A Critical Evaluation of Fire Suppression Effects in the Boreal Forest of Ontario

S.R.J. Bridge, K. Miyanishi, and E.A. Johnson

Abstract: Although fire suppression is widely believed to have changed the “natural” fire regime in the boreal forest, empirical evidence for this effect is limited and usually involves a comparison of fire sizes, average annual area burned, and fire cycle between areas with and without fire suppression. We critically evaluate this empirical evidence and discuss problems with untested assumptions, data quality, statistical analyses, interpretations, and inferences. Furthermore, to test the hypothesis that fire suppression has changed the natural fire regime, we apply time-since-fire techniques to spatial fire data (1921–1995) for the western and eastern boreal regions of Ontario and compare temporal and spatial variation in fire cycle for areas with and without fire suppression. There is no detectable temporal change in fire cycle between 1921 and 1995 in areas with aggressive fire suppression; however, interpretation of the fire cycle in areas without aggressive fire suppression is confounded by insufficient data. Also, although the western region shows an increase in fire cycle from fully protected to less protected areas, the eastern region shows the shortest fire cycle in the most protected area. Thus, to date there is insufficient empirical evidence that fire suppression has significantly changed the fire cycle in the boreal forest of Ontario. FOR. SCI. 51(1):41–50.

Key Words: Forest fires, fire frequency, fire cycle, time-since-fire, emulating natural disturbance.

Fire is the dominant natural disturbance in the boreal forest, determining the age distribution and spatial age mosaic of the forested landscape (Johnson 1992, Weir et al. 2000). Numerous studies have been done on spatial and temporal variation in fire frequency across the North American boreal forest (Woods and Day 1977, Johnson 1979, Yarie 1981, Suffling et al. 1982, Bergeron 1991, Bergeron and Archambault 1993, Larsen 1996, Weir et al. 2000, Bergeron et al. 2001). The extent to which humans influence (or have control over) the fire regime of the forested landscape is of interest to ecologists for understanding forest and landscape dynamics and to forest managers and policy makers for determining sustainable harvest levels. Since, in many instances, burned trees cannot be commercially harvested, the setting of appropriate sustainable harvest rates must take into consideration the loss of trees to forest fires. Therefore, a key question is the extent to which fire suppression has affected the “natural” fire regime.

It is often believed that fire suppression has reduced the average annual area burned across the Canadian boreal forest (e.g., Stocks 1991, Ward and Tithecott 1993, OMNR 1996, Davis 1999, Ward and Mawdsley 2000) and that, in some cases, this has made available as much as 35% of today’s annual allowable tree harvest (OMNR 1997, Ward and Mawdsley 2000). This belief in the effectiveness of fire suppression in reducing the “natural” fire frequency is widely accepted by resource managers yet, until recently (e.g., Miyanishi and Johnson 2001, Ward et al. 2001, Martell 2002, Miyanishi et al. 2002), there has been little or no discussion of this belief in the refereed literature. The objective of this article is to present a critical evaluation of the arguments and evidence on the effects of fire suppression on the average annual area burned (and therefore on the fire frequency and fire cycle) in the boreal forest of Ontario. Specifically, we address the questions of whether fire suppression has changed (1) the sizes of fires, (2) the average annual area burned, and (3) the fire cycle. We also present new data that may help to clarify some of the misunderstandings apparent in the interpretation of data presented in previous studies.

Fire Management in Ontario

Because much of the evidence we evaluate and present involves comparisons between areas with and without aggressive fire suppression policies in Ontario, we provide here some information on the areas being compared and their fire suppression policies. The province of Ontario is divided into several fire management zones (OMNR 1997, Ward and Mawdsley 2000), each zone falling into one of three levels of protection classified as intensive, measured, or extensive (Figure 1). Fire management in the intensive protection zone, where fires have the potential to cause

Kiyoko Miyanishi, Department of Geography, University of Guelph, Guelph, Ontario N1G 2W1, Canada—Phone: (519) 824-4120, ext. 6720; Fax: (519) 837-2940; kmiyanis@uoguelph.ca. Simon R.J. Bridge, Northeast Science and Technology, Ontario Ministry of Natural Resources, PO Bag 3020, South Porcupine, ON P0N 1H0; Current address: Policy, Planning and International Affairs, Canadian Forest Service, Natural Resources Canada, 580 Booth Street, Ottawa, Ontario K1A 0E4, Canada—Phone: (613) 947-9034; Fax: (613) 947-9038; sbridge@nrcan.gc.ca. E.A. Johnson, Department of Biological Sciences, University of Calgary, Calgary, Alberta T2N 1N4, Canada—Phone: (403) 220-3570; Fax: (403) 289-9311; johnsone@ucalgary.ca.

