USDA U.S. Department of Agriculture

U.S. Forest Service
Superior National Forest

Ecological and Fire Conditions

for the Boundary Waters Canoe Area Wilderness

FOSTER WHEELER ENVIRONMENTAL CORPORATION

April 2000

FINAL
ECOLOGICAL AND FIRE CONDITIONS
BOUNDARY WATERS CANOE AREA WILDERNESS

Submitted to:

U.S.D.A. Forest Service
Superior National Forest

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OVERVIEW

The Boundary Waters Canoe Area Wilderness (BWCAW) on the Superior National Forest is one of the most heavily used wildernesses in the United States. It encompasses approximately 1.1 million acres of the north woods lake country of northeastern Minnesota and is bordered to the north by Canada. It is the Nation's only extensive canoe area. Combined day and overnight visitor use during summer is approximately 200,000. The area also receives visitors during other seasons. On an average summer day, over 3,000 visitors could be within the BWCAW. Additionally, areas surrounding the BWCAW receive high recreation use, and include many homes, cabins, resorts, campgrounds, youth camps, Wilderness entry points, and boat landings.

On July 4, 1999, heavy rains and straight-line winds greater than 90 miles per hour caused extensive forest blowdown and flooding throughout northeastern Minnesota and adjacent areas in Canada. This weather event resulted in 477,000 acres of blown-down trees across the Superior National Forest. Most (367,000 acres) of the blowdown occurred in the BWCAW. The largest affected area is approximately 30 miles (48 kilometers) long and 4 to 12 miles (6 to 19 kilometers) wide lying in a west to east direction.

The BWCAW storm damage was caused by a derecho, which is defined as a characteristic pattern of straight-line wind damage over a widespread area (main axis of damage >250 miles in length) caused by repeated downbursts that originate from thunderstorms moving across the landscape. The July 4, 1999 storm was a rare event. Although southern Minnesota has a very high frequency of derechos, northern Minnesota normally has a low derecho frequency. Derechos cover much larger areas than tornadoes and are the main agent of wind-caused forest damage in the Upper Midwest. They can produce winds up to 113 to 157 miles per hour (mph). Since winds of 100 to 110 mph or more are necessary to cause catastrophic forest damage, the most intense derechos can easily level vast areas of forest and cause the most extensive forest damage of any weather phenomenon in the interior of North America. The July 4, 1999 derecho that hit the BWCAW and a similar one that hit northern Wisconsin on July 4, 1977, caused damage similar in scope to that of a major hurricane making landfall in a forested region.

The windstorm increased the amount of dead and down materials on the ground in the areas blown down in the BWCAW. These materials, called “slash fuel,” increased from 5 to 20 tons per acre up to 50 to 100 tons per acre. This increase in material on the ground will allow ignition, development, and rapid spread of high-intensity fires that are difficult to control under a wide variety of weather conditions. Under the right weather conditions, there is an increased potential for wildfire within the Wilderness that could move from within the Wilderness to adjacent private, State, and National lands or across the international border into Canada.

HISTORICAL ROLE OF FIRE IN THE BWCAW, 1600 TO 1900

The July 4th windstorm set the stage for major changes in the composition and structure of the area's forest. The forest has been changing for several hundred years and will continue to change in the future. Individuals will observe only one small segment of this change, so it is necessary to know past and potential future conditions to understand the impact of management decisions.

Humans caused large changes in the forests of the BWCAW prior to the blowdown, and these changes influenced how the blowdown occurred on the forest landscape. Historically (1700 to 1900), most forests were young and even-aged, and were not very susceptible to wind damage. Crown fires that replaced stands of trees would occur every 50 to100 years in the jack pine, black spruce, and aspen forests which occupied the majority of the BWCAW landscape. European settlement brought with it human fire suppression and fire exclusion. Fire suppression and fire exclusion over the last century have resulted in large stands of older forest that are highly susceptible to wind damage. Just as fire control shaped today's forest and contributed to the blowdown, the blowdown will in turn determine the future characteristics of the BWCAW forest. The blowdown is yet another step towards a much different forest than was found at the time of European settlement in the late 1800s.

Major fires have always played a role within the BWCAW ecosystem. In *Boundary Waters Wilderness Ecosystem*, Heinselman (1996) noted that major fires burning more than 100 square miles occurred at least nine times between 1684 and 1894 (Table 1). The average interval between major fires was 21 years for the settlement period (1868 to 1910), 28 years for the pre-settlement period with good records (1727 to 1868), and 48 years for the total period of record (1542 to 1972). Based on this pattern, the BWCAW is due for a major fire because a century has gone by without one. The fuels caused by the blowdown increase the odds that just such a major fire will occur in the near future.

For example, in similar conditions, a fire burning in one-year-old blowdown fuels occurred in 1974 in northwestern Ontario, Canada, and over a period of 7 days, spread to a size of nearly 80,000 acres. Fires are expected to occur in the blowdown area over the next several years; however, the exact scenario that these fires will follow is difficult to predict and dependent upon weather conditions. There is the possibility that only a few relatively small, scattered fires would occur. There is also the possibility that a fire burning under the influence of high winds from a passing cold front could result in a very large fire (>500,000 acres) covering much of the blowdown and surrounding areas. Much more likely, however, is an intermediate scenario where several moderate-sized fires and many smaller ones occur, with various intensities and at various places throughout the blowdown over a period of several years. Counting fires of all sizes, about 19 to 20 fires occurred annually in the BWCAW from 1986 through 1998, with a range of 3 to 49. Approximately 60 percent of these fires were lightning-ignited with the remaining 40 percent human-caused.

Table 1. Total Acreage and Percentage of Virgin Forest Burned by Major Historical Fires Impacting More Than 100 Square Miles between 1600 and 1973

Year	Known Acreage of Burns (thousands of acres)	Percentage of Virgin Forest Burned
1894	265	16.8
1875	350	22.2
1864	696	44.1
1824	131	8.3
1801	162	10.3
1759	312	19.7
1727	207	13.1
1692	103	6.5
1681	154	9.7

Landscape Patterns of Fire

Between 1600 and 1900, fires in the BWCAW tended to be very large, with an average size of 10,000 acres. Only a few major fires burned most of the landscape. Three percent of fires were from 100,000 acres to 400,000 acres. Small fires (several hundred to a few thousand acres) reported by Heinselman (1996) for red and white pine forests were a consequence of the small size of the stands themselves.

