COMPARISON OF FOREST FIRE REGIMES BETWEEN HEILONGJIANG IN CHINA AND ONTARIO IN CANADA

by

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Source: Molly Gibson Kirby 2014.

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Major Advisor

Second Reader

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ABSTRACT

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This research summarizes and compares the differences in forest fire regimes in the provinces of Ontario, Canada, and Heilongjiang, China, as it relates to fire suppression techniques, human activities, and climate change. Before 2007, the total burned area in Heilongjiang was much larger compared than Ontario. From 2000 to 2013, the total forest fire occurrences in Ontario were greater than Heilongjiang. Compared to Ontario, Heilongjiang experienced more forest fires >100 ha in size. The main causes of forest fires in Heilongjiang and Ontario are human activities and lightning, respectively. Most tree species in Heilongjiang and Ontario are fire resistant. But forest fires are major driver of forest ecology and forest stand dynamics in both Heilongjiang and Ontario. The Fire Weather Index system used in Ontario can also be applied in Heilongjiang. Historically, Heilongjiang had relatively higher Fine Fuel Moisture Code and temperature compared to Ontario. Further, the rolling topography in Heilongjiang causes the forest fire spread easier compared to Ontario. Climate change projections for this century suggest that forest fire regimes will become severe. We will experience more frequent fires, and more extreme weather events. In addition to climate change, human activities and the development of fire suppression technology can hold the key to the changes in fire regimes.

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INTRODUCTION

Many countries in the world are facing the threat of forest fires. A forest fire is one of the natural disturbances that cause damages to forest ecosystem and affect human beings. Fires can affect forest resource availability and pose threats to property. As a result of climate change, forest fires have become more frequent, and thus an increased risk to humans and forest resources. Understanding the changes in fire regimes and the causes of these changes can promote the better management of forest resources.

Heilongjiang is a province in northeastern China and is located along similar latitudes as Alberta. This province is not only one of the most forested provinces in China but also experiences the most severe fire hazard. The average annual area burned has been a topic of concern in China. Heilongjiang plays an important and active role in fire prevention (Wang, Shu, Tian and Zhao 2010). In 1987, the Great Black Dragon Fire in Heilongjiang was ten times larger than the Yellowstone National Park fire and shocked the world (Salisbury 1988). Located in the east-central region of Canada, Ontario also has the high frequency of forest fire occurrences (OMNR 2014). Forests occupy 85% of Ontario’s land mass, and forest fires have shaped the majority of the forest environment. The main causes of forest fires in Ontario were lightning, human-caused fires in the summer in both remote and urban locations.

A fire regime is a general pattern in which fires naturally occur in a particular ecosystem over an extended period (Weston 2010). It is an integral part of forest fire ecology and is an essential foundation for explaining and describing effects of changing climates on fire patterns as it combines all kinds of impacts on vegetation and the carbon cycle. Fire regimes can be changed by a number of factors, such as climate changes, and human activities. This thesis aims to compare the differences of fire regimes between Ontario in Canada and Heilongiang in China and to analysis the

LITERATURE REVIEW

In 1987, the Great Black Dragon Fire in China burned 3.2 million acres and spread into another 15 million acres in Siberia. It incinerated an area as large as New England and destroyed prime timberlands the size of Scotland (Salisbury 1988). The fire started in the Greater Khingan Range, a mountain range in the Heilongjiang province of northeastern China. There had been almost no precipitation during the summer and winter of 1986. It caused a severe drought in the spring of 1987 when the fire started. The fire was started when gasoline spilled from the brush-cutting machine caught fire (Fuller 1991). The immature fire prevention technologies were not effective at controlling the fire immediately and thus triggered a large-scale fire spread. It was one of the largest forest fires in the world, and China had not experienced such a fire in over 300 years (Salisbury 1988).

Fire behavior in wildland fires is determined by how fuels, weather, and topography interact (Natural Resources Canada 2016). These three things consist of the fire behavior triangle. Topography refers to the shape and features of a region and is the most constant variable in the fire triangle. The topography incorporates elevation, position on a slope, aspects, the shape of the county, and steepness of the slope. A slope can affect fire spread by preheating the fuels higher on the slope and enabling spotting to occur from rolling and flying firebrands. Elevation can influence the amount and timing of precipitation (Bennett 2010). Higher elevations tend to have a cold and wet climate, so fire seasons tend to be shorter. Fuel is the most easily controlled in the fire triangle. A forest can provide different kinds of fuels. Surface fuels include dead needles, leaves, twigs, bark, cones, and small branches, all of which are called litter. Also, surface fuels refer to grasses, shrubs and woody material lying on the ground (Fuller 1991). Ladder fuels are between surface fuels and crown fuels, comprising live and dead small trees, shrubs, lower branches from larger vegetation. Crown fuels are above the ground in treetops. Ladder fuels can enable the fire to climb upward into crowns. Crown fires caused by excessive fuel accumulation and poses severe threats to ecosystem and human life (USDA 2003). Climate and weather have overriding importance in determining if fuel will burn and how much or how the fire behave (Thomas and McAlpine 2010). Temperature, humidity, and winds can influence fire development. Warmer temperature can accelerate the speed of ignition and burn, increasing the rate at which wildfire spreads (Bonsor n.d.). A further common division of fire behavior is “plume dominated” and “wind-driven.” The behavior of plume dominated fires can be strongly influenced by conditions above the ground; the conditions even can cause abrupt changes in direction or rate of spread. The Wind directly affects fire spread by speeding up the flames to heat the fuel effectively, blowing the heat of the fire through the trees ahead to preheat; dry burnable duff, mix in more oxygen and carry burning ember ahead to create spot fires (Thomas and McAlpine 2010). Relative humidity is the ratio of the water vapor to the maximum water vapor of the air at the same temperature. The dead forest fuels and the air can exchange moisture. Air mass with low relative humidity can take moisture from fuels. And fuels also can take moisture from the air when its relative humidity is high. Relative humidity is crucial because the low relative humidity can make fine fuels drier, thus increase fire behaviors (U.S. Department of the Interior n.d.).

The Forest Fire Weather Index (FWI) System is a sub-system of Canadian Forest Fire Danger Rating System, which can be used to account for the impacts of weather on forest fuels and forest fires. The FWI System contains six components, three fuel moisture codes, and three fire behavior indexes, the integral components are necessary to indicate burning conditions (Natural Resources Canada 2008). Fire behavior indexes consist of ISI (Initial Spread Index) and BUI (Buildup Index). In fuel moisture codes, FFMC means Fine Fuel Moisture Code, DMC is Duff Moisture Code, and DC is Drought code (Natural Resources Canada 2008). The FWI system was introduced in Ontario in 1969 and was applied throughout the province since 1970 (Stocks 1974). In China, different province shows various applicability and sensibility for FWI system. Heilongjiang is one of the provinces that show high feasibility for this system (Wang 2009).

