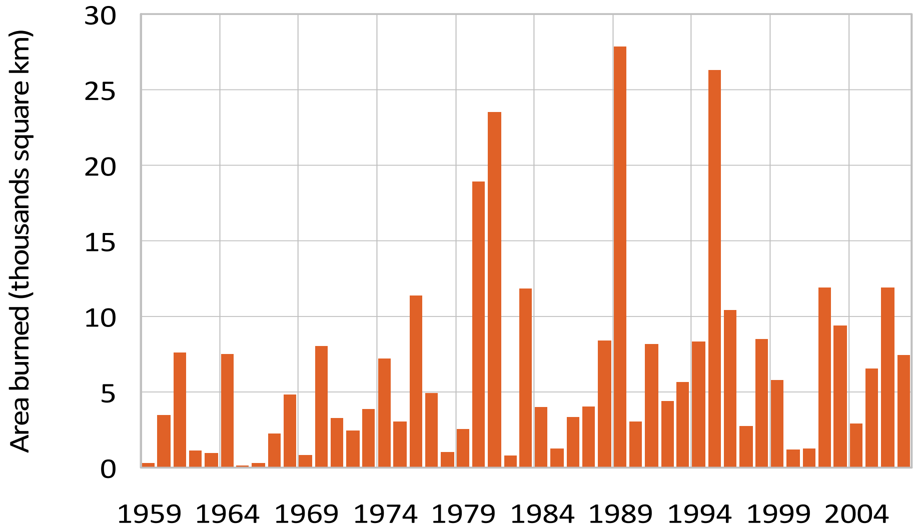

Figure 5. Annual area burned by large fires for the Boreal Shield, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

Fire frequency in the Boreal Shield Ecozone+, represented by the percent annual forested area burned, is not the largest in the country. At 0.49% of the forested area of the ecozone+, the Boreal Shield Ecozone+ burns less frequently than the Taiga Plains (0.71%) and Taiga Shield (0.77%) (See Table 1 on page 5). This lower percent area burned may be related to higher levels of fire protection in the Boreal Shield, especially in the southern part of the ecozone+ or alternatively it may be related to the regional variability in fire weather conditions (Girardin and Wotton, 2009). Approximately 64% of the Boreal Shield is protected through suppression efforts compared to 20% of the Taiga Plains and 2% of the Taiga Shield (Parisien et al., 2006).

The Boreal Shield, the largest of the ecozones+, has two distinct fire regimes. For this reason, most fire analyses divide it into east and west components (Stocks et al., 2003; Beverly and Martell, 2005; Flannigan et al., 2005; Kasischke and Turetsky, 2006; Parisien et al., 2006; Burton et al., 2008; Flannigan et al., 2009). The line of division is just east of Lake Nipigon in northwestern Ontario. Stocks et al. (2003) calculated the percent annual area burned for the Boreal Shield west and Boreal Shield east separately using the large fire database data and found that the Boreal Shield west is within the same range for percent annual forested area burned as the Taiga ecozones+ (0.60 to 0.80%), compared to the Boreal Shield east, which is significantly lower (0.00 to 0.20%). Stocks et al. (2003) analysis included the Newfoundland Boreal in Boreal Shield east.

The difference in fire regime across the Boreal Shield is attributed to more severe fire weather, such as longer dry spells and lack of precipitation, in the Boreal Shield west (Beverly and Martell, 2005; Girardin and Wotton, 2009), as well as a higher ratio of conifer to deciduous species in the Boreal Shield east (Parisien et al., 2006; Amiro et al., 2009). Another contributing factor is that a greater percent area of the Boreal Shield east is protected by suppression efforts compared to the Boreal Shield west (70 and 54% respectively) due to greater human population in eastern Ontario and Western Quebec. The end result is a lower average annual area burned in the Boreal Shield east (772 km^2) compared to the Boreal Shield west (5,147 km^2) (Parisien et al., 2006). This decreased fire frequency in the Boreal Shield east has resulted in longer fire cycles that have led to an increased proportion of uneven-aged old growth forests, characterized by more shade tolerant, less fire prone species, such as balsam fir (*Abies balsamea* (L.) Mill), compared with the Boreal Shield west (Bergeron et al., 2001; de Groot et al., 2003).

Using data from the large fire database, the average duration of the active fire season lasted 143 days from 1959 to 1999, with fires most commonly occurring between May and August (Figure 6). Fires can occur as early as March and into November but these occurrences are rare. The peak month of fire occurrence is June. There was little change in the seasonality of fire occurrence in this ecozone+ from the 1960s to 1990s (Figure 6).

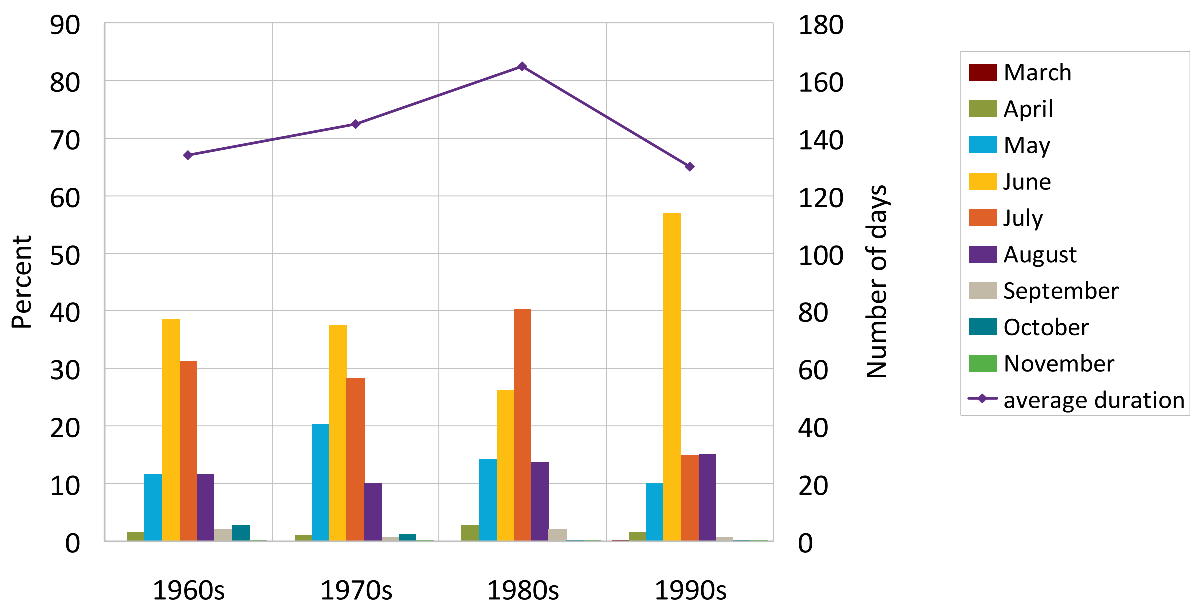

Figure 6. Proportion of large fires that occur each month in the Boreal Shield and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Long term trends in area burned in the Boreal Shield suggest significant increase from the 1960s to the 1980s (Figure 7). The reason for this increase is similar to that given for Canada overall: partly due to warmer temperatures (Podur et al., 2002; Gillett et al., 2004), and partly due to changes in detection methods and completeness of fire monitoring coverage, especially in areas outside the protection zones, such as northern Quebec and Ontario (Podur et al., 2002; Stocks et al., 2003). Increased human activity, which is one of the reasons attributed to the increase at the national level, is unlikely to be part of the cause here because the proportion of total area burned by human ignitions decreased between the 1960s and 1990s (Table 3).

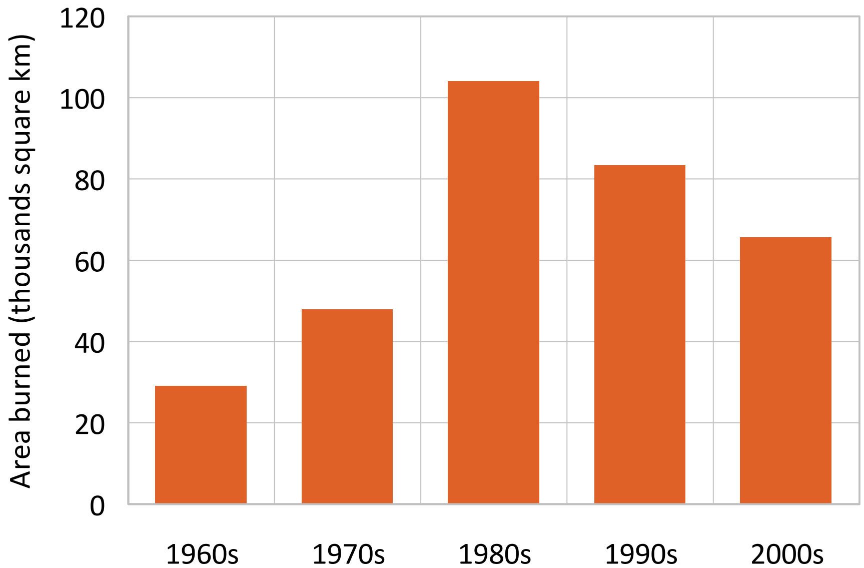

Figure 7. Total area burned by large fires per decade for the Boreal Shield, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Table 3. Proportion of the number of large fires ignited by lightning compared to humans and the total area burned by each ignition source by decade for the Boreal Shield, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	673	62	38	19,231.9	9,701.9
1970s	828	71	29	37,198.2	10,581.5
1980s	1,356	85	15	87,392.2	16,559.5
1990s	1,159	89	11	68,120.3	11,301.2
Total	**4,016**	**77***	**23***	**211,942.6**	**48,144.2**

* average not total

Source: data are from the large fire database

Following the peak in area burned in the 1980s, a decline in area burned is evident for the remainder of the record (Figure 7). This decline is not as dramatic as the increase from the 1960s to 1980s, which is similar at the national level (see Figure 4 on page 8). What is different from the national trend is the timing of the decline; it commences in the 1990s in the Boreal Shield compared to the 2000s at the national level. A similar earlier decline is shown in the Boreal Plains, but not in the Taiga Shield or Taiga Plains (see respective ecozone+ sections), which show similar trends to the national data. One of the primary differences between these ecozones+ is that larger proportions of the Boreal Shield and Boreal Plains are protected by suppression efforts compared to the Taiga Plains and Taiga Shield. Also, the Boreal Plains and Boreal Shield influence a larger proportion of the ecozone+ area as expressed by percent land use statistics in Parisien et al. (2006). The decline in area burned from the 1980s to the 1990s may be a result of successful forest suppression efforts (Cumming, 2005; Martell and Sun, 2008). The continued decline into the 2000s may be due to a combination of changing climatic oscillations that have been show to have an influence on fire weather in the Boreal Shield (Flannigan and Wotton, 2001; Skinner et al., 2002; Girardin et al., 2006a; Girardin et al., 2006b) and the increased management of human impacts.

As mentioned above, the number of human caused large fires declined over the period of record, decreasing from 38% in the 1960s to 11% in the 1990s ($R^2 = 0.95$, $p = 0.019$) (Table 3). It is important to note that these data do not include small fires that may have been ignited by humans but were suppressed before they were large enough to be recorded. This reduction is consistent with findings by Kasischke and Turetsky (2006) who state that government policies implemented in the 1970s and 1980s nation wide resulted in a 50% reduction in all human ignitions. Human ignitions of both small and large fires are still the dominant cause of fires in Canada; nevertheless, they result in a much smaller area burned compared to lightning ignitions (Weber and Flannigan, 1997; Wotton et al., 2003). Lightning fires were the cause of 80% of the large forest fires and made up the majority of the area burned in the Boreal Shield Ecozone+ from the 1960s to 1990s (Table 3).

Newfoundland Boreal

Like other coastal ecozones+, fire is not a significant natural disturbance in the Newfoundland Boreal. Average area burned is higher than the Pacific Maritime and Atlantic Maritime ecozones+ at 123 km² per year, and the percent annual area burned is also higher at 0.13%, but the contribution to total area burned in Canada is still less than 1% (see Table 1 on page 5). Its contribution to total area burned in Canada has changed over time (see Figure 3 on page 7), making a greater contribution in the 1960s at 4.7%. This was due to an extreme fire year that occurred in 1961 during which 3,962 km² burned. Apart from this, there is little variability in annual area burned and more commonly there are many years throughout the period of record were there are no large fires in this ecozone+ (Figure 8).