Interactions Between Fire and Topography

The pattern of topography, with regard to lakes, rock outcrops, and soil depth, interacted with climate to produce unique fire patterns on ecological units known as Land Type Associations (LTAs) (Figure 1). Over time, these burn patterns, along with soil characteristics, determined the forest type. Historical forest types and their associated soil characteristics and fire regimes are described in Table 2.

Fires in northern Minnesota tended to run from southwest to northeast. Therefore, those LTAs with many large lakes, or with the long axis of lakes oriented east-west or northwest-southeast, had severe fires relatively infrequently, because the lakes restricted the flow of fires across the landscape. As a result, fire killed forest stands every 150 to 300 years in these areas, and they were dominated by red and white pines. The Ely-Knife Lake LTA is a good example of this type of landform. Other LTAs, such as Gabbro Lake and Saganaga Lake were themselves oriented southwest to northeast and had shallow soils and/or relatively few lakes, allowing unrestricted movement of fires across the landscape. Stand-killing fires commonly occurred every 50 to 70 years in these areas, which were covered mainly by jack pine forest. On such a landscape, there are small areas protected from frequent fire, such as small depressions in the bedrock, rock outcrops, some lakes, and islands where fire did not occur as often. Although small

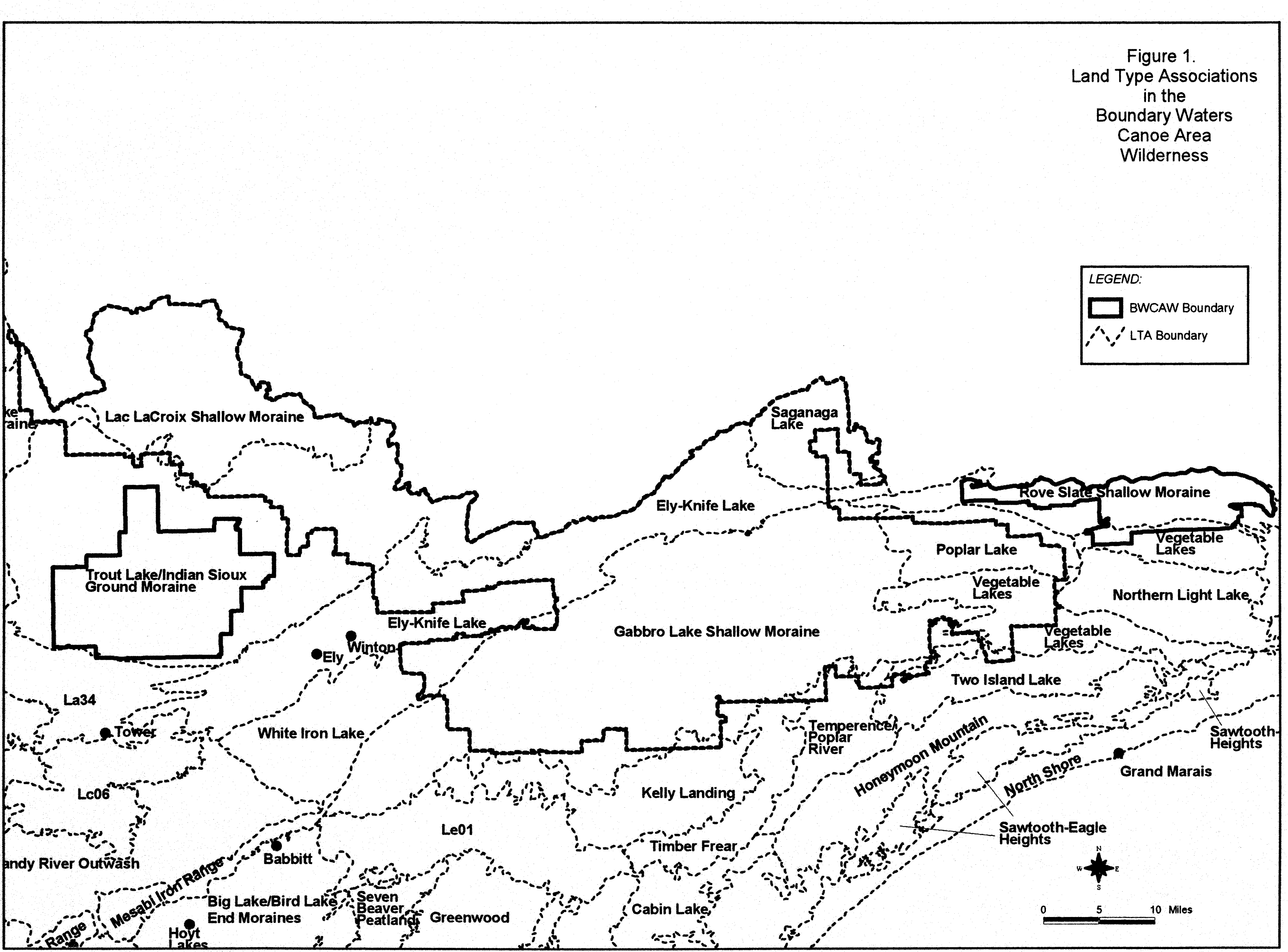

Figure 1.
Land Type Associations
in the
Boundary Waters
Canoe Area
Wilderness

in proportion to the landscape, these areas did allow the persistence of small pockets of white pine and other long-lived species within the landscape of jack pine.

Table 2. Forest Types Developed over Time within the BWCAW

Historical forest type	Soil characteristics	Fire regime
Red and white pine	Poor-good / shallow-moderately deep	Mixed regime; infrequent stand-killing fires (150-300 year fire interval), with frequent stand-maintenance surface fires (20-40 year fire interval)
Jack pine, aspen, and black spruce	Poor / shallow	Frequent stand-killing fires (fire interval 50-100 years)
Aspen-birch, spruce, and fir	Good / moderate depth	Frequent stand-killing fires (50-100 year fire interval)
White cedar, fir, black spruce, and paper birch	Various	Infrequent stand-killing fires (>200 year fire interval); depends on sheltering topographic features or chance lack of fire in any of the previous three forest types
Lowland black spruce	Deep nutrient-poor peat	Infrequent stand-killing fires (150-300 year interval)

Chance Events and the Landscape Mosaic

In addition to the previously mentioned topographic features, chance elements also played a significant role in structuring the landscape. The probability of burning in the pre-settlement forest was uniform (or random) with respect to stand age. As a result, the probability of fire was the same for young and old stands, and many stands burned at a young age. In the case of jack pine-dominated LTAs with average fire intervals of 50 to 70 years, there was an approximately 10 percent chance that a stand would burn twice within 10 to 15 years. In such stands, most of the jack pine trees would be too young to bear many seeds. As a result, aspen would take over areas that burned twice, because of its ability to sprout roots and transport seeds long distances. The large area of aspen forest in the east end of the Gabbro Lake LTA originated after two burns in 1864 and 1875.