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major social disruption and significant impacts on values and resources, is designed to minimize area burned and uses extensive prevention measures, proactive, organized detection and aggressive initial attack of all fires. Response to fire in the measured protection zone, with less concentrated values but importance for tourism and potential future industrial development, consists of aggressive initial attack, which attempts to suppress the fire. However, fires that escape initial attack are assessed and the costs of the firefighting commitment are balanced with the values at risk in determining continued action. The extensive protection zone encompasses the northern portion of the fire region, where response to fire is designed to ensure human safety and minimize property damage. Only fires that threaten these values are aggressively attacked until the threat has passed. All other fires are monitored to ensure they do not threaten identified values but are not actively suppressed; there is no policy to minimize area burned in this zone. Because the policies in both the intensive and measured zones involve initial attack of all fires detected, these areas are considered here to have aggressive fire suppression policies, and data from these zones are compared with those from the extensive zone, which is considered to be without an aggressive fire suppression policy.

**Has Fire Suppression Changed the Sizes of Fires?**

One way to evaluate whether fire suppression has affected the fire regime is to determine whether it has decreased the sizes of fires in the boreal forest. Two studies, using similar data from Ontario government fire records, compared the size distributions of fires in areas with and without aggressive fire suppression policies (i.e., the intensive and measured zones versus the extensive zone) and argued that areas without aggressive fire suppression have larger average fire sizes and hence greater average annual area burned (Stocks 1991, Ward and Tithecott 1993). These
distributions, presented either as actual or percentage mean annual numbers of fires by size class, reveal a highly right-skewed distribution for areas with aggressive fire suppression policies and a relatively flat distribution for areas without such policies (Figure 2). The explanation given for this difference in distribution shape was that fire suppression prevents fires from becoming large so areas with aggressive fire suppression have proportionately more small fires; however, unsuppressed fires grow into large fires, resulting in proportionately more large fires. These results have been reiterated in the literature (e.g., Weber and Stocks 1998, Ward and Mawdsley 2000).

The problem with this evidence, as recognized by Ward and Tithecott (1993), is the difference in detection of fires, particularly small ones, between areas with and without aggressive fire suppression policies. In the zone with the lowest level of protection the policy doesn’t require initial attack of all fires; thus there is no formal system for detecting all fires. Detection often relies on public reports from settlements or commercial aircraft (OMNR 1997). Given the remoteness of this area from human settlements and roads, most small fires are likely to go undetected or unreported. An examination of the provincial fire records, which show the starting location and final size, but not the mapped area burned, for all fires between 1976 and 1990 further supports this detection bias (Figure 3). Only 352 fires <10 ha were detected in the extensive zone compared with 25,176 in the intensive and measured zones, of which 9,592 were caused by lightning. Furthermore, Figure 3 indicates that a similar number of large fires burn in both the intensive + measured zone and the extensive zone; this is also supported by examination of Ward and Tithecott’s (1993) Figures 4 and 5 and Ward et al.’s (2001) Figure 6. Therefore, the difference in shape between the fire size distributions for the two zones can be explained simply by the under-detection of small fires in the extensive zone.

Ward et al. (2001) tried to resolve the problem of underestimation of small fires in the extensive zone by attempting to quantify the discrepancy between the number of small fires detected and the actual number of small fires believed to have occurred. They fit a power law function to a subset of the fire size distribution (deleting data on fires <4 ha and >20,000 ha) and then extrapolated the function to the fire size classes between 0.1 and 4 ha. Based on these extrapolated estimates, they argued that the numbers of missing small fires from the data set would not be sufficient to change the overall flattened shape of the fire size distributions for the extensive zone (i.e., that there really are proportionately fewer small fires in the absence of fire suppression). In their analysis, Ward et al. (2001) state that it “seems reasonable that this power law should hold down to the 0.1 ha end of the fire size distribution as well.” However, this assumption has since been shown to be unfounded by Reed and McKelvey (2002), who presented empirical evidence for the failure of the power-law function to describe complete (uncensored) fire size distributions. They examined empirical size distributions derived from extensive fire records for six regions in North America, including data for 5,478 fires in northeast Alberta (1961–1998) and 2,544 fires in the Northwest Territories (1992–1999), to test the claim by Malamud et al. (1998), Ricotta et al. (1999), and Cumming (2001) that empirical fire-size distributions exhibit power-law behavior. They concluded that “power-law behavior, at best [our italics], only holds over a limited range of sizes,” that is, the midrange of fire sizes, and not for either very small or very large fire sizes. Thus, there is still insufficient justification for using comparisons of fire size distributions between the different fire management zones in Ontario to infer the effects of fire suppression.

