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Forest Fires and Fire Management in the Circumboreal Zone: Past Trends and Future Uncertainties

A Discussion Paper

General

Stretching in two broad transcontinental bands across Eurasia and North America, the global boreal zone covers approximately 12 million square kilometers (km^2), two-thirds in Russia and Scandinavia and the remainder in Canada and Alaska. Situated generally between 45 and 70 degrees north latitude, with northern and southern boundaries determined by the July 13°C and July 18°C isotherms respectively (Larsen, 1980), the boreal zone contains extensive tracts of coniferous forest which provide a vital natural and economic resource for northern circumpolar countries. This closed forest region of the boreal forest covers 9.2 million km^2, corresponding to 29% of the world's total forest area and 73% of its coniferous forest area (ECE/FAO, 1998).

The boreal forest is floristically simple, and is composed of hardy species of pine (*Pinus* spp.), spruce (*Picea* spp.), larch (*Larix* spp.), and fir (*Abies* spp.), mixed, usually after disturbance, with deciduous hardwoods such as birch (*Betula* spp.), poplar (*Populus* spp.), willow (*Salix* spp.), and alder (*Alnus* spp.), and interspersed with extensive lakes and organic terrain. This closed-crown forest, with its moist and deeply shaded forest floor where mosses predominate, is bounded immediately to the north by a lichen-floored open forest or woodland which in turn becomes progressively more open and tundra-dominated with increasing latitude. To the south the boreal forest zone is succeeded by temperate forests or grasslands.

Forest fire is the dominant disturbance regime in boreal forests, and is the primary process which organizes the physical and biological attributes of the boreal biome over most of its range, shaping landscape diversity and influencing energy flows and biogeochemical cycles, particularly the global carbon cycle since the last Ice Age (Weber and Flannigan, 1997). The physiognomy of the boreal forest is therefore largely dependent, at any given time, on the frequency, size and severity of forest fires. The overwhelming impact of wildfires on ecosystem development and forest composition in the boreal forest is readily apparent and understandable. Large contiguous expanses of even-aged stands of spruce and pine dominate the landscape in an irregular patchwork mosaic, the result of periodic severe wildfire years and a testimony to the adaptation of boreal forest species to natural fire over millennia. The result is a classic example of a fire dependent ecosystem, capable, during periods of extreme fire weather, of sustaining the very large, high intensity wildfires which are responsible for its existence (Stocks, 1991).

Human settlement and exploitation of the resource-rich boreal zone has been accomplished in conjunction with the development of highly efficient forest fire management systems designed to detect and suppress unwanted fires quickly and efficiently. Over the past century people throughout northern forest ecosystems have, at times somewhat uneasily, coexisted with this important natural force, as fire management agencies attempted to balance public safety concerns and the industrial and recreational use of these forests, with costs, and the need for natural forest cycling through forest fires. Canadian, Russian, and American fire managers have always designated parts of the boreal zone, usually in northern regions, as "lower priority" zones that receive little or no fire protection, since fires occurring there generally have little or no significant detrimental impact on public safety and forest values. This policy has become more widely accepted with the realization that total fire exclusion is neither physically possible nor ecologically desirable, which initiated a gradual move toward the widespread adoption of fire management strategies that prioritize protection of high-value resources while permitting natural fire in more remote areas. This is particularly true in the boreal forest regions of Canada, Russia, and Alaska where lower population densities and forest use allow more flexible fire management strategies (Stocks, 1991).

A detailed examination of forest fire statistics from northern circumpolar countries shows that, while humans have had an influence on the extent and impact of boreal fires, fire still dominates as a disturbance regime in the boreal biome (Goldammer and Furyaev, 1996; Kasischke and Stocks, 2000), with an estimated 5-15 million hectares (ha) burning annually in this region, with a high degree of inter-annual variability (Soja et al., 2006). At least 50% of the area burning occurs in largely unmanaged forests. Canada and Alaska, despite progressive fire management programs, still regularly experience significant, resource-stretching fire problems. In contrast, Scandinavian countries do not seem to have major large fire problems, due to more moderate (and less continental) climates, and increased accessibility resulting from intensive forest management over virtually all of the forested area of these countries. Russian fire statistics are available over the past four decades but, until recent years, these statistics are considered very unreliable, having been deliberately underestimated and obfuscated for political reasons. Over the past decade, improved remote sensing has permitted a more accurate assessment of the area burning annually in Russian boreal forests, revealing that Russia generally has the largest area burned among boreal countries.

Boreal Fire Characteristics

Boreal forest fires may be classified, based on their physical fire behavior characteristics, into three general categories (Van Wagner, 1983): smoldering fires in deep organic layers with frontal fire intensity levels <10 kW/m, surface fires with intensities ranging between 200 and 15 000 kW/m, and crown fires with intensities from 8 000 to >100 000 kW/m. Frontal fire intensity is the product of a fire's rate of spread, the amount of fuel consumed in the flaming front, and the latent heat of combustion (Byram, 1959). Crown fires can be either intermittent (trees torching individually) or active (with solid flame development in the crowns), with active crown fires being by far the most common. Crown fire development depends on a number of interacting factors: the height of the crown layer above the ground, the bulk density of crown foliage, the crown foliage moisture content, and the initial surface fire intensity. In general, surface fires must generate sufficient intensity to involve the crown layer, resulting in ready access to the ambient wind field which largely determines the rate of spread of the fire. The surface and crown phases of the fire advance as a linked unit dependent on each other. The fast-spreading active crown fires that dominate the boreal landscape are primarily the result of strong winds, and are aided by both short- and long-range spotting of firebrands ahead of the flame front. High-intensity boreal crown fires often develop energy-release rates and towering convection columns that can loft smoke directly into the upper troposphere and lower stratosphere, promoting transboundary smoke transport across the circumboreal zone (Fromm et al., 2004; Stocks et al., 1997)

Fire-adapted forests can generally be divided into two categories (Van Wagner, 1983): those species able to regenerate although all trees have been killed over a large area, and those species of which some individuals must remain alive to provide seed for the next generation. Species of the first type are either conifers that store seed in insulated serotinous cones that require heat to open, or hardwoods that regenerate through suckering from the root layer following fire. Species of the second type are conifers that release seed every year when the cones mature. Canadian and Alaskan boreal forests are dominated by species that bear serotinous cones and require lethal fire to regenerate, e.g. jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*). The boreal landscape in North America reflects this, consisting almost entirely of large tracts of pure, even-aged stands of fire-origin species resulting from high-intensity, active crown fires. Alternatively, Eurasian boreal forests are dominated by conifer species not generally considered serotinous. Many Eurasian species such as Scots pine (*Pinus sylvestris*) and larch (*Larix* spp.) have adapted to periodic, lower-intensity surface fires, releasing seed annually and creating a much more heterogeneous, uneven-aged forest. It can be assumed then, that active crown fires are far less common in the Eurasian boreal forest, and this is borne out in the Russian fire literature (e.g. Artsybashev, 1967; Korovin, 1996) which shows that crown fires account for ~25% of the total area burned in Russia during normal years, but that this can rise to ~50% during extreme fire years.

Extent and Impact of Boreal Fires

Canada

Canadian fire management agencies have been largely successful in controlling a major percentage of the fires that occur in high-value areas of the country. However, extreme fire danger conditions, often coupled with multiple fire starts, occasionally overwhelm fire suppression resources, and large areas burn.