Just as some stands burned at intervals shorter than the average, other stands went much longer than the average fire interval before burning. For example, we know that about one-third of all jack pine stands survived for twice the average fire interval before burning, and a few even survived three times the average fire interval (as long as 200 years). These stands had a chance to become dominated by late-successional species such as black spruce, balsam fir, and white cedar.

Major Ecosystem Types

Four major ecosystem types occur in and around the blowdown area (Table 3). The frequency of disturbance determines the proportion of the landscape dominated by stands in various stages of succession. Succession in forests is defined as replacement of a given species of tree by other species over time. Early successional species such as aspen and jack pine are adapted to the open conditions that occur immediately after a major fire. Late-successional species such as balsam fir and white cedar are shade tolerant, are capable of growing underneath aspen and jack pine, and eventually replace them if another fire does not occur. For example, a landscape with frequent fire may have many young even-aged stands of aspen or jack pine, while a landscape with very infrequent fire may have mostly old-growth stands of cedar and fir. It is possible to estimate the landscape structure—or the proportion of all stands across the landscape in each stage of succession—for a given disturbance regime (stand-leveling wind, stand-killing fire, or surface fire). The following sections describe the range of variability in landscape expected over the time period from 1600 to 1900, using the range of stand replacement disturbances from Table 3.

Table 3. Summary of Time Between Disturbance in Each Ecosystem Type

	Range of Years		
Ecosystem	**Stand-leveling wind**	**Stand-killing fire**	**Surface fire**
1. Dry-mesic white and red pine	1000-2000	150-300	40
2. Mesic birch-aspen-spruce-fir	1000-2000	50-100	
3. Lowland conifer	1000-2000	150-300	
4. Dry jack pine	1000-2000	50-100	

Dry-mesic Red and White Pine Forest

This ecosystem with a mixed fire regime of frequent low-intensity fire and infrequent high-intensity fire was dominated by multi-aged red and white pine forests. Usually there was one or two dominant ages of trees in the stand, mixed with a few other ages. Each new age entered the stand after a surface fire that did not kill the entire stand. Stand replacement fires occurred every 150 to 300 years, with light surface fires at 20- to 40-year intervals.

There was always a chance in this ecosystem that a high-intensity fire could occur if a few decades passed without a ground fire. This would have allowed a fir and spruce understory to conduct fire into the canopy, killing the entire stand. In such cases, paper birch was the primary pioneer tree. Reforestation by pine seedlings normally took 20 to 40 years, because these trees have good seed years every 4 to 6 years. Several good seed years are necessary to restock the understory of the young birch forest. It takes 50 to 100 years for these pine seedlings to mature and make their way into the canopy. Low-intensity fires could maintain the multi-aged red and white pine forests for centuries if they occurred evenly over time. If there were no surface or crown fires for a few centuries, then succession to black spruce, white cedar, and balsam fir was likely. Windstorms could level older pine stands, accelerating succession to spruce-fir and cedar by releasing seedlings of these species from competition. Wind could also level older spruce-fir-cedar stands, creating sapling stands of spruce-fir-cedar in the process (Table 4).

Table 4. Estimated Range of Variability for Dry-Mesic Red and White Pine

Vegetation Growth Stage	Age	% Landscape
Sapling birch	0-10	3.2-6.3
Pole-mature birch	11-50	1.3-2.4
Mature birch-pine	51-100	13.4-22.1
Mature pine	101-140	9.8-14.6
Multi-aged pine-spruce-fir	141-200	10.3-12.0
Multi-aged spruce-fir	201	29.8-50.8
Sapling-pole pine	0-50	0.7-1.7
Sapling-pole spruce-fir	0-50	1.3-1.6
Multi-aged white pine	121	9.3-9.5

Mesic Birch-Aspen-Spruce-Fir

This ecosystem features frequent high-intensity fire on relatively good soil (20 to 40 inches deep). Aspen and birch tend to flourish after fire, and outcompete jack pine. In addition, succession to fir and spruce proceeded relatively rapidly, again because of the relatively good soil quality. The average time period between fires was about the same as the length of time it took conifers to replace the aspen through succession. Because of this, the landscape was a relatively evenly mixed mosaic of aspen and conifer stands (Table 5). Fires set succession back to sapling aspen and birch, while windstorms could either advance succession of mixed birch-aspen-conifer stands towards conifers, or create sapling conifer stands where there were older conifer stands.

Lowland Conifer

This ecosystem was characterized by lowland conifer (black spruce) on lowland areas called peatlands with moderate frequency of high-intensity fires. Small peatlands are embedded in all the other ecosystem types throughout the BWCAW. Heinselman (1996) thought that these lowland areas were susceptible to stand replacement fire, but at less than half the frequency of the dominant jack pine forests of the region. Because fires were relatively infrequent in the peatlands, many stands reached old ages. About two-thirds of all stands were even-aged. Generally, conifers that were about the same age

Table 5. Estimated Range of Variability for Mesic Birch, Aspen, Spruce, Fir

Vegetation Growth Stage	Age	% Landscape
Sapling birch	0-10	9.2-15.3
Pole-mature birch	11-50	26.1-38.0
Mature birch-	51-80	15.0-17.5
Multi-aged conifer	81	27.6-48.0
Sapling-pole conifer	0-50	1.1-1.1
Pole-mature conifer	51-80	0.4-0.5

dominated a stand for about 160 years. Stands over 160 years old become multi-aged, and occupied the remaining third of the landscape. A few stands survived as long as 400 to 600 years before burning. Fire and wind were infrequent disturbances in these forests because black spruce is generally the only species that survives the water-logged, nutrient-poor soil. Because black spruce tended to dominate this ecosystem, both types of disturbance regimes didn't disrupt succession from one type of tree to the next, but merely set back the black spruce forest to the seedling stage (Table 6).