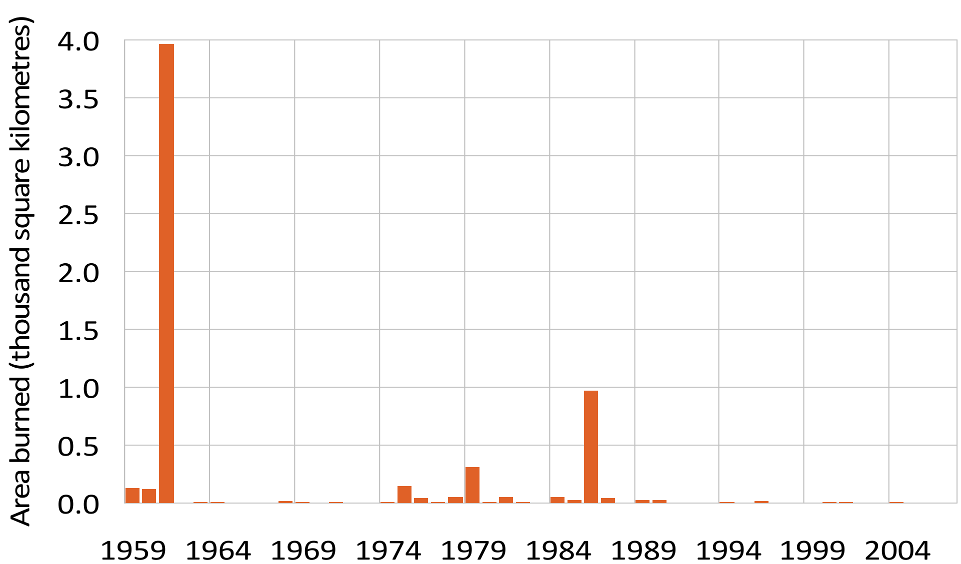

Figure 8. Annual area burned by large fires for the Newfoundland Boreal, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

The average active fire season duration, 35 days, is approximately the same as it is for the Atlantic Maritime Ecozone+ (see Table 2 on page 9). Fire occurrence peaks in May but fires commonly occur between May and July. Also, similar to the Atlantic Maritime and Pacific Maritime, the dominant cause of fire ignitions is humans at 96%. Lightning ignitions are rare occurrences that have only been documented four times in the large fire database for the Newfoundland Boreal.

Area burned decreased dramatically since the 1960s (Figure 9). The decline was most likely due to successful government policies aimed at preventing and suppressing fires (Stocks et al., 2003) and to the one extreme year, 1961. The doubling in area burned from the 1970s to the 1980s may be related to warmer temperatures (Podur et al., 2002; Gillett et al., 2004) that resulted in more fire escapes from suppression efforts. Area burned declined again in the 1990s and has remained small into the 2000s, which only had 12 large fires between 2000 and 2007. Similar to the Atlantic Maritime and Pacific Maritime ecozones+, these trends should be assessed with caution because they are based on a small number of fires, especially in more recent decades.

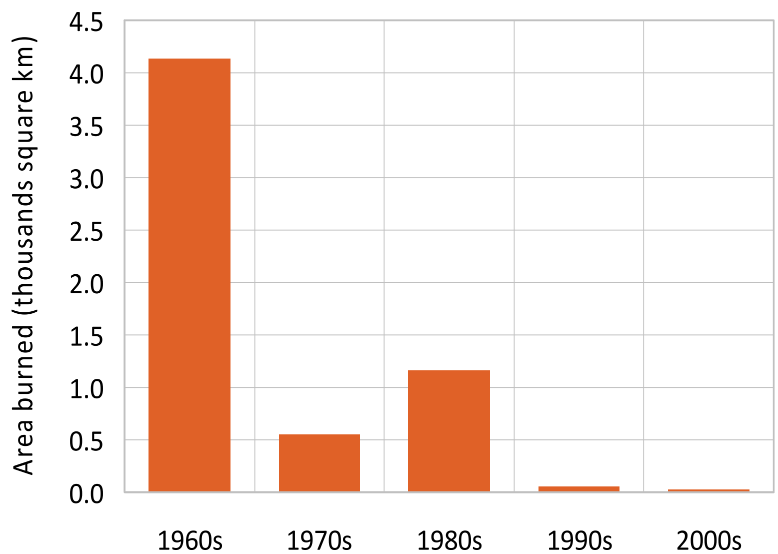

Figure 9. Total area burned by large fires per decade for the Newfoundland Boreal, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Boreal Plains

Similar to other areas of the boreal forest in Canada, fire is an important natural disturbance in the Boreal Plains Ecozone+. On average 2,213 km^2 burns in this ecozone+ each year, but this varied from less than 200 km^2 in some years, to over 6,000 km^2 in others (Figure 10). The most extreme fire year on record was 1981 when 18,760 km^2 burned. At the national level, the area burned in the Boreal Plains is a significant contribution to the total area burned in Canada. At 11%, it makes the fourth largest contribution to area burned in the country (see Table 1 on page 5). There has been some variability in this statistic over time, from a high of 19% in the 1960s to a low of 5% in the 1970s (see Figure 3 on page 7). Of the available forest fuels, the proportion that burn annually (0.15%) is not as high as for the neighbouring Taiga Cordillera, Boreal Cordillera, and Hudson Plains ecozones+ (0.47, 0.38, and 0.17% respectively) (see Table 1 on page 5). The reason for the discrepancy may be attributed to fire protection levels in the Boreal Plains and forest fuel types. Approximately 90% of the Boreal Plains is protected by fire suppression activities, compared to 0% for the Taiga Cordillera, 41% for the Boreal Cordillera, and 0% for the Hudson Plains (Parisien et al., 2006). Also 24% of the Boreal Plains forests are deciduous species (Parisien et al., 2006; Amiro et al., 2009), which are less prone to burning (Burton et al., 2008). Although the proportion of their forests that burn each year are higher for the Taiga Cordillera, Boreal Cordillera, and Hudson Plains than for the Boreal Plains, the Boreal Plains has a much greater total annual area burned (see Table 1 on page 5).

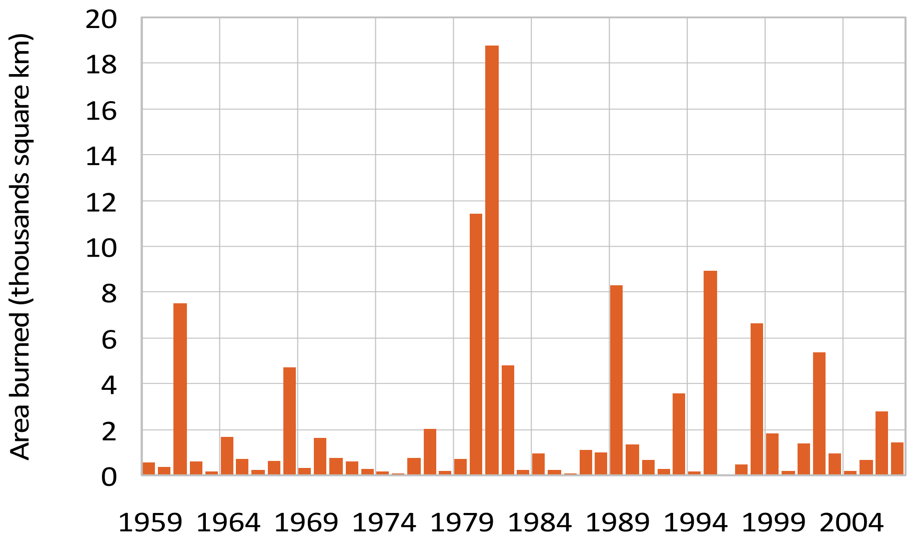

Figure 10. Annual area burned by large fires for the Boreal Plains, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

The Boreal Plains has the highest fire protection levels of all the boreal forest ecozones+ (Parisien et al., 2006). Protection levels are elevated to compensate for extensive human interaction within the forest and high values- at-risk in surrounding areas (Stocks et al., 2003). As a result, the fire regime in the Boreal Plains is highly influenced by humans. In addition to suppression efforts, humans also have a significant impact on the fire regime through ignitions. Human caused fires represented 57% of the total number of large fires that occurred in this ecozone+ between the 1960s and 1990s (Table 4). Over this period, the proportion of human caused fires decreased significantly ($R^2 = 0.98$, $p = 0.004$) such that, by the 1990s, lightning was the dominant cause. Overall, lightning fires resulted in a larger area burned; 42% of fires were caused by lightning but they were responsible for 69% of the area burned (Table 4). The reason for the discrepancy is because most human caused fires are commonly closer to human settlement resulting in earlier detection and response. Therefore, the success rate of fire suppression techniques is often higher on these fires, reducing their growth to larger areas compared to lightning fires that can often occur in more remote locations (Stocks et al., 2003).

Table 4. Proportion of the number of large fires ignited by lightning compared to humans and the total area burned by each ignition source by decade for the Boreal Plains, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	444	26	74	4,334.3	12,560.9
1970s	321	40	60	3,846.5	3,310.7
1980s	468	47	53	35,177.3	11,773.4
1990s	380	58	42	26,375.2	3,214.4
Total	**1,613**	**43***	**57***	**69,733.3**	**30,859.5**

* average not total

Source: data are from the large fire database

The Boreal Plains also has the longest active fire season of all the ecozones+ (see Table 2 on page 9). The average duration of the active fire season was 158 days (approximately 5 months) from 1959 to 1999. Fires most commonly occur April to August, but they can extend into the month of December (Figure 11). The peak month of fire occurrence is May (Figure 11). The dominance of spring fires translates into less severe fires in this area compared to others (Burton et al., 2008). Based on fire weather indices the Boreal Plains does experience quite severe fire weather, but this does not translate into severe fires (Amiro et al., 2004; Parisien et al., 2006; Burton et al., 2008). The occurrence of both human and lightning caused fires is the reason behind the long fire season. Human caused fires are more prominent earlier in the season, while lightning caused fires occur more commonly later in the season. There were only minor changes in the duration of the active fire season, or shifts in the seasonality of fire occurrence based on the 40 years of available data.

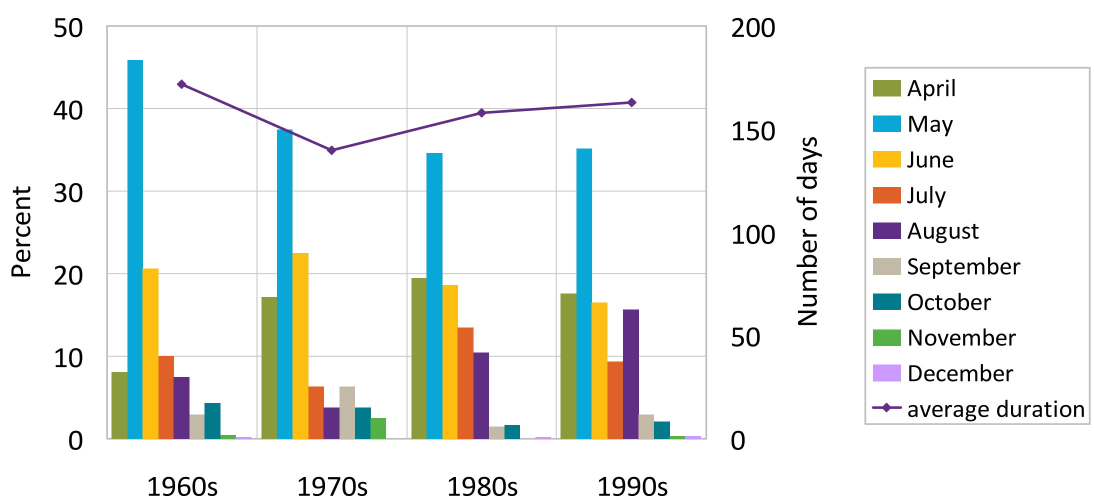

Figure 11. Proportion of large fires that occur each month in the Boreal Plains and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

There are trends in the area burned over the last 50 years, many of which are again tied to human interactions within this ecozone+. Over the past five decades the area burned peaked in the 1980s (Figure 12). Prior to this there was a decrease from the 1960s into the 1970s. A similar decline was also evident in the Boreal and Montane Cordilleras, Newfoundland Boreal, and Atlantic Maritime ecozones+ (see respective ecozone+ sections), all of which have significant human impacts on forest fire, either through suppression and/or ignitions. Therefore, the cause of the decline may be attributed to a change in human behaviour, either through advanced fire fighting techniques or increased prevention efforts. Monitoring and detection methods were also questionable during this early period, which could be another factor in the decline (Podur et al., 2002; Stocks et al., 2003). For the remainder of the record the pattern is similar to the nearby Boreal Shield Ecozone+. The peak in the 1980s has been attributed to a combination of warmer climate (Podur et al., 2002; Gillett et al., 2004), increased forest use by humans, and better detection methods (Stocks et al., 2003). Since the 1980s, area burned has declined in the Boreal Plains, similar to the pattern shown in the Boreal Shield. As is stated in the Boreal Shield section, the reason for the decline may be in part due to increased management of human impacts and changes in fire weather (Flannigan and Wotton, 2001; Skinner et al., 2002; Cumming, 2005; Girardin et al., 2006b).