Forest fire statistics have been archived since 1920 in Canada. Prior to the advent of satellite coverage in the early 1970s, it is believed that many fires in remote regions were not detected or monitored, such that the record for this period is somewhat incomplete. Bearing this in mind, the annual number of recorded fires in Canada (Figure 1) has increased rather steadily from around 6 000 fires in the 1930-1960 period, to an average of around 9 000 fires during the 1970-2000 period, most likely the result of a growing population and expanded forest use, along with an increased detection capability (Martinez et al., 2006). From Figure 1, it is also evident that the area burned by Canadian forest fires fluctuates greatly from year to year, from under 0.5 million ha to more than 7 million hectares in extreme years. In comparison to the 1950s and 1960s, average annual area burned has been increasing over the past three decades (Figure 2). Major fire years occurred in 1980, 1981, 1989, 1994, 1995, and 1998. During the 2000-2004 period, unofficial statistics indicate annual averages of 7 321 fires and 1 68 9424 ha burned. Although variable between regions of the country, lightning is responsible for an average of 35% of Canadian fires, yet lightning fires account for 85% of the total area burned. This is due to the fact that lightning fires occur randomly, often in significant numbers, over large areas, presenting access problems not usually associated with human-caused fires. As a result, lightning fires often grow larger, as detection and subsequent initial attack is often more delayed. Lightning fires dominate in the northern remote regions of Canada where population levels are low. Recreational activities, forest industry operations, and homeowners living in or near the forest, are primarily responsible for accidental human-caused fire occurrence, which dominates in the intensively protected forest regions of Canada.

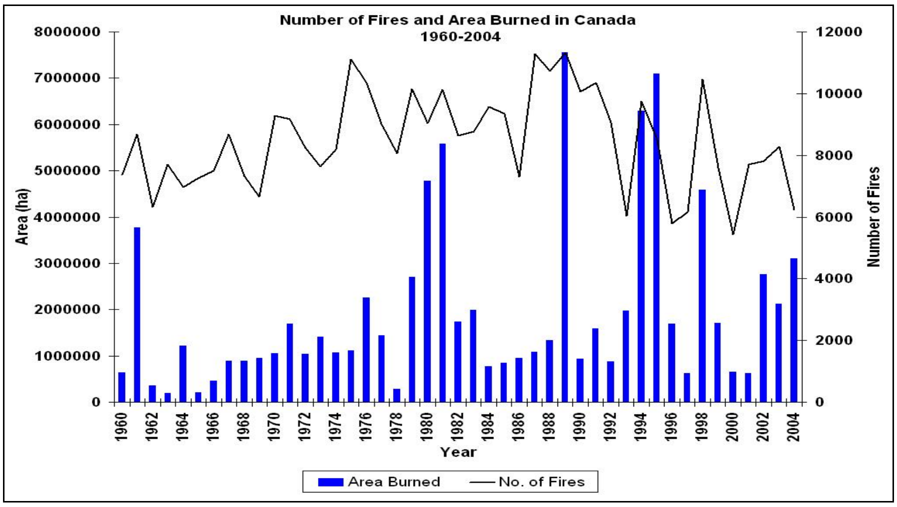

Figure 1: Annual number of fires and area burned in Canada 1920-2004 (post-2000 statistics are not yet official).

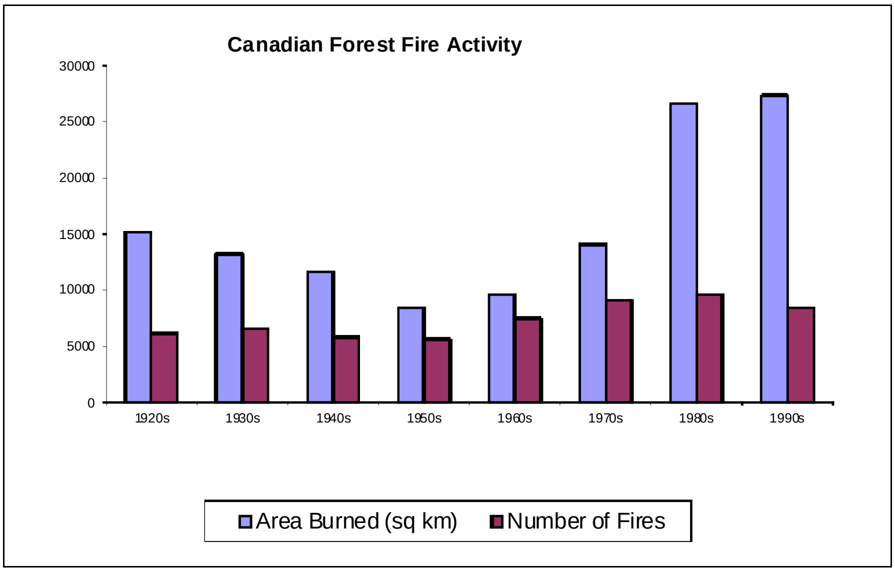

Figure 2: Annual number of fires and area burned in Canada, averaged by decades (1920s through 1990s).

The sophisticated fire suppression systems in place across Canada are largely successful, in that the vast majority of fires (approx. 97%) are contained at an early stage (<200 ha). However, the approx. 3% of fires that exceed 200 ha in size, account for around 97% of the total area burned. Over the past four decades, an average of approx. 2 million ha burned annually in Canada, with close to 50% of this area burning in remote "modified suppression" zones, primarily in the northern regions of west-central Canada (Stocks et al., 2003). The significant contribution of these fires to the total area burned in Canada can be seen in Figure 3, which shows the distribution of 1980-2003 large fires (>200 ha in size) across Canada.

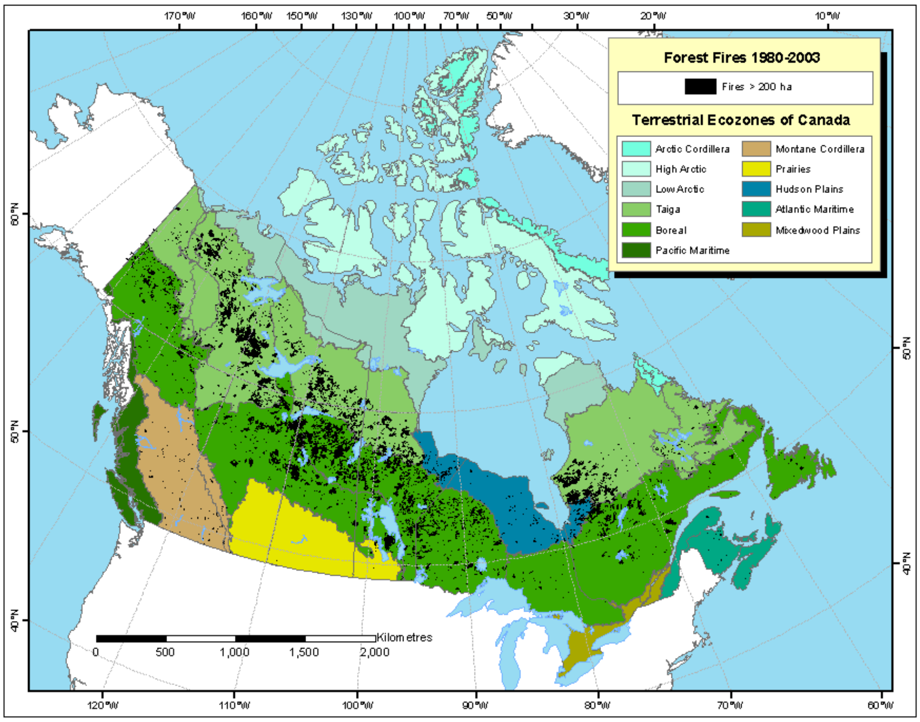

Figure 3: Distribution of fires >200 ha (black polygons) during the 1980-2003 period.

Clearly, the largest areas burned occurred in west-central Canada, in a band running from northwestern Ontario through northern Manitoba and Saskatchewan into the Northwest Territories, regions containing large areas where extreme fire weather and lightning activity are common, values-at-risk to not warrant aggressive fire suppression, and fires most often burn naturally. Most forested regions of southern Canada sustained fewer large fires as a result of intensive protection, although large fires are still a factor in these areas. Fires in excess of 100 000 ha are not uncommon in Canada, and fires exceeding 1 million hectares have been recorded. The difference in fire dynamics between the intensively protected regions of Canada and those areas where "modified" suppression is practiced and fires for the most part burn naturally. Although the number of fires occurring in "modified" zones is much smaller than in the intensively protected regions, the area burned is proportionally larger, primarily due to the policy of letting fires burn naturally where possible (Stocks et al., 2002). Fires in "modified" suppression zones are generally only attacked when they threaten communities, and even then, usually only in a "defensive" mode.