RESULTS

Both Ontario and Heilongjiang have the high frequency of forest fires, but the different environments have different fire regimes. The forest occurrences can be fluctuate in different years. Also, the total burned area and fire size will not be same. The different culture and geographic locations can make diverse causes of forest fires. And the fire season and fire weather index data will not be same in each province.

<u>Forest Occurrences</u>

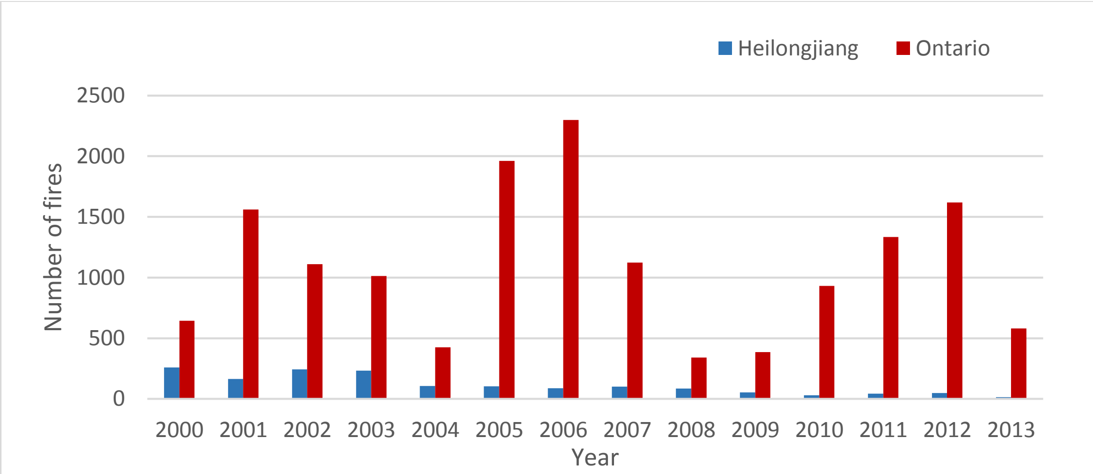

Figure 1. Number of Fires in Heilongjiang and Ontario from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

The fire occurrences in Ontario were more frequent than the figures in Heilongjiang during the period from 2000 to 2013 (Figure 1). The fire occurrences in Ontario demonstrate fluctuant trend during this period, while the fire incidents in Heilongjiang went through a downward trend from 2000 to 2013. For Ontario, the highest fire occurrences occurred in 2006. The peak for Heilongjiang was in 2000.

Burned Area

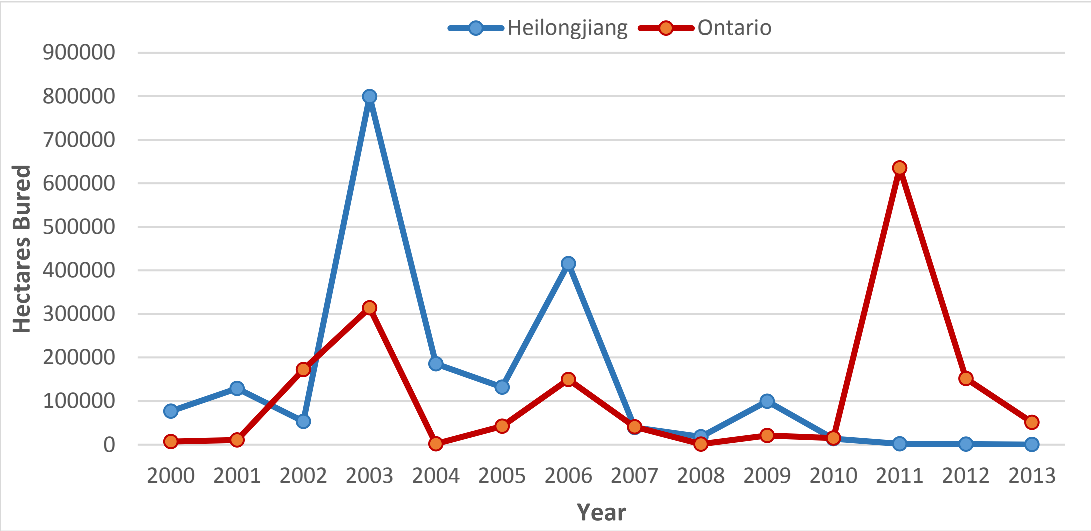

Figure 2. Area Burned in Heilongjiang and Ontario from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

Although the fire incidents in Heilongjiang were less than Ontario, the burned area was larger in some years, especially in 2003, at 799306.9 ha (Figure 2). The highest fire occurrences in Ontario happened in 2006, but the largest burned area during this period occurred in 2011, reaching 635375 ha. It is apparent that there is no connection between the fire occurrences and fire size in these two provinces. And the total burned area in Heilongjiang was 1,965,840.2ha, the figure for Ontario was 1,612,723ha.

Fire Size

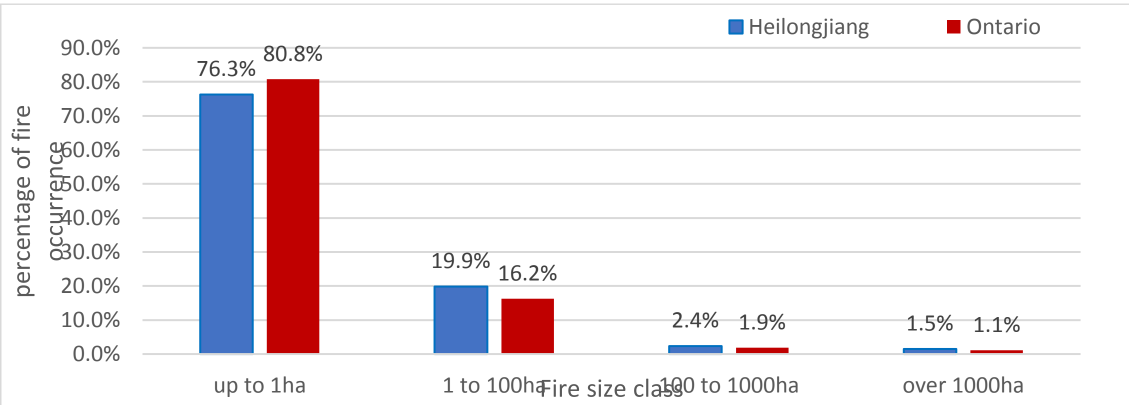

Figure 3. Percentage of Forest Fire Occurrences by Fire Size Class from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

As seen above (Figure 2), the total burned area in Heilongjiang was larger than Ontario in some years even if the number of fire occurrence in Heilongjiang was much bigger than Ontario. Although the number of forest fires in Heilongjiang was smaller than Ontario, the fire size was relatively bigger. About 80% fire in Ontario burned less than 1 ha. However, about 76% fire's size is below 1 ha in Heilongjiang (Figure 3).