Has Fire Suppression Changed the Average Annual Area Burned?

The effects of fire suppression have also been addressed by spatial comparisons of average annual area burned between areas with varying levels of fire suppression (e.g., Martell 1994, 1996, Ward et al. 2001, Li 2000). It has been argued that far more lightning-caused fires are detected in the intensive and measured zones and yet the average annual area burned is much higher in the extensive zone; thus,
fire suppression must be reducing the area burned by lightning fires (Li 2000, Ward and Mawdsley 2000). Because the underdetection of lightning-caused small fires in the extensive zone is not debated and the actual numbers of lightning-caused fires in the extensive zone are unknown, the first part of the argument can be dismissed.

One major problem with the use of spatial comparisons to infer fire suppression effects is the assumption that the only difference between the areas being compared is the fire suppression policy (Miyanishi and Johnson 2001, Miyanishi et al. 2002). This assumption is never rigorously tested and ignores confounding effects like numbers of human- versus lightning-caused fires, fragmentation of the forest, and differences in climate, landscape, and land use, all of which may influence fire regimes (Johnson et al. 1996, Keeley et al. 1999, Weir et al. 2000). For example, Weir et al. (2000) showed the significant impacts on fire regime within the southern half of Prince Albert National Park due to agricultural settlement and boreal forest fragmentation in the areas surrounding the Park. Given the more or less latitudinal zonation of Ontario into the different fire management zones (Figure 1), spanning latitudes from 44°N to 54°N with levels of protection related to human population density and land use, these other factors cannot be ignored (although Ward et al. (2001) do try to control for this to some extent by narrowing their examination of fire suppression effects to a single ecoregion). In the next section on fire suppression effects on fire cycles, we present an illustration of the problem arising from attributing spatial differences in fire regime to fire suppression.

A second problem with such spatial comparisons of average annual area burned (as used by Ward and Tithecott 1993, Martell 1994, 1996, Li 2000, Ward and Mawdsley 2000) is the short period of fire records used in these studies to estimate average annual area burned. Ward and Tithecott used 25 years of data while Martell used 13 years of data. The extreme inter-year variability in annual area burned (Figure 4) makes averages over short time periods highly unstable and difficult to interpret (Johnson and Gutsell 1994, Johnson et al. 1996); the occurrence of a single large fire in one year can have a very large effect on the average (Weir et al. 2000, Miyanishi et al. 2002).

**Has Fire Suppression Changed the Fire Frequency/Fire Cycle?**

Another approach to investigating the effects of fire suppression is to determine whether there has been a change in fire frequency or fire cycle between the pre and post-suppression period within a given area. Fire cycle is the inverse

![Figure 3. Fire size distributions for the intensive and measured versus the extensive protection zones across the entire province of Ontario (1976–1990).](https://academic.oup.com/forestscience/article-abstract/51/1/41/4617264)

![Figure 4. Annual area burned by wildfire within Ontario’s fire region (1968–1999).](https://academic.oup.com/forestscience/article-abstract/51/1/41/4617264)
of fire frequency and is defined as the time required to burn an area equal in size to the study area. The fire frequency, therefore, is the probability of an element burning within the study area per unit time (i.e., the longer the fire cycle, the lower the fire frequency and the longer it takes to burn an area the size of the study area). Estimates of the fire cycle can be determined from maps that show the time-since-last fire for all stands within a study area (Van Wagner 1978, Johnson and Wagner 1985, Johnson and Gutsell 1994, Reed 1994, 1997). Time-since-fire distributions have been found to be negative exponentials that plot as straight lines in semi-log space. The slope of the line gives the estimate of the fire cycle: the steeper the slope, the shorter the fire cycle. Statistical methods have been developed to determine the occurrence of significant changes in the fire cycle as well as confidence intervals for the estimated fire cycles (Reed 1997, 1998, 2000, 2001).

