1973

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Recommended Citation

Heinselman, M. (1973). Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research, 3(3): 329-382. doi: 10.1016/0033-5894(73)90003-3

QUATERNARY RESEARCH 3, 329–382 (1973)

Fire in the Virgin Forests of the Boundary Waters Canoe Area, Minnesota

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Received July 11, 1973

Fire largely determined the composition and structure of the presettlement vegetation of the Boundary Waters Canoe Area as well as the vegetation mosaic on the landscape and the habitat patterns for wildlife. It also influenced nutrient cycles, and energy pathways, and helped maintain the diversity, productivity, and long-term stability of the ecosystem. Thus the whole ecosystem was fire-dependent.

At least some overstory elements in virtually all forest stands still date from regeneration that followed one or more fires since 1595 A.D. The average interval between significant fire years was about 4 yr in presettlement times, but shortened to 2 yr from 1868 to 1910 during settlement. However, 83% of the area burned before the beginning of suppression programs resulted from just nine fire periods: 1894, 1875, 1863–4, 1824, 1801, 1755–9, 1727, 1692, 1681. The average interval between these major fire years was 26 yr. Most present virgin forests date from regeneration that followed fires in these years. Significant areas were also regenerated by fires in 1903, 1910, 1936, and 1971. Most major fire years occurred during prolonged summer droughts of subcontinental extent, such as those of 1864, 1910, and 1936. Many fires were man-caused, but lightning ignitions were also common. Lightning alone is probably a sufficient source of ignitions to guarantee that older stands burned before attaining climax. Dry matter accumulations, spruce budworm outbreaks, blowdowns, and other interactions related to time since fire increase the probability that old stands will burn. Vegetation patterns on the landscape were influenced by such natural firebreaks as lakes, streams, wetlands, and moist slopes. Red and white pine are most common on islands, and to the east, northeast, or southeast of such firebreaks. Jack pine, aspen-birch, and sprout hardwood forests are most common on large uplands distant from or west of such firebreaks.

A *Natural Fire Rotation* of about 100 yr prevailed in presettlement times, but many red and white pine stands remained largely intact for 150–350 yr, and some jack pine and aspen-birch forests probably burned at intervals of 50 yr or less. There is paleoecological evidence that fire was an ecosystem factor before European man arrived, and even before early man migrated to North America. Probably few areas ever attained the postulated fir-spruce-cedar-birch climax in postglacial times. To understand the dynamics of fire-dependent ecosystems fire must be studied as an integral part of the system. The search for stable communities that might develop without fire is futile and avoids the real challenge of understanding nature on her own terms.

To restore the natural ecosystem of the Canoe Area fire should soon be reintroduced through a program of prescribed fires and monitored lightning fires. Failing this, major unnatural, perhaps unpredictable, changes in the ecosystem will occur.

INTRODUCTION

The Boundary Waters Canoe Area, a unit of the American Wilderness Preservation System within the Superior National Forest, contains a 532,000-acre (215,000 ha.) remnant of the natural ecosystems of Minnesota's Laurentian Shield country

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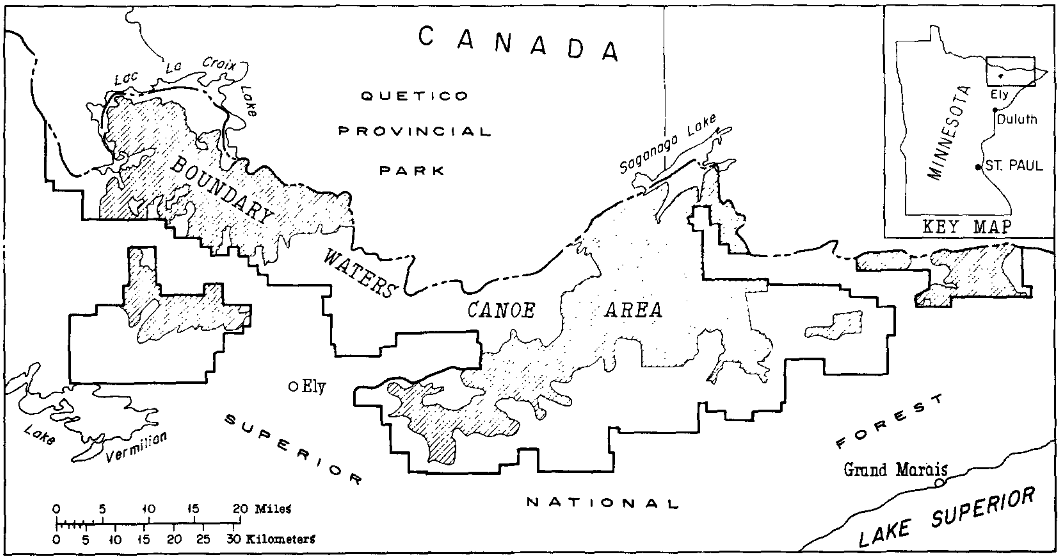

FIG. 1. Location of study area (bounded by heavy line) and of the remaining virgin forests of the Boundary Waters Canoe Area (shaded areas).

(Fig. 1). Both the flora and fauna of the remaining virgin areas[2] are nearly intact. Even the area's largest carnivore, *Canis lupus,* the endangered eastern timber wolf, still maintains a viable population. We have long known that fire was a factor in the ecology of the Great Lakes conifer forests (Ayres, 1899; Maissurow, 1935; LeBarron, 1939; Spurr, 1954), but an ecosystem view of its influence was hampered by lack of knowledge of the historical role of fire in a complete functioning natural ecosystem such as the Canoe Area's.

My fire history studies conducted from 1966 to 1972, reported here, and the related researches of Swain (1972, this symposium), leave no doubt that fire was a dominant factor in the entire primeval system. Fire largely determined the species composition, age structure, and mosaic of successional stages of the forests, and thus also the habitat patterns for wildlife. It was also a major factor controlling nutrient cycles and energy pathways, and in maintaining the diversity, productivity, and stability of the whole ecosystem. But the crucial ecological role of fire has not been recognized in the Canoe Area's management, and fire exclusion has been a nearly achieved management goal for 60 yr.

Thus this area is the principal Wilderness Area in the central and eastern United States that contains the elements of a growing national dilemma. For we must soon reintroduce fire into such fire-dependent ecosystems or accept major unnatural, perhaps unpredictable, changes in the plant, animal, and environmental complex. The problems are similar in principle to those in many other major nature reserves. Resolving this dilemma will test both our competence to apply ecological principles to nature-pres-

[2] The virgin areas of virgin forests are those areas or forests never directly altered by man through logging, land clearing, tree planting, farming, mining, road building, or similar activities. Essentially all areas have burned in the past 400 yr, and many virgin forests are postfire successional communities 110 yr or less in age. Virtually all of the natural forests still contain first-generation postfire stand elements, and I include all such forests in the term virgin. To do otherwise would require setting a totally arbitrary stand age beyond which the forests would be called virgin.

ervation problems and our commitment to retain or restore some essentially natural ecosystems.

ECOSYSTEM CHARACTERISTICS

The Canoe Area stretches for 110 miles (177 km) along the U.S.–Canadian boundary, ranging from 10 to 30 miles (16–48 km) in width. Its gross area is 1,030,000 acres (417,000 ha.), of which about 172,000 acres (69,000 ha.) are in lakes and streams over 10 acres (4 ha.) in size.[3]

Situated near the center of North America, the region has a cool continental climate, with short warm summers and long cold winters. Annual precipitation averages about 71 cm (28 in.), 64% falling as rain during the growing season—May through September. The mean annual temperature is 2°C (36°F); the mean July, 17°C (63°F); the mean January, −15°C (6°F) (Baker and Strub, 1965; Baker *et al.*, 1967). Temperature and precipitation variations from these norms are marked, and significant droughts occur every few years. Prolonged droughts, with precipitation only 50–70% of normal for 1 or more years, have occurred several times in the century since weather records became available. The mean annual snowfall is about 152 cm (60 in.), and the ground is normally snow-covered from mid-November to late April. Late-winter snow accumulations of 50–100 cm (20–40 in.) are usual. Thunderstorms are common from May through September, and lightning ignition of forest fuels during dry storms is common. Prevailing winds are from the west, especially during dry weather.

The area is within the Laurentian Upland physiographic province (Fenneman, 1938). Its landscape, of generally slight relief, is broken by numerous, occasionally parallel, low ridges with locally steep scarps. Local differences in elevation range between 30 and 150 m. Most of this relief is related to the contours of the pre-Cambrian bedrock: granite, gabbro, graywacke, felsite, slate, schist, greenstone, and conglomerate (Sims, 1970). The area was glaciated repeatedly during the Pleistocene, the final advance being the Vermillion phase of the Rainy Lobe, during the late Wisconsin glaciation (Wright and Watts, 1969). Deglaciation occurred about 16,000 y.a. (Wright, 1971). Glacial scouring predominated over deposition, and the scant covering of till, outwash, and lacustrine deposits varies strongly over short distances. Coarse-textured, heterogeneous soils formed on gravels, sands, or boulder till are usual, but lacustrine clays also occur. Bedrock is exposed on many ridgetops, cliffs, and lakeshores. A labyrinth of over 1000 interconnected lakes and streams occupies the bedrock troughs and basins. Thousands of filled-lake bogs and forested peatlands have overspread the lowlands.

The biotic communities are transitional between the Great Lakes–St. Lawrence and boreal forest regions of Rowe (1959). The boreal trees are abundant: jack pine (*Pinus banksiana*), black and white spruce (*Picea mariana, P. glauca*), balsam fir (*Abies balsamea*), tamarack (*Larix laricina*), northern white cedar (*Thuja occidentalis*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). But so are the two pines characteristics of the Great Lakes Forest—the eastern white pine (*Pinus strobus*) and red pine (*P. resinosa*). Red maple (*Acer rubrum*), northern red oak (*Quercus rubra*), American elm (*Ulmus americana*), black ash (*Fraxinus nigra*), bigtooth aspen (*Populus grandidentata*), and balsam poplar (*Populus balsamifera*) also occur on certain sites. Basswood (*Tilia americana*) and yellow birch (*Betula alleghaniensis*) are rare. Conspicuous by their absence are sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga*

[3] Hereafter land measures are in the English units *acres* (1 acre = 0.40 hectares, or 1 ha. = 2.47 acres), or *miles* (1 mile = 1.61 kilometers or 1 km = 0.62 mi.), because all maps and public records for the Canoe Area are in these units, and the U.S. land survey grid exists on the ground.

TABLE 1

Area of Virgin Landscape[a] by Plant Communities in the Boundary Waters Canoe Area, Minnesota, January 1973

Plant community[b]	Virgin areas, all zones	Virgin areas, all zones
	Acres	Percent
Upland types		
Lichen outcrop	20,900	4.7
Jack pine–oak	20,900	4.7
Red pine	17,300	3.9
Jack pine–black spruce	49,900	11.2
Jack pine–fir	28,000	6.3
Black spruce–feathermoss	28,000	6.3
Aspen–birch	28,000	6.3
Aspen–birch–white pine	20,900	4.7
Maple–aspen–birch	31,400	7.1
Maple–aspen–birch–fir	28,000	6.3
Fir–birch	71,300	16.0
White-cedar	17,300	3.9
Total upland types	361,900	81.4
Lowland types		
Mixed conifer swamp	2200	.5
Black spruce bog forest	32,100	7.3
Tamarack bog forest	400	.1
Sphagnum–black spruce bog	9300	2.1
Ash–elm swamp	400	.1
Shrub carr	11,100	2.5
Marsh and open muskeg	19,500	4.4
Open water communities	7100	1 6
Total lowland types	82,100	18.6
Total all communities	444,000	100.0
Lakes and streams	88,000	—
Total virgin areas	532,000	—

[a] Virgin areas are those never logged, cleared, roaded etc. Nearly all areas have burned within the past 400 yr. Only solid contiguous tracts within generally uncut regions are included.

[b] Upland plant community types from Grigal and Ohmann (1973), after Ohmann and Ream (1971b). Lowland types adapted from Superior National Forest Timber Management Plan July 1, 1964–July 1, 1974 for Extensive Zone BWCA.

canadensis), the climax dominants often identified with the Great Lakes–St. Lawrence forest. Küchler (1964) has mapped the potential natural vegetation of the Canoe Country as Great Lakes Pine Forest and Great Lakes Spruce–Fir Forest.

The plant communities of the virgin upland forests have been quantitatively described and classified by Ohmann and Ream (1971a, b), and Grigal and Ohmann (1973) Table 1). The jack pine communities are the most abundant types today even after 60 yr of attempted fire exclusion. The broadleaf group, dominated chiefly by aspen and birch, is a close second. White pine and red pine communities comprised only 10% of 106 randomly sampled virgin stands (Ohmann and Ream, 1971b). The wetland communities have not been fully treated, but a preliminary study by Dean (1971) suggests that they are closely related to peatland communities of the glacial Lake Agassiz region, 100 miles to the west (Heinselman, 1963, 1970c). Earlier studies by Buell and Niering (1957) and Maycock and Curtis (1960) described some of the spruce–fir communities of this region.