Table 6. Estimated Range of Variability for Lowland Black Spruce

Vegetation Growth Stage	Age	% Landscape
Seedling black spruce	1-40	18-32
Sapling-pole black spruce	41-80	15-23
Pole-mature black spruce	81-160	21-23
Multi-aged black spruce	161	22-46

Dry Jack Pine Forests

This ecosystem was characterized by dry jack pine forests on shallow soil with frequent high-intensity fires. These areas were historically dominated by jack pine forests, mixed with some aspen and black spruce. Stand-replacing fires occurred every 50 to 70 years. The aspen stands occurred mixed in with the jack pine stands in areas burned twice within 15 years. Stands composed of a fine-grained mixture of white cedar, balsam fir, black spruce, and paper birch occurred were also in the mix in areas that had not burned for two centuries or more. Areas protected by topography (mainly islands and peninsulas) had small, multi-aged red and white pine stands. In pre-settlement times even-aged jack pine from seedling to large-sized dominated most of the landscape. Stands in the process of transforming to spruce-fir-cedar occupied about 9 to 15 percent of the landscape, and late-successional fir-spruce-cedar occupied about 7 to 22 percent of the landscape. Very few seedling or sapling fir-spruce-cedar stands reestablished after blowdowns.

Table 7. Estimated Range of Variability for Dry Jack Pine Forest in the BWCAW from 1600 to 1900

Vegetation Growth Stage	Age (years)	% Landscape
Seedling jack pine	1-10	9.2-17.1
Sapling jack pine	11-20	8.4-14.2
Pole jack pine	21-50	19.4-26.5
Mature jack pine	51-70	10.6-12.2
Large jack pine	71-110	13.2-14.9
Jack pine-fir-spruce	111-180	9.2-14.9
Multi-aged fir-spruce-cedar	181	6.5-21.3
Seedling fir-spruce-cedar	1-30	0.6-0.6
Sapling fir-spruce-cedar	31-50	0.3-0.3
Pole/mature fir-spruce-cedar	51-80	0.2-0.4

ROLE OF FIRE IN FOREST SUCCESSION—1900 TO 1999

Largely due to increases in settlement and related practices, the four major ecosystems historically present in the BWCAW area changed in the twentieth century. Changes in the frequency and size of fires have led to changes in forest structure and succession. These changes are described in the following subsections.

Changes in Frequency and Size of Fires

During the twentieth century, fires were less frequent than in the previous three centuries due to climate change, fire suppression, fire exclusion, and changing land use around the BWCAW. Most of the large historical fires in the BWCAW started outside the area, and burned into it coming from the southwest. Today, these fires rarely occur because human settlement and the associated fire control has prevented them or excluded them from occurring at all. The average size of fires and fire stand replacement intervals from 1900 to 1999 were much reduced from the previous three centuries. For example, the largest annual burned area in the last century was 80 square miles in 1910, and the largest burn since 1910 was the 24-square-mile Little Sioux Fire of 1971. The comparison of these twentieth century fires with major historical burns in Table 1 indicates a major decline in fire size during the last century.

Changes in Forest Age Structure and Successional Patterns

Within the modern BWCAW prior to the blowdown, there were more old stands than in the last few centuries, due to the decrease in the frequency of fires since the early 1900s. According to available data, reduction in fire frequency has led to an increase of at least double the proportion of stands in late-successional stages (i.e., stands with presence of spruce, fir, and cedar). Today, most red and white pine stands have dense understories of fir, spruce, red maple, and/or shrubs. If fire exclusion continues, these species will eventually replace pine. The suppression of surface fires has been very effective, and the result is that red and white pine forests may age differently; successional patterns may not be the same as they are now. For example, the successional pathway for red and white pine may not include much naturally regenerated red and white pine in the future.

The buildup of fuels directly beneath pine crowns—especially balsam fir—may also lead to fires of increasing severity in the future. These fir reach to the base of the crowns of the taller white and red pines, and can serve as a fuel ladder that allows ground fires to climb into the crowns. These crown fires will be hard to control and could kill the remaining large red and white pine. The result of that would be to exclude white and red pine from the future forest, because regeneration depends on mature trees surviving the fire to provide a seed source for the future forest. Much of the former jack pine forest has similarly succeeded to a spruce-fir-cedar-birch mixture, and many stands no longer have enough jack pine to ensure reestablishment of that species after future fires. Composition of lowland black spruce would not be much affected by the lack of fire, since the species is so dominant in those lowland areas. However, the proportion of older stands of lowland black spruce is higher than it has been in the past.

The continuing trend towards older forests and later successional stages has increased the susceptibility of the forest to two other sources of potential disturbance. First, older stands are more susceptible to wind damage. Stands younger than 50 years old suffer relatively little wind damage, even in very severe storms, while 50- to 100-year-old stands are seriously affected. Stands older than 100 years can be totally leveled by 113 to 157 miles per hour winds. Small-scale wind damage is also increased in older forests, where small groups of trees (0.01 to 0.1 acres in size) fall during routine windstorms.

The second additional source of potential disturbance related to the greater presence of older forests on the landscapes is an increase in infestations of spruce budworm. In pre-settlement times, fire systematically removed balsam fir from large areas of the landscape. Fir was constantly re-invading stands after fire, but was unable to form contiguous stands over large areas. The removal of fir no longer occurs as it would have during pre-settlement fires, because wind is now the major disturbance, and small fir seedlings are not usually killed by wind. Therefore, fir stands are now distributed more widely and continuously across the landscape. Spruce budworm finds it easier to spread from one fir grove to the next, leading to prolonged and serious infestations. Balsam fir rarely live longer than 40 years, so younger fir are always present in the understory beneath dying mature fir. This enables the pest to move from one generation of fir to the next within a given stand.

FIRE OCCURRENCE, FUELS, AND FIRE BEHAVIOR WITHIN THE BLOWDOWN

The previous sections have provided information on the forest ecosystems and structure within the BWCAW. Wildland fire plays a significant role in these ecological processes. The following sections examine fire occurrence in the recent past, historic fuel qualities, the effect of the blowdown on fuels, and the expected behavior of fires burning within the BWCAW prior to and after the blowdown event.

Fire Occurrence—1970 to 1998

From 1970 to 1998, 2,182 wildland fires, an average of 75.4 fires per year, occurred on the Superior National Forest. Most (73 percent) of these fires were caused by humans, while the remainder had natural causes (lightning). More recently (1986 to 1998), about 62 fires occurred annually, 15 of which originated in the BWCAW (Table 8). In contrast to the Superior National Forest overall, most (59 percent) wildland fires in the BWCAW are lightning-caused.