Causes

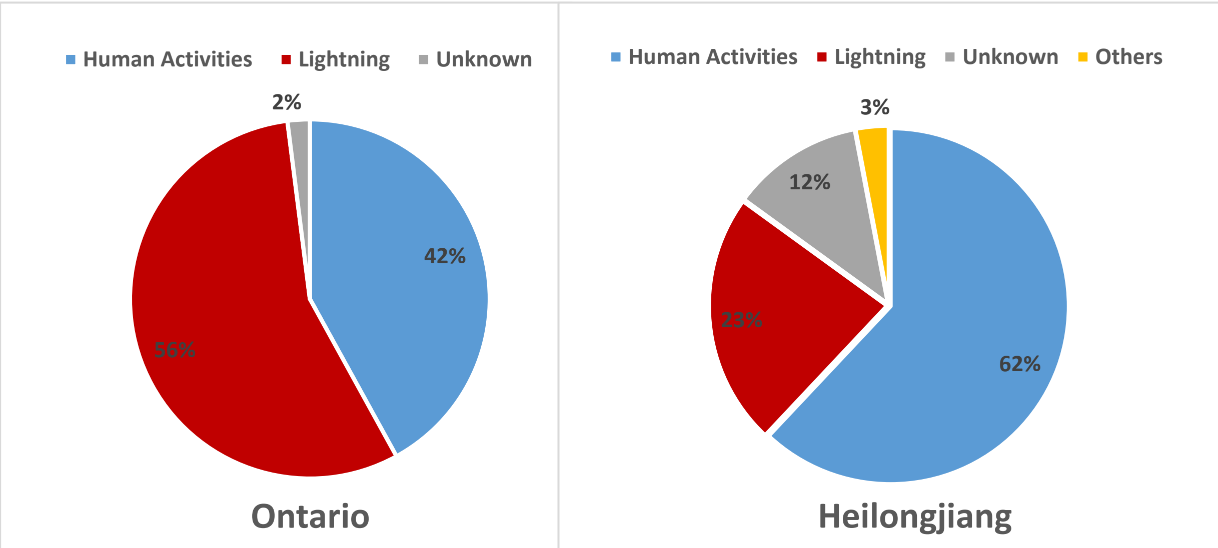

Figure 4. Percentage of forest fires by cause class in Ontario and Heilongjiang from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

The causes of forest fires in Ontario can be divided into three parts, human activities, lightning, and unknown cause. The human activities included recreation, forest industry, railways, incendiary, residents and other industry. Except for these three causes, the causes of forest fires in Heilongjiang contained some other causes, such as the spread of other provinces' or other countries' fires and other natural factors. The human activity causes in Heilongjiang can be classified as two parts, productive (like prescribed burning and domestic heating) and non-productive (like the funeral ritual and electric wires). The main reason that caused forest fires in Ontario during this period was lightning, accounting for approximately a half of the total causes (Figure 4). Different from Ontario, human activities caused the largest proportion of forest fires about 62% (Figure 4).

<u>Fire Season</u>

Weather is one of the important factors that can determine the type and behavior of individual forest fires. Forest fires in Heilongjiang mainly concentrated in spring and fall. In spring, the temperature increased rapidly, which speeds up the melting of snow. The air was dry and wind was strong. Moreover, there was a large amount of fuel, so it is easy to cause forest fires. Moreover, the fire danger period can be up to 3 to 4 months in spring (Zhang et al. 2012). The average temperature in fall was 6.99 °C, the weather was dry, and much dry fuel accumulated on the surface of the ground and caused a surface fire in certain weather (Chen 2013). The fire danger period was 1 to 2 months (Zhang et al. 2012).

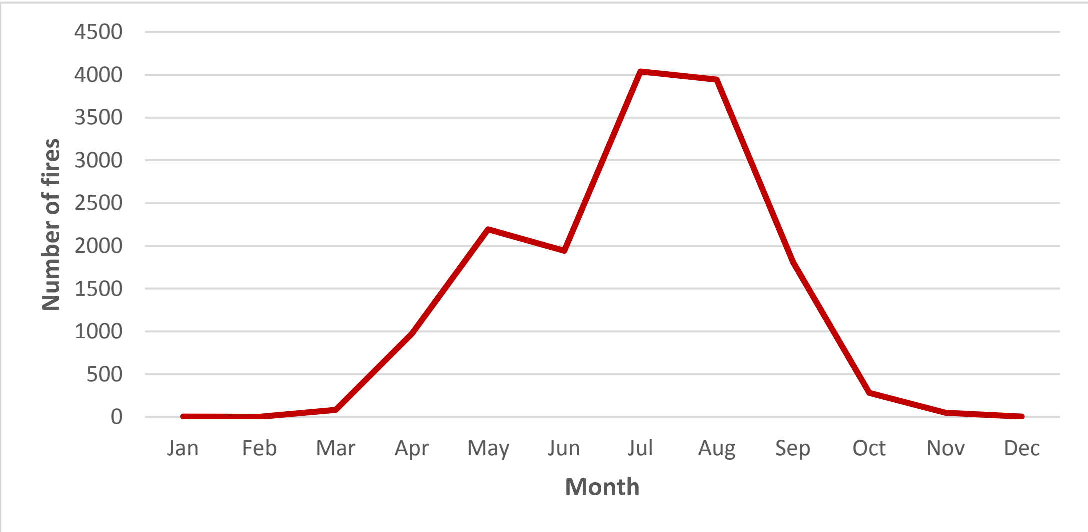

Figure 5. Number of fires by Month in Ontario from 2000 to 2013 (Source: Data from National Forestry Database).

Forest fires in Ontario usually occur from April to October, especially in July and August (Figure 5). The risk of lightning-caused fires varies throughout the fire season (Woolford et al. 2014). And the Ontario's Forest Fires Prevention Act R.S.O. (1990) stipulates the risk normally begin on 1 April and end on 31 October

(Woolford et al. 2014). The peak risk occurs in midsummer and the figure decreases back to zero at the end of fire season (Woolford et al. 2014).