Alaska

Forest fire statistics are available for Alaska since 1940 (Barney and Stocks, 1983; Murphy et al., 2000; Kasischke et al., 2002) and are summarized in Figures 4 and 5. Over the six decades between 1940 and 2000, the area burned each decade in this northernmost U.S. State has remained relatively constant. Since 2000, however, the area burned has increased sharply, primarily due to two severe fire years in 2004 and 2005. The average annual number of fires has increased steadily since the 1940s when ~100 fires were detected, through the 1990-2005 period when ~470 fires were reported

As is the case in Canada, annual area burned in Alaska exhibits a highly episodic nature (Figure 4) with most of the area burning during a limited number of severe fire years. Seasonal fire statistics indicated that severe fire years are frequently the result of larger fire events that occur later in the fire season (mid- to late-summer). Fires at this time of year tend to grow large if precipitation deficits result in drier organic soil layers in combination with seasonal thawing of permafrost, making much more fuel available for combustion. Fire activity is concentrated in the interior of Alaska, in a region bounded to the north and south by the Brooks Range and Alaska Range respectively (Figure 6). Although some large fires do occur in other regions of Alaska (e.g. the Kenai Peninsula), these fires are much less common than in the interior region of the state.

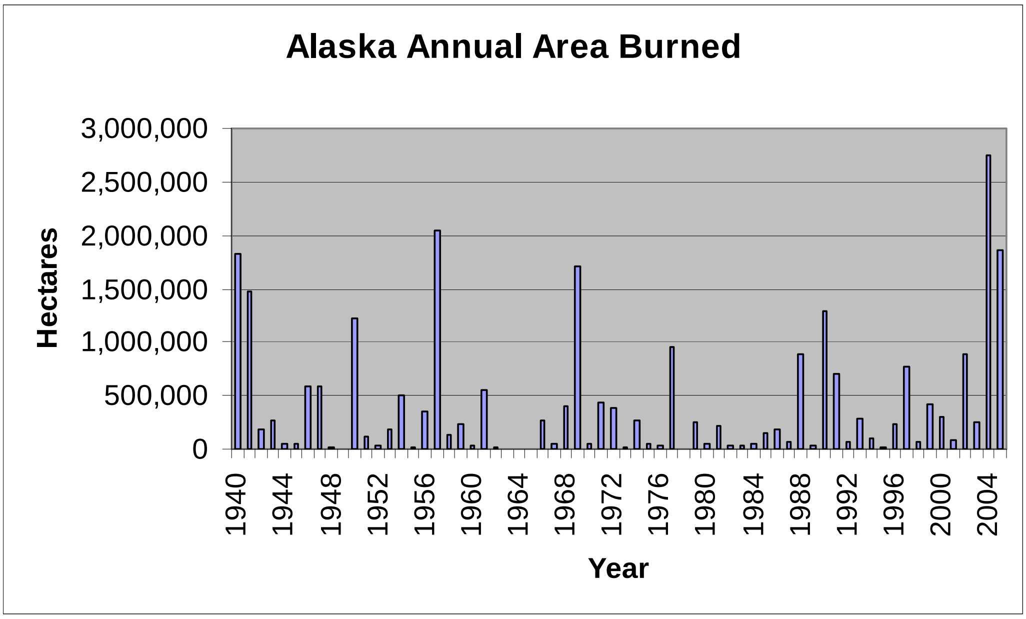

Figure 4: Annual area burned in Alaska 1940-2005

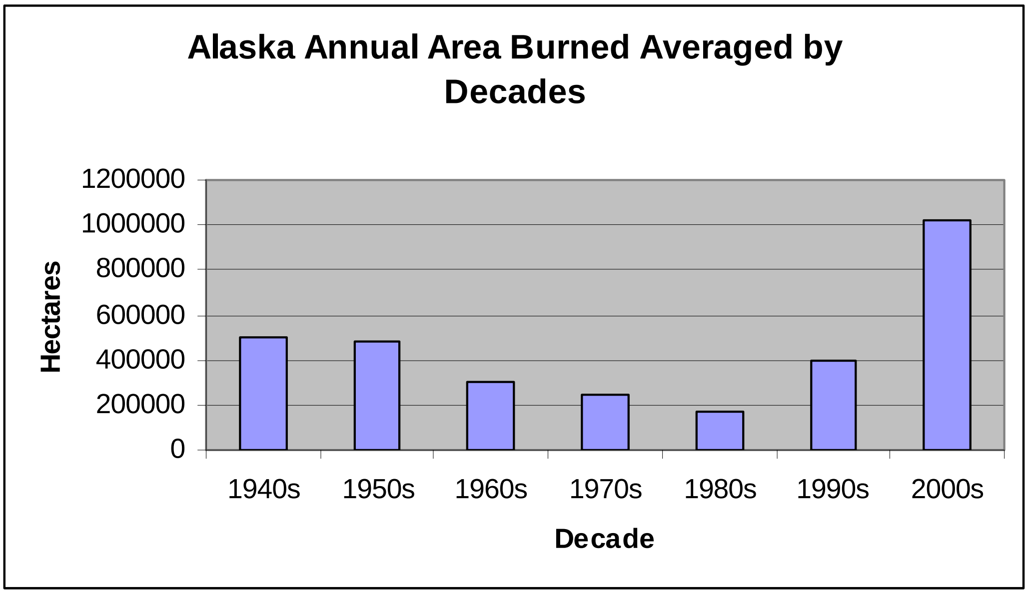

Figure 5: Annual area burned in Alaska 1940-2005, averaged by decades

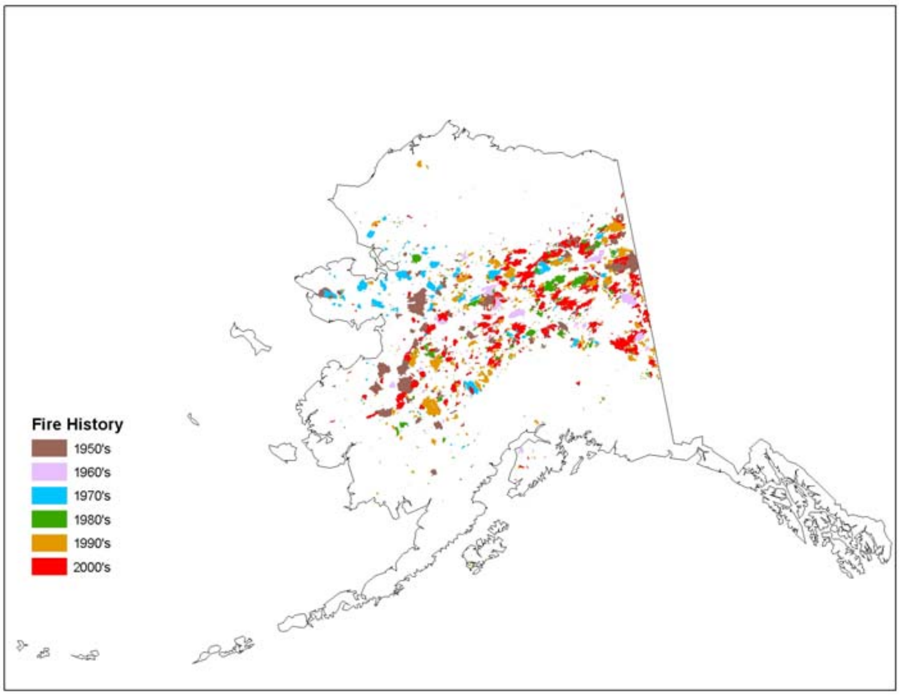

Figure 6: Distribution of large fires in Alaska by decades (1950s – 2000s)

Russia

In Russia forest fires are a major factor leading to the declining state of forests (Kondrashov, 2008). 5.3 million hectares of forest were estimated to be dead in the 1994-2005 period, with forest fires accounting for 70% of this total area, most significantly in Siberia. During this period the area burned was almost 5 times higher than the area harvested. Fire occurrence and area burned follow a distinct seasonal trend in Russia, moving from south to north as the fire season progresses Fire incidents and their area have a clearly expressed seasonal and daily dynamics.