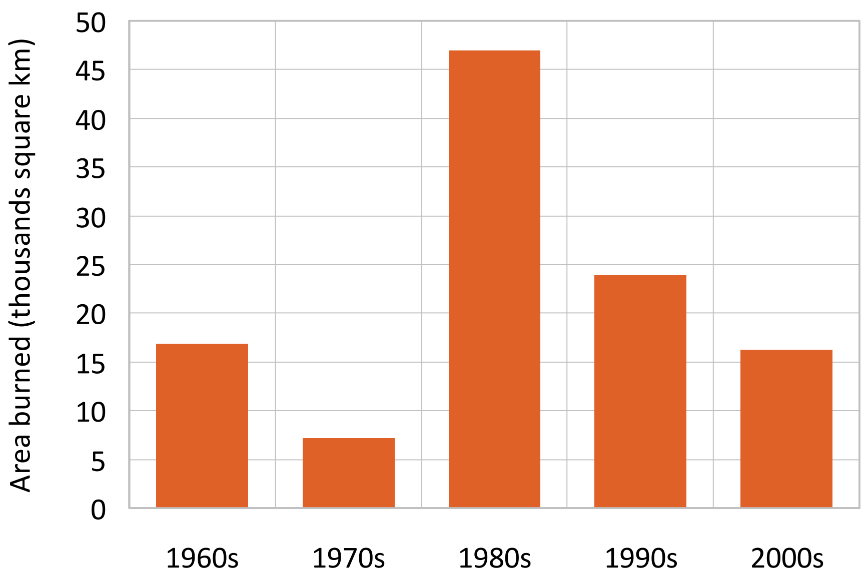

Figure 12. Total area burned by large fires per decade for the Boreal Plains, 1960s-2000s.
The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Taiga Plains

Some of the largest fires in the country occur in the Taiga Plains Ecozone+ (Parisien et al., 2006; Burton et al., 2008). The reason behind this is a cumulation of factors including: a dry continental climate (Stocks et al., 2003), remote location with little suppression efforts (approximately 20% of the area undergoes suppression) (Parisien et al., 2006), and a dominance of boreal fuel types at relatively high, average fuel loads that lead to higher consumption rates (Amiro et al., 2001; Amiro et al., 2009). These factors result in relatively severe fires that burn over large areas. Burton et al. (2008) found the Taiga Plains to have some of the most severe fires in the country.

On average 2,858 km^2 burn each year in this ecozone+ with large variability from year to year (Figure 13). There are many years where annual area burned is less than 100 km^2, while others have been as high as 17,354 km^2 (1995). Some low years early in the record may be due to limited monitoring in this northern ecozone+, however this trend continues in more recent decades validating the occurrence of very low fire years (for example, 1991, 1997, and 2002). Despite the occurrence of low fire years, the percent annual area burned is high at 0.71% of the forested ecozone+ area compared to other ecozones+ (see Table 1 on page 5). This is the second highest – only the Taiga Shield is higher at 0.77%. On a national level, the Taiga Plains constitutes 14% of the area burned in Canada, which is the third largest contribution following the Boreal Shield and Taiga Shield. Over time this contribution has varied from a low of 7.5% in 2000s to a high of 21.5% in the 1970s (see Figure 3 on page 7). There is no trend to this variation. The low number in the 2000s should be looked at with caution as it does not include data for the full decade.

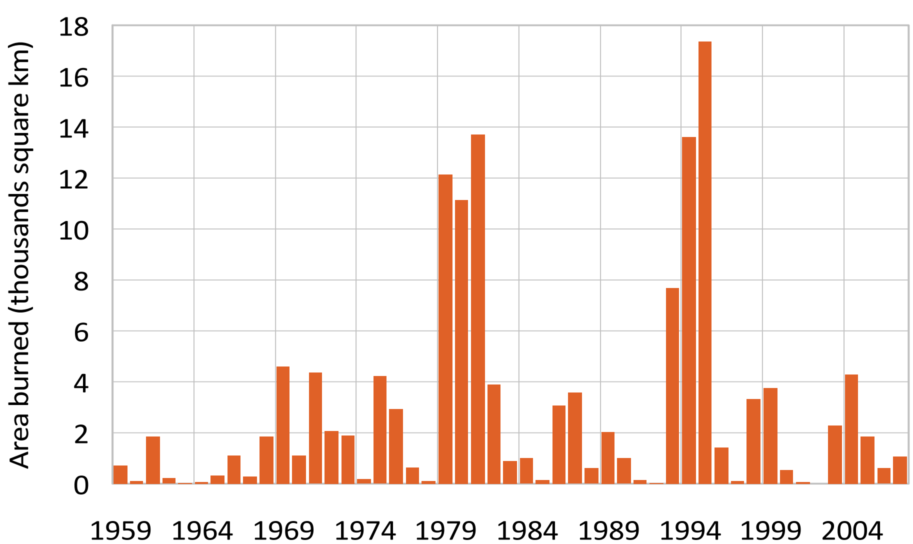

Figure 13. Annual area burned by large fires for the Taiga Plains, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

The long term trend in area burned is similar to trends at the national level (Figure 14). Area burned increased from the 1960s until the 1990s and then fell sharply in the 2000s. Since the Taiga Plains Ecozone+ is located in northern Canada, the low numbers at the beginning of the record may be attributed to data collection techniques that improved starting in the 1970s (Stocks et al., 2003). Although the numbers presented for 2000s should be considered with caution because they do not include the full decade, the reason behind the recent decline requires further research to fully elucidate, but may be related to changes in large atmospheric oscillations as discussed in the National Trends section on page 5.

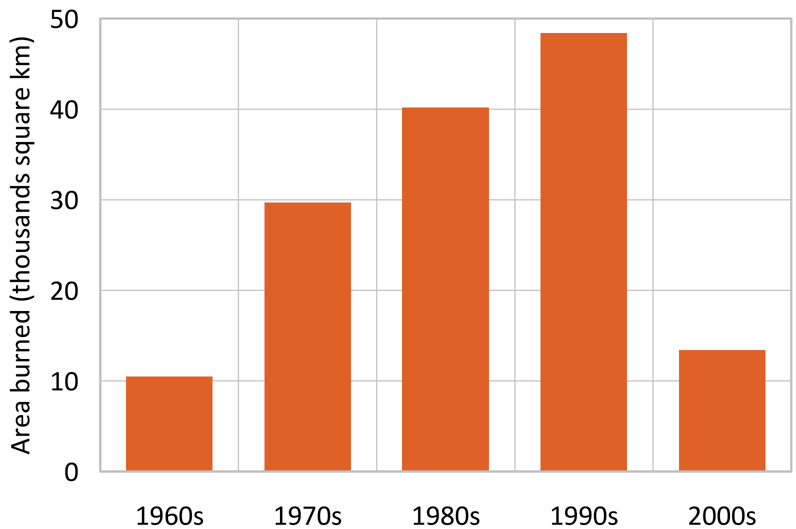

Figure 14. Total area burned by large fires per decade for the Taiga Plains, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

The average duration of active large fire season from the 1960s through 1990s, was 81 days (approximately 4 months) and did not change much over this time period. Fires most commonly occur June through to August, but can occur as early as April and as late as September (Figure 15). Although the average duration of the period of fire occurrence did not change, the distribution of fires within the fire season made some subtle changes over the 40 year period. The proportion of fires that occurred in April shifted from zero in the 1960s to 1.2% in the 1990s and the proportion of fires that occurred in May steadily increased ($R^2 = 0.93$, $p = 0.035$) (Figure 15). All fires that occurred in April were human caused; those in May were equally distributed between humans or lightning. More data are needed to determine if these small changes are the start of a real phenomenon, such as lengthening of the fire season, or are artefacts of the large fire database limitations.

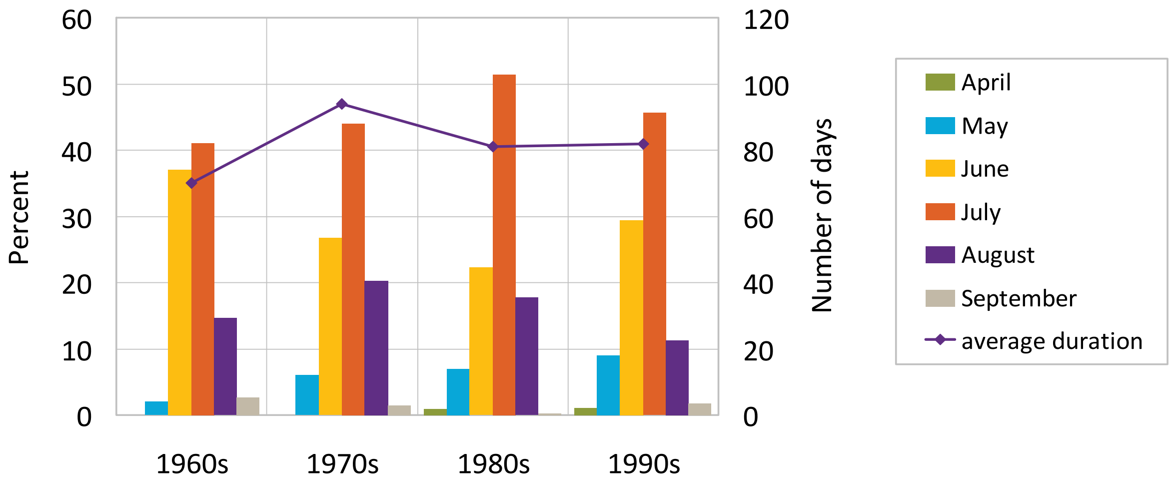

Figure 15. Proportion of large fires that occur each month in the Taiga Plains and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Fires that occur later in the season do not appear to be changing in their distribution (Figure 15). These fires are predominately caused by lightning – an average of 83% of the total number of fires that occurred in the Taiga Plains from 1960s and 1990s were ignited by lightning (Table 5). Table 5 shows that the proportion of the number of fires caused by lightning increased compared to ignitions by humans. There is no clear trend in the lightning ignitions which differs from findings by Kasischke and Turetsky (2006) for the North American forest and Stocks et al. (2003) for Canada who found increases in the recent years. The total area burned as a result of lightning ignitions increased over the 40 years (Table 5). This increase in area burned by lightning is most likely due to warmer temperatures during the fire season in the 1990s (Podur et al., 2002; Gillett et al., 2004).

Table 5. Proportion of the number of large fires ignited by lightning compared to humans and the total area burned by each ignition source by decade for the Taiga Plains, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	149	58	42	3,455.6	6,987.9
1970s	262	87	35	27,463.5	2,199.3
1980s	326	96	13	39,920.4	217.8
1990s	254	91	22	54,691.9	1,282.6
Total	**991**	**83***	**17***	**125,531.4**	**10,687.6**

* average not total
Source: data are from the large fire database

Taiga Shield

The fire regime in the Taiga Shield Ecozone+ is characterized by large, severe fires (Stocks et al., 2003; Parisien et al., 2006; Burton et al., 2008), similar to the fire regime in the Taiga Plains. The annual area burned in the Taiga Shield is 3,789 km^2, which is higher than the nearby Taiga Plains (2,858 km^2), but second to the Boreal Shield (6,467 km^2). The large annual area burned results in a contribution of 18% to the Canadian total (see Table 1 on page 5). The low contribution to annual area burned in the 1960s is most likely due to limited detection methods during this time. At the ecozone+ scale, 0.77% of the available forested area burns on average each year. This is the largest percent annual area burned in Canada (see Table 1 on page 5).

Like the Boreal Shield, the Taiga Shield is commonly broken into two separate areas for analysis in the fire literature (Amiro et al., 2001; Stocks et al., 2003; Parisien et al., 2006; Burton et al., 2008; Amiro et al., 2009). The divide is on either side of the Hudson Plains Ecozone+ separating the area into eastern and western portions based on different fire regimes. The reason for the difference in regimes is significantly different climates. This occurs despite other similarities between the two sides including: fuel types, both sides are predominately conifer fuels (Parisien et al., 2006; Amiro et al., 2009); ignitions, both are dominated by lightning; and human influence, both have little to no suppression (Parisien et al., 2006). The Taiga Shield west has more severe fire weather due to its continental location, compared to the Taiga Shield east, which is cooler and wetter because of its coastal location (Parisien et al., 2006; Burton et al., 2008). As a result, the fire regime in the Taiga Shield west is represented by larger, more severe and frequent fires than in the Taiga Shield east (Stocks et al., 2003; Amiro et al., 2004; Parisien et al., 2006; Burton et al., 2008). Burton et al. (2008) calculated the percent annual area burned to be 0.83 in the Taiga Shield west and 0.25 in the Taiga Shield east (based on data from 1959 to 1999), using an average annual area burned of 2,632 and 1,126 km^2 respectively.