Most of the common trees, shrubs, and herbs have developed means to reproduce following fire, although these features have been studied for only a few species (Ahlgren and Ahlgren, 1960; Fowells, 1965). Most striking are the serotinous cones of jack pine (LeBarron and Eyre, 1939; Beaufait, 1969; Roe, 1963; Cayford, 1971), the semiserotinous cones of black spruce (LeBarron, 1939; Heinselman, 1957), and the root suckering and light seeds of quaking aspen (Fowells, 1965). The fire resistance of mature, thick-barked red and white pines is well known, but specific studies are lacking. To reproduce, individuals of these species must survive the fire, because good seed crops are intermittent and their cones are neither persistent nor serotinous (Van Wagner, 1971). Blueberries (*Vaccinium angustifolium* and *V. myrtilloides*) may reproduce by sprouting from the roots, which are usually not burned out, as may beaked hazel (*Corylus cornuta*) (Buckman, 1964b), mountain maple (*Acer spicatum*), and green alder (*Alnus crispa*), common tall shrubs. Paper birch, red maple, and red oak reproduce by sprouting from the root collar as well as by seeding. Some species are easily fire-killed but maintain themselves through their ability to compete well on moist sites and topographic situations that usually prevent a clean burn (valleys, lower slopes, islands, lakeshores, edges of wetlands). White spruce, balsam fir, and northern white cedar seem to fit this pattern. Some plants, such as *Aralia hispida, Corydalis sempervirens,* and *Geranium Bicknellii,* occur sparingly on land not burned for many years but reappear abundantly and flower profusely the first year following fire (see Ahlgren, 1960 for details).

The mammals and birds of the Canoe Country also reflect its position on the Boreal–Great Lakes forest ecotone. Among species with boreal affinities are the moose (*Alces alces*), Canada lynx (*Lynx canadensis*), fisher (*Martes pennanti*), pine marten (*Martes americana*), snowshoe hare (*Lepus americana*), spruce grouse (*Canachites canadensis*), Canada jay (*Perisoreus canadensis*), and (formerly) the woodland caribou (*Rangifer caribou*). Species more typical of the Great Lakes forests are the northern white-tailed deer (*Odocoileus virginianus*), and bobcat (*Lynx rufus*), while the following range (or formerly ranged) widely over both regions: (eastern) timber wolf, red squirrel (*Tamiasciurus hudsonicus*), red fox (*Vulpes fulva*), beaver (*Castor canadensis*), otter (*Lutra canadensis*), mink (*Mustella vison*), black bear (*Ursus americanus*), ruffed grouse (*Bonasa umbellus*), bald eagle (*Haliaeetus leucocephalus*), and others.

CULTURAL HISTORY OF REGION

European man apparently did not directly contact the Indians north of Lake Superior until the explorations of Radisson and Groseilliers, about 1660 (Nute, 1941). About this same time the Chippewa pushed the Sioux out of that region. Until about 1700 these native people probably engaged in their traditional hunting, fishing, and gathering of wild rice, berries, and maple sugar, little affected by European ways. Their populations were low, and their lifestyles seminomadic. Firearms, flint and steel, and other European trade goods probably did not come into general use until the fur trade began, near 1730. The native population of the entire Rainy River country was about 450 individuals in 1823 (Nute, 1941). By 1885, when European settlements adjacent to the Canoe Country began to spring up, there were small Indian villages on Lac LaCroix and Kawnipi on the Canadian side of the border, and near the present towns of Tower, Winton, Ely, Nett Lake, and Grand Portage on the American side. Deliberate burning of some jack pine land to stimulate blueberry production was practiced, at least by the late 19th century. But the extent of this practice in earlier times, or of the burning of forest to drive game, improve hunting, or in tribal warfare, has not been established.

The "Voyageurs era" of the French and English fur trade began in 1731 with the building of a trading post on Rainy River by La Verendrye (Nute, 1941). These people did not farm, clear the forests, or build permanent settlements, except very locally. Most of the trapping was done by the Indians, and the Voyageurs functioned chiefly as traders and in transporting the catch to European markets. The heyday of the fur trade lasted barely a century, and the fur traffic along the border canoe route declined to a low level when the Grand Portage Post was abandoned in 1804. The impact of the Voyageurs on the ecosystem seems to have been mainly to reduce the populations of furbearers—especially the beaver, pine marten, fisher, and wolverine. Even this effect was temporary: beaver and fisher are abundant again, although the marten and wolverine are still rare.

A period of exploration, minerals prospecting, and land claimstaking followed the fur trade, from 1820 to 1900. Exploration was limited to canoe travel until a wagon road, the Vermillion Trail, linked Duluth with Lake Vermillion in 1869. Railroads did not reach the region until the iron mines at Tower and Ely were opened between 1884 and 1890. The prospectors, speculators, and settlers were extremely careless with fire and must have caused many of the burns of that era (Ayres, 1899; Braniff, 1903; Higgins, 1908). But again they built no permanent settlements within the Canoe Area. A few dozen homesteaders' cabins were built from local timber, and a few small gardens were cultivated briefly, but these were soon abandoned as the poor agricultural potential became clear.

About 1895 timber cutting for sawmills at Tower and Winton reached portions of the present Canoe Area. White and red pine were the main species sought, and only old trees (generally 100–350 yr old) were large enough. But, because of a long history of fires, only about 20% of the region supported mature pines (Ayres, 1899). A popular account of the early logging has been published (Heinselman, 1969), and just a few points need be added. First, it is precisely because recurrent forest fires had kept three-fourths of the region in recent burns and commercially immature forests that only a small fraction of the Canoe Area was subjected to the usual logging practices of this era. Most of the older stands were "high-graded" for the best pine, and little else was cut. But state laws required slash burning to reduce the fire hazard, and most cutover areas eventually burned, often eliminating white or red pine seed trees and reproduction. Where such burning occurred, major changes in stand composition often resulted because seed sources were altered, and no reforestation work was done. Quaking aspen and paper birch or jack pine usually replaced the red and white pine in such areas because of their ability to reproduce vegetatively (aspen and birch) or from seed on fire-killed trees (jack pine).

But unlike so much of the Lake States' pine region, settlement and land clearing did not follow the logging. And most of the slash fires did not spread far into the young forests on the adjacent public domain. Thus the young stands, recent burns, and scattered areas of older forests that clothed three-fourths of the region were little affected by this early logging era. They were left for worthless, to become the nucleus of the Superior National Forest, created from the remaining public domain by President Theodore Roosevelt in 1909. It is this forgotten land that is the legacy of virgin forests of the Canoe Area today.

There was little appreciation of the ecological role of fire at the turn of the century. Most government reports describing the public domain deplored the ravages of fire and considered the forests to have been "destroyed" by the fires of the 19th century. Such fires were always ascribed to human carelessness, and there was no recognition that lightning ignitions were also common and natural. Few could have imagined that the regeneration already established on those burns would become a hotly contested timber resource in less than a century. For example, consider this from a public domain withdrawal report of E. A. Braniff (1903):

> The lands were once covered with a forest of conifers, but almost all of it has been burned over and replaced by a dense growth of aspen and paper birch. The original stand of conifers was neither heavy nor composed of valuable species. Judged from what remains of it, the chief species were jack pine, white spruce, and balsam fir, with the jack pine predominant. White pine and red pine never formed any considerable part of the stand in the great bulk of the lands. . . .—At present there are two great types of forest, the aspen and birch, and the jack pine. The aspen and birch is the type that has succeeded the fires, the jack pine is mostly part of the original forest.

The area to which this statement applies includes the country from Lakes Malberg and Alice west to Insula and Hudson—a region supporting much virgin forest more than 100 yr old today. It also pertains to the vast region south of these lakes from which hundreds of thousands of cords of jack pine and spruce pulpwood have been harvested in the past 30 yr. (His understanding of jack pine regeneration after fire was certainly less than complete!)

A slightly more sophisticated attitude toward fire is evidenced in the following description of the public domain from the withdrawal report of S. M. Higgins (1908):

> The commercial forest in this area is much broken up by burns. . . . For some twenty years, cruisers have gone over this land selecting all the best descriptions. Perhaps 150,000 acres of the alienated lands are covered with a growth of white, Norway, and jack pine, spruce, tamarack and balsam, which will average a cut of 5,000 feet per acre. The bulk of the public lands are found on burnings from one to sixty years old. . . .
>
> Jack pine, balsam and spruce in mixed stand comprise most of the merchantable forest. White and Norway pine excepting in a few locations occur scattered throughout the stand. Tamarack and spruce occupy the wooded swamp lands. Cedar is found only in small quantities. . . .
>
> There is a plentiful regeneration of balsam and spruce in the mature stand. A dense reproduction of jack pine, white birch, and poplar follows the fire. Perhaps one-half the burns within the forest are covered with stands of this description from forty to sixty years old, with a diameter of four to six inches. As this stand begins to thin out with age balsam and spruce regeneration comes in. No better guide could be had for the division of the mature forest from the forest following the burn than the alienated and public lands. . . .
>
> Fire has destroyed the mature timber on more than half the proposed area. The damage to the soil, a clay loam, which is constantly added to by the disintegrating rock, is not great.

The areas described by Higgins included the land south of Lac LaCroix and Crooked Lake, and the country southwest, south, and southeast of Saganaga. His descriptions can easily be visualized by one familiar with these areas today. Most present forests date from burns in 1903–04, 1894, 1875, 1863–4, 1854, 1822–27, and 1801–03. There are significant areas of older forest, but they are small in relation to these age classes. Those dating from the burns of 1875 or earlier were Higgins' forests "forty to sixty years old." The burns of 1894 and 1903–04 would have still looked barren in 1908.

H. B. Ayres, of the U.S. Geological Survey, spent much time at the turn of the century mapping the timber resource on the public domain in several states. His report on Minnesota's "pine region" is one of the more ecologically perceptive early descriptions. His map showing the locations of merchantable timber and burned-over regions in 1899 is the only forest map based on fieldwork covering the entire Canoe Area before logging.[4] The following quotations give one a feeling for the evidence of fire in the ecosystem as he perceived it (Ayres, 1899, pp. 684–685):

> . . . much of the so-called virgin forest has been burned and is now in the various stages of restocking. . . . Where undisturbed by cutting, the forest of today differs from that of a hundred years ago only as affected directly or indirectly by fire. The oldest woods are fire-scattered, especially where composed of young or middle-aged pine, having large trees scattered among it. These large trees have almost invariably been marked by fire at a date older than the younger portion of the forest.
>
> Thus it is seen that fires are not a novelty in these old woods, but have for hundreds of years been a prominent factor in their history. The coming of the whites and the general distribution of trappers and 'couriers du bois' through the woods by the Hudson Bay Company and the American Fur Company 100 to 140 years ago seem to have been prolific of fires, for a very large proportion of the trees of the older uniform forests are 100 to 140 years of age, and must have started during that period.

This, then, is the historical background from which the new Superior National Forest came in 1909. As soon as staff could be assembled, first priority went to fire con-

[4] A map of the original forests of Minnesota based on General Land Office Survey notes was prepared by F. J. Marschner in 1930. It shows generalized forest cover types for the Canoe Country and checks well with areas known to have been cut later for white and red pine, but unfortunately it does not show recent burns or tree sizes or ages (see Marschner, 1930).

trol. The next year, 1910, saw the last major fires on the old public domain until the severe drought of 1936 and the Little Sioux Burn of 1971.

When the sawtimber on the alienated land was cut, by 1930, the sawmills dependent on northeastern Minnesota's forests closed for lack of timber and the early logging ended. It was not until World War II that the maturing stands on the old public domain attracted a new and burgeoning pulpwood and crating lumber market. Since then, additional land in the Canoe Area, aggregating some 215,000 acres gross area, has been generally cut over for jack pine and spruce pulpwood, and for occasional old red and white pine. These areas are mostly part of the original public domain, and were harvested under National Forest or State timber sales.

As of 1973, some 532,000 acres gross area (land and water) of virgin landscape remain within the Boundary Waters Canoe Area in large contiguous blocks uncommitted to timber sales. Most of it is located in four blocks, the largest of which encompasses about 260,000 acres (Fig. 1). The net land area undisturbed by cutting is a little over 415,000 acres, mostly within the original public domain.

FIRE HISTORY METHODS

Five related techniques were used to document the dates and areas covered by past fires in the virgin forests:

1. A fire year chronology was developed through tree ring counts of sections or cores from fire-scarred trees, according to principles first outlined by Clements (1910) and elaborated by Spurr (1954).

2. Historical sources and the General Land Office Survey township notes were searched to check fire occurrences and obtain firm fire dates where possible. Such checks also tested the validity of the tree ring methods.

3. Stand origin dates were determined in the field for the major virgin forest stands. Ring counts were used to esbtalish years of origin. Fire scars on older trees, or historical records, were used to identify the actual fire year.

4. All major stands were mapped by year of origin. Airphotos and forest type maps were used to locate stand boundaries between lakes, streams, portages, roads, and trails.

5. Fire year maps were made from the stand origin maps and the field evidence; these show the general burn areas for all known significant fires from 1610 to 1972.

If possible, fire-scarred trees were located and examined where needed to determine actual fire years. Most scar dates are from small wedges sawn from the scarred area without felling the tree. A few are from cross sections cut from wind-felled trees or dead snags, and some are from cores taken with a Swedish increment borer. Red pine, jack pine, and northern white cedar were used most, because they keep scars well and have distinct rings. Initial ring counts were made onsite with a hand lens so that the stand origin maps could be drawn in the field. Difficult tree sections were rechecked in the laboratory.