Climate Effects


Ward and Tithecott (1993) and Ward et al. (2001) argued that the longer fire cycle in the 20th century compared to the historic fire cycle for the boreal forest of Ontario was due to fire suppression. However, the relatively synchronous timing of this change across the North American boreal forest in areas with and without fire suppression and its coincidence with the end of the Little Ice Age indicates climate change as a more reasonable explanation than fire suppression effects. Furthermore, contrary to what one might expect, these fire frequency studies show that the fire cycle in the boreal forest was shorter (i.e., more area burned) during the cooler period of the Little Ice Age (Johnson 1992, Bergeron and Archambault 1993, Larsen 1996, Weir et al. 2000, Bergeron et al. 2001). Despite this evidence of a longer fire cycle associated with climatic warming, one perception of the impact of global warming is that, in the absence of fire suppression, circumboreal forests will see an increase in fire activity and area burned. Indeed, Ward et al. (2001) made this assumption, based on the results of the 2 x CO₂ climate modeling simulations by Stocks et al. (2000), which predicted an increase to moderate fire danger levels in eastern Canada with the projected greenhouse warming. However, the evidence for this is still equivocal, particularly in Ontario, where a simulation study by Flannigan et al. (1998) predicted a decrease in fire danger over the eastern boreal forest due to a projected increase in precipitation. Given these contradictory results obtained from general circulation model (GCM) simulations, the recognized problems of using GCMs for making regional-scale projections across the boreal forest zone (Stocks et al. 2000), and the agreement among empirical studies of an increase in fire cycle with early 20th century warming, there appears to be little basis to assume that 20th century warming in the absence of fire suppression should have led to a decrease in fire cycle across Ontario. Therefore, there is little support for the argument by Ward et al. (2001) that, despite this expected increase in fire activity and the increased forest harvesting over the 20th century, the reduction in area disturbed by fire and harvesting together (as indicated in the age distribution of the forest) is probably attributable to the effects of fire suppression.

Suppression Effects

None of the previous time-since-fire studies were specifically looking for the effects of fire suppression on the fire cycle. In fact, some of the studies cited by Ward et al. (2001) are largely anecdotal, and sometimes stand-specific (Burgess and Methven 1971) or based on lake sediments (Swain 1973). Therefore, we present here the results of a study (see Appendix for description of methods) whose objective was to apply time-since-fire distribution techniques to fire data from Ontario for the period 1921–1995 in areas with and without aggressive fire suppression policies to determine whether there was any evidence of fire suppression effects.

In Ontario, fire suppression activities began sometime in the late 1910s, but these suppression activities are generally thought to be minimal compared with post-1950, when fire suppression began in earnest and technological advances made firefighting more effective (OMNR 2002, Thompson 2000). Many parts of northern Ontario were only first being settled by 1920 (McDermott 1961); therefore, changes in fire cycle before 1920 are usually not attributed to fire suppression. If fire suppression has been effective in reducing the average annual area burned (i.e., increasing the fire cycle), then areas that have aggressive fire suppression policies should show a clear change to a longer fire cycle after 1950, while areas with no policy of aggressive fire suppression should show no change in fire cycle around 1950. Ontario is divided into east and west fire regions. The data for these two regions were analyzed separately due to potential differences in climate and vegetation that may exist between these two parts of the province. For example, Ontario’s western boreal region tends to have more thunderstorm days in summer (Johnson 1992) and be slightly warmer, with a longer growing season and less annual
precipitation (Hills 1959, Mackey et al. 1996, Baldwin et al. 2000) than the eastern boreal region.

As shown by the six time-since-fire distributions (for each of three levels of protection and two regions) in Figure 5, there has been no detectable change in the fire cycle between 1921 and 1995 for the four areas (the intensive and measured zones in both the east and west regions) with aggressive fire suppression policies. There has also been no detectable change in the east extensive zone without aggressive fire suppression. These results agree with other published fire history studies in and around Ontario that show no change in the fire cycle since about 1920 (Heinselman 1973, Woods and Day 1977, Suffling et al. 1982, Bergeron 1991, Bergeron et al. 2001). Unfortunately, interpreting the time-since-fire distributions and the estimated fire cycles in the two extensive zones is confounded by the fact that the fire data north of 52°N (Figure 1) are incomplete before 1975 (Perera et al. 1998). This shows up clearly in the west extensive zone, where the time-since-fire distribution indicates a change to a shorter fire cycle after 1975 (Figure 5). Given the incomplete data before 1975, we cannot conclude that this break in the distribution at 1975 represents any real change in fire cycle. For the same reason, we would not put much faith in the estimated fire cycles for these two zones.