The area burned varies greatly from year to year in the Taiga Shield, with some years early in the record having no fires greater than 2 km^2 compared to extremes in 1989 (28,120 km^2) and 1994 (31,279 km^2) (Figure 16). The extremely low numbers in the 1960s do not occur again later in the record, thus one may assume these are due to detection problems (Podur et al., 2002; Stocks et al., 2003). Over the long-term the area burned increased from the 1960s until the 1990s (Figure 17). The same pattern is shown in the Taiga Plains. The increase has been attributed to a combination of changes to detection methods and warmer temperatures during this time frame (Podur et al., 2002; Gillett et al., 2004). The decline since the 1990s is also similar to the pattern shown for the Taiga Plains. The magnitude of the decline is of the same magnitude as changes between previous decades; therefore it may signify a real response despite being based on only seven years of data pro-rated over the decade. The reason for the decline may be related to changes in large atmospheric oscillations as discussed in the National Trends section on page 5.

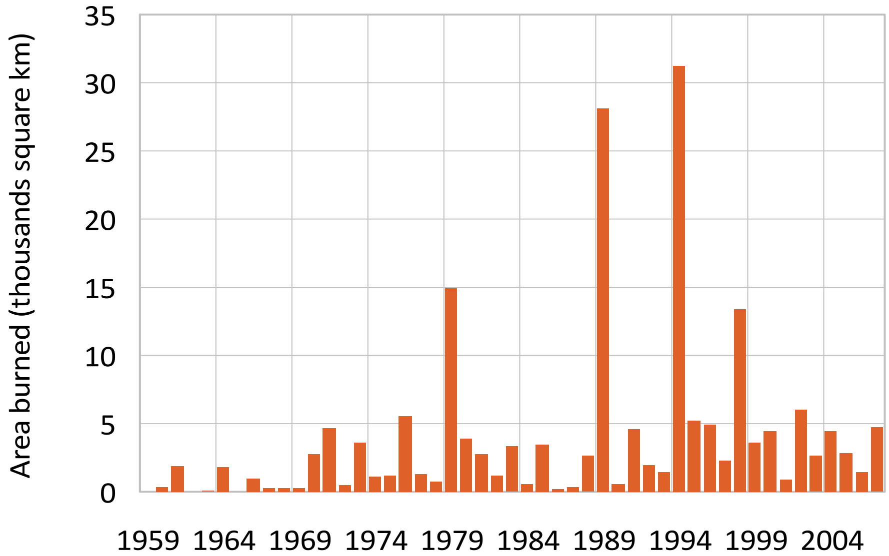

Figure 16. Annual area burned by large fires for the Taiga Shield, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

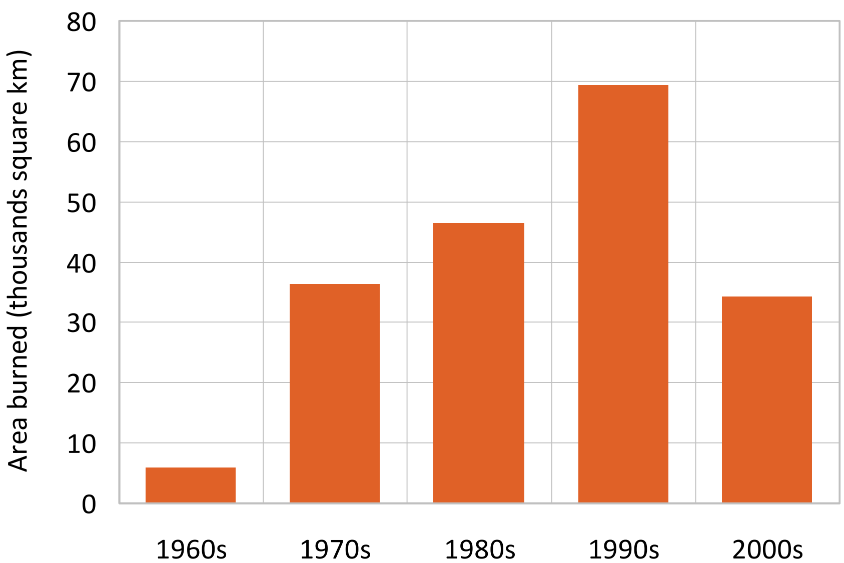

Figure 17. Total area burned by large fires per decade for the Taiga Shield, 1960s-2000s.
The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

The average duration of the active fire season is relatively short compared to the other boreal ecozones+ (see Table 2 on page 9). The long-term average between 1959 and 1999 was 75 days, which did not change much since the 1970s. Fires most commonly occur between June and August, peaking in July (Figure 18). There was a significant increase in the occurrence of fires in the month of May ($R^2 = 0.99$, $p = 0.002$), from no fires in the 1960s to 2.4% of the fires in 1990s (Figure 18). Fires in the Taiga Shield east generally occur earlier than fires in the Taiga Shield west (Kasischke and Turetsky, 2006), therefore the increase in the number of May fires may be from this side of the ecozone⁺. There was also an increase in fires late in the fire season (August).

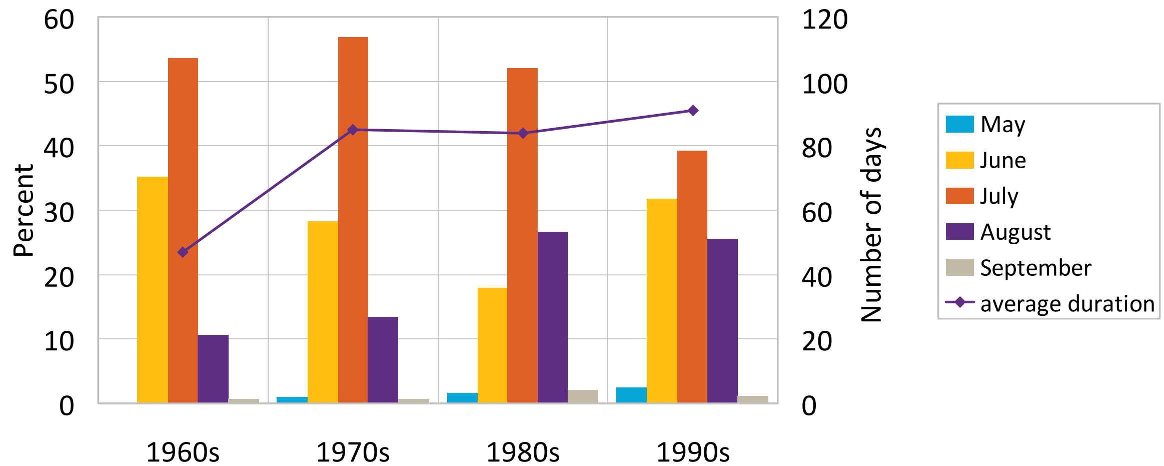

Figure 18. Proportion of large fires that occur each month in the Taiga Shield and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Similar to the other northern boreal ecozones⁺, fires are predominately caused by lightning ignitions. On average 92% of the large fires that occur in the Taiga Shield are caused by lightning (Table 6). The ratio of human to lightning caused fires is consistent from one side of the ecozone⁺ to the other (Parisien et al., 2006). The proportion of fires caused by lightning (due to a decrease in human caused fires) and the number of fires caused by lightning increased from the 1960s to 1990s but this increase is not statistically significant. Kasischke and Turetsky (2006) also found an increase in lightning ignitions over time. The average area burned by lightning ignitions increased between the 1960s and 1990s, but again the increase was not statistically significant.

Table 6. Proportion of the number of large fires ignited by lightning compared to humans and the total area burned by each ignition source by decade for the Taiga Shield, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	151	88	12	4,739.2	1,263.6
1970s	468	87	13	32,711.1	3,627.2
1980s	509	95	5	44,744.6	1,830.1
1990s	583	97	3	68,358.6	121.8
Total	**1,711**	**92***	**8***	**150,553.6**	**6,842.7**

* average not total

Source: data are from the large fire database

Hudson Plains

The Hudson Plains Ecozone⁺ has one of the world's largest network of wetlands that extend across the flat landscape (Amiro et al., 2001; Parisien et al., 2006). As a result of this extensive network, fuels are discontinuous, which leads to smaller fires in the Hudson Plains than the surrounding Boreal Shield and Taiga Shield. The average annual area burned of 547 km^2 in the Hudson Plains contributes only 3% to the total national area burned, compared to 18% from the Taiga Shield and 37% from the Boreal Shield (see Table 1 on page 5). Over time, the percent contribution to the total area burned in Canada increased form 1.5% in the 1960s to 4.8% in the 1990s (see Figure 3 on page 7). Comparatively, the area burned in this ecozone⁺ is more significant at the ecozone⁺ scale. The percent annual area burned for the Hudson Plains is 0.17%, which is a little larger than the Boreal Plains which is 0.15% but has an annual area burned of over 2,000 km^2. The reason for the difference my be related to the extensive network of wetlands which have been shown to be more resistant to fires (Burton et al., 2008). Burton et al. (2008) also showed that fire severity in the Hudson Plains was moderate compared to other ecozones, and that individual fires were more homogenous in severity, which is probably related to the extensive and relatively homogenous wetlands common to this region.

From one year to the next there is large variability in the area burned in the Hudson Plains (Figure 19). Some years, particularly early in the fire record do not show any fires that burned over 2 km^2. Low years are also present in more recent times however, for example 1993 and 2004, indicating these lows are common and not just a problem with limited monitoring early in the record. Years of extreme fire activity include 1989 (4,572 km^2) and 2003 (3,455 km^2). Trends in decadal data indicate a significant increase in area burned after the 1970s (Figure 20). Based on the limited area burned in the 1960s and 1970s and the remote, northern location it is likely that the frequency of low area burned values may be to limitations in detection methods. Fires in the Hudson Plains go largely unsuppressed (Ontario Ministry of Natural Resources, 2004; Parisien et al., 2006; Burton et al., 2008) and other authors have documented that detection was non-existent or limited in these non-suppressed areas at the beginning of the large fire database records especially in Quebec and Ontario (Stocks et al., 2003). The increase in area burned from the 1980s to the 1990s, may be climate induced (Podur et al., 2002; Gillett et al., 2004; Girardin, 2007) similar to trends at the national level. Finally, the data show a slight decline in the last decade, although not as marked as the changes between other decades. Therefore, it is difficult to determine if this is real or a result of pro-rating the data for the 2000s based on the first seven years only.

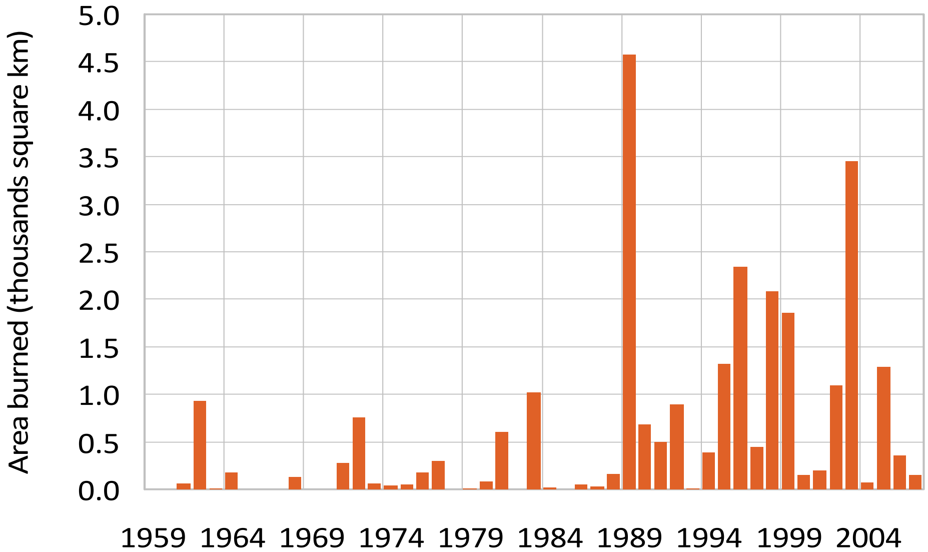

Figure 19. Annual area burned by large fires for the Hudson Plains, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

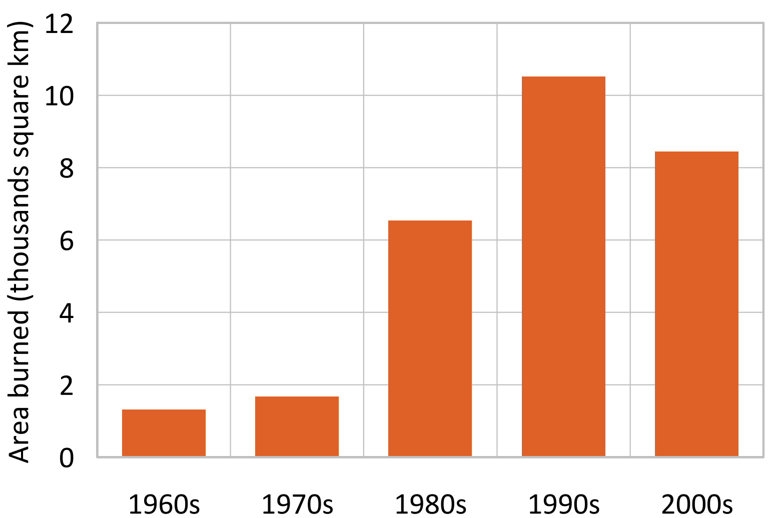

Figure 20. Total area burned by large fires per decade for the Hudson Plains, 1960s-2000s.
The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Similar to other remote northern ecozones⁺, the Hudson Plains is dominated by lightning caused fires. Lightning ignitions on average account for 89% of the large fires that occur (Table 7). This proportion varies slightly depending on the decade but lightning is consistently the dominant cause of fires. The proportion of fires caused by lightning does not appear to be changing, but the number of large fires caused by lightning has increased. In the 1980s, only 80 fires where caused by lightning, this almost doubled to 143 in the 1990s. More records are required to determine if this is a significant upward trend in lightning occurrence.