Forest fire statistics for Russia have been compiled for a number of years, but were never officially published or made available to western observers until the early 1990s when the USSR dissolved and cooperation with western fire managers and scientists began. Korovin (1996) published statistics for the 1947-1992 period for Russia that showed great variability in both the number of fires and the annual area burned within the protected territory of Russia. The number of fires ranged from 10 000 to 34 000 annually, with the annual area burned varying between 200 000 and 2.7 million ha. During that period fires burned about 60 million hectares on actively protected territory, including 42.3 million ha of forest lands. When fires on unprotected lands are taken into account, it is estimated that the burned area was 100-120 million ha, including 80-90 million ha of forest lands (Korovin, 1984).

While the number of fires reported by Russian authorities may have been reasonably accurate, the area burned seemed extremely low considering the vast boreal region of Russia. Concern over the reliability of official area burned numbers grew when, in 1987, satellite analysis of the Great China Fire revealed large areas burning in eastern Siberia (Cahoon et al., 1991, 1994). This analysis revealed 40-50 fires, ranging in size from 20 000 ha to 2 million ha, had burned over a total of approximately 10 million ha in this region in early 1987, yet this was not reflected in the official Russian statistics for that year. Official underestimation of area burned was also reported by some Russian scientists (Rylkov, 1996).

The establishment of a National Aeronautics and Space Administration (NASA) satellite downlink station in central Siberia in the mid-1990s permitted the accurate documentation of fire activity over almost all of Russia, including previously unmonitored regions. As a result, area burned figures for Russia since that time are considered much more accurate. Figure 6 combines area burned data from official Russian government records for the 1980-2007 period, as reported by *Avialesookhrana* of the Federal Forest Agency, with satellite-derived measurements post-1995, and highlights the significant increases over the past 12 years (Goldammer 2006; Goldammer et al., 2008). During the 1980-2007 period, agency data confirms that area burned has shown high inter-annual variability, fluctuating by an order of magnitude between ~226,000 and ~3 million hectares. Satellite-derived numbers for the 1996-2007 also show the highly episodic nature of area burned, fluctuating between ~3 million and ~18 million ha. The distribution of large fires for two particularly severe years (2002 and 2003), based on satellite data, is shown in Figure 7. Reconstruction of more accurate data for the 1980-1995 period is currently underway, and involves the detailed analysis of all available NOAA AVHRR satellite imagery over Russia for this period. Preliminary results indicate much larger area burning in many years during this period than officially reported.

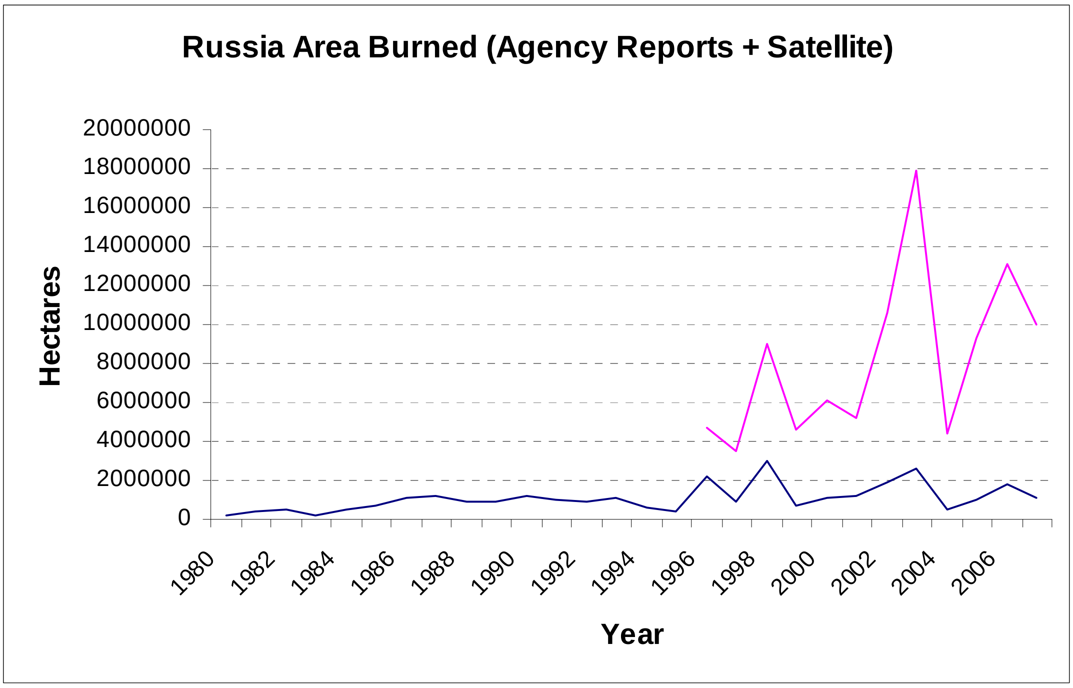

Figure 6: Russian area burned statistics from agency official statistics (1980-2007) and satellite measurements (1996-2007). Source: Goldammer et al. 2008.

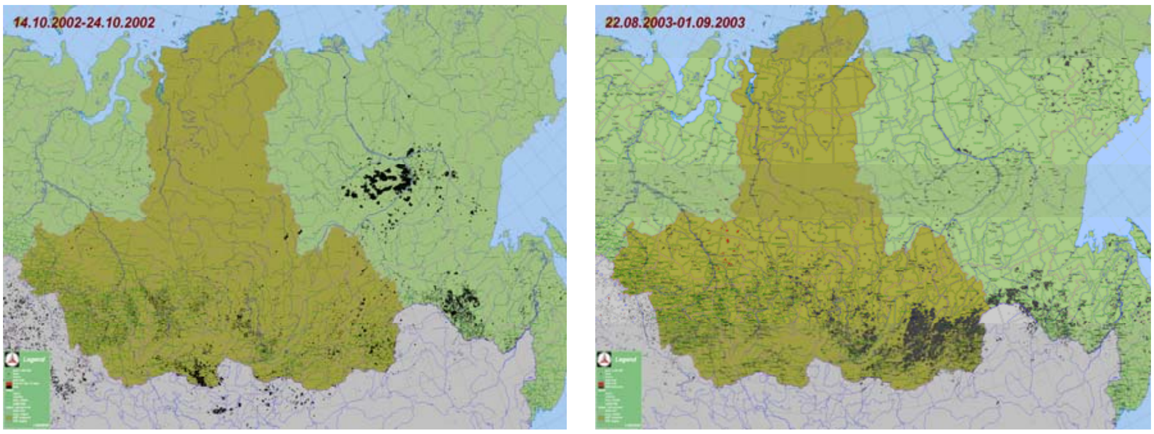

Figure 7: Spatial distribution of large fires in Siberia in 2002 (10.6 million ha burned) and 2003 (17.9 million ha burned)

A recent report from Russia states that, over the previous 10 years, close to 72% of the forest fires were caused by humans, with about 7% resulting from agricultural burnings, and an additional 7% originating from lightning (14% of fires are due to other causes). However, in some regions – especially in the Northern areas of European Russia, Siberia and the Far East, particularly in sparsely inhabited territories where forest fires are not suppressed – the share of lightning-caused ignitions is considerably higher (up to 50-70 %) (Davidenko and Kovalev, 2004).

In spite of the reliability problems mentioned above, forest fire statistics in Russia reveal some emerging trends, as the number of fire incidents and area burned areas are increasing and showing great variability over the protected territory. According to official Russian statistics, during the 1986-1990 period an annual average of 17 800 fires burned over an average of 1 005 400 ha annually. For the 1991-1995, 1996-2000, and 2001-2005 period these numbers were 21 700 fires and 603 800 ha, 30 000 fires and 1 431 500 ha, and 29 300 fires and 1 201 500 ha respectively. These official area burned numbers, as mentioned earlier, are in stark disagreement with satellite-derived data. Fire incidents ranged from 12 100 to 43 400 annually, with the annual area burned varying between 490 000 and 2 496 900 ha. Surface fires account for 97-98% of all fires and 87-90% of burned area; crown fires represent 1.5-2.0% of all fires and 10-12% of burned area. The remainders are underground fires.