Fire Weather Index Data

Table 1. Fire danger classification from 1986 to 2010 for Heilongjiang province (March through October)

Fire Danger Class	FFMC	DMC	DC	ISI	BUI	FWI	Fire Days Proportion
Low	0~71.0	0~10	0~50	0~2.2	0~13.5	0~4.0	48.3%
Moderate	71.1~80	11~23	50~135	2.3~6.0	13.6~30.0	4.1~10.0	24.6%
High	80.1~87	24~40	136~210	6.1~10.0	30.1~48.0	10.1~18.0	15.2%
Very high	87.1~92	41~73	211~300	10.1~18.0	48.1~80.0	18.1~30.0	9.4%
Extreme	92.1+	74+	301+	18.1+	80.0+	30.1+	2.5%

(Source: Chen 2013)

According to the fire weather date from 1986 to 2010 in Heilongjiang province, Chen (2013) divided fires into five danger classes, low, moderate, high, very high, and extreme. Each class account for fire days 48.3%, 24.6%, 15.2%, 9.4%, and 2.5%, respectively.

Table 2. The Average of the FWI indexes by month from 1986 to 2010

Month	FWI	FFMC	ISI
3	5.3	85.4	5.1
4	19.4	88.7	8.6
5	34.3	91.3	15.3
6	8.4	84.4	4.6
7	13.9	82.7	5.7
8	9.5	85.2	4.5
9	27.6	89.9	14.8
10	15.2	87.5	9.4
11	9.6	83.6	8.7
Average	16.7	86.9	8.5

(Source: Chen 2013)

Most fires occurred in May and September with the relatively high FWI and ISI. In March, only FFMC showed the high value, the ISI and FWI were low, it means that the forest fire was influenced by the fine fuel moisture code (FFMC).

Table 3. Canadian Climate Centre GCM mean probability of sustained flaming, FFMC, DMC, DC, temperature and total summer precipitation for 11 ecoregions in Ontario (April 1 through September 30).

Ecoregion	PsusF	FFMC	DMC	DC	Mean Summer Temperature (°C)	Mean summer precipitation (mm)
	1975-1995					
89	0.25	77.3	18	154	12.8	335
90 (int)	0.29	79.2	20	166	14.1	360
90 (ext)	0.29	79.2	20	160	14.6	377
91	0.29	79.1	22	161	15.7	386
93	0.23	77.0	17	122	15.4	491
94	0.22	76.6	15	119	14.5	467
95	0.28	77.6	17	144	12.5	376
96	0.22	76.6	15	114	15.0	504
97	0.20	74.7	13	94	15.5	576
98	0.17	72.9	11	79	15.5	629
217	0.27	78.6	17	132	14.1	445
Average	0.25	77.16	16.82	131.36	14.52	449.64

(Source: Wotton, Martell and Logan 2003)

Canadian General Circulation Models (GCMs) can be used to predict the increases in surface air temperature across the entire boreal region. Moreover, these model scenarios were obtained from the Canadian Climate Centre (CCC) and the UK's Handley Centre (Wotton et al. 2003). Daily data in the former was obtained from the first generation coupled ocean-atmosphere model (Flato et al. 2000). According to the Table 3, the average FFMC from 1975 to 1995 during fire season was 77.16, which was relatively lower than the average data in Heilongjiang. The average DC was 131.36, and the mean temperature was 14.52, mean precipitation was 449.64.

DISCUSSION

Ontario and Heilongjiang are located in different latitude regions. Forest conditions are not same. Different forests have various adaptions and reactions to forest fires. Some species will show strong fire resistant, but some will be distroyed by fries. Also, various types of forests can provide different fuel types. Compared to Heilongjiang, the topography in Ontario is flatter. Different altitudes pose different opportunities for fire spread. Unlike fuel and topography, the weather is the most variable of fire environment. Warmer weather and low precipitation are beneficial to forest fires. Climate change and the linked natural disturbance also can provide opportunities to fire occurrences, cause the changes in fire regimes. If fires are controlled in time, fires will not cause very serious consequences. Fire suppression plays an important role in fire regimes. Human activities and their awareness of forest fires can efficiently influence fire regimes. My discussion focused on the differences of the following elements of forest fire environments between Heilongjiang in China and Ontario in Canada.

Forest

Heilongjiang Province is one of the largest forestry provinces in China. The main body of forest resources in this province is secondary natural forests; the forest coverage rate reaches to 43.6%. The zonal vegetation in Heilongjiang Province can be divided into three parts, temperate deciduous, coniferous forest region in the northern part, temperate meadow steppe in West, and temperate broad-leaved mixed forest in the east (Deng 2012). Forest resources mainly distributed in Greater Khingan Mountains, and Lesser Khingan Mountains, Zhang Guangcai Mountains, Laoye Mountains, and Wanda Mountains (Liu and Du 2010). The forests in Great Xin’an Mountains belong to temperate coniferous forests; the main species is

Dahurian larch (*Larix gmelinite* (Rupr.) Kuzen), and the minor species contain Scots pine (*Pinus sylvestris var. mongolica Litv*.), Japanese white birch (*Betula platyphylla*) and other species. The main species in Xiao Xin'an Mountains is Korean pine (*Pinus koraiensis* Sieb. et Zucc.) (Wang 2009).

Majority tree species in Heilongjiang are fire-resistant. Dahurian larch (*Larix gmelinii* (Rupr.) Kuzen) has thick bark and strong fire resistance, the forest fire even can stimulate the increase of tree bark thickness (Tian, Shu, and Wang. 2005). Fire burns the litter layer, which is beneficial for the Dahurian larch seed generation. Scots pine (*Pinus sylvestris var. mongolica Litv*.) does not have fire resistance, but trees diameter more than 28cm can survive in severe fires. Scots pine has serotinous cones; fires can promote the cones to split up and release seeds (Tian et al. 2005). Dragon spruce (*Picea asperata* Mast.) can adapt to many harsh environments like dry and cold places but is susceptible to fire. If there is no fire, the dragon spruce distribution will increase (Zhou 1991). Japanese white birch is a pioneer species that invades burned area. This species will go through the succession of the coniferous forest under the lack of fires for the long term (Tian et al. 2005).

In Ontario, 66% of the land is forested, which is approximately 17% of Canada's forests. Moreover, forests in Ontario can be divided into four main regions, the Hudson Bay Lowlands in the far north, the boreal forest region in the northern Ontario, the Great Lakes-St. Lawrence forest in southern and central Ontario, and the deciduous forest in the south of Ontario (OMNR 2014). Each region has the unique characteristics and species. Hudson Bay lowlands region locates in the northernmost part of Ontario, occupied by bogs and fens, sparse and slow-growing forest and tundra. Some common tree species grow in this region are white birch, dwarf birch, and willow. Boreal forest region is the largest region in Ontario, accounting for twothirds of Ontario's forest. The main species in this region are black spruce, white spruce, jack pine, balsam fir, poplar and white birch. The Great Lake-St. Lawrence forest region is the second largest, some common species like sugar maple, oak, birch, white pine and red pine. The southernmost region is deciduous forest region, covered by agriculture and urban areas (OMNR 2014).