Table 8. Number and Cause of Fires Occurring in the BWCAW and Superior National Forest from 1986 to 1998

	Fires	Natural	Human
BWCA	230 or 15/yr	135 or 59%	95 or 41%
Non-BWCA	686 or 47/yr	77 or 11%	609 or 89%
Forest Total	916 or 62/yr	212 or 23%	704 or 77%

Notably, fire occurrence varies from day-to-day and from year-to-year. Between 1970 and 1998, annual numbers of wildland fires on the Superior National Forest ranged from 20 in 1986 to as many as 177 in 1988. During this period, the Forest experienced as many as 14 lightning-caused wildland fires on the same day (August 3, 1997). These fires were about evenly split between the BWCAW and other areas of the Forest. Human-caused fires can also occur in episodes. On July 4, 1988, 14 human-caused fires occurred on the Forest; the source was primarily railroads.

The majority of the time, three or fewer wildland fires occur daily within the Superior National Forest. However, there are a days when the number of wildland fire ignitions can significantly strain fire fighting capability. Frequently, there are periods of 7 to 10 consecutive days with multiple wildland fire ignitions, which compounds the situation.

The frequency of lightning fires may increase in the blowdown areas due to the increased amount of dead and dying surface fuels (i.e., downed material on the ground surface). As these materials die and dry out more quickly since the blowdown has left them unshaded, they become more susceptible to ignition from lightning.

Fuels

The behavior of a fire burning in the wildland can be determined if one has knowledge of the fuels the fire is burning in, knowledge of the weather conditions that are occurring, and knowledge of the topographic conditions of the area the fire is burning in. The following section explains how fuels are classified and described. Subsequent sections discuss weather and topography and describe expected changes in the behavior of fires burning in the blowdown fuels.

Fire Types

Fires that burn in the surface without extension of their flames into the crowns are called surface fires. If the fire is intense enough to ignite the branches and crowns of individual trees, these individual trees or small groups of trees are said to be “torching.” Torching frequently is an indicator that the potential exists for a fire to burn consistently through the crowns of trees. A crown fire is one that is spreading through the crown layers of trees. Generally, it is supported by an intense fire in the surface fuels as well as high wind speeds.

Fuel Models

Surface fuels are categorized by "fuel models" to assist in the description of different fuel profiles as well as their use in fire behavior prediction models. The Fire Behavior Prediction System (FBPS) provides a basis for these fuel models. In general, fuel models can be associated with vegetation types as summarized in Table 9 and in the following descriptions.

Table 9. Correlation of FBPS Fuel Model and Vegetation Types in the BWCAW

Fuel Type	Fuel Model	Vegetation Types
Shrub	5	Regenerating conifer and acid bog conifer
Forest	8	Closed canopy: hardwoods, cedar, black spruce, and tamarack
Forest	9	Younger jack pine and red pine/hardwood
Forest	10	Older jack pine; aspen and birch stands with conifer component; high density white and red pine stands; spruce fir; and light blowdown
Slash	13	Heavy loading—timber cutting; moderate and heavy blowdown

Fuel Model 5—This model describes areas where non-volatile shrub species occur. Fire spread is low and limited due to the high moisture content in the living shrubs.

Fuel Model 8—This model describes areas where closed canopy stands of hardwoods have leafed out and can support fire in a compact layer of leaf litter on the ground. Slow- and low-burning ground fires are generally the types of fires that occur in these areas, although the fire may encounter occasional heavy fuel concentrations that can flare up. Crowning, spotting, and torching of individual trees are highly infrequent in this model.

Fuel Model 9—This model describes stands where long needles from mostly red and white pines and hardwood leaves have recently fallen to the ground to form a loose layer of leaf litter. Fire can spread moderately fast in these areas, but with less intensity than fires affecting Fuel Model 10 (below). Crowning, spotting, and torching of individual trees can occur if there are a lot of trees close together and if tree crown layers are low to the ground.

Fuel Model 10—This model describes old-growth short-needle conifer stands (mostly jack pine) that are beginning to accumulate large-diameter dead and down woody fuels as a result of trees dying from overcrowding and insect and disease disturbance. Fires in this fuel model burn in surface and ground fuels with greater fire intensity than in Fuel Model 8. Dead and down fuels include greater quantities of large limbs resulting from natural stem fall or from windstorms that create a large loading of dead woody material on the forest floor. Crowning, spotting, and torching of individual trees are more frequent in this fuel situation. In fact, crown fires are the primary cause of rapid fire spread in these stands.

Fuel Models 11,12, and 13—These models describe a fuel bed generally created from timber cutting or from events that create large amounts of dead woody material laid somewhat horizontally to the ground. Among Fuel Models 11, 12 and 13, Fuel Model 13 contains the largest amount of dead down woody material and Fuel Model 11 the least. Fires burn in these fuel models with a rapid rate of spread and a high intensity under moderate to dry weather conditions. If standing trees are also present, crowning, spotting, and torching of individual trees can be expected.

Blowdown Areas

Areas where there is moderate to heavy blowdown are best represented by Fuel Model 13. Fuel inventory data have been taken that will allow for development of a custom fuel model for these areas. Table 10 summarizes the changes in fuel models after the blowdown event. In the heavy and moderate blowdown areas, surface, small-diameter dead and down woody fuel loads have increased 5 to 10 times. In addition, dead foliage has dried and is volatile . The foliage will remain in this condition for 2 to 4 years depending on the tree species, until it decays. Small-diameter dead and down woody fuel on the forest floor will most likely not return to pre-blowdown conditions for 15 years or more in hardwood stands and 30 or more years in conifer stands under natural decay processes (Spaulding and Hansbrough, 1944). It is highly likely that fire will occur in these areas before the downed materials have decayed.

Table 10. Changes in Percentages of Various Fuel Models Pre- and Post-Blowdown in the BWCAW

		BWCA		Non-BWCA	
Fuel Type	**Fuel Model**	**Pre-Blowdown**	**Post-Blowdown**	**Pre-Blowdown**	**Post-Blowdown**
Shrub	5	~3%	~2%	~3%	~3%
Forest	8	~20%	~14%	~35%	~31%
Forest	9	~1%	~1%	~1%	~1%
Forest	10	~55%	~36%	~49%	~41%
Slash	13	~0%	~26%	~0%	~12%
Water	99	~20%	~21%	~12%	~12%

Prior to the blowdown, surface fuels in forested areas categorized under Fuel Models 8 and 10 were shaded from the sun and partially or fully sheltered from the wind by tree canopies (overlapping limbs of standing trees). After the blowdown, however, surface fuels are unshaded, allowing for more drying of material. In addition, these fuels are not sheltered from winds. This increases wind speeds by three to four times, which would cause fire to spread more quickly than it would have under pre-blowdown conditions.