Fires larger than 25 hectares in the zone of ground protection and 200 hectares in the zone of air protection are classified as large fires. Most large fires originate during droughts and strong winds and spread quickly for several days, often as high-intensity crown fires with significant spotting downwind. Such fires usually easily overcome suppression efforts, often creating abundant smoke which hampers aerial fire suppression and generates transboundary smoke flows. Fires in the Russian Far East frequently result in smoke transport to Japan, China, Korea, Alaska and beyond.

Sweden

Almost all of Sweden lies within the boreal and hemiboreal zone, and fire has, until recently, played a major role in shaping forest composition in this region. Most of the terrain is covered by flammable vegetation such as coniferous trees (e.g. *Pinus sylvestris*, *Picea abies*), ericaceous dwarf shrubs, and mosses. In recent decades, fire has been virtually eliminated as a force in Sweden due to intensive forest management, and the Swedish public has been largely unaware of the fact that fire was once a major and natural force in Swedish boreal forests. This has begun to change in recent years, as fire research has increased in response to growing environmental concerns (e.g. biodiversity, forest health) over the consequences of virtually eliminating fire in ecosystems where it is essential and natural.

During the 1950-1980 period an annual average of 2 000-3 000 fires burned over between 2 200 and 3 600 ha in Sweden, a remarkably low area burned considering the number of fires (Stocks, 1991). This has been attributed to the high degree of accessibility (road networks) associated with intensive forest management. Fire was considered such an insignificant problem in Sweden by the late 1970s, and the collection of official statistics was abandoned until the early 1990s. Between 1992 and 1996 the average annual area burned was approximately 2 500 ha (Granström, 1998).

At the present time the area burned in Sweden varies between a few hundred hectares in wet years and a few thousand hectares in dry years (Niklasson and Granström, 2004; Vanha-Majamaa, 2006), with the number of forest fires ranging from 2 100 to 3 500 annually. From these numbers it is evident that fire is not a major disturbance regime in Swedish forests, and that fire activity has not changed significantly over the past half-century.

Finland

Boreal forests in Finland cover 86% of the land area, with the major tree species (as in Sweden) being Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Finland has compiled continuous fire statistics since 1952. Between 1952 and the late 1980s, while the average number of fires remained relatively constant at approximately 500/year, the area burned decreased substantially from ~5 700 ha/year to ~300 ha/year (Parviainen, 1996; Vainio, 2001; Stocks, 1991). During the 1990s forest fire occurrence increased substantially, with an average of close to 1000 fires annually burning an average of 500-600 hectares (Vanha-Majamaa, 2006).

Fire Management in the Boreal Zone

Canada

The settlement of Canada in the 1800s and early 1900s was accompanied by devastating wildfires which resulted in significant loss of life and property. As a result of this threat, and the growing need to protect an expanding forest industry, fire control organizations were created across the country in the early 1900s. The use of Canadian forests, for both industrial and recreational purposes, has increased dramatically in the past century. Along with the increased access and utilization has come a concurrent increase in forest fire incidence and the fire suppression capability mobilized to address this problem. Organized fire suppression became more successful, but significant wildfire years were common. During periods of extreme fire weather, Canadian forests continued to sustain the large, high-intensity wildfires to which they had become adapted over millennia. During the 1970s there was a growing realization in Canada that total fire exclusion was neither economically feasible nor ecologically desirable. The pursuit of this goal had entailed considerable social and economic costs and, despite constantly increasing expenditures, there was no corresponding decrease in the number and impact of forest fires. This was coupled with an increasing awareness of the important and natural role of fire in maintaining forest health, productivity, and biodiversity, particularly in the boreal and temperate forest regions of Canada. These changes led to the evolution of a new fire management strategy in which consideration is given to the ecological role of fire, the economics of fire suppression, and the priority of values-at-risk. At the top end of the priority scale an ever-increasing number of wildland-urban interface (WUI) areas, and high-value forest industry and recreational sites receive vigorous protection. On the other hand, fire is often allowed to operate naturally in lower priority areas such as wilderness parks or remote forested areas of limited economic value where fire is a natural and necessary shaper of forest ecosystems. This policy of "modified suppression" is in effect in the northern regions of the provinces of Quebec, Ontario, Manitoba, and Saskatchewan, as well as most parts of the Northwest and Yukon Territories.

In Canada, responsibility for forest management, and therefore fire management rests with each of 13 autonomous provinces and territories, as the bulk of forested land in Canada is public, and owned by the provinces/territories. The federal government, after turning over responsibility for forest protection in western Canada to provincial agencies in the 1930s, is responsible for fire management on federal lands (National Parks and First Nations reserves, Department of National Defense). In National Parks an emphasis is placed on maintaining ecological integrity by reintroducing periodic landscape-scale fire through prescribed burning and wildfire monitoring. In addition, 80% of aboriginal communities are located in forested areas and these communities negotiate agreements for protection. While provincial governments in Canada have the primary responsibility for forest fire management, the federal government has a primary responsibility for the health and safety of Canadians, and is also the “insurer” of last resort in providing disaster assistance. A number of federal agencies are involved in some aspect of wildland fire.

Fire suppression costs are constantly rising in Canada, due to a number of factors, including changes in fire weather, the use of more costly equipment, the expansion of fire protection zones northward to match growing forest operations, and increased costs associated with protection of an expanding wildland-urban interface. Annual suppression costs, not including public and industrial losses, are highly variable annually, but are averaging Can$500 million and can be as much as Can$1 billion in an extreme fire season. The provinces of British Columbia, Ontario, Alberta and Quebec generally account for approx. 80% of total Canadian fire management expenditures.

The nationally decentralized provincial fire management systems work quite efficiently in low and moderate seasons; by when fire activity becomes extreme, provinces rely on one another to supplement suppression resources. After a series of major fire seasons in the early 1980s, the Canadian Committee of Resource and Environment Ministers created the Canadian Interagency Forest Fire Centre (CIFFC) in 1981. Located in Winnipeg, CIFFC is a cooperative venture established to share information and fire management resources among its federal, provincial, and territorial member agencies. Over the past two decades, CIFFC has made a major contribution to fire management in Canada by conducting information and resource exchanges (including personnel, equipment and aircraft), establishing national standards for equipment and personnel, negotiating a pre-arranged cost recovery system, formulating working groups to address common interagency issues, and serving as a contact point for international requests and cooperation. Agencies have increasingly recognized that there are considerable economic efficiencies to be gained (estimated to be millions of dollars annually) in risk management by sharing resources through CIFFC and these practices have become an important part of the fire management business.

Over the past 80 years, Canadian fire management agencies have grown in size and sophistication to address expanding responsibilities in protecting Canadian forests from unwanted fires. Operational fire managers and fire scientists in Canada have worked closely together to develop highly sophisticated systems to predict the occurrence, behavior, and impact of forest fires in various ecosystems across the country. Two key objectives in successfully controlling fires are early detection and initial attack when fires are small. This involves prediction of the most likely locations where fires will start (both lightning and human-caused fires), and the implementation of enhanced detection (primarily aircraft patrols) in those areas. When fires are detected, initial attack forces are deployed by land or helicopter, and are often supported by aircraft dropping water, foam, or fire retardant chemicals.

Alaska

Fire is recognized as a natural and essential force in cold-dominated boreal ecosystems in Alaska. As a result fire protection options in Alaska provide for a full range of suppression responses from aggressive control and extinguishment to surveillance and monitoring. Fires that threaten human life and property are aggressively attacked with the goal of containing fires while small. Modified, or limited, suppression action is provided on fires in areas where values at risk do not justify the expense of full protection. These fires are allowed to burn naturally, with defensive action being taken only if isolated values are threatened, and significantly contribute to the overall area burned in Alaska.