Stand-origin dates were obtained mostly from cores of dominant trees of species known to reproduce well after fires. Ring counts were made onsite with a hand lens. Usually two to five trees were cored for ages on each plot. Jack pine and red pine were used whenever available. Other trees used occasionally were white pine, black spruce, white spruce, and aspen. Dominant trees of fire-adapted species were used because the objective was to get an estimate of the time of origin of the stand. Total ages were obtained from cores taken as low on the trunk as possible and extending to the heart. Appropriate additions were made for height of boring and, if necessary, for distance to the heart. Dates were verified with fire scar dates from trees in the vicinity when necessary and possible.

So far, 823 stand-origin plots have been taken. Of these, 142 include fire-scarred trees, and some 295 fire scars on 178 trees were used to establish the fire chronology. In addition, about 100 data sets with tree ages were made available by my co-workers Drs. L. F. Ohmann and R. R. Ream. Personnel of the Superior National Forest kindly made available all of their compartment stand origin data and fire maps. Maps showing the location of all study plots are available.

The final stand-origin maps (Fig. 2) show stand boundaries defined either by natural features, such as lakes, streams, and swamps, or by stand limits taken from 1948 cover-type maps of the Superior National Forest. The latter are published, high-quality maps based on stereoscopic interpretation of 1948 airphotos. Many fire boundaries were easily traced on these maps once the contrasting stand ages were established in the field. Some independent interpretation of 1934, 1937, and 1961 airphotos was also made. Type maps and airphotos were carried in the field to aid in locating fire boundaries, and to build the stand origin maps onsite. Small stands (generally less than 5 acres) are not shown. Where no data were obtained, the stand-origin dates are extrapolations from the nearest similar stands with known origins. Transfer of stand boundaries from airphotos and type maps to U.S. Geological Survey quadrangles was done with a projector (Map-o-Graph). The area covered by the stand-origin maps is a 1,300,000-acre "study area" that includes all of the Canoe Area and some adjacent land. In 1948, the base year for these maps, there were about 1 million acres of virgin forest within that area. Stand origins were mapped for those virgin areas, even though the original forest has since been cut in many cases.

Concurrent with this work, the limits of the early logging were mapped so that the fire history would not be confused with stand origins related to logging. This work produced a logging history map (Heinselman, 1969) and accurately located the uncut areas. Long-time residents and authorities on the history of the area were interviewed to supplement field mapping and other phases of the study.[5]

When the final stand-origin maps were completed, a set of "fire year maps" was prepared (Fig. 3). These maps include the entire 1-million-acre study area referred to above, giving a wider base for certain fire statistics than would just the present virgin forests. They show my best estimates of where the larger and more severe fires burned for each fire year. They were made by interconnecting the mapped limits of all stands that seem to have resulted from coalescent burns of the same year. Some very old burns could be traced only with fire scars, but most mapped burns are based on combinations of stand origin and scar evidence or on historical records.

A problem in preparing such maps is to reconstruct the paths of burns that have since been overlapped by later fires. Stand boundaries alone suffice to map the *last* fire in any area, but extrapolation is necessary to trace earlier fires. I believe this task was accomplished for the larger burns since about 1800. Between 1700 and 1800, at least the major burns are approximately shown. For the years before 1700, only two major burns are shown and their limits are speculative. There certainly were many other burns in the 1600s. Thus, my fire year maps are a *conservative estimate* of the actual fire history. As each succeeding fire sweeps the landscape, former stands or scar-bearing trees are further obliterated.

After about 400 yr all the tree ring evidence is gone. Finally in addition to the large burns, there certainly were hundreds of creeping surface fires that scarred few trees, if any. All traces of such fires are already gone—even fires of the 20th century.

[5] I thank the following for their contributions: L. R. Beatty, Duluth, Minnesota (deceased); J. A. Bolz, Grand Rapids, Minnesota; G. A. Limstrom, Duluth; W. H. Magie, Duluth; E. C. Oberholtzer, Rainier, Minnesota; S. F. Olson, Ely, Minnesota; J. W. Trygg, Ely (deceased); J. W. White, Duluth; and J. F. Wolff, Duluth.

Fig. 2. Stand origins on the Gillis Lake Quadrangle (U.S.G.S.), Boundary Waters Canoe Area, 1973. Forests within types date from after indicated fire year. Where stands consist of two or more age classes dating from separate fires, the years for each fire are given, with earliest fire above line. This map is an example of 45 stand origin maps covering all of the virgin forest as it existed in 1948.

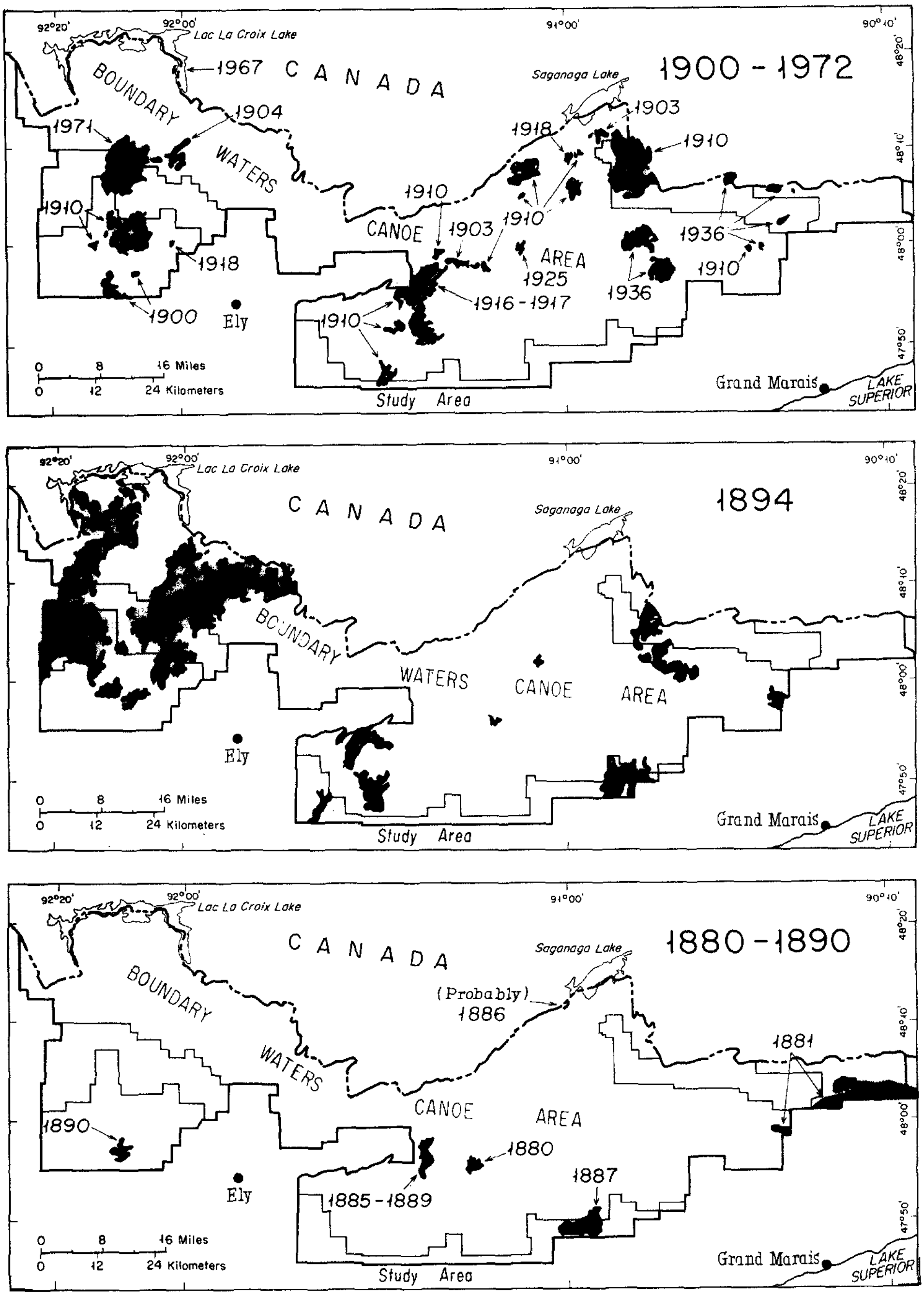

Fig. 3. Areas known to have been burned by significant forest fires in the Boundary Waters Canoe Area and vicinity, 1610–1972 A.D., based on stand origin maps, field evidence, and historical records. Shaded areas show general areas burned by fires of indicated years.

These points must be considered in interpreting the data to follow.

Historical sources confirm the fire scar dates and burn areas for certain fires. For example, the General Land Office township description for T64N, R15W reads: "Timber is very good Norway and white pine in the Southwest. The North half being