Weather and the Fire Season

Knowledge of how weather elements such as wind, temperature, and the relative amount of moisture in the air affect how a fire burning in wildland fuels will behave.

Fire Season

The fire season in the BWCAW tends to have two fairly distinct periods. The first fire season (spring) begins in May and continues through June; the second season (summer) begins in July and continues through October. A common springtime phenomenon in northern Minnesota is the persistence of a high air pressure zone which is called the Hudson Bay High. If the air mass is stable enough, the high pressure area can block the invasion of the Gulf or Pacific air masses for many days, resulting in long periods of clear, dry weather. As the high pressure persists, the days may become warmer with resulting low relative humidity. This situation often sets the stage for wildland fires in May or early June. Needles of living conifers are very dry during this period until new growth begins. Dead needles, leaves, and grasses from the previous summer dry quickly on the long, warm sunny days that often come with spring dry spells, especially when the relative humidity is less than 30 percent and winds exceed 15 to 20 miles per hour. These winds almost always blow from the northwest to southwest direction toward the northeast to southeast directions. Crown fires are possible during high winds associated with dry cold front passages due to high wind speeds and low moisture content in needles/leaves. Some of the largest fires of the late twentieth century in Minnesota have occurred in May and June (Leuschen et al., 2000).

Generally in early July, rains combined with new vegetation growth interrupt fire season and normally provide enough moisture to stop most fires from occurring and help fire resources contain large fires already burning. Summer fires (months of summer) in most vegetation types require a longer drought buildup and more severe fire weather than spring or fall fires. Late summer and early fall (months) fires come when the moisture content of the soil is much lower. Summer and early fall are normally the heaviest rainfall periods of the year, so it is only in years of exceptional drought (such as 1910, 1936, 1961, 1974, and 1976) that major summer or early fall fires occur (Leuschen et al., 2000). The dryness of the spring fire season is generally more severe than the dryness in the summer and fall fire season.

Percentile Weather

Percentile weather refers to the weather conditions that occur in each of four weather categories. The Low category features the wettest conditions. About 15 percent of the days during the fire season are in this category. The Moderate category occurs the most frequently (75 percent of the days) and represents average weather conditions during the fire season. The High category (7 percent of the days) and the Extreme category (3 percent of the days) represent the driest and windiest days within the fire season.

Fire-ending Rains

The onset of significant rains can extinguish a wildland fire. In some cases, it can slow the spread of the fire so that management actions can be taken effectively and safely. For a fire burning in pre-blowdown fuels, 0.75 inches of rain over a period of 5 days is sufficient to extinguish fires. In areas with moderate and heavy blowdown, it generally will take at least 2 inches of rain over a period of 5 days to achieve the same effect on a wildland fire. In the summer, the amount of rain that it would take to end a fire burning in the blowdown is 2.5 to 3 times more than in pre-blowdown fuels. For the period from June 1 until September 1, the probability of a fire-ending rain event in the post-blowdown fuels is significantly less than in the pre-blowdown fuels. This means that fires will be able to burn for a longer period of time in the blowdown fuels.

Topography—Land Form

The topography of the blowdown area has modest relief, but it is very complex. Frequent rock outcrops, peatlands, other wetlands, and lakes make the movement of fire a very complex process. Elevations are generally in the range of 1,200 to 1,600 feet, although Eagle Mountain, just to the southeast of the main axis of the blowdown area, rises to 2,301 feet, and several ridges in the eastern part of the BWCAW reach 1,900 feet. Rocky ridges are numerous, and generally rise 50 to 100 feet above the lakeshores, although in the Brule-Winchell-Gunflint region near the eastern end of the blowdown area, sheer cliffs rise 200 to 400 feet above the lakes. Soils are generally shallow in the region, with the exception of a few deep pockets in rocky crevices, peaty soils, and on some moraines. Even soils considered deep in the BWCAW, at 20 to 40 inches, would be considered shallow in much of the rest of the world. The shallow soils allow drought to dry out the vegetation relatively quickly during the fire season.

Some of the more important Land Type Associations (LTAs) in the blowdown area are displayed in Figure 1 and include the following:

- Ely-Knife Lake—an area with a high density of large lakes (2 to 6 miles in length) occupying 20 percent of the area, with many irregular, angular broken slopes composed of metasedimentary rocks
- Saganaga—an area with a high density of large lakes (up to 10 miles long with 29 percent of the area occupied by water), rolling to abrupt topography on granite
- Gabbro Lake Shallow Moraine—an area of rolling topography on gabbro rock formations, with many smaller lakes (1- to 2-miles-long, occupying 13 percent of the LTA)
- Rove Slate Shallow Moraine—an area of relatively high relief, with strong east-to-west oriented ridges 400-feet-high with lakes in the valleys occupying 24 percent of the LTA
- Poplar Lake—an area of gabbro rocks with rolling terrain, oriented east-to-west, with small- to medium-sized lakes occupying 14 percent of the area.

Fire Behavior

The speed at which a fire moves across the landscape (i.e., rate of spread), the length of the flames, and the amount of area anticipated to burn are key factors in describing "fire behavior." Table 11 provides estimates of wildland fire spread rate, flame length, and the size of a free-burning fire after 4 hours. The sub-table in the upper right provides the relative rate of spread in comparison to a Fuel Model 13 (blowdown fuels). The comparison is presented because the moderate and heavy blowdown areas are best represented by this fuel model.

Approximately 55 percent of the BWCAW fell under Fuel Model 10 prior to the blowdown and this value was reduced to 36 percent following the blowdown event. Of the 26 percent of the BWCAW that is now in fuel model 13 following the blowndown event, 19 percent of that came from Fuel Model 10. The conversion of this forest to Fuel Model 13 as a result of the blowdown event is the key issue of concern (see Table 10).

Rate of Fire Spread

Due to increased fuel loading, the lack of shading from the sun, and less shelter from the wind in blowdown (Fuel Model 13) versus pre-blowdown (Fuel Model 10) conditions, expected rates of spread of fires (spread rate) in the blowdown area under low, moderate, and high percentile weather conditions are expected to be 4 to 10 times greater than under pre-blowdown conditions. In the past, significant fire spread distances only occurred as a result of significant but infrequent crown fire events associated with high winds brought on by cold front passages. Only under these extreme percentile weather conditions, where a crown fire would be expected in Fuel Model 10, would a high spread rate have occurred prior to the blowdown. This is no longer true. The average spread rate expected through the fire season increases from about 92 feet per day to 1,320 feet per day, a 14-fold increase.