Wildland fire management in Alaska is a highly-integrated interagency effort. There are three agencies responsible for wildland fires in Alaska: the Bureau of Land Management, Alaska Fire Service (AFS); the State of Alaska, Department of Natural Resources, Division of Forestry (DOF); and the US Forest Service (USFS).

The Alaska Interagency Coordination Center (AICC) in Fairbanks serves as the focal point for initial attack resource coordination, logistics support, and predictive services for all state and federal agencies involved in wildland fire management and suppression in Alaska. In addition, AICC is responsible for coordinating and providing support for all-hazard emergency response activities for federal landholding agencies in Alaska, and for providing support to Alaska BLM for non-emergency resource activities.

Russia

In the early 1920s it was recognized that effective protection of the vast Russian taiga required aircraft, with the beginnings of a formal aerial protection program initiated in the early 1930s when organized, operational flights for fire detection and monitoring began in the central Urals, Siberia, and the Far East regions of Russia, This formalization of aerial fire protection led quickly to rudimentary attempts at dropping chemicals and water from aircraft and, in 1934 a smokejumping program was initiated. New bases were established across Siberia, and the program expanded dramatically after World War II using surplus military aircraft and demobilized paratroopers. *Avialesookhrana* - the aerial forest protection service - began using helicopters to transport firefighters and equipment (some mechanized) in the mid-1970s, and began to exert a major influence on the area burned throughout Russia, especially with regard to suppression of human-started fires near settlements. By the 1990s the Soviet Union had amassed the largest firefighting system in the world. However, when the Soviet political system collapsed in 1991, budgets for fire control were greatly reduced. With these political and economic changes in Russia, the past gains in fire suppression became difficult to sustain as the area receiving fire protection, the frequency of reconnaissance flights, and the numbers of fire fighters that could be hired and deployed were all substantially decreased.

Comprehensive reports about the fire situation in the Russian Federation have been published in the pages of UNECE/FAO International Forest Fire News (IFFN) since the early 1990s. During this time period the resources available for fire detection, monitoring and suppression as well as for fire prevention decreased substantially in comparison with the 1970s. At that time over 8 000 smokejumpers and rappellers were employed in the Aerial Fire Protection Service *Avialesookhrana*. On average they were able to suppress about 70% of fires on initial attack. During this peak period, about 600 aircraft were rented from aviation enterprises. As a consequence of the reduction in available aircraft, permissible flight hours and personnel (in 2005 the number of smokejumpers and helirappellers was reduced by 50% from the 1970s levels), fire detection is often delayed substantially. Consequently the average size of fires at detection and initial attack has constantly increased over the past decade resulting in an increase of the number of large fires (Figure 8). Official records indicate that aerial patrols detect 42% of Russian fires, with 7% being detected by ground resources, while satellite monitoring accounts for the detection of 51% of fires nationally.

Despite severe budget restrictions *Avialsookhrana* was still responsible for the protection of 690 million hectares across Russia, and operated 24 regional airbases with a large fleet of state-owned and privately leased aircraft and helicopters in 2004. At that time close to 4 000 smoke jumpers and helirappellers and about 400 aerial forest observers were employed by *Avialesookhrana* (Davidenko and Kovalev, 2004). Russia also makes extensive use of lightning detection systems and a variety of remote sensing platforms to detect and monitor fires throughout the country.

While, at the federal level, the Federal Forestry Agency (Ministry of Natural Resources) maintains responsibility for national policies, responsibility for fire management in Russia was recently delegated to regions in an attempt to decentralize operations and improve suppression capabilities. In accordance with the Forest Code, fire suppression is assigned to the regions, and implemented on the basis of subventions from the federal budget. Beginning in January 2007 regional-level responsibilities include preparation for the fire season, fire prevention and suppression. At that time, the Federal Forestry Agency's (*Rosleskhoz*) territorial agencies in the regions were abolished. The regions assumed control of 1 870 forestry enterprises (*leskhozes*), 2 300 fire-chemical stations, basic assets worth 1.4 billion USD and 170 000 personnel. All 24 affiliates of *Avialesookhrana* were also passed to regions, the air bases received practically full independence from the federal center and the cooperation is arranged on the basis of the agreements. Local air bases now coordinate all aspects of fire suppression in their areas, including maintenance of fire chemical stations which can vary in size, depending on values being protected. Small stations in remote areas may only employ 4-6 persons, while intermediate stations (typical) employ 20-30 people. Large fire chemical stations are also set up to provide fire suppression for several forestry enterprises. During extreme fire situations the local population and military personnel also participate in suppression activities.

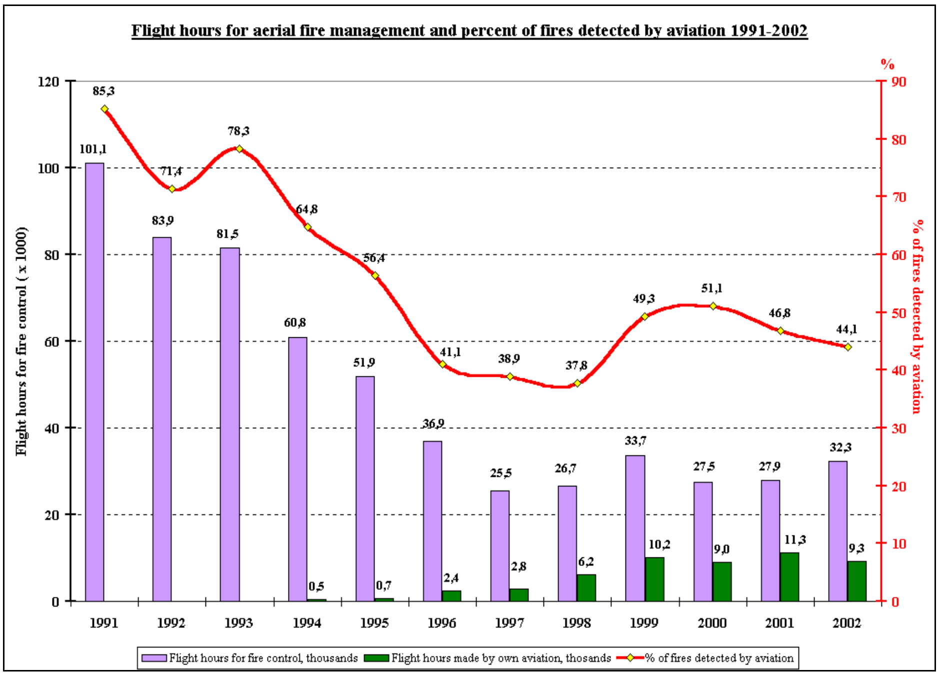

Figure 1. Flight hours for aerial fire management and percent of fires detected by aviation 1991-2002. Source: Davidenko and Eritsov (2003).

According to recent preliminary information from *Avialesookhrana*, responsible for analyzing the data and controlling the regional activities on spending (about 29 million USD in 2007), the regional approach has experienced some difficulties. This resulted in restructuring, with a decrease in the number of air bases and fire suppression personnel, in turn resulting in a decrease in detection and initial attack effectiveness, resulting in more large fires. Existing Regional fire centers in the Far East and Siberia were abolished and the work underway to create such centers in the Ural, North-East and Central Districts was stopped.

Further evidence of declining fire suppression effectiveness is the fact that the number of fires suppressed within two days declined by 35% in 2007 compared to the previous five years, with a substantial increase in the percentage of large fires. Fire expenditures were twice the levels of 2006.

However, the regionalization of fire suppression responsibilities made the transfer of resources and funds between regions much more difficult. The management transformation as usual in Russia requires much money and resources, and leads to the loss of the effectiveness and time in implementing forest fire protection duties, creating unresolved issues between federal and local authorities. According to Rosleskhoz, in 2007 regional agencies were only 40% prepared for the beginning of the fire season, and a lack of resources to control spring agricultural burning resulted in a significant number of large spring wildfires.