In Ontario, boreal forest covers the largest area. The deep crowns with relatively low crown base heights, the high canopy bulk intensity with abundant fine twigs and needles, and high resin and low foliar moisture content make boreal conifer forests show the high configuration of fuels (Miquelajauregui et al. 2016). Compared to other fuel types, boreal conifer stands are architecturally easier to burn. Boreal forest ecology can be shaped by fire (Weber and Stocks 1998). Fires create a mosaic of differently sized and shaped patches of forest with different tree ages and species and provide various habitats for wildlife (Environmental Commissioner of Ontario 2015). Most boreal tree species can adapt to severe fires. Jack pine requires fire to regenerate. Without the heat from the fire to melt resin that bond the cone scales, the seeds cannot be released. Also, forest fires can create a mineral soil seedbed for germination and the seedling growth, and reduce overstory shade to provide more sunshine for understory species (Weber and Stocks 1998).

Topography

In Heilongjiang Province, the characteristics of topography are roughly low northeastern and southwestern parts, large northwestern, northern, and southeastern parts (Deng 2012). The provincial topography can be divided into five areas, northwestern Great Xin'an Mountains area, northeastern Xiao Xin'an Mountains area, southeastern mountains area (such as Wanda Mountains), western Songnen plain area, and eastern Sanjiang xingkai lake plain area. The mountains occupy

58.9%, altitude is 300 to 1600m, and the plain occupy 41.1%, altitude is 35 to 200m (Wang 2009).

The elevation of the plains less than 200m is hardly forested, the numbers of forest fires occurred are small. The elevation more than 200m is mountain area, the forest fires decreased along with the elevation rise. But the elevation between 200 to 600m areas had the highest fire occurrences. And the most severe fire often occurred in the Great Xin'an Mountains (Zhang et al. 2012).

In Ontario, the northern part is the boreal shield, extending from south-central Ontario to most of northern Ontario. The flattest areas in Ontario can be found in the lowlands of the far north, southwestern and eastern part (Wikipedia 2016). There are three major forest types: Boreal, Great Lakes-St. Lawrence, and Carolinian in Ontario (Rowe 1972). Great Lakes forests have a longer growing season and more precipitation than the drier and colder boreal forests. The rolling topography of much of the Great Lakes forests influences fire size by restricting fire trajectories (Thompson et al. 1996).

Weather

The climate in Heilongjiang belongs to the northern temperate climate zone in the eastern Eurasia, the western shores of the Pacific Ocean, and the northeast China (Zhen 2013). The climate in Heilongjiang is regard as continental climate, which means that the characteristics of the weather in Heilongjiang are cold and dry in winter, hot and rainy in summer, windy and low air humidity in spring and autumn (Liu and Du 2010). The average temperature of Heilongjiang is 4 to 5 °C, the lowest temperature in winter is -31 to 15 °C; the highest temperature in summer is 18 to 23 °C. The highest precipitation occurs in the central mountainous area, the next in eastern part, and the lowest in northern and western parts. The annual average relative humidity is 60% to 70%, the highest in the central and eastern mountainous areas, the lowest in southwestern parts (Chen 2013).

The majority of fires occurred in days that were no precipitation. The lightning-caused fires mainly happened in the Great Xin'an Mountains area in summer. The cold air mass came from polar region passed into Heilongjiang by three ways. The Great Xin'an Mountains area was the path. The low temperature and low humidity air mass caused a low precipitated thunderstorm in cold front, which can cause lightning fires in many places (Wang et al. 2006.). Moreover, when the relative humidity was less than 40%, it was easy to cause fires. The highest temperature ranging during 25-35°C and the average temperature ranging 15-25°C all can pose positive effects on forest fire occurrences. If the sunshine duration more than 6h, or the average wind speed less than 3m/s, also can increase the probability of fires occurrences (Wang et al. 2008).

Climate Change

In Canada, an obvious warming trend has occurred since the end of the Little Ice Age, and the rate of warming has accelerated in recent years (Thompson et al. 1996). The recent hundred year's climate research shows that Northeast China is very sensitive to global warming and is one of the most significant warming areas in both China and the world (Sun et al. 2006).

Along with the climate change, the greenhouse gases and aerosols increased, and surface air temperatures will increase while seasonal precipitation amounts will remain relatively constant or increase slightly during the forest fire season. During 1986 to 2010, the seasonal severity rating (SSR) of forest fires in Heilongjiang showed the obvious fluctuations, especially in spring and fall. If the SSR was high in spring, the SSR in summer was low. From 2000 to 2010, the SSR in fall had the obvious increased. From 2005, the gaps of the SSR between spring, summer, and fall has narrowed (Chen 2013). It means that some fires even did not happen in the past fire season. The future forest fire prevention will become more challenging. In Ontario, the main causes of forest fires are lightning. Woolford et al. (2014) studied the significant increase in lightning-caused fire risk between 1963 and 2009 in Northwestern Ontario and forecasted the lightning-caused forest fire would increase by over 50% by the middle of this century. Wotton et al. (2003) predicted along with the climate change, the number of human-caused fires in Ontario will increase by approximately 18% by 2020-2040 and 50% by the end of the 21st century.

The global warming can cause warmer and drier conditions and a longer fire season in the Canadian boreal forest. And increased fire severity not only can strain current levels of fire suppression resources but also can pose negative effects to boreal forest distribution and biodiversity (Michael 1998). Wang et al. (2013) found the northern boundary of broad-leaved forests in Heilongjiang has extended northwestward about 290 km between 1896 and 1986 and estimated the future climate change might cause the northern deciduous needle forest moving out of the original region.

The certain teleconnections, such as the Pacific Decadal Oscillation or the El Niño Southern Oscillation can trigger the increase of the risk of lightning-caused fires (Fauria and Johnson 2006). Liu and Yu (2003) found the El Niño Southern Oscillation (ENSO) caused the unusual weather like dry summer and high temperature. These extreme weathers increased the summer forest fire occurrences in Heilongjiang during 2000 to 2002. The total amount of summer forest fires in 2002 even arrived at 59, which was rare in the history of Heilongjiang forest fires histories. By researching the forest fire data from 1980 to 1999, Wang et al. (2010)

found the influence of La Nina was less than El Niño, and the burned area and forest fire occurrences increased abnormally after warm ENSO events year.