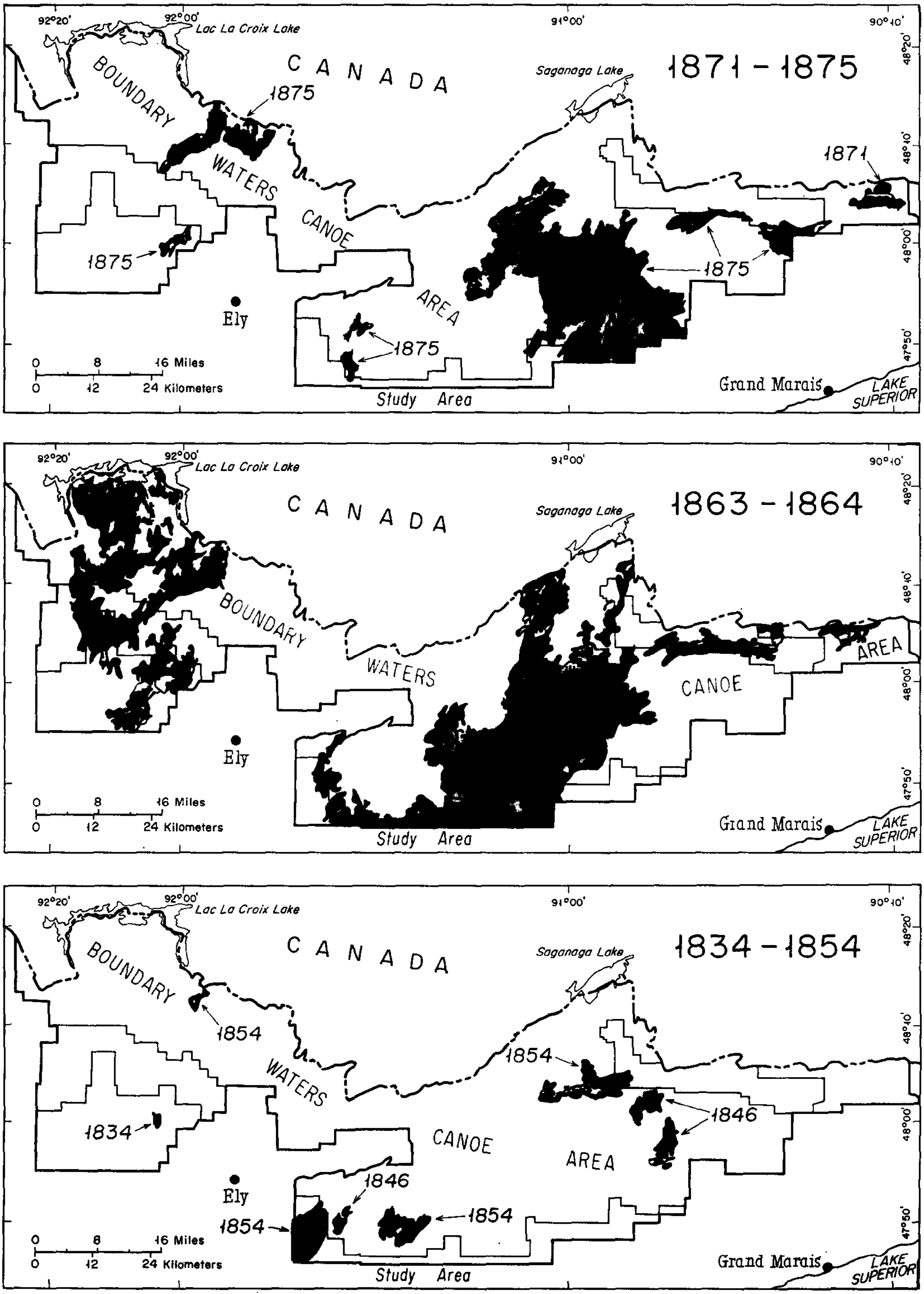

FIGURE 3—*Continued.*

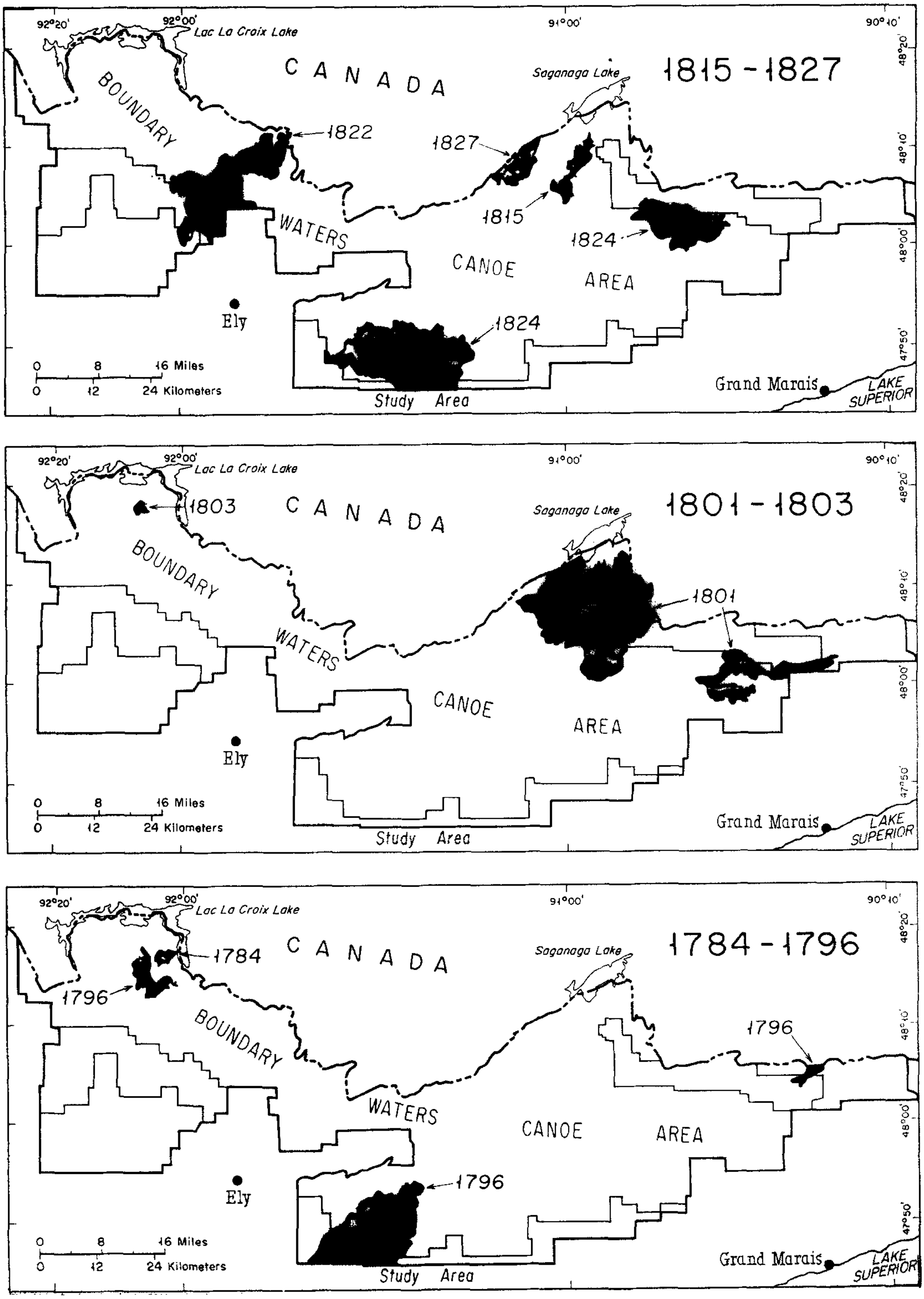

FIGURE 3—*Continued.*

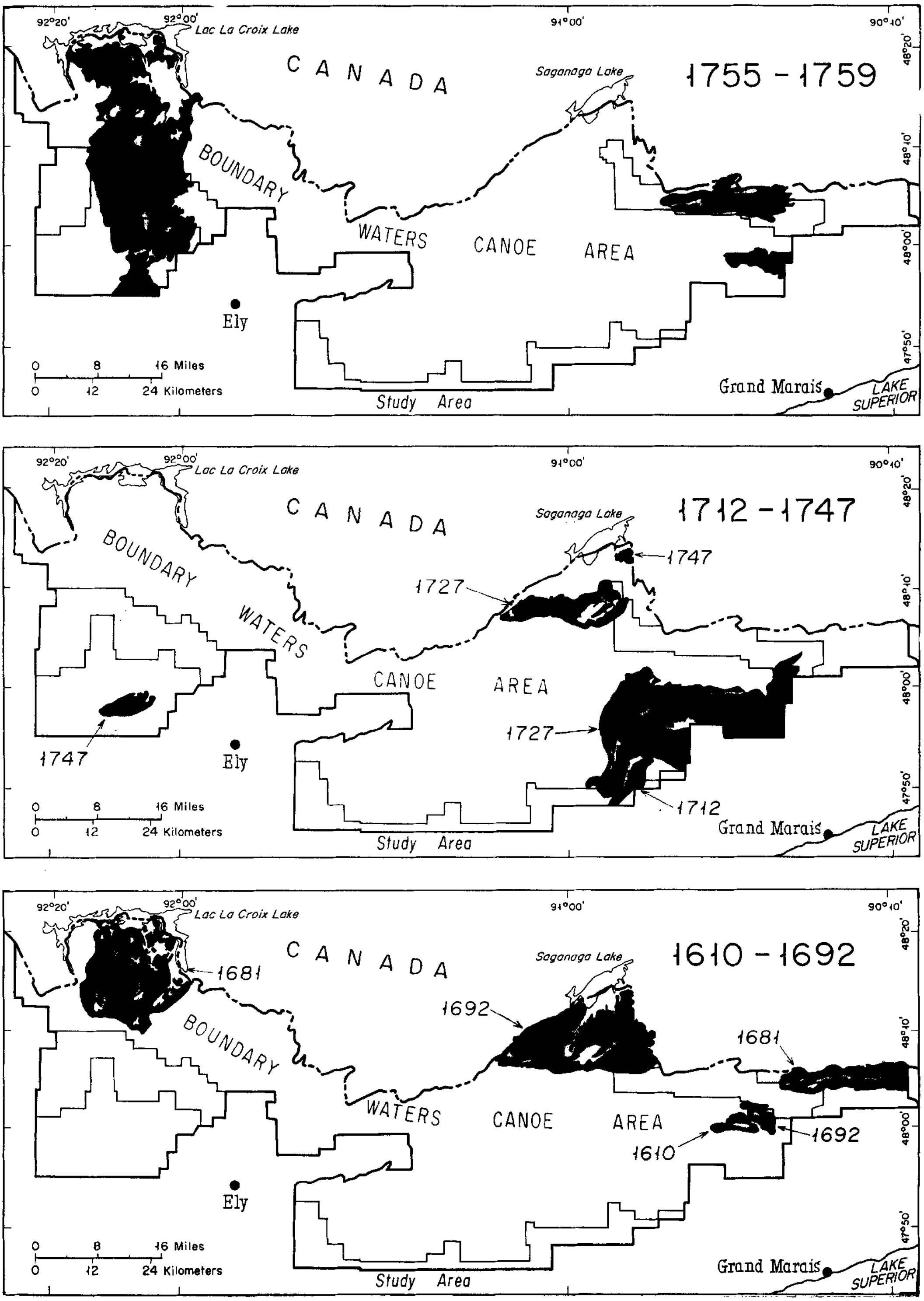

Figure 3—*Continued.*

badly burned about twenty years ago." These notes were made in 1883, placing the fire referred to in about 1863. The southwest half of this township is shown on my maps as cut for pine between 1895 and 1915. The north and east sides show virgin stands, chiefly jack pine, dating from 1863–4, 1894, and 1910. The notes for T65N, R16W, to the northwest, were not taken until May 1895. They read: "The East two-thirds of this township is a barren rock without any soil to speak of, and all timbers growing thereon has been killed by the forest fires of the summer of 1894." My maps show almost all of this area to have supported jack pine of 1894 origin, intermingled with limited areas of black spruce, aspen, and red pine. The 1894 burn recorded here also covered much of the adjoining townships to the east, southeast, and north, accounting for the elimination of many stands of 1863–4 origin in T64, R15, and regenerating the forests of 1894 origin still present. In 1968, at the time of my fieldwork there, a fire scar on an 1863–4 origin jack pine on the portage from Maude to Astrid Lakes (in Section 13) gave 1894 as the year of the last fire. The "barren rock" referred to was being logged for its 70- to 73-yr-old jack pine and spruce!

THE FIRE HISTORY SINCE 1595 A.D.

The stand origin and fire year maps indicate that virtually all of the 1-million-acre virgin forest study area was burned one to several times in the 377-yr period 1595–1972 A.D. (This record begins in 1595 because that was the approximate year of origin of the oldest living stand found—a group of red pines on Three Mile Island in Seagull Lake.) The nearly universal occurrence of charcoal at the base of the litter and humus layers confirms the widespread extent of past fires. Most areas clearly burned several times in the period of record, but it is often possible to document only the last one to three fires.

The fire chronology is based on the total body of evidence from stand origins, fire scars, and historical data (Table 2). The data on known area of burns and the proportion of virgin forest burned are based on area estimates from the fire year maps for the entire 1-million-acre virgin forest study area as it existed in 1948. Three points about the chronology should be noted:

1. There is evidence of significant fires somewhere in the area at 1- to 8-yr intervals from 1926 back to 1739. After 1926, and before 1739, the intervals between fires widen.

2. Major fire years, marked by fires burning more than 100 sq miles or more than 6% of the virgin forest, occurred at much longer intervals.

3. Most of the total area burned in the period of record is accounted for by fires in these major fire years.

To generalize from this record, it is helpful to group the data by cultural history periods (Table 3). Effective fire control began soon after the Superior National Forest was created. The last year that saw major burns in the virgin forests was 1910. I therefore call the period from 1911 to 1972 the "Suppression Period." The period of active settlement, prospecting, and timber looking, spanned the years from 1868 to 1910, and I term it the "Settlement Period." The fire scar and stand origin record begins to fade about 1727—note the erratic and widening intervals between fire years before then. Of course, such a change could be due to actual decreases in fire incidence before the influence of European man. But no records at all were obtained for fires before 1542 because of the absolute limit set by the longevity of trees in the region, and the limit of durability of exposed wood in fire-killed snags. Work by Swain (1972) indicates that there was as much or more fire prior to my record. I therefore call the period before 1727 the "Period of Fading Record."

This leaves the 184 yr 1727–1911 as the period of "good record" also largely un-

TABLE 2

Fire Year Data for the Virgin Forests of the Boundary Waters Canoe Area, Minnesota, 1542 to 1972 A.D.[a]

Fire year	Time since previous year	Fire scars found	Known area of burns	Proportion of virgin forest burned	Fire year	Time since previous year	Fire scars found	Known area of burns	Proportion of virgin forest burned
	Years	Number	Square miles	Percent		Years	Number	Square miles	Percent
1971	4	—	24	1.5	1834	4	3	2	0.1
1967	31	1	1	.1	1830	1	1	—	—
1936	10	—	16	1.0	1829	2	2	—	—
1926	1	1	—	—	1827	3	4	13	.8
1925	4	—	1	.1	1824*	2	2	131	8.3
1921	1	—	1	.1	1822	7	2	75	4.7
1920	2	1	—	—	1815	4	2	12	.8
1918	1	—	1	.1	1811	3	1	—	—
1917	3	—	4	.3	1808	1	1	—	—
1914	4	1	—	—	1807	2	1	—	—
1910	6	14	80	5.1	1805	2	1	—	—
1904	1	6	4	.3	1803	2	9	2	.1
1903	3	3	4	.3	1801*	5	5	162	10.3
1900	6	5	6	.4	1796	2	5	92	5.8
1894*	2	32	265	16.8	1794	4	1	—	—
1892	2	2	—	—	1790	6	7	—	—
1890	2	6	4	.3	1784	4	2	3	.2
1888	1	5	—	—	1780	11	1	—	—
1887	1	1	10	.6	1769	3	3	—	—
1886	1	2	1	.1	1766	7	4	—	—
1885	1	1	5	.3	1759[c]*	4	8	312	19.7
1884	1	4	—	—	1755	3	6	—	—
1883	1	3	—	—	1752	5	2	—	—
1882	1	4	—	—	1747	5	2	15	.9
1881	1	3	24	1.5	1742	3	2	—	—
1880	5	7	2	.1	1739	12	4	—	—
1875*	4	23	350	22.2	1727*	15	3	207	13.1
1871	3	4	10	.6	1712	15	—	9	.6
1868	4	3	—	—	1697	5	1	—	—
1864[b]*	1	50	696	44.1	1692*	11	2	103	6.5
1863	7	8	—	—	1681*	33	1	154	9.7
1856	2	1	—	—	1648	11	—	—	—
1854	8	4	60	3.8	1637	27	1	—	—
1846	4	5	21	1.3	1610	15	—	9	.6
1842	8	1	—	—	1595	53	—	—	—
					1542	?	—	—	—

[a] Basis for table is the 1-million-acre virgin area defined on 1948 forest-type maps, including some areas outside the BWCA. Some of this forest has since been cut.
[b] 1863–64 burns cannot be separated on the ground. The total area for both years is given under 1864, which was the major year.
[c] 1755 and 1759 burns cannot be separated in most cases. Total area for both years is given under 1759.
* = "Major fire year," burning more than 100 square miles.

affected by fire control. That period can be divided into the Settlement Period (1868–1911) and a "Presettlement Period with Good Record" (1727–1868) to examine the effect of increased carelessness with fire during settlement. One measure might be

TABLE 3

FIRE YEAR INTERVALS AND BURN PERCENTS BY CULTURAL HISTORY PERIODS FOR THE VIRGIN FORESTS OF THE BOUNDARY WATERS CANOE AREA, MINNESOTA, 1542 TO 1972 A.D.[a]

Cultural period	Average interval between fire years	Average interval between major fire years[b]	Burned area accounted for by major fire years[b]	Virgin forest burned per year	Virgin forest burned per century	Length of record
	Years	Years	Percent	Percent	Percent	Years
Total period (1542–1972)	6.1	48	82	0.43	43	430
"Suppression Period" (1911–1972)	6.1	—	—	.05	5	61
"Settlement Period" (1868–1910)	2.1	21	80	1.15	115	42
Presettlement period with "good" record (1727–1868)	4.3	28	84	.82	82	141
Presuppression period with "good" record (1727–1910)	3.5	26	83	.88	88	183
Early period of "fading" record (1542–1727)	20.6	—	—	.10	10	185

[a] Basis for table is the 1 million-acre virgin area defined on 1948 forest-type maps, including some areas outside the BWCA. Some of this forest has since been cut.