Reduced fire management capacity in Russia often combines with other factors to produce extreme fire years. This was the case in 2003 when an extended drought, inappropriate forest management (illegal logging and extensive clearcuts), and economically motivated arson combined with a greatly reduced fire management capacity to create an extreme fire situation in which close to 18 million hectares burned.

The growth of illegal logging and timber trade in recent years in Russia has attracted global attention, and has resulted in demands that forest protection responsibilities and capabilities at the federal and regional levels be strengthened to combat this rampant forest exploitation. It remains to be seen whether these demands will actually result in any concrete action. In the final analysis, despite a wealth of aircraft and human resources available for suppressing fires, there is little evidence that Russia is willing to commit the monetary resources to improving a declining fire suppression capability.

Sweden

Sweden does not have a separate agency that is responsible for managing and controlling forest fires. Suppression is organized by communes, over which the state has little control. Communes can also include cities, and range in population from 3 000 to 700 000. Large communes have fire brigades operated by full-time professional firefighters, whereas smaller communes utilize part-time firefighters as required.

The approach to fire suppression usually involves fire engines carrying water to the fire. However, if the fire location is not accessible by road lightweight pumps and hose connected to a nearby water supply (lake, river, and stream). Helicopters have also been used more in recent years. Forest fire costs are shared by the communes and the state.

The virtual elimination of fire from Swedish forests where it was once natural and critical to ecosystem maintenance has recently resulted in a growing awareness among forest managers of the need for a more balanced amount of fire on the landscape. Swedish forest certification criteria encourage more prescribed burning, and this has been increasing in recent years. However, much more needs to be done, and there is a recognition that forest companies and legislators need to become more comfortable with reintroducing fire to Swedish forests. This will require more resources, along with expanded training and public education (Niklasson and Granström, 2004).

Finland

With an average fire size currently less the 0.5 ha, fire is currently not viewed as a significant problem in Finland. A well-developed fire monitoring and suppression system, in combination with summers that tend to be cool and damp, and an extensive road network resulting from intensive forest management, means that fires are detected and suppressed quickly, often under benign fire danger conditions.

In Finland a network of Regional Rescue Services, supported by local fire brigades (professional and volunteer), are responsible for forest fire suppression. The Finnish Meteorological Institute monitors weather and determines a daily forest fire index for different regions of the country. This information is passed along to the public through various media outlets as fire danger rises. Prior to 1970 fire detection in Finland was accomplished through a series of lookout towers, but by the end of the 1970s these had been totally replaced by aerial fire detection patrols. In recent years an operational satellite-based (NOAA AVHRR) system has been developed to support fire detection in Finland and surrounding Baltic countries.

The latest statistics available (Vanha-Majamaa, 2006) indicate that 70-80% of fires are detected and reported by the public, which seems logical given that 60-70% of Finnish fires are human-caused. An additional 10-15% of fires are detected by aircraft. Approximately 13% of fires are caused by lightning.

International Cooperation on Boreal Fire Science and Policy Issues

The International Boreal Forest Research Association (IBFRA)

Although North American and Russian fire research and fire management specialists had sporadic contact during the past four or five decades due to the Cold War, the relaxation of political tensions in the 1990s presented the opportunity to pursue cooperative fire research initiatives. Following the "White Sea Declaration" that resulted from the 1990 International Symposium on Boreal Forests in Arkhangelsk, Russia, The International Boreal Forest Research Association (IBFRA) was formed in 1991 at a meeting of Russian, American, and Canadian representatives in Mezhgorje, Ukraine. The IBFRA soon expanded to include Sweden, Finland and Norway and, over the past 15 years has met once or twice in every member country, with the latest meeting in Umea, Sweden in 2006.

The Fire Working Group (FWG) was one of the first working groups created under IBFRA, and to date it has been the most active. Following an organizational meeting in Siberia in 1992, the IBFRA FWG has strongly promoted and facilitated cooperative international and multi-disciplinary boreal forest fire research between Russia and western boreal countries. At this initial meeting in Krasnoyarsk, a number of collaborative studies dealing with global change/fire issues, remote sensing, fire behavior, fire danger rating, fire history and fire ecology and effects were conceived. In collaboration with the International Global Atmospheric Chemistry (IGAC) Project of the International Geosphere Biosphere Program (IGBP), the IBFRA FWG organized a major fire research campaign (Fire Research Campaign Asia North – FIRESCAN). This campaign involved organizing a major 1993 international forest fire conference in Krasnoyarsk (Goldammer and Furyaev, 1996), followed by a high-intensity experimental fire along the Yenisei River in central Siberia (FIRESCAN Science Team, 1996). This led to the establishment, in the late 1990s of FIREBEAR (Fire in the Boreal Eurasian Region), a collaborative experimental burning program, sponsored primarily by NASA, in central Siberia aimed at developing fire behavior models for major Russian fuel types, while validating remote sensing-based estimates of fire emissions, carbon loss and fire severity (McRae et al., 2006).

IBFRA was also a major sponsor of the International Crown Fire Modelling Experiment (ICFME), carried out in Canada’s Northwest Territories between 1997 and 2000 (Stocks et al., 2004). ICFME involved a series of the most heavily instrumented and documented high-intensity experimental crown fires ever carried out, with scientific representation for more than a dozen countries including Russia. IBFRA was also involved in the conception and conducting of a major landscape-scale experimental prescribed fire in Alaska in 1999.

Cooperative Canadian Forest Service/Russian Federal Forestry Agency Initiative

In 2005, senior representatives from the Canadian Forest Service (CFS) Natural Resources Canada, and the Russian Federal Forestry Agency (RFFA) met to discuss future cooperative of forest research and management issues. At that time, cooperation on forest fire issues was identified as a major priority by the RFFA, and a group of fire managers/researchers met in Moscow to develop a work plan. The key areas for cooperation emerging from this recent exercise were in fact very similar to those identified in the 1992 IBFRA Fire Working Group meeting in Krasnoyarsk, and are as follows:

- Evaluation of the suitability of the Canadian Forest Fire Danger Rating System (CFFDRS) for use in Russia.
  - Hourly data for Russian weather stations has been obtained for the post-1953 period, and has been used to develop a spatial and temporal fire danger climatology for Russia for the past 5 decades. CFFDRS fire danger components are displayed daily, weekly and monthly in a GIS database.
  - A trial operational evaluation of the CFFDRS is underway in the Krasnoyarsk Region of central Siberia, using weather data collected in real time to predict fire danger and potential fire activity in order to assist operational fire management agencies in pre-positioning suppression resources and detecting fires.

- Development of a joint remote sensing/experimental burning program designed to provide a better ability to accurately monitor the spatial and temporal distribution and environmental impacts of wildfire across Siberia.
  - The FIREBEAR (Fire in the Boreal Eurasian Region) Project has been ongoing since 1999 in central Siberia. This study will provide important information for developing recommendations on the management of biomass carbon and fire regimes to reduce CO_2 and CH_4 emissions, to enhance carbon storage and sustainable forest management, and to minimize negative impacts of fire on the global environment.
  - Fire behavior prediction models created for pine and larch forests will be used in implementing the Canadian Forest Fire Danger Rating System (CFFDRS) in Russia.
- Reconstruction of post-1980 fire activity in Russia using archived NOAA AVHRR satellite imagery.
  - Official Russian fire records for the 1980-1995 period are grossly incomplete, and will be reconstructed using satellite data, in order to augment more accurate post-1995 data and provide a recent historical baseline of Russian fire activity.
  - This database will be used as a basis for projecting future Russian fire regimes under a changing climate, information essential for projecting impacts and developing adaptation strategies.

Major Drivers for Increasing Forest Fire Risk and Vulnerability

A recently-developed Canadian Wildland Fire Strategy (Canadian Council of Forest Ministers, 2005) identified a number of emerging vulnerabilities that will affect fire activity/impacts and management in coming decades. Although developed with Canada in mind, many of the areas of increasing risk and vulnerability apply to other boreal countries as well.