Linked Disturbance

Pre-disturbance climate can influence the vulnerability of tree to later events (Johnstone et al. 2016). Moreover, disturbance can be "linked" (Simard et al. 2011), it means that the material legacies of one disturbance alter the likelihood, extent, or severity of another disturbance (Johnstone et al. 2016). Warmer temperature can increase the forest drought stress, which contributes to higher recruitment and survival rates of bark beetles (Natural Resources Canada 2016). The beetle outbreaks can increase tree mortality, which increases fuel loads during drought years and leads to more severe forest fires (Brando et al. 2014). An experimental burning program was carried out in Ontario between 1978 and 1982, and it showed forest fire potential in budworm-killed balsam fir stands was significantly higher for a number of years following stand mortality (Stocks 1987). Severe insect disturbance can decrease the fire intensity. Chen et al. (2011) used the spatially intuitional landscape model to simulate the long-term interaction between forest pest and forest fire in Huzhong area of Great Xin'an Mountains. They found that severe white-lined silk moth damage led to the large amount of Dahurian larch death. The original forests were occupied by Japanese white birch, which had higher moisture content than Dahurian larch. Then the forest fire intensity decreased after the succession.

Fire Suppression

Except for the rolling topography, fuel conditions, and weather, the immature fire suppression is another reason to influence fire regimes. The main fire prevents project in Heilongjiang includes aviation fire control system, information communication system, fire prevention and slow-down system, fire danger prediction and monitoring system, fire prevention publicity and education project (Anonymous 2016). Fire prevention system consist of natural fire lines (like rivers and wetlands), forest fireproof roads, engineering block belt (like firebreak), and biological block belt (like hardwood deciduous tree belt) (Zhang 2008).

In Canada, forest fire managements is the provincial and territorial governments' responsibility; federal government takes responsibility for fire management in national parks only (Podur et al. 2002). Provincial governments make suitable fire suprression plans based on their own conditions. In Ontario, to mitigate the undesirable impacts of wildland fires on the public's properties and values, the government work with FireSmart Canada, positively promoting the FireSmart program to engage landowners, municipalities, and industry in reducing property loss in wildland fires (OMNRF 2014). FireSmart is a guideline to educate communities, private landowners and business owners to develop and implement fire prevention and mitigation plans (Environmental Commissioner of Ontario 2015). These plans involve some actions, such as thinning or pruning shrubs and trees, planting fire-resistant species to replace volatile trees, and promoting homeowners use fire-resistant building materials and practices (FireSmart Canada 2017).

Some fire prevention measures include public education, following best practices and regulations of fire risk activities, especially in high wildland fire danger periods. For instances, the proposals stipulate the type and timing of activities in forested areas for those industrial activities based on the risk of fires starting from that activity (OMNR 2014). Also, fire managers are required to work with interested partners to identify values and communicate resource and management objectives at risk from wildland fire (OMNR 2014). Ontario natural resource management program use prescribed burns to reduce the amount of fuel in forest stands to diminish the risk of a more severe fire, maintain or restoring healthy ecosystems, and to prepare sites for forest regeneration (Environmental Commissioner of Ontario 2015).

Ward et al. (2001) estimated the fire return interval in northern Ontario is 190 year without fire suppression, and the figure can be 600 years with fire suppression. Heilongjiang province saw a downward trend of fire occurrences from 2000 to 2013. However, the total burned area in Heilongjiang was larger than Ontario. Before 2007, the total burned area in Heilongjiang was much larger than Ontario. Moreover, the fire size in Heilongjiang had more percentage in more than 1ha than in Ontario. Suppression technology was the main reason for the reduction. Heilongjiang forests are the relatively less developed than national forest regions. The forest areas are large. However, the management techniques have some shortcomings, which caused difficulties to prevent the forest fires (Pan 2007). Although forest fires can cause damages to personal properties, the total occurrences are high. It leads to some public does no notice the importance of fire prevention and monitor (Hu 2015). In the northern part, there is not a clear boundary between the agricultural land and forest land. Many residents live in forests, which increased the difficulty of fire control. And lush vegetation and low road density in the forest also easily pose the opportunity to the spread of forest fires (Li 2006). Some forest fire isolating zones were deserted and were covered by dense vegetation due to the lack of the long-term maintenance. The deserted isolating fire zones cannot be used to obstruct forest fires (Hu 2015). Along with the improvement pf fire suppression techniques and the legal regulations, the forest fire conditions get alleviated. The total burned area saw an obvious downward trend after 2007.

Human Activities

In results, it is obvious that human activity is one of the main causes of fires in Ontario and Heilongjiang (Figure 4). Human influences play an important role in forest fire regime all the time. Frequent human activities can shorten the fire return interval. In Ontario, the Aboriginal people had burned the forest to improve access and hunting until the arrival of European settlers. Fur traders who arrived in northern Ontario in the late 18th century also may have affected fire occurrences (Fritz et al. 1993). Some recreation activities (like camping, hiking, or hunting) and industrial activity also can cause huge fires. Due to the climate conditions, the agricultural production in northern Heilongjiang often delayed to the forest fireproof period in spring (From March 15th to June 15th). However, no permission can be issued for fire use for production during the fireproof period. Moreover, burning was the most efficient way to agricultural reclamation. Therefore, once the fireproof period ended (June 15th), the agricultural burning started. Due to the climate change in recent years, the safe fire utilization has become the source of the high-risk ignition (Wang et al. 2006). Some cultural activities especially sacrificial culture also can cause wildfires.

CONCLUSION

Many climate simulation models predict the global climate will become warmer in the future, especially in the northern hemisphere. Along with the climate change, the abnormal weather has become more and more frequent. The extreme weather can trigger the forest fires. The fire regime will change, like the extended fire season and the varying fire return intervals, which will pose challenges to forest fire management operations. The forest conditions will be influenced by the variable weathers and fires. It is means that the types of fuel will change.

To adapt to forest fire dynamics and the varying fuel, it is necessary to increase the fire monitoring system, improve the scientific fire prevention techniques. Due to human-caused fires occupied a large part of total forest fires, it is important to increase the forest fire awareness of the public. Fire is an important tool to change landscape and land utilization. It is feasible to conduct the small size fires and prescribed burning to maintain the stability of ecosystem and protect the biodiversity.

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APPENDIX I

Table 1. Fire danger classification from 1986 to 2010 for Heilongjiang province (March through October)

Fire Danger Class	FFMC	DMC	DC	ISI	BUI	FWI	Fire Days Proportion
Low	0~71.0	0~10	0~50	0~2.2	0~13.5	0~4.0	48.3%
Moderate	71.1~80	11~23	50~135	2.3~6.0	13.6~30.0	4.1~10.0	24.6%
High	80.1~87	24~40	136~210	6.1~10.0	30.1~48.0	10.1~18.0	15.2%
Very high	87.1~92	41~73	211~300	10.1~18.0	48.1~80.0	18.1~30.0	9.4%
Extreme	92.1+	74+	301+	18.1+	80.0+	30.1+	2.5%

(Source: Chen 2013)

Table 2. The Average of the FWI indexes by month from 1986 to 2010

Month	FWI	FFMC	ISI
3	5.3	85.4	5.1
4	19.4	88.7	8.6
5	34.3	91.3	15.3
6	8.4	84.4	4.6
7	13.9	82.7	5.7
8	9.5	85.2	4.5
9	27.6	89.9	14.8
10	15.2	87.5	9.4
11	9.6	83.6	8.7
Average	16.7	86.9	8.5

(Source: Chen 2013)

Table 3. Canadian Climate Centre GCM mean probability of sustained flaming, FFMC, DMC, DC, temperature and total summer precipitation for 11 ecoregions in Ontario (April 1 through September 30).