Table 7. Proportion of the number of large fires ignited by lightning compared to humans by decade for the Hudson Plains, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused ignitions (%)	Proportion of human caused ignitions (%)
1960s	12	92	8
1970s	46	80	20
1980s	90	89	11
1990s	150	95	5
Total	**298**	**89***	**11***

* average not total

Source: data are from the large fire database

Corresponding to the cause of fires, the occurrence of fires is predominately later in the season. Most fires in the Hudson Plains occur between May and August, peaking in July (Figure 21). The duration of the active fire season is on average 40 days, which is shorter than the nearby Taiga Shield and Boreal Shield (see Table 2 on page 9). The duration of the active fire season increased from 9 days in the 1960s to 59 days in 1990s. This increase is significant ($R^2 = 0.97$, $p = 0.026$), but the results should be looked at with caution due to the high probability that there are missing data in the 1960s and 1970s (Stocks et al., 2003). Lastly, the seasonality of fire occurrence appears to be shifting to later in the season (Figure 21) with an increased proportion of fires in August, although this pattern was not statically significant. These changes are consistent with changes noted by Kasischke and Turetsky (2006) and predictions made by Wotton and Flannigan (1993) that warmer temperatures, due to climate change, would result in a lengthening of the fire season later into the year in eastern Canada.

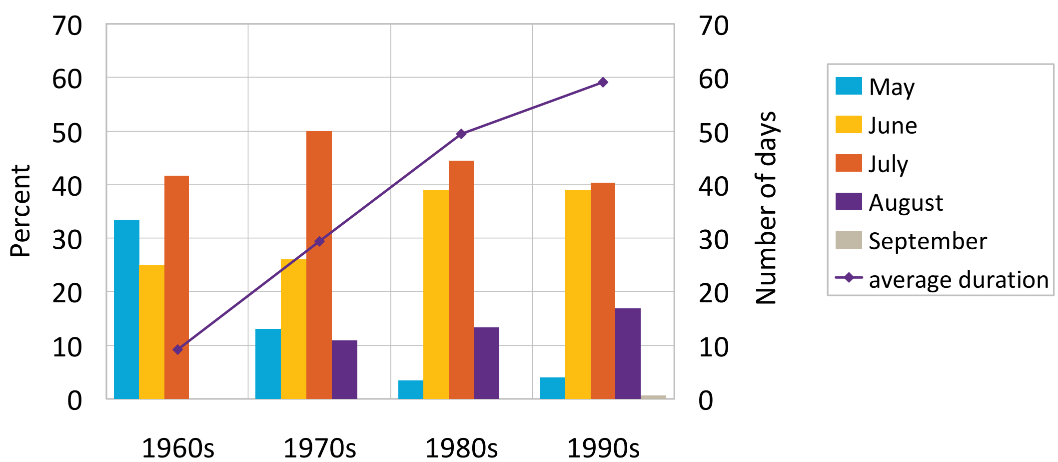

Figure 21. Proportion of large fires that occur each month in the Hudson Plains and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Taiga Cordillera

Despite the similarities in fuel type to the other taiga ecozones+, Parisien et al. (2006) showed that fires in the mountainous regions of the Taiga Cordillera are more similar to the Montane and Boreal Cordillera than the taiga or boreal ecozones+. The continental location of the cordillera areas results in drier burning conditions (Burton et al., 2008) and the mountainous terrain creates fuel discontinuity limiting fire spread (Parisien et al., 2006). The result is smaller, more severe fires that occur less often (Amiro et al., 2001; Stocks et al., 2003; Burton et al., 2008).

On average, 857 km² burn in the Taiga Cordillera Ecozone+ each year, which translates into a 4.5% contribution to the total area burned in Canada (see Table 1 on page 5). This proportion has fluctuated over time, from a low of 2.2% in 1980s to a high of 7.4% in the 2000s (see Figure 3 on page 7). On an annual basis, as with all the other ecozones+, there is much variability in area burned from year to year (Figure 22). During extreme fires years, for example 2004, 7,000 km² burned compared to years where no large fires occurred, such as 1970 and 1997. When area burned is calculated as a proportion of the total forested area, the Taiga Cordillera is larger than the national average at 0.47% (see Table 1 on page 5). It is also much higher than the Montane Cordillera (0.10%) and Boreal Cordillera (0.38%). The higher number may be related to differences in suppression efforts. Fires that burn in the Taiga Cordillera reflect the natural fire regime because there are no areas of intense fire suppression; compared to 100% suppression in the Montane Cordillera and 41% in the Boreal Cordillera (Parisien et al., 2006).

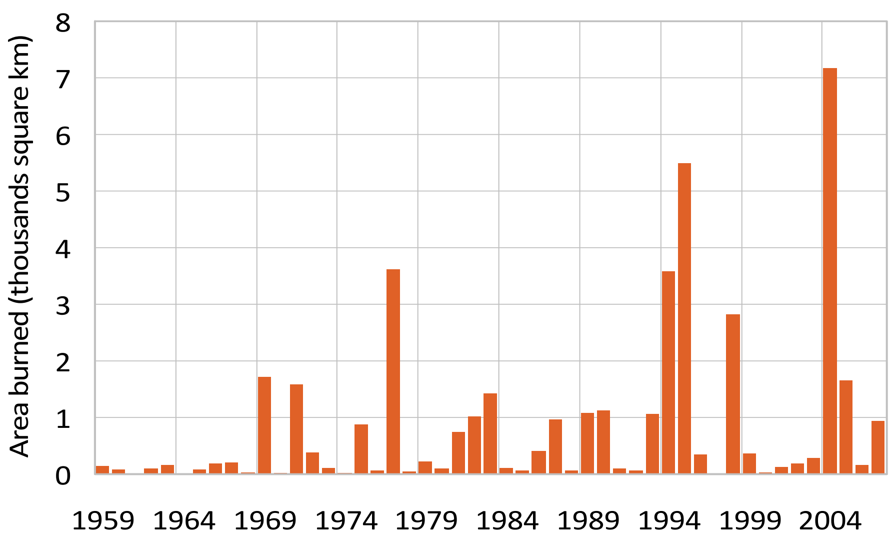

Figure 22. Annual area burned by large fires for the Taiga Cordillera, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

At the decadal scale there is no consistent pattern in area burned for the Taiga Cordillera Ecozone+ (Figure 23). The increase from the 1960s to 1970s is most likely due to limited monitoring in this northern ecozone+, which is a problem throughout the country (Podur et al., 2002; Stocks et al., 2003). The small decline in the 1980s is not seen in any of the other limited or non-suppressed ecozones+ (see Hudson Plains or Taiga Shield sections), which all showed increases in area burned attributed to warmer climate conditions (Podur et al., 2002; Gillett et al., 2004). Area burned doubles between the 1980s and 1990s and remains high, but drops slightly into the 2000s. The increase into the 1990s is consistent with the Montane and Boreal cordilleras, but the decline in the 2000s is not. A decline in area burned was shown, however, in the taiga and boreal ecozones+. Hence, the Taiga Cordillera may be responding to the same climate patterns as the other boreal areas, or the decline may be an artefact of using only eight years of data to represent 2000s.

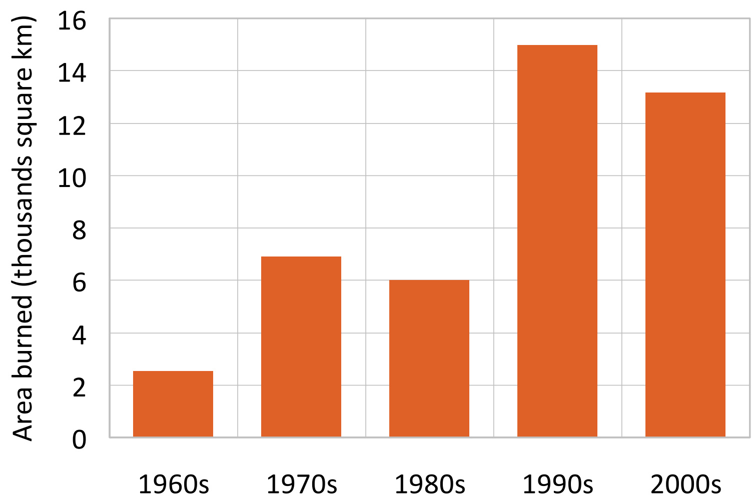

Figure 23. Total area burned by large fires per decade for the Taiga Cordillera, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

The fire season in the Taiga Cordillera is relatively short at 44 days on average (see Table 2 on page 9). From the 1960s until the 1980s, the duration the active fire season was consistently around 41 days, until the 1990s which saw an increase of 14 days (Figure 24). More data is required to determine if this increase is significant. Fires most commonly occur in June and July in this ecozone+. There has been a steady increase in the occurrence of fires in the month of August ($R^2 = 0.91$, $p = 0.04$). The number of fires that occurred during this month increased three fold from the 1960s to the 1990s (Figure 24).

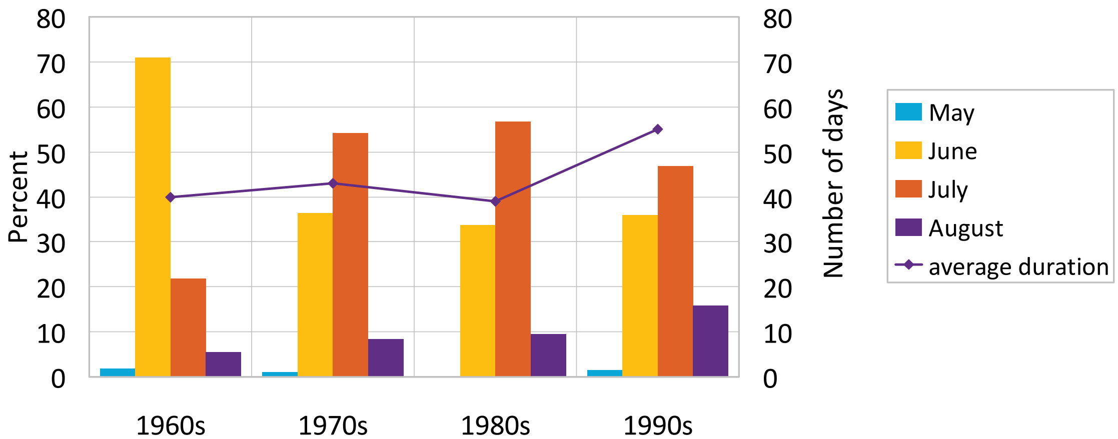

Figure 24. Proportion of large fires that occur each month in the Taiga Cordillera and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

The short duration during which fires occur and their occurrence late in the fire season are due to the prevalence of lightning ignitions in the Taiga Cordillera. Ninety-five percent of fires are caused by lightning in this ecozone+ (Table 8). Human caused large fires are rare and appear to be becoming more rare overtime (Table 8), although this decline was not shown to be significant. The ratio of human to lightning caused fires in the Taiga Cordillera is the lowest in the country at 0.05 (see Table 2 on page 9).