[b] "Major fire years" are defined as those with burns of over 100 square miles. There were only nine such yrs: 1894, 1875, 1864, 1824, 1801, 1759, 1727, 1692, 1681.

changes in the intervals between fire years. There is such a change (Table 3), although it is not so great as for Itasca Park, 180 miles to the West (Frissell, 1971; this symposium). The change in the Canoe Area, from 4.3 yr in the Presettlement Period to 2.1 yr in the Settlement Period, may still be due in part to a somewhat faded record for the earlier period.

Another measure of any effect of settlement would be changes in the proportion of the area burned in some standard time unit. The percentage of the virgin forest burned per century is such a measure. When this statistic is calculated for the cultural periods, an increase in burning is indicated for the Settlement Period (Table 3). Note also the drastic reduction in burns for the Suppression Period. If the rate of burning recorded since 1910 were sustained, some 2000 yr would be required to burn an area equal to the entire study area. In contrast, during the Settlement Period, only 87 yr would have been required. The Presettlement rate required only 122 yr. The difference between the last two periods could again be due in part to obliteration of the evidence of some earlier fires by reburns. Probably there was some real increase in both incidence and burn area in the Settlement Period, but it was not major.

Much of the burned area for both the Settlement and Presettlement periods can be accounted for by just a few major fire years. In the Settlement Period, the fires of 1875 and 1894 created 80% of the total burn. And in the whole Presettlement Period with good record, just five brief fire periods account for 84% of the total: 1863–4, 1824, 1801, 1755–9, and 1727 (Table 3). These facts indicate that without control measures, large acreages were burned at rather long intervals when weather and fuels combined to yield optimum burning conditions. The average interval between such major fire years only varied from 21 to 28 yr among cultural periods—a difference probably related to climatic circum-

TABLE 4

Virgin Forest Areas of the Boundary Waters Canoe Area, Minnesota, by Stand Origin Years, March 1973[a] (Land Areas Only)

Stand origin year	Area in 1973	Percent of total	Cumulative percent of total
	Acres		
1971	2032	0.5	0.5
1967	128	—	.5
1936	7968	1.9	2.4
1925	400	.1	2.5
1918	576	.1	2.6
1917	1856	.4	3.0
1914	32	—	3.0
1910	34,000	8.2	11.2
1904	1952	.5	11.7
1903	2368	.6	12.3
1900	512	.1	12.4
1894	96,944	23.2	35.6
1890	32	—	35.6
1889	256	.1	35.7
1887–8	176	.1	35.8
1885–7	384	.1	35.9
1882	288	.1	36.0
1881	9968	2.4	38.4
1875	90,614	21.8	60.2
1871	5856	1.4	61.6
1863–4	83,600	20.1	81.7
1854	8112	2.0	83.7
1846	2656	.6	84.3
1827	912	.2	84.5
1824	1616	.4	84.9
1822	6128	1.5	86.4
1815	5200	1.3	87.7
1803	176	.1	87.8
1801	17,072	4.1	91.9
1796	5840	1.4	93.3
1784	432	.1	93.4
1766	48	—	93.4
1755–9	12,240	2.9	96.3
1747	768	.2	96.5
1739	160	—	96.5
1727	3408	.8	97.3
1712	240	.1	97.4
1692	1472	.4	97.8
1681	8560	2.0	99.8
1648	64	—	99.8
1610	720	.2	100.0
1595	16	—	100.0
Total	415,782	100.0	100.0

[a] Virgin areas are those never logged, cleared, roaded, etc. Essentially *all* areas have burned since 1595 A.D. Stand origin years are the year of the last major fire from which the *overstory* dates. Many stands established prior to 1900 have been burned through one or more times without total overstory kill. For such stands the year given is the year of the fire from which the *overstory* dates, even though there may be significant stand elements dating from later fires.

stances rather than human activities. The average interval between major fire years for the Presuppression Period with good record was 26 yr, but this actually ranged from 11 to 42 yr, and if both 1863 and 1864 are counted, two successive years even occurred. Important fire years in common with Itasca Park included 1712, 1727, 1759, 1803, 1864, and 1875 (Frissell, 1968; 1971; this symposium).

Perhaps more startling than any of the statistics, however, is the simple fact that virtually all present virgin forest stands are still of postfire origin, even after 60 yr of effective fire control. That is, most of their overstory elements still consist of the first generation of trees to repopulate the burns in question. The mosaic of age classes and successional stages on the landscape is still a fire-created pattern (Table 4). One can only appreciate the intricacies of this pattern and its fit to the landforms and waterways by actual aerial reconnaissance or by study of the full stand-origin map set (which, unfortunately, it is impractical to present here). But study of the stand-origin year classes will yield some understanding of the stand age patterns and diversity created by 377 yr of varying fire occurrence (Table 4).

There is a distinct hiatus in the age class distribution since 1910, due to fire control. And before 1900 there is a gradual decline in year classes with time, punctuated by irregular, but also declining, jumps in year class areas for the major fire years. This pattern of year classes has been modified by man only to the extent that cutting may have selectively eliminated certain year classes in areas beyond the remaining virgin forests. There certainly has been selective elimination of the older pine forests, for example. But this problem exists for any forest ecosystem today, and there is much to be learned from the available record.

Many individual stands exhibit a simple, even-aged overstory structure with one age class of postfire pioneers still dominant, indicating that the last fire killed virtually all above-ground elements of the former stand. This is the most common situation, especially in jack pine, black spruce, and aspen forests. Fine examples are the 1864 age class of these species on the north, west, and south shores of Lake Insula, and the 1910 burns around Amoeber, Topaz, and Cherry Lakes, and Lake of the Clouds.

If a second major fire came only a few years after a pervious burn, many conifers could be eliminated, because most species do not bear cones until 20–50 yr old (jack pine and black spruce begin bearing at 10–15 yr). Reproduction might then be chiefly from the sprouters—aspen, birch, red maple, and oak. This may be the history of a large region around Wine, Hub, Mesaba, Dent, and Barto lakes. The last major fire there was in 1875, but much of the area probably also burned in 1863–4. The sprouters, a few jack pines, and scattered spruce dominate that area today. Fir, cedar, and white and red pine are conspicuously rare.

Another frequent fire-produced structure consists of two or more overstory age classes, each dating from a separate fire. Such compound stand origins were mapped separately when feasible. Often the older overstory trees tend to be segregated into small groups, or even fair-sized groves. These are common patterns in red and white pine, although large, truly even-aged stands of these species are also common. Still another common pattern is a rather fine-scale mosaic of two or more age classes. Many examples of these fire-produced stand structures can be found in the old red and white pine forests near Boulder Bay of Lac La Croix and on the islands of La Croix, Saganaga, and Seagull Lakes.

In addition to the fires severe enough to introduce the new stands reflected in Table 4, many surface fires in red and white pine stands killed few trees. The average return interval for fires in pine stands where some or all trees survived was 36 yr, based on ring counts for 190 scars from 76 trees with multiple scars. These intervals were extremely variable, however, with some stands showing repeat burns as close as 5 yr and others as long as 100 yr. Many of these fires burned in the same major fire years that elsewhere killed entire stands, while some occurred in years that are seldom reflected in new stand origins. Where possible, the fire year maps include surface fire evidence, and the area of such burns is partially reflected in Tables 2 and 4. Certainly there were also many light surface fires for which no evidence remains.

CLIMATIC FACTORS

It is useful to consider the possible weather and climatic factors associated with past fires in the Canoe Area's virgin forests because these fires burned intact natural stands. In contrast, the historic fires of the Lake States, about which so many accounts have been written, burned largely on cutover land carrying logging slash, or even encompassed some open hay land. This was the case, for example, with the great Peshtigo, Hickley, Baudette, and Cloquet-Moose Lake fires discussed by Haines and Sando (1969). Both the behavior and the ecological effects of such slash fires may greatly differ from those in virgin forests because of differences in fuels and in tree seed supplies following the burn. Even most of the region's literature on prescribed fire concerns burns in logging debris, or on semiopen land burned to improve wildlife habitat (Beaufait, 1962; Buckman, 1964a, b; Ahlgren, 1970; Johnston, 1971; Van Wagner, 1966). The behavior, size, and ecological effects of past fires in the virgin forests depended on many interacting factors. Among the most important were season, preceding weather patterns, weather during the fire, vegetation types, fuel types, and the physical landscape.

Season is important. Given an adequate climatic buildup and suitable weather, spring and fall fires burn readily and spread quickly. This is because the low vegetation is cured and the fallen needles of conifers and dried leaves of deciduous trees and shrubs add to ground fuels. And the succulent green vegetation of summer is absent, eliminating a critical energy-absorbing "heat sink." Under these conditions, fires can be spectacular. "Crowning" in conifers and total kill of the overstory over large areas are possible if fuels are dry, and humidity below about 30%, and winds exceed 15–20 mph (Sando and Haines, 1972). But in spring, wet, frozen soils and organic layers as well as moisture in heavy fuels usually prevent thorough consumption of organic layers, snags, and fallen trees. "Spring" burning conditions may occur between mid-April and early June. "Fall" conditions can develop early in September or even in late August in exceptionally dry years. Light surface fires, causing little injury to fire-resistant red pines, are also possible under spring or fall conditions if it is not too dry and the wind not excessive (Buckman, 1964a).

Summer fires in most vegetation types require a longer climatic buildup, and more severe fire weather than spring or fall fires to achieve similar intensities and rates of spread. But in prolonged drought, evapotranspiration dries out the litter and humus layers, and these become part of the fuel. Snags, fallen trees, and other heavy fuels also dry out and may be consumed. In the past, many summer fires must have been smouldering and slow-moving as these heavy fuels and organic layers burned with the retardant effect of a green undervegetation. Today most such fires are extinguished by control crews before they reach significant size; without control they could burn large areas during prolonged droughts. Some may have held over into the fall when more rapid spread is likely. Fall fires have the potential both to move rapidly *and* to consume heavy fuels and organic layers.

Some nearly pure conifer stands with only lichen, moss, and heath-shrub undervegetation may burn much the same in spring, summer, or fall. I am thinking here of black spruce–feathermoss types and some jack pine–black spruce or red pine stands where there is little seasonal change in fuels.

The ecological effects of these various types of burns seem to depend on two results of the fire: the extent of crowning and direct overstory kill, and the depth of humus layer consumption, which affects the survival and regeneration of many trees, shrubs, and herbs and determines seedbed characteristics.

Now, what can we say about the climatic circumstances associated with past fires, and what can we therefore infer about their ecological effects? First, it is clear from the fire maps, fire scar dates, and climatological data that the total number of fires was large, and that many fires did burn even in years not marked by prolonged regional drought. For example, in the 32 yr 1863–1894, fire scars were found for 17 yr. And for the whole "settlement period," 1868–1910, fires were recorded at intervals averaging just 2.1 yr. The climatological summaries for Minnesota (Martin, 1934a, b) document numerous short-term spring, summer, or fall droughts at various stations during these periods. Some of these rather brief droughts set the stage for fairly large burns in local areas. The probability of ignition during favorable weather was certainly high, considering the activity of prospectors, timber cruisers, and settlers, plus the expected natural frequency of lightning ignitions.

But just 5 fire yr account for 90% of the stand origins still present in the BWCA that date from the full 70 yr 1840–1910 for which some weather records are available and suppression was minimal. In fact, 73% of all remaining virgin stands date from these same 5 yr: 1863, 1864, 1875, 1894, and 1910 (Table 4). Some useful insights can be derived from the precipitation data for these years (Table 5).