Still, Figure 5 clearly illustrates the problem addressed earlier of using spatial comparisons to infer fire suppression effects. Previous comparison studies had examined just the western portion of Ontario (Martell 1994, 1996, Li 2000, Ward et al. 2001). The western portion of the province does show a decrease in fire cycle with decreased level of protection, from 406 years in the Intensive Zone to 300 years in the Measured Zone. However, in the eastern portion of the province, the opposite trend is observed where the fire cycle in the Intensive Zone (527 years) is shorter than in the Measured Zone (1,735 years). There are a number of possible reasons for this trend in the eastern portion of the province, such as the coastal climate effect produced by Hudson Bay. The general trend of increasing length of the fire cycle toward the northeast of the province also matches with observed trends of decreasing thunderstorm-days and decreasing duration of the fire season toward the north and east (Johnson 1992). Likewise, a decrease in the frequency of drought events since the end of the Little Ice Age in the late 1800s has been tied to an increase in the length of the fire cycle in northwestern Quebec (Bergeron and Archambault 1998, Lefort et al. 1999) and may help explain the longer fire cycles in northeastern Ontario. Whatever the explanation, it is apparent that differences in fire cycle can

Figure 5. Time-since-fire distributions for the areas with intensive, measured, and extensive levels of protection in eastern and western Ontario. Data points show the cumulative percentage area (on a logarithmic scale) with time since fire exceeding the time (in years) on the horizontal axis. The solid line represents the fitted fire cycle calculated using a maximum likelihood estimator. FC = fire cycle
arise for reasons other than fire suppression and, therefore, comparisons of these areas cannot be used to infer fire suppression effects.

Conclusions

The empirical basis for the belief in fire suppression effects on the fire regime of the boreal forest in Ontario can be found essentially in two studies by Stocks (1991) and Ward and Tithecott (1993); subsequent studies have reinforced this belief by repeating it without presenting any new data (e.g., Martell 1994, 1996, Welsh and Venier 1996, Bourgeau-Chavez et al. 2000, Li 2000, Murphy et al. 2000), and at times presenting the same or similar data in a different format (Stocks et al. 1996, Weber and Stocks 1998, Ward and Mawdsley 2000). In a previous article, Miyanishi and Johnson (2001) briefly pointed out some problems with the empirical study by Ward and Tithecott (1993), both in the data and its interpretation. In this article we provide a more detailed critical evaluation of the evidence for fire suppression effects, including problems in subsequent analyses and arguments presented by Ward et al. (2001). Furthermore, a more complete analysis of the spatial fire data for Ontario provides further support for some of our major criticisms of previous studies, leading to the conclusion that there is, to date, insufficient scientifically sound empirical evidence for the effects of fire suppression on the fire regime of the boreal forest in Ontario.

Fire suppression efforts can be effective at protecting lives, personal property, and infrastructure. Furthermore, educational campaigns may have reduced the number of human-caused fires. However, large fires and large-area burned years are strongly associated with the development of persistent blocking high pressure systems, conditions that usually consist of long periods of hot, dry weather that lead to severe drying of fuels (Stocks and Street 1983, Stocks and Flannigan 1987, Johnson 1992, Johnson and Wowchuck 1993, Johnson et al. 1995). When fires start in these conditions they are difficult to control, and it is these fires that account for almost all of the average annual area burned (Johnson and Wowchuck 1993, Moritz 1997). Even in situations where fire management agencies are presumably the most prepared, such as during a prescribed burn, fires still escape given certain weather conditions (Droog, W.N. Unpublished report, Ontario Ministry of Natural Resources, 1996). Some fires, which start during marginal conditions, may be prevented from becoming larger fires by putting them out before the weather conditions become extreme. However, the impact of this on the average annual area burned is undetectable, both in Ontario and across the North American boreal forest (Woods and Day 1977, Bergeron 1991, Suffling et al. 1982, Johnson 1992, Weir et al. 1995, Bergeron et al. 2001). Instead, it seems that in large-area burned years, the conditions are such that the sheer number of fire starts and their quick rate of spread can overwhelm fire management agencies (KPMG 1999), and it is unlikely that suppression can significantly influence the total area burned.