Table 8. Proportion of the number of large fires ignited by lightning compared to humans by decade for the Taiga Cordillera, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	55	93	7	2,480.8	70.4
1970s	96	95	5	6,636.5	286.1
1980s	157	95	5	5,697.5	311.3
1990s	139	99	1	16,839.9	539.0
Total	**428**	**95***	**5***	**31,654.7**	**1,206.9**

* average not total
Source: data are from the large fire database

Boreal Cordillera

The fire regimes in the cordillera ecozones+ have been shown to be unique when compared to the boreal forest (Parisien et al., 2006). The continental location of the cordillera results in drier burning conditions (Burton et al., 2008) while the mountainous terrain creates fuel discontinuity limiting fire spread (Parisien et al., 2006). Of the three cordillera ecozones+, the Boreal Cordillera has the highest area burned and most severe fires (Stocks et al., 2003; Parisien et al., 2006;

Burton et al., 2008). Average annual area burned is 1,206 km^2 (see Table 1 on page 5) which varies annually from less than 10 km^2 (for example, 1973 and 1987) to 11,014 km^2 (2004) during extreme years (Figure 25). The average relative contribution to total area burned in Canada is 8%, which is essentially double the other two cordillera ecozones+ (see Table 1 on page 5). At a local scale, the average percent of forested area that burns annually in the Boreal Cordillera is 0.38%, which is slightly higher than the Canadian average.

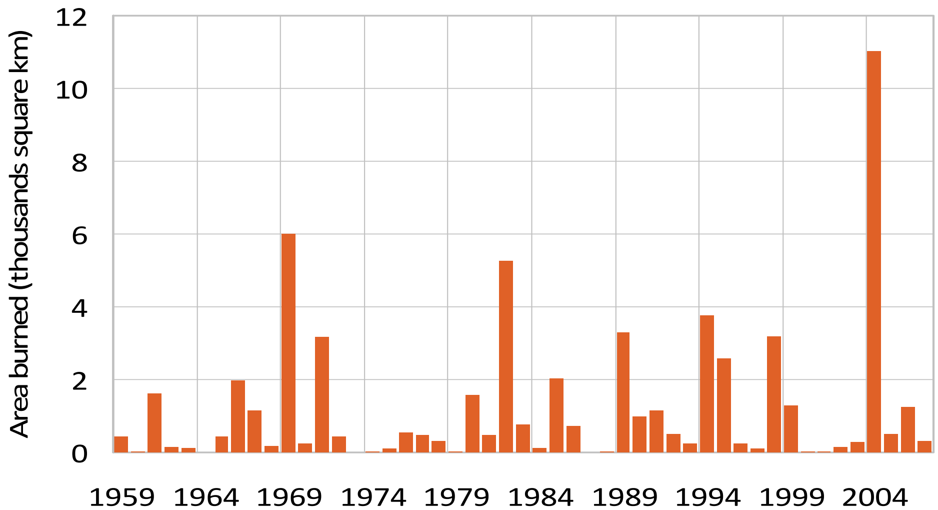

Figure 25. Annual area burned by large fires for the Boreal Cordillera, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

From a decadal perspective, there has been little variation in area burned over the last five decades, with the exception of the 1970s (Figure 26). The decline in area burned in the 1970s can be attributed to changes in human behaviour, either through advanced fire fighting techniques or increased prevention efforts. This trend is also shown in other ecozones+ that have some degree of suppression efforts (such as, Montane Cordillera and Boreal Plains). According to Parisien et al. (2006), 41% of the Boreal Cordillera is protected by intensive suppression activities. The increased success of suppression efforts has been attributed to the introduction of water bombers in the 1970s (Bergeron et al., 2001). An alternative explanation for the decline in burns in the 1970s is poor detection methods that lead to questionable values in the 1960s and 1970s, especially in northern regions (Podur et al., 2002; Stocks et al., 2003). Total area burned rose by about 9,000 km^2 between the 1970s and 1980s, after which it remained stable into the 1990s and rose slightly in the 2000s (Figure 26). The large increase from the 1970s to 1980s is not seen in either the Montane or Taiga cordillera ecozones+. This trend was evident in some of the boreal ecozones+ and was attributed to a combination of warmer climate (Podur et al., 2002; Gillett et al., 2004), increased forest use by humans, and better detection methods (Stocks et al., 2003). The increase in area burned in the 2000s is evident in all of the western ecozones+. There are a number of factors that may be causing these increases (see Montane Cordillera section on page 34). Changes in climate oscillations are most likely the cause of the increase in the Boreal Cordillera (Volney and Hirsch, 2005).

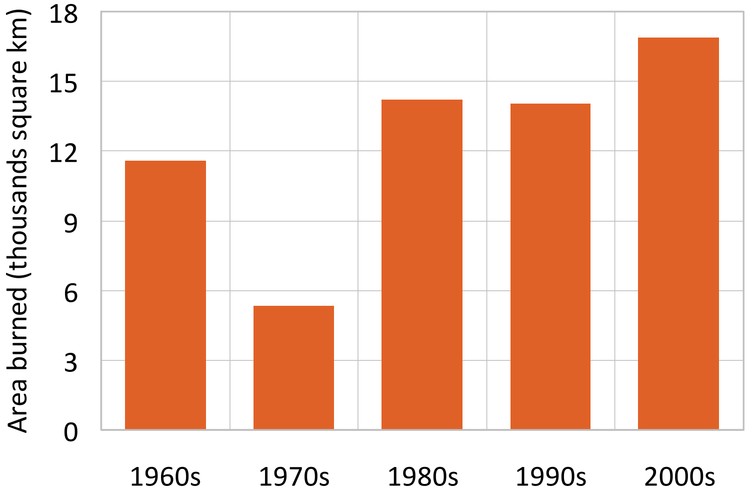

Figure 26. Total area burned by large fires per decade for the Boreal Cordillera, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

The duration of the active fire season is relatively short (37 days) in this ecozone+, compared to the nearby Taiga Cordillera (44 days), Taiga Plains (81 days) and Montane Cordillera (101 days) (see Table 2 on page 9). Fires most commonly occur between May and August, peaking in June or July (Figure 27). Fires have been recorded as early as April and as late as September, but these are rare occurrences. No significant changes occurred between the 1960s and 1990s in the duration or seasonality of fires in the Boreal Cordillera (Figure 27).

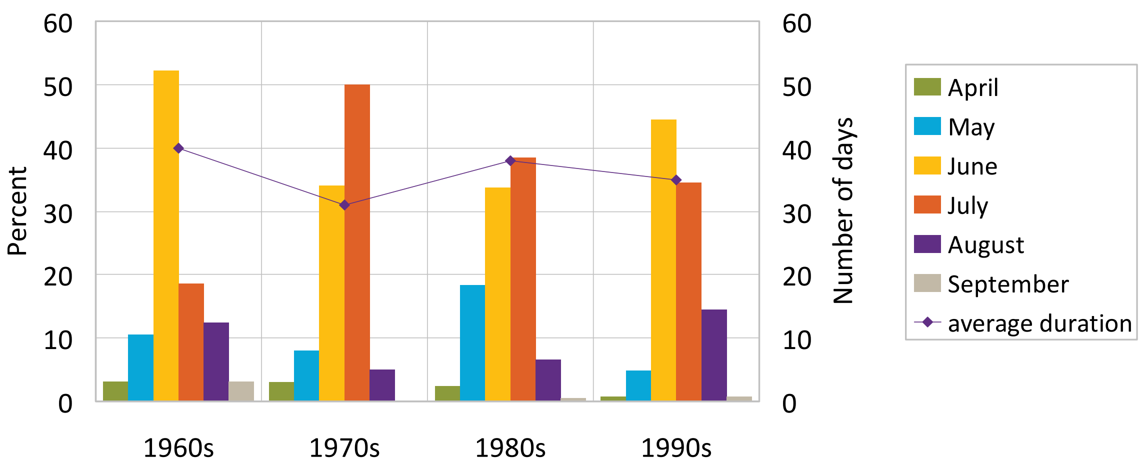

Figure 27. Proportion of large fires that occur each month in the Boreal Cordillera and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

The majority, 78% on average, of large fires that occur in the Boreal Cordillera are caused by lightning ignitions (Table 9) and human influence is relatively low. Parisien et al. (2006) identified 19% of the area as affected by human land use. This is similar to the Boreal Shield west and Taiga Plains. There was no significant change in the proportion of lightning to human ignitions up to between 1959 and 1999 (Table 9). The area burned by human ignitions increased over time, but this trend was not statistically significant.

Table 9. Proportion of the number of large fires ignited by lightning compared to humans by decade for the Boreal Cordillera, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	161	76	24	10,978.5	611.6
1970s	100	84	16	5,242.5	84.0
1980s	213	69	31	10,581.1	3,630.6
1990s	264	84	16	13,934.3	1,538.4
Total	**738**	**78***	**22***	**40,736.3**	**5864.5**

* average not total

Source: data are from the large fire database

Montane Cordillera

The Montane Cordillera Ecozone+ experiences the most severe fire weather of all the ecozones+. Despite this strong positive climatic influence, the fire regime is characterized by many small, low intensity fires (Stocks et al., 2003; Parisien et al., 2006). Topography and humans have a greater influence on fires in the Montane Cordillera limiting fire spread. Area burned for this ecozone+ ranged from zero (1993) to about 2,500 km² (1961 and 2003) during extreme years Figure 28), with a long-term average of 316 km² per year. The average contribution to the total area burned in Canada is almost 3.0% (see Table 1 on page 5), which fluctuated from a high of 5% in the 1960s to a low of 0.6% in the 1980s and 1990s (see Figure 3 on page 7). The percent of forested area that burns is also small at 0.10% per year on average (see Table 1 on page 5).

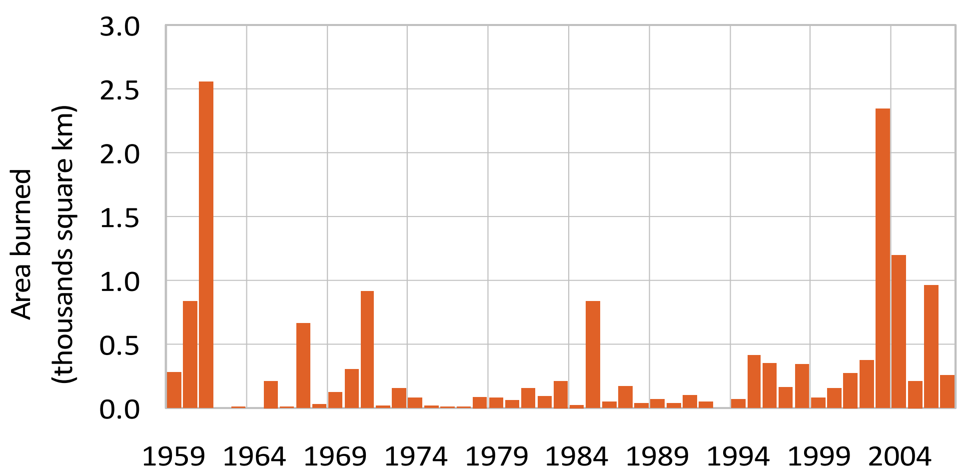

Figure 28. Annual area burned by large fires for the Montane Cordillera, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

The Montane Cordillera is the only ecozone^{+} that is completely encompassed by fire suppression activities (Parisien et al., 2006). These forest management efforts are evident in the long-term pattern of area burned (Figure 29), which is strongly influenced by humans. There is a sharp decline in area burned from the 1960s to the19 70s, most likely due to increased fire management and suppression efforts (Stocks et al., 2003). Area burned remained stable over the next three decades unlike any of the other ecozones^{+}. The reason again is likely tied to successful suppression efforts due to high values at risk in this area (Stocks et al., 2003; Parisien et al., 2006). During the 2000s, there was a dramatic increase in area burned (Figure 29). Extreme fires years in 2003, 2004, and 2006 contributed to this increase (Figure 28). A number of factors may be responsible for this increase including: climate oscillations such as an El Niño event in 2002/2003 and a warm phase PDO from 2003 to 2005 (Volney and Hirsch, 2005), increased fuel loads in the forest due to long-term suppression of fires (Allen, 2001; Parker et al., 2006), and a positive interaction between forest fires and the mountain pine beetle epidemic that struck this ecozone^{+} in the last decade (Jenkins et al., 2008).