In 1863, Beaver Bay, Fort Ripley, and St. Paul all recorded very light precipitation from April until August. Thereafter, rainfall was probably sufficient to check or

TABLE 5

Precipitation at Selected Minnesota Stations for Some Important Fire Years[a]
(Inches)

Fire year	Station	April	May	June	July	Aug	Sept.	Oct.	Annual Total
1854	Fort Ripley	.97	4.34	3.68	.62	1.69	4.40	.91	—
	St. Paul	2.51	4.30	3.31	3.92	1.75	6.55	1.23	26.59
1863	Beaver Bay	—	1.01	1.95	1.16	4.35	2.76	2.44	—
	Fort Ripley	.61	1.89	.28	.60	5.17	4.32	1.97	—
	St. Paul	.80	2.87	.02	.63	3.17	1.23	1.44	15.77
1864	Beaver Bay	.25	1.65	.29	3.16	2.28	2.32	2.13	—
	Fort Ripley	1.35	.92	.90	4.82	1.37	.90	—	—
	St. Paul	1.10	.47	1.62	4.14	2.00	1.14	1.60	15.53
1875	Breckenridge	1.07	3.85	4.95	.70	3.31	1.80	.37	—
	Duluth	2.82	2.45	1.84	.47	6.19	3.77	2.60	27.03
	Fort Ripley	1.95	4.40	2.33	3.99	3.59	3.05	.36	—
	St. Paul	2.27	3.06	4.33	.82	8.74	2.16	1.56	30.66
1894	Duluth	5.85	5.62	1.80	.92	1.08	2.08	4.99	31.70
	Virginia	4.75	3.89	4.98	1.67	.94	4.64	5.69	34.73
	Winnibigoshish	3.92	2.72	3.97	.49	.88	2.50	3.43	23.50
	St. Paul	4.30	6.63	1.51	.13	.36	1.82	4.49	25.80
1910	Duluth	1.40	1.18	.11	3.89	2.41	4.20	.81	18.11
	Virginia	2.67	1.41	.35	4.60	1.04	3.83	1.41	18.39
	Winnibigoshish	2.10	1.90	.84	3.39	.53	4.10	1.10	17.16
	St. Paul	.59	1.76	.91	.99	.98	1.77	.75	10.21
1936	Duluth	2.65	2.76	.93	.63	1.93	1.48	1.28	20.99
	Grand Marais	1.95	4.59	1.72	1.09	2.18	1.84	1.30	24.72
	Tower	1.30	3.19	1.68	2.00	3.09	2.52	.96	21.50
	Virginia	1.17	3.00	1.65	1.53	2.95	1.88	.82	20.31
	Winnibigoshish	1.05	1.91	2.37	.59	2.28	1.75	.17	15.35
	Minneapolis	1.48	2.25	2.29	.11	3.48	.78	.63	18.47
Period of record	**Station**				Normal precipitation				
Years									
59	Duluth	2.03	3.24	4.14	3.83	3.15	3.53	2.36	28.42
42	Font Ripley	1.79	2.90	3.98	2.86	2.83	2.48	1.49	21.57
27	Grand Marais	1.50	2.01	3.00	2.91	2.83	3.43	2.25	24.71
38	Minneapolis	1.95	3.40	4.27	3.44	3.26	3.40	2.19	27.31
93	St. Paul	2.29	3.30	4.13	3.38	3.37	3.21	2.00	27.17
19	Tower	1.60	3.00	4.03	3.50	3.80	3.88	2.37	27.38
40	Virginia	1.60	2.81	3.70	3.64	3.57	3.58	2.11	26.04
40	Winnibigoshish	1.73	2.94	3.64	3.36	3.75	2.82	1.76	24.04

[a] Source: Climatological summaries, Minnesota, Martin 1934a, b; and unpublished data in historical files, Minnesota State Climatologist, Earl L. Kuehnast, St. Paul, Minn. (Personal communication) for Fort Ripley and Beaver Bay.

extinguish most fires. But the following spring (1864) again little rain fell, the drought persisting until July, returning again in August and September at Fort Ripley and St. Paul. The fires of these 2 yr cannot be separated on the ground, but they consumed the forests thoroughly in most areas where they burned. Remnants of former stands are not common, and large areas are know clothed with even-aged jack pine, spruce, aspen–birch, and sometimes red and white pine stands that reproduced in their wake. The region around Lake Insula is an example familiar to present-day visitors.

The weather records suggest that the fires of 1863 came in the spring or early summer, while the 1864 fires might have burned almost the whole season, except perhaps for a few weeks in July. At Fort Ripley, the weather chart for June 1863 notes: "The drought is very severe, the grass upon the prairie is nearly or quite dried. The Mississippi River at the point is lower than it were ever known before." (Unpublished records, courtesy of Minnesota State Climatologist, E. L. Kuehnast, St. Paul, Minn.)

An idea of the regional extent of the 1863–4 droughts can be gleaned from scattered historical records and from other fire studies similar to mine. For example, notes from a Samuel Taylor's journal at Fort Garry, (now Winnipeg) Manitoba confirm the severity of the 1863–64 droughts in that region, some 300 miles northwest of the Canoe Area. On July 1, 1863, Taylor wrote: ". . . a dry hot day this is the dryest summer that anyone can remember the wheat looks short and thin. . . ." And on September 25, 1863, ". . . only 9 bushels (potatoes) from 9 bushels of cut seed owing to dry weather all summer. . . ." On August 9, 1864, he writes: ". . . the fire is burning the hay on all directions the very earth is burning the like is never been known. . . ." and on August 14th ". . . a terrible squall of wind . . . like to blind people with dust. . . ." (From the original journal, courtesy of the Laboratory of Anthropology, University of Manitoba, Winnipeg.)

On the Cutfoot Sioux Experimental Forest, about 100 miles west of the Canoe Area, there are extensive even-aged red pine (and formerly jack pine) stands dating from 1863–4 fires. The local lore there speaks of "the fire of two summers." At Itasca Park, 180 miles west, first Spurr (1954) and later Frissell (1968, 1971, and this symposium) identified large areas burned by 1864 fires. Spurr gives the year as 1865, but the subsequent more extensive studies of Frissell confirm 1864. Grange (1965) reports 1,000,000 acres burned by 1864 fires in Wisconsin.

The most remote record of 1864 fires comes from the pioneering study of Frederick E. Clements at Estes Park, Colorado (Clements, 1910). He concluded that the burns of 1864 were the most extensive of any in his study area (just as I have, 60 yr later and 1000 miles to the northeast!). This work, incidentally, employed essentially the same techniques for dating and delimiting fires that Frissell and I have used.

I conclude from the foregoing that the droughts of 1863 and 1864 were major climatic anomalies, probably subcontinental in extent. The first fires may have occurred in May and June of 1863, under spring fire conditions. A complete overstory kill, but little consumption of organic layers or heavy fuels, might have then occurred. But as the drought intensified in July of 1863 and again in late June, July, August, and September of 1864, many summer and fall burns probably occurred. Some of these may have been of the slow-moving, smouldering type in midsummer, others fast-moving fall burns. Without suppression, many of the early summer fires probably survived the rains of July 1864, and fanned out over adjacent terrain in late summer and fall. Such a sequence fits well with the mapped extent of the 1864 burns as they are now known (Fig. 3). At the same time large areas of forest throughout northern Wisconsin, Minnesota, and adjacent Ontario and Manitoba were probably involved in fires. Such major fire periods as this may have occurred only once in a century or two. But when they came, very large areas of forest were transformed from advanced successional stages or maturing pioneer stands to new postfire plant communities. In the Canoe Country, at least 44% of the million-acre virgin forest study area became involved in the burns of these 2 yr (Table 2).

The next earlier period when a similar climatic and fire sequence may have occurred was 1755–1759—more than a century before. There are no climatic data and no eyewitness reports. But the silent testimony of many stands of even-aged forest dating from these years, and an abundance of fire scars still identify some of those burns. The forest regeneration that followed these fires must have been similar to that which occupied the 1863–64 burns because even today there are large areas where 215-yr-old jack pines dot the landscape within the 1755–59 burns.

The 1875 fires must have burned in July, as this is the only month that shows up consistently in the precipitation records as a drought period (Table 5). No actual reports of these fires have been found. The 1894 fires could have burned any time between late June and September, as the climatic data indicate drought persisting most of the summer that year. All stations cited show severe rainfall deficits for July and August. The great Hinckley Fire occurred on September 1, 1894, about 150 miles south of the Canoe Area. General Land Office Survey notes (quoted earlier) speak of "the fires of the summer of 1894" in the Canoe Country. Most of these fires probably burned in July, August, or early September because general rains did occur later in September.

The 1910 fires could have burned anytime between May and early October, although good rains were received at most stations in September. The precipitation at St. Paul in 1910 was the least ever recorded to the present. Some northern Minnesota Stations recorded fair rains in July, but the drought returned, and the historic Baudette Fire occurred on October 10. This was also the year of the great Idaho and Montana fires—implying a subcontinental drought. The actual dates for the fires in the Canoe Area have not been discovered, but it is likely that there were spring, summer, and fall burns. Several separate fires were clearly involved (Fig. 3). Some probably began as slash fires on logging operations and spread into adjacent virgin stands.

The last major drought year marked by large fires in the virgin forests of the Canoe Area was 1936. Precipitation was far below normal all summer for most northern Minnesota Stations (Table 5), and this year was the last of several successive years of subnormal precipitation. Hundreds of man-caused and lightning-caused fires occurred in the Canoe Country, but only three burned large acreages of virgin forest within the present BWCA. These were the Frost Lake and Cherokee Lake fires, and the Canadian Outbreak. They occurred in July and August and were lightning-caused. All three were heavily manned by Forest Service and Civilian Conservation Corps control teams and are covered by detailed reports and maps.

The Cherokee Fire burned from July 12 to 15, most of the burn occurring on July 13. That day the fire advanced 2.5 miles in 10 hr, burning about 2500 acres. The air temperature was about 90°F (32°C), the relative humidity 20%, and wind velocity 15–30 mph from the west and northwest. The total area burned was 3200 acres. A brief, heavy rain during the night of July 14 aided suppression by a crew of more than 600 men. About half of the burn was in 1727 origin mixed conifer and deciduous forest; the other half was in 90-yr-old jack pine of 1846 origin. Much dead balsam fir, killed by a spruce-budworm outbreak 10–20 yr earlier, augmented the fuels.

The Frost Lake Fire burned from August 12 to 22, consuming about 3500 acres of mixed conifer–deciduous forest, mostly of 1727 origin. Much of the burn involved insect-killed and blown-down balsam fir and spruce, probably resulting from a spruce-budworm outbreak early in the century. This fire made its largest advances on several fronts on August 17 and 18, with strong southwest and northwest winds. The longest single-day runs were between 1.5 and 2 miles. A prolonged soaking rain on August 22 aided 800 men in final control.

The Canadian Outbreak fires burned from August 3 to 9 on the American side of the international boundary near North, South, and Rose Lakes. On the Canadian side it was necessary to patrol this fire until October 15. Most of the burn was in Ontario; some of it in recent logging slash. In total, about 900 acres were burned on the U.S. side, some in spruce–fir–birch forest that had much dead material on the ground, and some in 1681 and 1755–1759 origin red and white pine, with a fir–spruce understory. On August 3 these fires spotted across Rose Lake on a strong northwest wind. Most of the other major advances of these fires on the American side were made on strong west, northwest, or north winds (south or southwest winds drove these fires toward Canada).

The severe summer drought that made all of these 1936 burns possible had two important effects: First, even today it is obvious that consumption of organic layers and dead and down timber was thorough. And second, in many areas the root systems of plants that reproduce by sprouting may have been consumed.

The Little Sioux Fire of May 14–17, 1971, is the most recent large burn in the Canoe Country. It burned a gross area of about 15,000 acres, but only about 2000 acres were in virgin forest within the Canoe Area. Much of the fire was in logging debris and budworm-killed fir left after timbering operations in mixed conifer and jack pine stands of 1755 and 1864 origin. The virgin stands burned included jack pine, aspen–birch–fir, and fir–birch stands of 1864 origin, and two areas of 1755 or 1681 origin red and white pine with a fir–spruce understory. Budworm-killed fir was a major fuel in all virgin stands. This fire, unlike the three just described, was a spring burn. Snowfall that winter had been heavy and the snow had been gone only about 3 wk, but there had been almost no precipitation since the snow left. Green-up of the vegetation had not yet occurred, and rapid spread was also aided by several large meadows and open cutover areas. Most of the burn occurred on May 14 between 2:00 PM and midnight. The maximum advance during this 10-hr period was about 7 miles. The gross area encompassed by this first day's run was about 8000 acres. During this run the air temperature was near 76°F (24°C), the relative humidity near 15%, and the winds southwest to northwest at 15–20 mph, with gusts to 30 mph (Sando and Haines, 1972). Spotting occurred up to three-fourths of a mile ahead of the main flame front. Tree lichens (*Usnea* and *Alectoria*) growing on budworm-killed fir and spruce facilitated spotting—both as a source of flying brands and as sites for quick ignition. Consumption of organic layers was not deep, and the root systems of most trees, shrubs, and herbs capable of vegetative reproduction by sprouting were still viable after the burn (Books, 1972). Rain (and later snow) commenced on May 17, greatly aiding 500 firefighters in control and mop-up.

In comparing what is known of the climatic circumstances that accompanied past major fire years with the detailed records for 1936 and 1971, one fact stands out. The major fire years for which climatic data are available were all characterized by summer droughts, or droughts that extended from summer into fall. This was the case for 1863, 1864, 1875, 1894, and 1910. These years had drought patterns similar to 1936, not 1971. Severe spring droughts also occurred, notably in 1863, 1864, and 1910. Possibly the major atmospheric circulation patterns and other climatic variables associated with these subcontinental droughts were all similar. When the underlying atmospheric factors causing such extensive droughts are better known, we may be able to identify the weather factors that lead to major regional fire years.