Ecoregion	PsusF	FFMC	DMC	DC	Mean Summer Temperature (°C)	Mean summer precipitation (mm)
	1975-1995					
89	0.25	77.3	18	154	12.8	335
90 (int)	0.29	79.2	20	166	14.1	360
90 (ext)	0.29	79.2	20	160	14.6	377
91	0.29	79.1	22	161	15.7	386
93	0.23	77.0	17	122	15.4	491
94	0.22	76.6	15	119	14.5	467
95	0.28	77.6	17	144	12.5	376
96	0.22	76.6	15	114	15.0	504
97	0.20	74.7	13	94	15.5	576
98	0.17	72.9	11	79	15.5	629
217	0.27	78.6	17	132	14.1	445
Average	0.25	77.16	16.82	131.36	14.52	449.64

(Source: Wotton, Martell and Logan 2003)

APPENDIX II

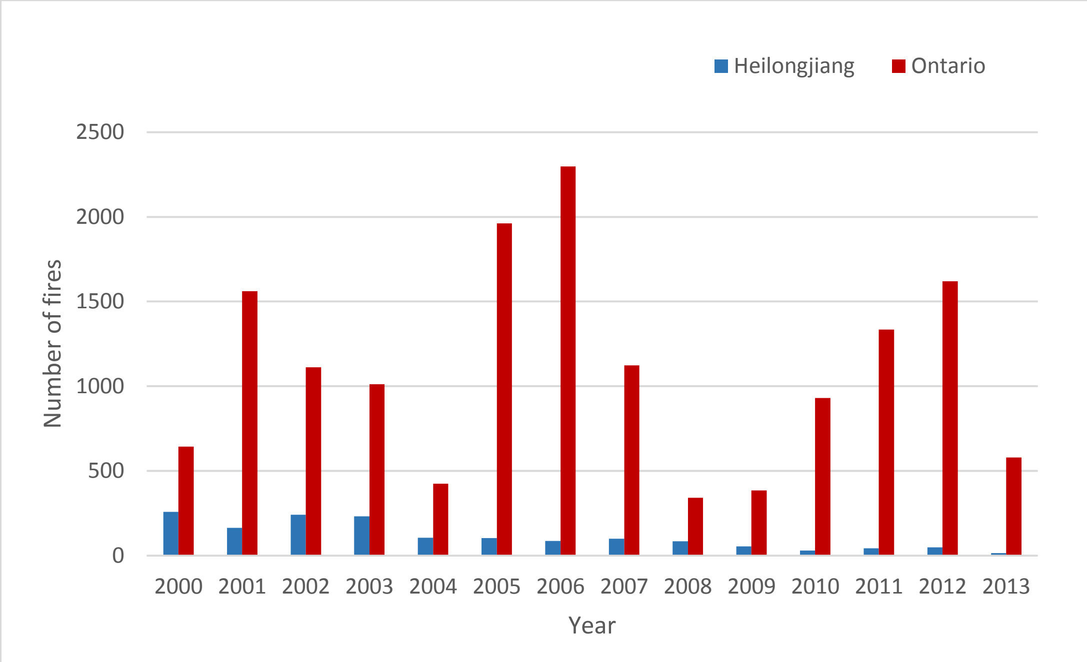

Figure 1. Number of Fires in Heilongjiang and Ontario from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

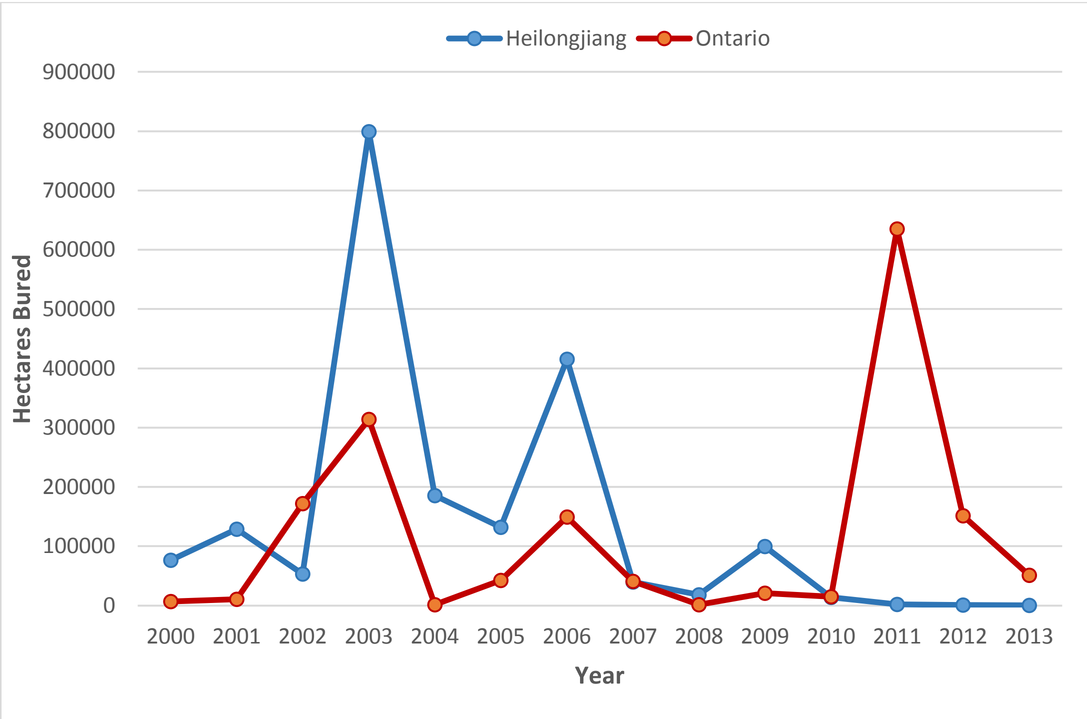

Figure 2. Area Burned in Heilongjiang and Ontario from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