Table 11. Estimates of Rate-of-Spread by Fuel Model, Estimates of Rate-of-Spread Relative to Fuel Model 13, Estimates of Flame Length, and Estimates of Fire Size for a Free Burning Wildland Fire after 4 Hours

Fuel Model	Rate of Spread (Feet/hr) Percentile Weather* Low	Mod	High	Extreme
8	13	33	59	99
10	53	152	304	5676**
11	0.0	297	554	845
13	264	825	1386	2158

Fuel Model	Rate of Spread Relative to Fuel Model 13 Percentile Weather Low	Mod	High	Extreme
8	0.050	0.040	0.043	0.046
10	0.200	0.184	0.219	2.630
11	0.000	0.360	0.400	0.391
13	1.000	1.000	1.000	1.000

Fuel Model	Flame Length (feet) Percentile Weather Low	Mod	High	Extreme
8	0.4	0.5	0.7	1.0
10	1.4	2.7	3.8	Crn Fire**
11	0.0	2.8	4.0	4.9
13	4.7	9.0	11.5	14.5

Fuel Model	Area of Free Burning Fire After 4 Hours (ac.) Percentile Weather* Low	Mod	High	Extreme
8	0.0	0.2	0.5	1.4
10	0.4	3.0	13	4654
11	0.0	13	44	103
13	10.0	98	278	672

* - Percentile weather refers to the weather conditions that occur in each of the categories.

** - Fire modeled as a crown fire

Flame Length

Flame length describes the length of the flames on a wildland fire and is measured as the distance from the base of the flames to the tip of the flames. Flame height is the height of the flames above the ground and is measured perpendicular to the ground. The flame height is always less than or equal to the flame length. In contrast to other fuel models examined, the flame lengths in blowdown areas would be expected to more than double pre-blowdown conditions and exceed 4 feet under all potential weather conditions. Notably, ground-based firefighters are only able to safely work next to flame lengths less than 4 feet. In most situations, it would not be prudent to use ground-based firefighters against wildland fires burning in blowdown fuels.

Fire Size

The potential size of a fire is affected by rate of fire spread, difficulty in constructing firelines and fire suppression efforts applied to the wildland fire. The expected size of fires in the blowdown will mostly likely be 10 to 15 times larger than fires prior to the blowdown (Leuschen et al., 2000). Fires in the blowdown can be expected to burn at a higher and more prolonged intensity. Fires occurring in the blowdown fuels will tend to grow slower than wind-driven fires under pre-blowdown conditions. However, in contrast to pre-blowdown conditions, fires in the blowdown will continue to increase in size under a broader range of weather conditions, and have the potential over time to cover more distance and acres. A steady fire growth can be expected during the majority of the fire season. The size of fires under moderate and high percentile weather conditions will be 20 to 30 times greater in the blowdown than under pre-blowdown conditions . Fire perimeters in the blowdown areas are expected to be more circular and fires may tend to cross natural barriers (Leuschen et al., 2000).

Spotting Potential

Spotting occurs when embers from a fire travel through the air and start new fires if they land on receptive fuel. Prior to the blowdown, most spotting across waterways was associated with strong winds. The remnant standing and hinged trees in the blowdown areas along with paper birch bark will provide ample sources of fuel for spotting. Since wildland fires occurring in the blowdown areas will burn under a broad range of weather conditions, the majority of the spotting on moderate weather days is expected to be relatively short range. However, the increased fuel loading will also increase the potential for a plume-dominated fire which can loft burning materials high into the atmosphere and increase the likelihood of longer range spotting. Spotting distances of 1 to 3 miles are not unusual in these types of fires (Leuschen et al., 2000). Historic accounts in the northwestern United States occurring in 1910 indicate that spotting up to 10 miles occurred in large plume-dominated fires.

Fire Potential

To identify areas with the highest likelihood of fire susceptibility, an Initial Fire Potential Index (IFPI) was assigned to areas within the BWCAW. The IFPI is a relative measure of an area's susceptibility to ignition based on patterns of past fires as well as expected fire size based on the fuel characteristics within the area.

The IFPI is determined for an area using two values: 1) the rate of fire occurrence which determines the probability of the area igniting, and 2) the fire growth potential in the area. Areas with a high rate of fire occurrence which also contain high fuel loads inferring a higher fire growth potential will have a higher IFPI value than areas having a low fire occurrence rate which contain low fuel loading. A comparison of the relative difference between IFPI values for areas is a good measure of the relative susceptibility of these areas. This comparison is of high value when prioritizing areas being considered for fuels treatment.

Fire Occurrence Areas (FOA)

To determine the probability of an area igniting, patterns of past fires occurrence were used to define Fire Occurrence Areas (FOAs) based on similarities in rates of fire occurrence. The Superior National Forest was categorized into FOAs based on fire occurrence data from 1970 through 1998. Fire occurrence rates in an individual FOA are described as the number of fires ignited (human-caused and lightning-caused) per 1,000 acres per year. Four distinct FOAs were identified on the Forest. Characteristics of each these FOAs are described in Table 12.

Table 12. Characteristics of Fire Occurrence Areas (FOAs) in the BWCAW Based on the Data from 1970 to 1998

FOA Category	Burnable Acres	Fires per Year	Fires per 1000 Acres per Year
1	3,206,629	26.21	0.0082
2	271,416	36.17	0.1333
3	24,541	6.10	0.2487
4	967	0.45	0.4636
	3,749,461	68.93	0.0197

The vast majority (> 90 percent) of the BWCAW is in FOA Category 1, which experiences an average of less than 0.01 fires per thousand acres per year. Areas of FOA Category 2 are scattered throughout the BWCAW, with most being concentrated in the west end, north of the Echo and Fernberg Trail Corridors. One distinct patch of FOA Category 2 is located at the northernmost end of the Gunflint Corridor; another is located on the south side of the easternmost end of the Fernberg Corridor. Only one relatively large patch of FOA Category 3 occurs in the BWCAW; it is located again at the northernmost end of the Gunflint Corridor. This area experiences an average of 6 fires per year. Two relatively small pockets of FOA Category 4 exist in the Wilderness; one on the south-central border and one near the north-central border of the BWCAW.