IGNITION SOURCES AND FUEL INTERACTIONS

Lightning is the only significant ignition source not man-related. It may well be sufficient to have produced the amount of fire recorded from 1595 until 1910 (when control began), even though we know many fires were actually man-caused. Thunderstorms occur about 25 days per year over northeastern Minnesota (USDA, 1941; Komarek, 1964) chiefly between April and October. They are usually more frequent in midsummer than in spring or fall, although yearly patterns vary greatly. Duff layers and dry snags are often ignited by lightning strikes, but most such fires are extinguished by rains that accompany the storm. Occasional storms with little or no precipitation occur, however, and if they coincide with drouth, forest fires may result.

Nearly all lightning fires are now quickly extinguished by control crews, but the fire records of the Superior National Forest still show the potential for lightning ignitions (Table 6). Most lightning fires occur in July and August, although some have been recorded for all months May through October. While the proportion of fires caused by lightning is now low, it must be remembered that the Canoe Area hosts some 160,000 recreational visits annually, and most campers cook with open fires. Several large logging operations were also sources of man-caused fires. Thus the potential for man-caused ignitions is probably greater now than in the Voyageurs' era, and perhaps greater than in the settlement era. It must be far greater than in pre-Columbian times, when the human population was much lower. Viewed in this context, lightning is still a surprisingly important cause of fire.

By comparison, in the Canadian and Alaskan boreal forests there are only 3–10 days with thunderstorms annually, but lightning is a relatively more important cause of fires because the human population is lower. Scotter (1971) states that 72% of all fires in the northwestern Canadian taiga were lightning-caused from 1961 through 1964. And in the Alaskan interior, lightning accounted for 35% of the ignitions, but 72% of the area burned from 1960 to 1969 (Barney, 1971).

TABLE 6

REPORTED WILDFIRES, BY CAUSE, BOUNDARY WATERS CANOE AREA, 1956 TO 1970[a]

Month	All fires	Man-caused fires	Lightning-caused fires	Percent lightning-caused
	Number	Number	Number	Percent
April	4	4	0	0
May	35	30	5	14
June	68	56	12	18
July	103	71	32	31
August	123	76	47	38
September	58	48	10	17
October	20	13	7	35
Total	411	298	113	27

[a] Data from records of the Superior National Forest, compiled by Rodney W. Sando, University of Minnesota, 1972 (unpublished summary, personal communication).

In the Canoe Area man was simply an added source of ignitions until about 1910. Thereafter, he also became a factor in limiting burn size. The relevant question, then, is how much burning would have taken place prior to 1910 if only lightning ignitions had occurred? A direct answer is unobtainable. But given only lightning ignitions, the burn patterns would result from interactions between, (1) the number, timing, and locations of ignitions, (2) climatic variations, (3) weather during fires, and (4) the mosaic of fuels on the landscape. The natural fuels mosaic is controlled by vegetation types, stand age classes, and successional stages—but these are themselves a function of past burn patterns. Man changed these patterns only insofar as his ignitions caused burns that would not otherwise have occurred.

To understand man's possible role in increasing natural fire we must, then, consider the interactions between vegetation types, stand ages, successional stages, fuels, climatic and weather patterns, and ignitions. Mutch (1970) argues that fire-dependent vegetation types burn with a nonrandom periodicity regulated by their flammability, which in turn is linked to inbred regeneration adaptations requiring fire. This general hypothesis has merit, and it may help us understand the interactions alluded to above for the Canoe Area. My version of this theory is simply that many factors linked to stand maturation and senescence increase the probability that older stands will burn. Let me outline how these factors operate:

1. Total above-ground biomass in living plants increases with stand age, up to some maximum for each first generation postfire forest type (see Loucks, 1970; Hegyi, 1972). Some living stand components are potential fuel, especially in crown fires (foliage, branches, portions of the bark of trees; shrubs, some herbs, most mosses and lichens). The time after fire at which biomass peaks varies with forest type, but for most types in the Canoe Area it is at least 100 yr. For stands with red and white pine as dominants it may be 150–250 yr.

2. There is a general relation between time since fire and dry weight of dead wood. Such fuel is initially high in successions following crown fires (snags from the fire-killed stand), but this first peak comes when other fuels are low, and the fuel-bed arrangement is not conducive to fire spread (the snags are standing and widely spaced). During midlife of the new stand this fuel decreases, probably reaching a minimum at 30–70 yr after fire. A resurgence of dead wood occurs as the first-generation trees begin to deteriorate and die at 100–300 yr after fire. Here fuel-bed arrangement is better, and other fuels also attain maxima.

3. Within 50–100 yr after fire an understory of fir, spruce, or cedar commonly develops beneath the pioneer forest, introducing "ladder fuels" capable of carrying fire into the crowns of the overstory. These understory species have very flammable foliage.

4. Within 100–150 yr after fire balsam fir may increase enough to sustain a spruce-budworm outbreak, especially if the burns are large, because old trees would then cover large areas (see Van Raalte, 1972). Once fir mortality from defoliations commences, dead fir adds to fuels. These fuels are augmented by tree lichens, which become tinder for spot fires. Stand openings permit increased solar isolation, rapid drying of fuels, and increased air movement (Haines and Sando, 1972).

5. As the pioneer forest ages, the first-generation overstory trees become more susceptible to wind breakage and uprooting. Individuals are felled or, rarely, most of the stand is blown down. Such trees are an additional source of dead wood (a partial explanation for 2, above).

6. Many pioneer stands contain paper birch, which develops loose scrolls and strips of highly flammable bark 50–150 yr after establishment. Wind blown birch bark causes spot fires.

7. Tree diseases such as the heart-rotting fungi, and plant parasites such as black spruce dwarf-mistletoe increase with stand age, eventually causing direct mortality and increased susceptibility of living trees to fire (relates to 2, above).

8. There is a gradual accumulation of litter, duff, and humus on the forest floor as postfire forests mature. Rough measurements during the present study indicate that accumulations of 1–3 in. are usual within the first 100 yr after fire. Local site, overstory, and groundcover factors control depth and actual dry weight values. On upland sites accumulations of 3–5 in. or more are possible beneath mixed-conifer stands 250–350 yr after fire. On cool north-facing lower slopes, seepages, and bog margins, indefinite accumulation and peat formation may occur. During severe drought these organic layers become fuel.

All of these factors and others tend to increase available fuels and the flammability of stands with advancing age. And a gradual increase in total dry matter per unit area on the landscape seems to occur up to at least 200–300 yr after fire. Quantitative estimates of the more important factors could now be made by actual field sampling, using the stand-origin maps as the basis for samples from a full range of postfire stand age classes and community types. Unfortunately such data are not yet in hand. Certainly these correlations of fuels with stand age are not simple, because some dense conifer stands become highly flammable at 30–50 yr of age (Sando and Wick, 1972). But it seems clear that the probability of ignition and of a high intensity fire generally increases as first generation stands reach maturity and senescence. With time the probability of a lightning-caused ignition approaches certainty. Once a significant fire occurs, the fuels are reduced, successions begin anew, and fuel patterns on the landscape are reordered. The burns themselves help control the mosaic. (See also Heinselman, 1970b; Dodge, 1972.)

My thesis, then, is that it was these fuel factors related to vegetation type, stand age, and successional stage—interacting with climatic oscillations—that regulated the pattern of burns in primeval times. Lightning and man were both sources of ignition, but it mattered little which was the actual cause. Fuels and weather determined whether a significant fire would occur, and lightning alone was an adequate source of ignitions to guarantee that all flammable stands would eventually burn. Man's best opportunity to burn forests when lightning ignition was less probable must have come in the spring. But even then lightning ignitions do occur. And if man fired a stand in the spring, he simply substituted a spring fire for a summer or fall fire that eventually would occur in any case. The ecological effects of spring fires may sometimes be different, as noted under CLIMATIC FACTORS, but certainly fires did occur in all possible fire seasons.

PALEOECOLOGICAL EVIDENCE OF FIRE

Charcoal fragments and fossil evidence found in lake sediments, peat bogs, and glacial deposits indicate that fire was a major factor in northern Minnesota's forest ecosystems long before the arrival of European man. Lake of the Clouds, a small, deep lake in the largest virgin region of the Canoe Area, contains annually laminated bottom muds that provide a detailed record of vegetation and fire over postglacial time. Craig (1972) prepared a pollen diagram for this lake showing the vegetational history since deglaciation, time-controlled by 9375 varves in the upper sediment, and Swain (1972, and this symposium) related fire frequency to this same chronology by counting the charcoal fragments in Craig's sediment samples.

Briefly, the history at Lake of the Clouds is this: After deglaciation a sparse vegetation producing little pollen existed for a time, followed by a period of tundra-like vegetation. A boreal spruce forest then entered from the south as the result of major climatic change. That forest was transitory, however, and with continued climatic amelioration, jack and perhaps red pine replaced spruce as the dominants about 9200 y.a. Paper birch and alder arrived about 8300 y.a., and 6700–7000 y.a. white pine appeared with the onset of the postglacial climatic optimum. Charcoal levels remain high until about 6000 y.a., when a decline seems to coincide with increases in white pine and decreases in jack and red pines. White pine then flourished as a major dominant until about 3000 y.a. Charcoal levels fluctuated but were generally lower during this time. Beginning about 3000 y.a. a return to moister and perhaps cooler conditions led to decreases in white pine and to increases in spruce, jack pine, and other elements to present levels. From about 3000 to 1200 y.a. decreased charcoal levels correspond with increases in northern white cedar and some decreases in pine—logical trends, inasmuch as cedar is fire-sensitive and the pines are fire-dependent. This entire sequence fits well with the previously known glacial and vegetational history of northeastern Minnesota (Wright, 1968; Wright and Watts, 1969), and adds a perspective on the role of fire.

Swain (1972, and this symposium) also prepared much more detailed charcoal and pollen curves for the last 1000 yr, based on close-interval sampling of the upper layers of laminated sediment in Lake of the Clouds. These studies indicate more fire in the ecosystem between 1000 A.D. and about 1420 A.D. than for most periods since. Charcoal maxima occur near 1300 and 1400 A.D., before any settlements of European man on the continent. A period of reduced fire then persists until about 1670 A.D. The next 80 yr, from 1670 to about 1750, show a strong charcoal peak, followed by an erratic decline to very low levels in the uppermost sediment. The vegetation reflected by the pollen curves was relatively stable over this 1000-yr period, showing only short-term shifts in the relative abundance of species following major fire episodes. Both the charcoal and pollen curves apparently record a mixture of regional and local contributions, because the charcoal counts are of very small, wind-borne fragments. Thus a precise record of fires at Lake of the Clouds itself has not yet been achieved, but the general pattern of past fires in the region is clear. My fire chronology for the last 400 yr evidently covers a period that saw somewhat less fire that occurred in several long periods before the influence of European man in North America.

Stratigraphic studies of peat bogs also reveal evidence of past fires in northeastern Minnesota. Several charcoal layers in the Lindford Peatland, 80 miles west of the Canoe Area, date fires only a few hundred years ago to near 3000 y.a. (Heinselman, 1963). And in the Lake Agassiz Peatlands Natural Area, about 70 miles southwest of the Canoe Area, charcoal was found in many peat strata, the oldest having ^{14}C ages of about 8000 y.a. (Heinselman, 1970c).

The oldest positive evidence of fire in Minnesota comes from charcoal finds in glacial drift. Rosendahl (1948) reported charcoal associated with remains of *Picea mariana, P. gluca, Larix laricina, Pinus banksiana, Populus,* and many shrub and groundlayer species. This material, found in a well boring near Bronson in northwestern Minnesota, has a ^{14}C age of more than 36,000 yr. A second find, from near the base of four Pleistocene drifts, was recovered in excavations for an iron mine at Bovey in northcentral Minnesota (Heinselman and Roe, 1963). A ^{14}C date (from wood) indicated dead carbon—placing the time before 38,000 y.a. Charred wood was found associated with two closed cones of jack pine, several open cones of black spruce, and wood identified as *Picea, Larix, Abies, Pinus, Populus,* and *Vaccinium*—all genera still present. Both sites evidently predate early man in America (see Irving and Harington, 1973; Martin, 1973). There is also some pollen evidence for jack pine in the Sangamon interglacial period, about 100,000 y.a. (Yeatman, 1967). Thus fire and some of the present fire-dependent forest dominants—at least jack pine, poplars, and black spruce—were associated in Minnesota before man was a possible source of ignition. Jack pine apparently evolved its cone serotiny in a lightning-fire environment in Miocene, Pliocene, or early Pleistocene time, 1 million–20 million y.a. (Mirov, 1967; Yeatman, 1967).