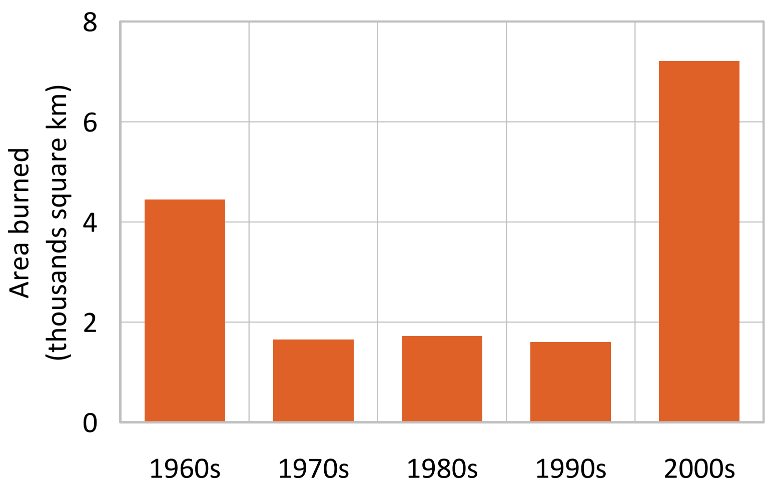

Figure 29. Total area burned by large fires per decade for the Montane Cordillera, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

The period during which fires occur in the Montane Cordillera spans from April to November, lasting 101 days on average (Figure 30). Fires are most common in June through August, peaking at the end of the summer, but can continue into the month of November. From the 1960s to 1990s, the duration of the active fire season did not changed, but the distribution of fires within the fire season did. Since the 1960s, there was an increase in the proportion of fires in both the spring and fall (Figure 30). The proportion of fires in the month of May increased from 2.7 to 17.9% ($R^2 = 0.94$, $p = 0.03$) and from 3.2 to 17.9% for the month of September ($R^2 = 0.93$, $p = 0.03$). These changes are consistent with predictions made by Wotton and Flannigan (1993) that the fire season would lengthen in both the spring and fall in British Columbia as global temperatures increase.

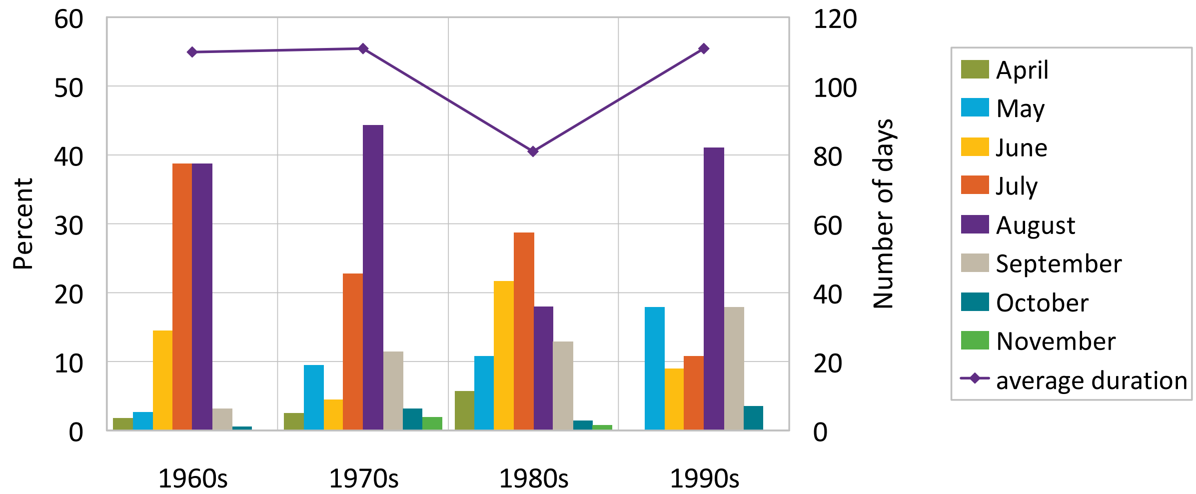

Figure 30. Proportion of large fires that occur each month in the Montane Cordillera and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

On average, fire ignitions over the long-term have been equally caused by humans and lightning in this ecozone+ (Table 10), thus the reason for the increase in both seasons. As stated in the National Trends section, spring fires are predominately human caused and summer fires are primarily caused by lightning (Stocks et al., 2003). There were slightly more lightning caused large fires than human caused fires on average between the 1960s and 1990s, at 52.8 and 47.2% respectively (Table 10). Over time these proportions changed significantly. At the beginning of the period of record lightning ignitions were responsible for 61% of the large fires; this declined to only 27% by the 1990s ($R^2 = 0.95$, $p = 0.03$) (Table 10). Area burned by lightning ignitions also declined significantly over the 40 year period by over 2,000 km^2 (Table 10). Despite the increase in the proportion of human ignitions there was also a decline in area burned by humans, although this decrease was not significant. Both sources of ignitions lead to similar areas burned.

Table 10. Proportion of the number of large fires ignited by lightning compared to humans by decade for the Montane Cordillera, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	222	61	39	2,345.5	2,095.6
1970s	159	55	45	1,073.2	578.0
1980s	137	45	55	817.0	901.0
1990s	62	27	73	181.6	314.2
Total	**580**	**47***	**53***	**4,417.4**	**3,888.9**

* average not total

Source: data are from the large fire database

Western Interior Basin

Large forest fires do not play a significant role in the disturbance regime of the Western Interior Basin. Previous ecological classifications have included this area as part of the Montane Cordillera Ecozone⁺ (see Preface on page i), therefore any supplementary information available in the fire literature for this area is the same as that presented for the Montane Cordillera. One can assume that similar conditions apply. Fire weather is severe for this region (Parisien et al., 2006), but even fewer large fires occur than in the Montane Cordillera. Fires in the Western Interior Basin range from years with no large fires to extreme years where up to 800 km^2 burned (Figure 31). On average, only 54 km^2 burned each year. This area contributes less than 1% to the total area burned in Canada (see Table 1 on page 5) and has varied little over the last 40 years (see Figure 3 on page 7). Within the ecozone⁺ the percent forested area that burns annually is slightly higher than the Montane Cordillera at 0.11% per year.

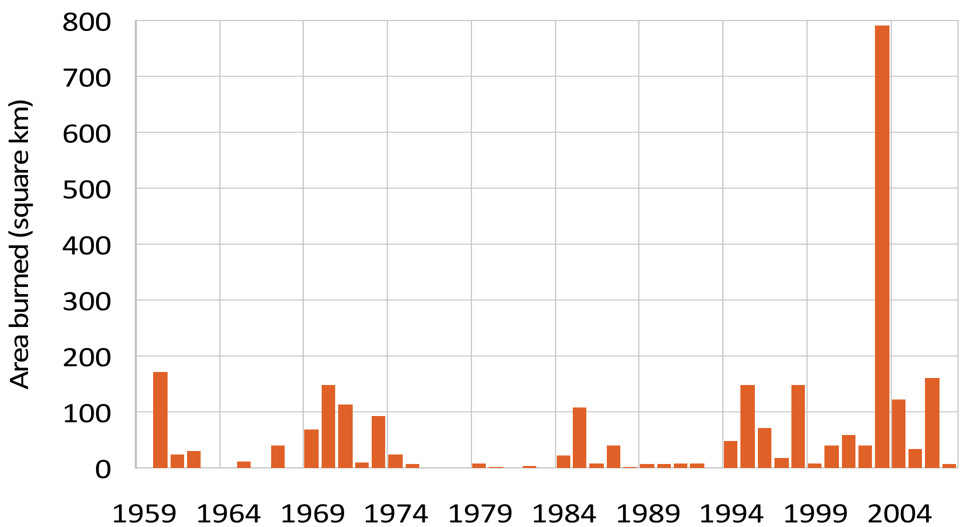

Figure 31. Annual area burned by large fires for the Western Interior Basin, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

Until the 2000s, area burned in the Western Interior Basin was relatively stable (Figure 32). There was a slight decline in the 1980s, a trend that also occurred in the nearby Pacific Maritime Ecozone⁺, and was attributed to a reduction in fires as a result of prevention education and aggressive fire attack (Stocks et al., 2003). This level was not sustained into the 1990s, which returned to levels of area burned similar to the 1960s and 1970s. The modest increase in the 1990s may be attributed to warmer temperatures (Stocks et al., 2003; Gillett et al., 2004). The most significant change over the past five decades occurred from the 1990s to the 2000s. Area burned increased by over 1,000 km^2. This trend also occurred in the Montane Cordillera. The same potential drivers apply to this ecozone⁺ including: positive climate oscillations such as an El Niño and a warm phase PDO (Volney and Hirsch, 2005), increased fuel loads in the forest due to long-term suppression (Allen, 2001; Parker et al., 2006), and a positive interaction between forest fires and the mountain pine beetle epidemic (Jenkins et al., 2008).

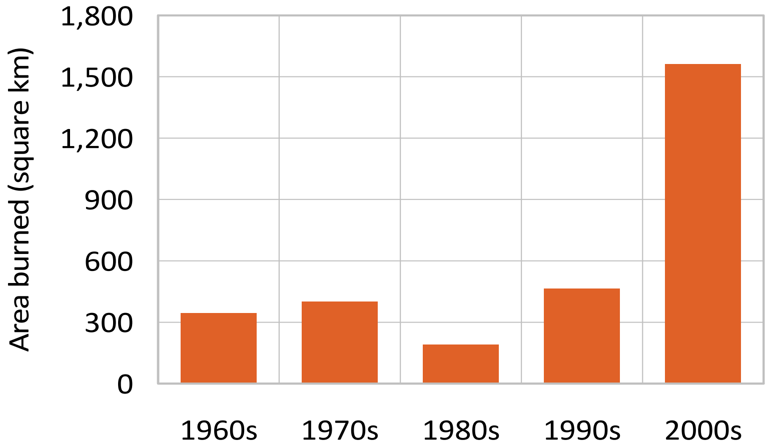

Figure 32. Total area burned by large fires per decade for the Western Interior Basin, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Fire suppression and human land use are also high in the Western Interior Basin. Areas such as the Okanagan Valley contain high values at risk for protection and increased concentration of land use due to extensive population in the area. All of the area is protected by fire suppression activities based on statistics for the Montane Cordillera (Stocks et al., 2003; Parisien et al., 2006). Compared to the Montane Cordillera, the average duration of the active fire season is much shorter – 45 days compared to 101 days (see Table 2 on page 9). Most fires occur from June to August, with the peak in July, but fires have been recorded as early as April and as late as October (Figure 33). There was no significant change in the duration of the fire season or in the distribution of fires during the season from 1959 to 1999. The duration of the active fire seasons decreased by 27 days but this decline was not statistically significant and may be linked to a significant decrease in the number of fires that have occurred over the last two decades (Figure 33). More data are required to make any definitive insights into these changes.

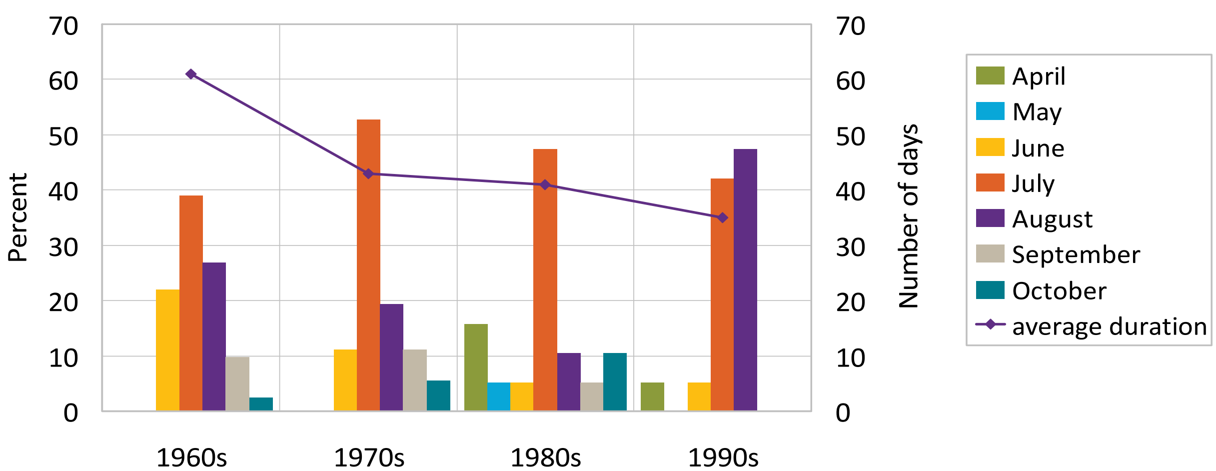

Figure 33. Proportion of large fires that occur each month in the Western Interior Basin and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Humans are the dominant cause of fires in the Western Interior Basin (Table 11). This trend is consistent from the 1960s to the 1990s. Lightning ignited fires are less common here than in the Montane Cordillera. The Western Interior Basin is more similar in this regard to the Pacific Maritime Ecozone+.