Fire Growth Potential

The second value used to determine the IFPI for an area was the fire growth potential for the area. Fire growth potential is affected by fuel loading, the fire spread rate, the resistance of fuels to fireline construction, and the fire suppression effort applied to the wildland fire. Based on estimates of expected fire sizes in the blowdown (Fuel Model 13) areas of the BWCAW (Leuschen et al., 2000) and based on estimates of expected fire sizes in the areas outside of the BWCAW on the Superior National Forest, separate relationships between rate of fire spread and expected fire size were developed for these two areas.

Initial Fire Potential Index (IFPI) Values

An IFPI was determined for each area on the Superior National Forest based on the FOA that the area is in and based on the fire growth potential in the area. Table 13 displays IFPI categories and the relative value of each compared to IFPI Category 1. When located next to areas of high concern for the protection of health and safety outside of the BWCAW, areas in IFPI categories 4, 5, and 6 will be examined closely for fuels treatment. Based on the IFPI values, under current conditions, most of the BWCAW (74 percent) has low fire potential and falls into IFPI categories 1 and 2. Areas with a moderate potential for fire (IFPI categories 3 and 4) cover about one-quarter of the BWCAW and are mostly concentrated in the blowdown areas in the north central and northwest portions of the BWCAW, spanning the Gunflint Corridor. High potential fire areas (IFPI categories 5 and 6) occur in less than 2 percent of the BWCAW, and are scattered in small pockets primarily throughout the expanse of the blowdown area.

Table 13. Acres in Various Initial Fire Potential Index Categories

IFPI Category	Acres	IFPI Relative To Category 1
1	801,465	1
2	69,348	3
3	18,515	130
4	263,903	13,808
5	4,676	154,752
6	17,674	845,219
	1,175,581	

Risk of the Fire Exiting the Wilderness

The Rare Event Risk Assessment Process (RERAP) can provide estimates of the probability of a wildland fire reaching a point of concern given environmental conditions, the location of a fire ignition, and no fire suppression. As an example, analysis was done assuming a wildland fire started in the BWCAW 6 miles southwest of the Gunflint Corridor. The relative change in probability of a fire entering the Gunflint Corridor was estimated to be 74 to 224 times higher than the pre-blowdown probability, depending on the date the fire starts.

CONCLUSION

Fire has played an important historical role in forest ecology and natural processes of succession in the BWCAW. Fire suppression and exclusion have held off a major fire in the BWCAW for over a century. Human settlement patterns and fire control techniques also altered forest composition so that there were more stands of older trees. Older stands are more susceptible to disease and to blowdown. This was a major contributing factor to the breadth of blowdown damage caused by the July 4, 1999 windstorm. The windstorm increased the amount of dead and down materials on the ground ("slash fuels") in the areas blown down in the BWCAW from 5 to 20 tons per acre up to 50 to 100 tons per acre. This increase in material on the ground creates a fuel load that will allow high-intensity fire under a wide range of weather conditions, and result in wildfires that are more difficult to control. The fuel load increases the chances that a major fire will occur in the near future. Under the right weather conditions, there is an increased potential for wildfire within the Wilderness that could move from within the Wilderness to adjacent private, State, and National lands or across the international border into Canada. The extent and severity of fires that will occur in the blowdown is unknown at this point, but it is very likely that some parts of it will be burned by high-intensity fires, some parts burned by low-intensity fires, and some parts not burned at all.

Because of the seriousness of the existing conditions, the BWCAW Fuels Treatment Environmental Impact Statement will evaluate options for treating fuels in the BWCAW, including prescribed burning options and a no action option. Treating fuels with prescribed burning can reduce the probability that a large high-intensity fire will have negative impacts on the lives and property of people adjacent to the BWCAW. It could also reduce the severity of those negative impacts that do occur. Strategically placing prescribed burns on a landscape has been shown to reduce the rate of spread of an uncontrolled wildfire significantly. With a slower rate of spread those in vulnerable areas such as the Gunflint corridor would have more time to prepare for the arrival of fire, and there is a better chance that a fire-ending event, such as heavy region-wide rainfall or first of the season snowfall could extinguish a wildfire before it reaches the Wilderness boundary.

Because fire occurrence is not uniform on a day-to-day or year-by-year basis, it is difficult to predict fires in the BWCAW and adjacent areas on the Superior National Forest in the near future. Past experience has shown that lightning storms can ignite many fires in one day on the Superior National Forest and adjacent lands. Fires that could occur in the blowdown can burn at a higher and prolonged intensity due to the uniform coverage of the high fuel loads. Historically, significant fire spread has been driven by southwest to northwest winds that occur during and immediately following the passage of cold fronts. These winds spread fire predominately toward the northeasterly to southeasterly directions. Weather patterns, in addition to information on past fire occurrences, condition of the fuels, topography, and fire behavior, help to identify areas where prescribed burning could be the most valuable.

Prescribed burning also has the potential to change the outcome of ecological effects that may occur if a major wildfire burns a large portion of the blowdown. It is possible to point out some specific effects that wind and fire may have in the blowdown. In general, the blowdown alone will accelerate succession towards the shade-tolerant conifers such as balsam fir, black spruce and white cedar; a high-intensity fire in the blowdown slash will set succession back to aspen or paper birch; and low-to-moderate-intensity natural fires will create variable mixtures of aspen and birch with conifers.

Some important specific effects include the following. Some stands with shallow soil that burn may be set back to bare rock, grasses and small shrubs. There is potential for blown down jack pine-black spruce stands to regenerate to those species after low-intensity fire, because the blowdown/low-intensity fire combination would be equivalent to one natural crown fire in its effects on the forest. Such regeneration would not work well in older jack pine, where black spruce would have an advantage. A blowdown-intense fire combination could possibly wipe out historical refuge populations in sheltered lakeshore areas for white cedar, white pine and red pine, resulting in an extreme long-lasting negative effect on recovery of these species within the blowdown.

Wilderness users in the BWCAW have long experienced forests of jack, red and white pine, which are a major factor in the quality of the wilderness experience. Therefore, it will be important to analyze the potential impacts of all alternative fuel treatments on the future successional pathway of the forest. Fuel treatments done for the purpose of enhancing safety of people outside the Wilderness will also have impacts within the wilderness. The EIS process will determine what those impacts are and suggest ways to protect public safety while considering ecological and wilderness values within the BWCAW.

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