Management Implications

These conclusions raise important concerns about our ability to emulate the effects of natural disturbance in producing landscape patterns, which is one approach to ecosystem management that has been advocated recently (Hunter 1993, Ontario Forest Policy Panel 1993, Galindo-Leal and Bunnell 1995, OMNR 2002). This approach often assumes that disturbance by harvesting has largely replaced disturbance by fire, but that ecosystem elements of form and function can be sustained by harvesting within a range of disturbance that approximates the natural range (Ontario Forest Policy Panel 1993, Galindo-Leal and Bunnell 1995). If, however, fire suppression has not altered the average annual area burned, then the area disturbed by harvesting does not replace that which might have been disturbed by fire. Instead, the area disturbed by harvesting is added to that disturbed by fire. This may pose significant challenges to harvesting within some range of “natural” disturbance and suggests that it will be difficult to have the spatial patterns of a harvested landscape emulate the patterns of a “natural” landscape.

Appendix: Description of Time-Since-Fire Study of the Ontario Boreal Forest

The data for this study come from Ontario’s Forest Fire History: An Interactive Digital Atlas (OFRI 1998, Perera et al. 1998). This spatial data source maps the locations and spatial extent of almost all fires larger than 200 ha that have burned between 1921 and 1995 within Ontario between 46°N and 52°N. North of 52°N, the data are incomplete before 1975 (see Figure 1). The absence of small fires in the data set should not be a problem, because almost all of the area burned is accounted for by only a few large fires (Strauss et al. 1989, Johnson 1992, Johnson et al. 1998, 2001) that determine the fire cycle. The data were analyzed with ArcView 3.1.

The empirical distribution of the forest area in each time-since-fire age-class can be used to estimate the historical fire cycle, even when, as in this case, the data are truncated beyond a certain date (Johnson and Gutsell 1994). Truncated time-since-fire maps, showing the time since last fire for areas that burned between 1921 and 1995, were constructed for fire management zones in Ontario by intersecting the boundaries of the fires with the OMNR’s current (1999) digital map of fire management zones (Figure 1). Time-since-fire maps were constructed only for zones that encompassed the boreal portion of Ontario (Rowe 1972). The area labeled EFR4 in Figure 1 was not included in the analysis because the entire zone is within the Great Lakes–St. Lawrence Forest Region and the area is extensively developed with most of the land base within municipal boundaries (OMRN 1997). Some of the fire polygons in the digital fire atlas have more than one date, reflecting the multiple times that a single area may have burned. Only the last fire date was used to produce the time-since-fire maps. For a more detailed description of the methods used, see Bridge (2001).
Ontario is divided into east and west fire regions (Figure 1). Even though the objectives and operational directions between zones with the same level of protection are similar, the data for the two regions were analyzed separately due to potential differences in climate and vegetation that may exist between these two parts of the province. For example, Ontario’s western boreal region tends to have more thunderstorm days in summer (Johnson 1992) and be slightly warmer, with a longer growing season and less annual precipitation (Hills 1959, Mackey et al. 1996, Baldwin et al. 2000) than the eastern boreal region. Time-since-fire distributions were produced for each level of protection zone for the east and west fire regions that cover the boreal forest in Ontario. From each distribution, fire cycles were estimated following the methods for truncated time-since-fire maps of Johnson and Gutsell (1994). Semi-log plots of the time-since-fire distributions were visually examined for changes in the fire cycle, which show up as changes in slope. Statistical techniques for testing the significance of changes in the fire cycle are well developed for complete time-since-fire maps (Reed 1994, Reed et al. 1998), but not for truncated ones.

The digital fire atlas data used here also suffer from some additional limitations. Most fire boundaries in the atlas were digitized from paper maps of burn perimeters. The boundaries of older fires, which were mapped by hand and from the ground, can be expected to be less accurate than for more recent fires, which are mapped from the air using global positioning system (GPS) and satellite image technology. A lack of detection may also be a problem with older fires, particularly in the early part of the 20th century and closer to 52°N, which may mean that not all fires are accounted for (Ward and Tithecott 1993, Li 2000). For example, a large fire in the measured zone of northeastern Ontario in 1924 was missed in the atlas (Sylvie Gauthier, Canadian Forest Service, July 6, 2000, personal communication). Finally, the digital fire atlas tends to map only the perimeter of the burn. Unburned islands and remnants, which would be accounted for in fire history studies using time-since-fire maps, are not accounted for in the calculations presented here. The effects of these data limitations are difficult to quantify, but are thought to be minor. Most large fires, which account for almost all of the area burned and have the largest impact on the fire cycle, are captured in the atlas. Likewise, unburned remnants and islands usually only occupy a very small proportion (<10%) of the total burn area (Eberhart and Woodard 1987), so their inclusion should not have a great impact on the estimates of fire cycle.

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