Table 11. Proportion of the number of large fires ignited by lightning compared to humans by decade for the Western Interior Basin, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	38	21	79	75.5	268.6
1970s	36	28	72	54.0	346.8
1980s	20	25	75	82.3	108.5
1990s	20	15	85	22.4	265.2
Total	**114**	**22***	**78***	**234.2**	**989.1**

* average not total

Source: data are from the large fire database

Pacific Maritime

Fire is not a significant natural disturbance in the Pacific Maritime Ecozone+ (Stocks et al., 2003; Amiro et al., 2009), nor has it been in the distant past (> 6,000 years) (Lertzman et al., 2002). The contribution to annual area burned in Canada is the lowest of all ecozones+ at 0.3% (see Table 1 on page 5). It is also insignificant at the ecozone+ scale, where only 0.02% of the forested area of the ecozone+ is affected by fires on average per year. Despite the inclusion of some subalpine and montane species along the eastern boundary of the ecozone+, fire is not a prominent feature on the landscape. These species readily burn in the adjacent Montane Cordillera but the wet, maritime climate of the Pacific Maritime is not conducive to fire.

Fires that do occur are predominately caused by humans (72%) through recreational activities and logging practices (Pew and Larsen, 2001). The average annual area burned is only 20.8 km^2 and ranges from zero in some years to an extreme of 144 km^2 in 1961 (Figure 34). The majority of fires that do occur are very small, in the range of 0.1 ha or less (Pew and Larsen, 2001). These small fires are not included in the data from 1959 to 1994. Over the last five decades there has been some change in annual area burned (Figure 35). From the 1960s through to the 1980s, the area burned decreased. This is most likely due to a reduction in fires caused by humans as a result of prevention education and aggressive fire attack (Stocks et al., 2003). Since the 1980s, the area burned has increased by 84 km^2, which is not a significant increase over 20 years. The trends in long-term area burned are purely speculation at this point as it is difficult to elucidate trends when the fire activity is infrequent and area burned is so low.

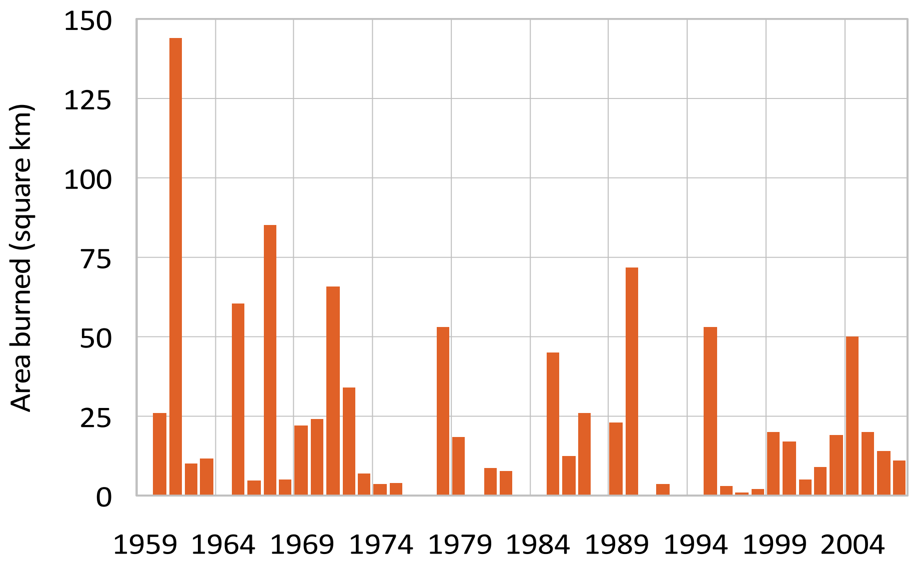

Figure 34. Annual area burned by large fires for the Pacific Maritime, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

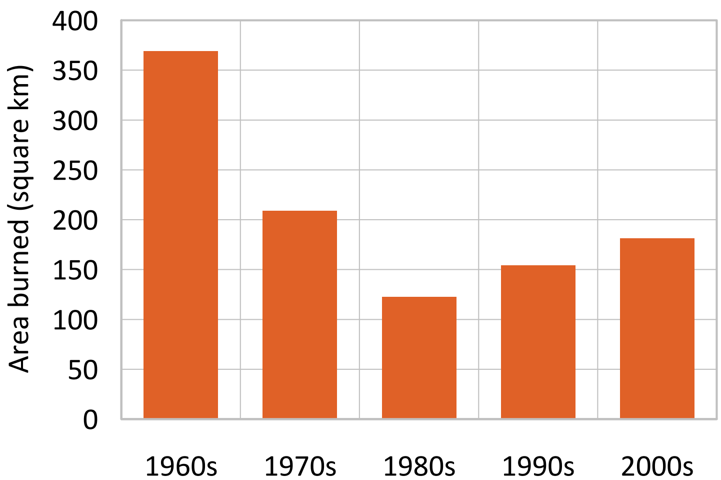

Figure 35. Total area burned by large fires by decade for the Pacific Maritime, 1960s-2000s.
The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

Atlantic Maritime

Forest fire is not a common or significant natural disturbance in the coastal climate of the Atlantic Maritime Ecozone+. On average 34 km² burns in this ecozone+ each year. This area is less than 1% of the total area burned in Canada and represents only 0.02% of the forested area of the ecozone+ (see Table 1 on page 5). There is some variability in area burned from year to year (Figure 36), but the magnitude is insignificant when compared to the range in the other ecozones+. Extreme fire years in 1986 and 1995 burned 374 and 296 km² respectively. It is common in the Atlantic Maritime to have years where there are no large fires.

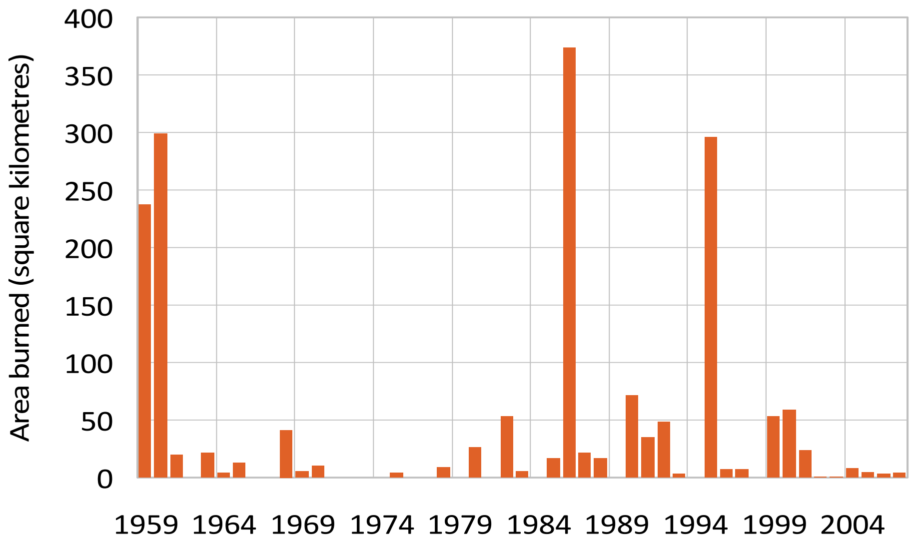

Figure 36. Annual area burned by large fires for the Atlantic Maritime, 1959-2007.
Source: data from 1959-1994 are from the large fire database; data from 1995-2007 are derived from remote sensing

The active fire season in the Atlantic Maritime Ecozone+ lasts an average of 32 days and fires most commonly occur in May to June, with the peak occurrence in May (Figure 37). The early peak in the fire season is related to the primary cause of fire ignition in this ecozone+, which is humans (Table 12). Areas dominated by human ignitions tend to have greater fire occurrence earlier in the year (Stocks et al., 2003). On average, humans ignited 86% of the fires in the Atlantic Maritime from the 1960s to 1990s and are the dominant contributor to area burned (Table 12). Lightning ignited fires are relatively rare in the Atlantic Maritime; there was an absence of lightning caused fires for almost 20 years in this ecozone+.

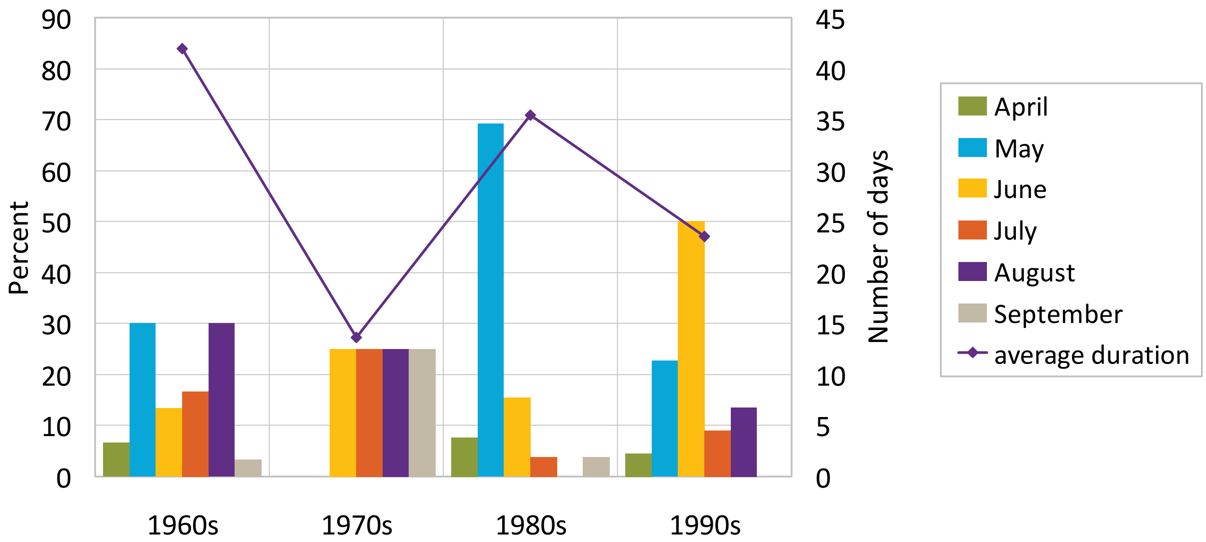

Figure 37. Proportion of large fires that occur each month in the Atlantic Maritime and the average duration of the active fire season (purple line), 1960s-1990s.
Monthly numbers are the percentage of the total number of fires that occurred during the month.
Source: data are from the large fire database

Table 12. Proportion of the number of large fires ignited by lightning compared to humans and the total area burned by each ignition source by decade for the Atlantic Maritime, 1960s-1990s.

Decade	Number of fires	Proportion of lightning caused fire ignitions (%)	Proportion of human caused fire ignitions (%)	Total area burned as a result of lightning ignitions (km^2)	Total area burned as a result of human ignitions (km^2)
1960s	30	23	77	48.4	356.0
1970s	4	0	100	0	23.1
1980s	26	0	100	0	514.9
1990s	22	32	68	215.4	235.2
Total	**82**	**14***	**86***	**263.8**	**1,129.1**

* average not total
Source: data are from the large fire database

Similar to the Pacific Maritime, it is difficult to determine significant trends in long-term area burned because the frequency of fires is so small; for example, there were only four fires in the 1970s (Table 12). Figure 38 shows the change in area burned over the last five decades. There was a sharp decline in the 1970s, which could be attributed to prevention and suppression efforts, but this would not explain the following rise in the 1980s that was sustained into the 1990s. The decline in the 2000s is similar to what occurred at the national level, but again it is difficult to explain why these trends are occurring without additional information.

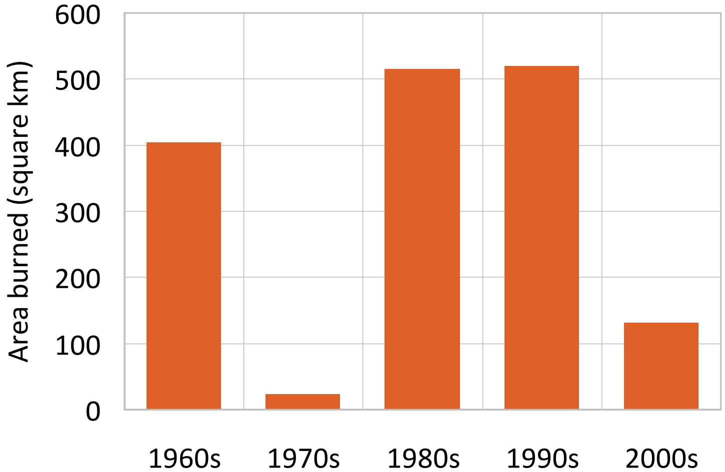

Figure 38. Total area burned by large fires per decade for the Atlantic Maritime, 1960s-2000s. The value for the 2000s decade was pro-rated over 10 years based on the average from 2000-2007.

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