Climate Change

It is generally accepted conclusion among scientists and a growing percentage of the public that climate change is a reality, and that impacts across the circumboreal zone will be profound, and largely unavoidable, over the next century. Climate change is expected to be most severe at northern latitudes, and boreal zone impacts are projected to be most significant over Siberia, west-central Canada, and Alaska (Stocks et al., 1998). Research to date indicates that both the incidence and severity of forest fires will increase dramatically Flannigan et al., 2000). The result will be longer fire seasons (Wotton and Flannigan, 1993), larger areas burned (Flannigan et al., 2005), shorter fire-return intervals, a shift to a lower forest age-class distribution, and a net loss of terrestrial carbon to the atmosphere, likely resulting in a positive feedback loop to climate change wherein more fire leads to greater atmospheric carbon which leads to greater warming and more fire (Kurz et al., 1995). Any trend towards increased fire activity and impacts will put extreme pressure on fire management agencies in the boreal region, and they will be unlikely to maintain their current level of control over fire impacts. Recent studies indicate substantial costs would be required to attempt to keep escaped fires at current levels, and escaped fires increasing significantly using current resource strength under a changing climate. It appears fire suppression as practiced today will not be economically sustainable in the future. This will have direct effects on wood supply, the competitiveness of forest industry, and the future of forest industry-based communities. It will also have a direct effect on carbon sequestration and greenhouse gas emissions, particularly with increased carbon loss through more severe forest fires and the new exposure of carbon-rich peatlands to future fire.

Forest Health

The attempted exclusion of fire in many regions of the boreal zone, particularly in the southern boreal where timber extraction is economically vital, has led to a shift to older age classes or forests in later successional stages. This could lead to significant changes in wildfire potential and the resultant fire regime, as increasing fuel accumulation levels would result in fires of higher intensity, increasing the difficulty and likelihood of control. Fire exclusion in many ecosystems also favors the development of major insect infestations over large areas (e.g. Carroll et al., 2006; Fleming et al., 2002), which in turn followed by large fires fuelled by excessive dead woody material. Recent examples are the Mountain Pine Beetle in western Canada, the Eastern Spruce Budworm in eastern Canada, and the Gypsy Moth in Siberia. Attempted fire exclusion also needs to be examined in the context of the commitment of boreal countries to the Convention on Biological Diversity and Sustainable Forest Management (The Montreal Process).

Competition for the Boreal Forest Land-Base

Boreal forests are now exposed to increasing and competing demands on the land-base. In Canada, forest industry is under pressure to continually increase wood supply to meet market demands while accessible Canadian forests are almost fully committed. There is growing pressure from environmental groups and the public in general to set aside and protect more forest areas for recreational activities, biodiversity conservation etc. Aboriginal groups also require expanded access to forest lands for traditional pursuits. In Russia, forest exploitation is rampant, particularly in Siberia, and government is doing little to control illegal logging and high-grading of prime wood supply areas. Managing the boreal forest in Russia in a sustainable manner seems a low priority at this time.

Fire Management Capacity

Across the boreal zone, fire management capacity varies considerably. In Scandinavian countries current fire management capacities seem adequate to keep area burned and fire impacts at an insignificant level, perhaps to the point where more natural fire is required to maintain ecosystem structure and health. Meanwhile, fire management capacity has eroded substantially in Russia since the fall of the Soviet Union in the early 1990s. Despite the fact that Russia realizes huge revenues from its forests, very little is currently being done to provide adequate fire protection. Heavy fire suppression equipment levels remain high, with large numbers of aircraft and helicopters, but there is no funding for utilizing these resources. Human resource levels are now about 50% of what they were in the early 1990s. As a result, budgets are depleted early in the fire season and fire impacts and area burned are growing at an alarming rate. This lack of an adequate protection capability, combined with growing forest exploitation (large clearcuts with extensive harvesting residue on-site) and increased fire occurrence/severity resulting from climate change, will likely result in large fire impacts in Russia for the foreseeable future.

In Canada, where a sophisticated fire management capability has been in place for decades, it is becoming apparent that the ability to manage wildland fire is coming under increasing stress, primarily because fire incidence and impacts are increasing while suppression capacity is not growing and has reached its limit of maximum effectiveness. Fire management costs are increasing, particularly when fires impact communities, and are becoming more variable and unpredictable on an interannual basis. This is occurring while fire management agencies are subject to frequent government budget reviews and constraints that can and do restrict their ability to most effectively manage fires. In addition, the current fire suppression infrastructure in Canada is degrading, as aircraft, facilities and equipment are aging. In addition, the demographics of fire management in Canada are changing, with government restraints on hiring resulting in a preponderance of older employees. Nearly 50% of current permanent fire management staff in Canada are due to retire in the next 10 years, and little is being done to hire and train replacement personnel.

Expanding Communities

Across the boreal zone there is a discernible trend toward more homes and communities being built in forested environments. While the Wildland-Urban Interface problem in boreal countries is not nearly as extreme as it is in Mediterranean countries and the western United States, it is a growing concern. There is a strong need for governments to regulate this type of development, and to put in place standards for home and community construction that include hazard mitigation measures. However, living in a more natural environment is highly attractive to ex-urbanites, resulting in community expansion and growth that is outpacing adequate mitigation measures and protection.

In addition, communities in the northern boreal zone, which are primarily indigenous peoples, and/or are associated with resource-extraction industries, currently, require better protection against fire impacts through hazard mitigation. These communities depend on the forest around them for their livelihood, so even fires that do not impact a town-site directly can significantly affect the future of that community. Evacuations of many northern communities occur almost annually to guard against direct or indirect (smoke/health effects) impacts from fire. With projected climate change and increased fire activity the need for community protection will expand significantly, and fire-related evacuations and impacts will increase proportionally.

Public awareness of forest issues, including fire management decisions, has been growing quickly in recent years, partly due to the success of public awareness programs. This is particularly true with First Nations peoples, forest land owners, and urbanites moving to the Wildland Urban Interface. All expect to be consulted before new policies are initiated, and also expect that their concerns will be heard and addressed in this process. In addition, they expect that that their immediate values will be protected. This growing emphasis on a civil society, with a greater public role/responsibility in resource management decision-making, requires fire management agencies to emphasize the inclusion of all stakeholders in policy development. It also requires an informed public that understands that not all fires are bad and that fire suppression effectiveness has limits.

Executive Summary/Key Messages

- Fire is natural and essential to boreal forest ecosystem maintenance and structure and fire management programs take this into consideration by creating “modified” or “limited” suppression zones where fire is allowed to burn more naturally.
- Despite a century of reasonably effective fire suppression, a number of boreal fires continue to grow large, either because suppression resources are overwhelmed, or because these fires occur in regions with limited protection.
- Boreal fires burn an average of 5-15 million ha annually, although this is highly variable interannually.
- Almost all of the area burned occurs in Canada, Russia and Alaska, where similar continental climates create fire danger conditions conducive to large fires over large areas.
- Fire has been virtually eliminated by intensive forest management in the Nordic counries, with an average of less than 5 000 ha burning annually, and there is growing concern that the reduced level of fire in this region is adversely affecting forest health and biodiversity. As a result, prescribed fire slowly being introduced.
- Since the collapse of the Soviet Union in the early 1990s there have been a number on cooperative international programs developed that have made some progress, although much remains to be done.
- There are a number of emerging vulnerabilities and risks in the boreal zone that virtually guarantee that there will be more boreal fire in the near future, with potentially huge impacts at national to global scales. The ability of boreal countries to effectively mitigate projected impacts at a large scale is severely restricted at best, with fire protection capabilities in North America at their effective physical and economic limits, and Russian fire management in a state of disarray.
- Adaptation to the emerging reality of more frequent and severe fire impacts will likely include the recognition that our current ability to manage fire will be greatly compromised in coming decades. This would likely result in a gradual reassessment and realignment of protection priorities wherein natural fire is permitted over larger areas, while intensive protection efforts will focus more narrowly on high-value areas and resources.
- Adaptation at this scale would also require a new policy paradigm, likely driven by greater public awareness/involvement and political will.

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