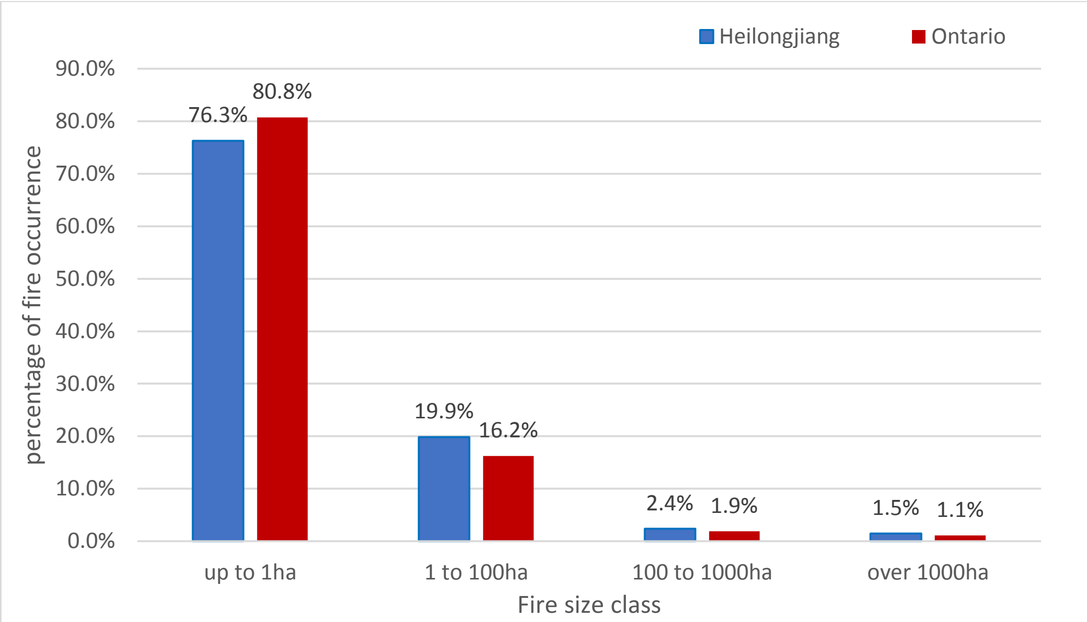

Figure 3. Percentage of Forest Fire Occurrences by Fire Size Class from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

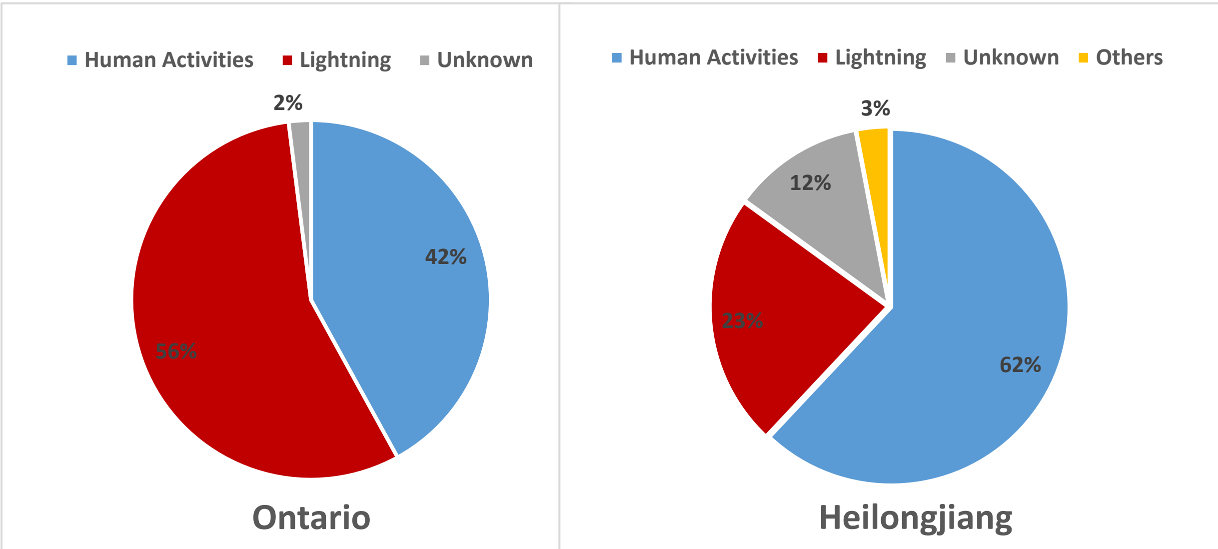

Figure 4. Percentage of forest fires by cause class in Ontario and Heilongjiang from 2000 to 2013. (Source: Data from National Forestry Database & China Forestry Statistical Yearbook)

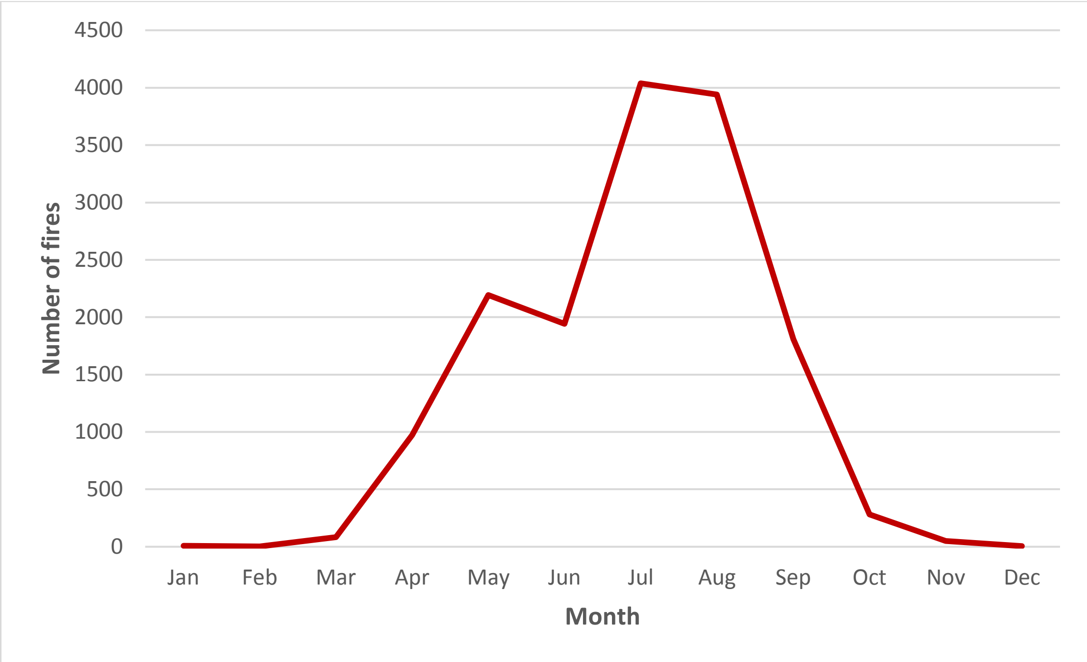

Figure 5. Number of fires by Month in Ontario from 2000 to 2013 (Source: Data from National Forestry Database).