PHYSIOGRAPHIC FACTORS

Study of the fire year maps, 1948 forest type maps, and stand-origin maps suggests interactions between historic fire patterns, vegetation, and several physiographic factors. These factors are:

1. Location, size, shape, and compass alignment of lakes, and the abundance of islands in them.

2. Location, size, shape, and alignment of streams.

3. Location, size, shape, and alignment of wetlands (forested swamps and peatlands, marshes, muskegs, etc.).

4. Location, size, relative elevation, and alignment of bedrock ridges and glacial landforms.

5. Location, size, relative depth, and alignment of fault lines, valleys, troughs, and other lowlands.

6. Soil textures and rockiness.

These landscape features apparently are linked to past fire movements because they relate to either natural firebreaks or firepaths. Some, such as ridges, valleys, wetlands, and soil texture, may also relate to fuels through their influence on slope, aspect, soil moisture, soil depth, fertility, and other factors that affect productivity and community composition. Alignment of landforms and water bodies evidently is important because fire weather usually came with west, southwest, or northwest winds that pushed fires along firepaths leading eastward. Even weak fire barriers often stopped north–south spread of fires, or spread from an easterly bearing. But only very large and effective barriers often blocked spread to the east, southeast, or northeast. These statements are based on careful study of the stand-origin maps, but each fire was a special case, and there were many exceptions. Yet 400 yrs of fire patterning left a clear record of the prevailing conditions, and this is what one sees today. Based on such map study, and on many field observations, I make the following generalizations:

1. The firebreaks most often effective were large lakes, especially those with few or widely spaced islands. Small or long-narrow lakes aligned east–west often checked north–south spread, but it was chiefly the large and wide lakes that checked west to east spread.

2. Streams, wetlands, valleys, and troughs frequently checked fire spread, especially to the north or south if aligned on a general west-to-east axis. They were less often effective in preventing west-to-east movements, even when aligned on a north–south axis across the fire's path.

3. The areas burned most frequently or intensely are large upland ridges and ridge complexes, distant from or west of natural firebreaks. Jack pine, black spruce, aspen, birch, and other sprout hardwoods often dominate such areas today. Long west–east ridges often burned full-length, serving as firepaths for eastward spread of major fires.

4. The areas burned least frequently or intensely are swamps, valleys, ravines, the lower slopes of high ridges (especially east or northeast faces), islands, and the east, north, northeast, or southeast sides of large lakes or streams—especially those with much open water in relation to island area. White pine, red pine, white spruce, northern white cedar, black ash, elm, and fir are relatively more abundant on such sites. Any site on the favorable side of a possible firebreak is more likely to support these species. The more effective the barrier, the higher the probability.

The relation of white and red pine to firebarriers is especially interesting. Both often reproduce well after fire, and are really fire-dependent. Both are resistant to moderate surface fires when mature, but can be killed by severe crown fires. Both have only intermittent seed crops and nonpersistent, open cones, although white pine is the more prolific seeder. Neither grows well in heavy shade, although white pine is the more shade-tolerant. Both seed-in well on bare soil or thin organic layers, but white pine can survive on thicker organic layers than red. These characteristics imply a need for the disturbance regime provided by combinations of occasional light surface fires and more severe fires only at long intervals. An occasional surface fire would keep down organic layers and understory trees, thus preventing fires severe enough to kill the overstory. If a more severe fire then came along once every 100–300 yr, this would be adequate to create the necessary stand openings and occasional killed-out areas for regeneration. This is the kind of fire regime that prevailed where many stands of these pines occur today. Their most common location is on islands, or on the east, north, northeast, or southeast sides of lakes, streams, swamps, or valleys. Fires in such locations are often ignited as spot-fires, and they burn as backfires moving against westerly winds—creeping downslope toward the lakeshore or swamp edge. The known locations of major stands of old pine that were cut in the early logging era also agree with this pattern. Many old red and white pine stands do bear scars from the surface fires that burned through them, and many of these fires occurred in the same major fire years that elsewhere killed forests over extensive areas, bringing in whole new generations of trees. This suggests that it was the physiographic location of such stands that ameliorated fire intensity and made the survival and regeneration of red and white pine possible. The average interval between fire scars in such stands is 36 yr.

Northern white cedar is very fire-sensitive, and has almost literally been driven to the lakeshores by fire. It is so uncommon on uplands that it is often considered a species requiring high soil moisture and mobile groundwater. But the proof that it can cope with dry sites is that it is sometimes abundant on ridges on certain islands and other sites where fires have been infrequent. Many lakeshores are lined with cedars, but the cedar fringe is usually narrow. A little detective work will quickly reveal the reason: many old cedars are fire-scarred on the side away from the lake, and the younger trees spreading inland usually date from after the last fire.

THE NATURAL FIRE ROTATION

We need a measure of the amount of fire in ecosystems that defines the average rate at which new forest generations were established in natural fire-dependent systems. I propose the term *Natural Fire Rotation* for this concept. By this I mean simply the average number of years required in nature to burn-over and reproduce an area equal to the total area under consideration. Such a statistic can be calculated with some precision only if fire history maps are available for a relatively long period when man had little direct effect on the system. But even if only crude approximations can be obtained, such estimates have value because they permit direct comparisons between ecosystems for scientific purposes and provide guidelines for fire management programs.

For the Canoe Area the natural fire rotation is about 100 yr. This is the average time required to burn and reproduce an area equivalent to the whole 1-million-acre virgin forest study area for the period 1727–1910, allowing for some lost record in the early years (Table 3). In addition to the fires involved in this statistic, there were many surface fires that merely scarred occasional red and white pines, and undoubtedly still more that left no trace. Surface fires that failed to introduce a new generation were most common in red and white pine stands, because all other trees are so fire-sensitive that most fires probably killed enough trees to regenerate the area.

Reducing all this fire history to a single statistic such as the 100-yr natural fire rotation may obscure the wide actual variability in stand life, both between and within community types. Let me hasten to correct any false impressions. It *is* a valid measure of fire's role in the total system, but each community type probably also had a characteristic average fire rotation of its own. I lack the data to calculate such statistics, but I obtained a feeling for the situation in the field.

Red and white pine stands often survive intact 200–300 yr, with a possible maximum for single trees or small groups of 400–500 yr. In nature, average stand life was probably 150–250 yr. The oldest red pine bored in my study is now 378 yr old. Older white pines may have been encountered, but all were too rotten to yield full cores. Many jack pine stands 100–215 yr old have undoubtedly escaped fire in the last 60 yr because of fire-control measures. Overstory mortality and the invasion of fir–spruce understories is commonly well advanced at 100–115 yr. I would guess that many jack pine stands formerly burned 50–100 yr from establishment. The oldest individual jack pines bored were approximately 245 yr old. Aspen–birch types evidently had average fire rotations similar to jack pine types, because they were almost always of the same age class in given areas. Few cores were taken because rings are difficult to count in old trees, but many individual quaking aspens undoubtedly attain ages of 150–200 yr. Paper birch has a maximum longevity of at least 250 yr. Black spruce is often a postfire pioneer, both on uplands and peatlands. On uplands its natural fire rotation seems to have been close to that for jack pine, and individual trees have lived at least 227 yr (the oldest upland specimen bored). On peatlands both fire rotations and maximum longevities were probably longer, but many spruce swamps burned in the same fires that consumed the adjacent uplands.

White spruce, balsam fir, and northern white cedar are common understory elements beneath the pines, aspen, or birch. So is black spruce in many cases. In a surprising number of such cases, however, many individuals of these four species are really not much younger than the pioneer overstory species they associate with. This suggests that reproduction often begins not long after the fire even for these "climax" species. They usually perish in the same fires that destroy the overstory pioneers, and in these cases at least they are caught up in the same fire rotations. Surface fires undoubtedly often eliminated understories of these species beneath red and white pine stands without killing the overstory. Now, many such understories are so advanced because of fire exclusion that a surface fire can be carried into the overstory. If protected from fire, white spruce probably has a maximum longevity of at least 300 yr, and white cedar 400–600 yr or more. Balsam fir rarely survives more than 200 yr.

Hopefully, it is clear from this discussion that great variability in fire patterns actually produced the fire records that add up to a neat 100-yr average fire rotation. What really happened over a given century on any large landscape unit was the result of an extraordinarily complex series of interactions between lightning and man-caused ignitions, fuel patterns, vegetation types, physiographic factors, past burn patterns, and the vagaries of weather, season of the year, and climatic buildup for each specific fire.

SUCCESSION, DIVERSITY, AND STABILITY IN RELATION TO FIRE

Much ecological literature indicates that succession often leads to increased species diversity and stability in plant communities (see Krebs, 1972; Whittaker, 1970). But Loucks (1970) has suggested that in some temperate forest ecosystems periodic random perturbations by fire are essential to the maintenance of long-term diversity and stability. I join this view, and will suggest here that fire was the key rejuvenating factor in the Canoe Area, maintaining a dynamic mosaic of forest-age classes and community types, keeping species diversity and production high, and maintaining long-term stability of the system. Fire exclusion is now causing widespread successional changes that could impoverish the flora and fauna, block nutrient cycles and energy pathways, and lead to reduced system stability.

We cannot really be sure what vegetation types might develop through prolonged successional change, because in the past fire always terminated successions before steady-state conditions were reached. Proof of this is that I did not find satisfactory examples of climax vegetation in 7 yr of fieldwork covering the entire 500,000 acres of virgin forest—and this after 60 yr of almost complete fire exclusion! Rigorously defined, a climax community is one that has attained a dynamic steady-state equilibrium with the environment and biota, and is self-reproducing without further major disturbances or perturbations of the system. This status is reached only when all elements of earlier successions have been replaced by climax species, and adjustment to the new conditions has been demonstrated by a complete cycle of self-reproduction. Stands that contain significant elements of first-generation postfire communities hardly qualify. But the time required for the development of such a convincing case of climax is long—longer than the actual period of development of virtually all existing stands in the Canoe Area. This being so, one wonders whether the climax concept is useful in understanding the real-world ecosystem here.

Nevertheless, it is instructive to consider what is known about succession in the region. Numerous phytosociological studies have predicted a climax vegetation, or at least the direction of successions, by extrapolating from data on the composition and structure of the existing vegetation. The earliest was the pioneering work of Cooper (1913) on Isle Royale, an island in Lake Superior 60 miles east of the Canoe Area. He defined several successions converging toward a white spruce/balsam fir/paper birch climax. Buell and Niering (1957) obtained data on a series of old fir–spruce–birch communities in the Canoe Area and in Itasca Park, but they recognized that all of their stands still showed evidence of a pine generation and thus were not climax. (My stand-origin map shows their Moose River stand to be a first-generation postfire community dating from a 1755–1759 burn.) Fir was prominent and reproducing successfully in all of their stands—suggesting that it would maintain a dominant role, barring fire or other disturbances. Scanty white spruce regeneration suggests a secondary role for this shade-tolerant species. They saw paper birch as capable of maintaining its role by sprouting.

The extensive studies of my colleagues Ohmann, Ream, and Grigal utilized a large, randomly drawn field sample of the upland virgin forests of the Canoe Area, and computerized analytical procedures to define plant communities and to study environmental and successional relations (Ohmann and Ream, 1971a, b; Grigal and Ohmann, 1973). With continued fire exclusion they foresee the following successional trends: 1. Lichen communities may acquire a partial tree canopy and perhaps eventually develop into a black spruce/feather moss community, 2. Jack pine-dominated communities (where black spruce is important) and the red pine community may eventually be succeeded by a black spruce/-feather moss community, 3. The jack pine community (where fir is important) and most other communities seem headed toward dominance by fir, paper birch, white cedar, white spruce, and to a lesser extent, black spruce. The tall shrub layer may become dominated by mountain maple and fly honeysuckle, the low shrubs by dewberry, and the ground flora by scattered mosses and such herbs as *Clintonia borealis, Cornus canadensis, Aster macrophyllus, Trientalis borealis, Aralia nudicaulis, Coptis groenlandica, Linnaea borealis,* and *Galium.*

They recognize that these trends may be interrupted by fire, windstorms, insect outbreaks, diseases, and the influence of many animals. The most significant tree added to the list of potential climax-dominants is northern white cedar, which they believe may have the highest potential for replacing other species in the absence of fire. They also point out, however, that the structure and composition of the virgin forests are more closely related to the length of time since the last fire for each stand, and probably to the character of that fire and the age and composition of the former stand than to all of the other environmental factors studied (slope, aspect, elevation, soils, etc.).

These studies all rely on extrapolations from data collected largely in stands of postfire origin, but the actual number of years since fire was not a variable in most analyses. My stand-origin maps provide a record of the present age-class mosaic, and the gross areas occupied by Grigal and Ohmann's communities are known (Table 2). Yet we still lack a plant community map that can be related to stand ages and to the successional projections of Ohmann, Ream, and Grigal.

In another study, too extensive to publish in full here, Albert Swain and I did relate the stand composition and age structure of certain postfire communities to the actual time interval since the last fire. Data were taken in 32 stands: 22 jack pine-dominated communities, 6 red pine, 3 white pine, and 1 spruce–fir. In each stand we collected data on: 1. age structure by tree species and crown position in the canopy, 2. stocking by species, crown position, and diameter, and 3. composition, abundance, and cover for the shrub, herb, and ground layers (by a modified Braun–Blanquet system). Stands were selected to cover the full available range of age classes in the jack pine series, and a few key stand ages in the other communities. The fire history of each stand was determined by tree-ring and fire-scar analyses. Here I summarize certain findings relevant to the present discussion.

Our plots in jack pine-dominated communities show succession to either fir–spruce–birch or black spruce–feather moss types, as predicted by Ohmann and Ream (1971b). However, these successions were never entirely completed (Tables 7, 8 and Figs. 4–8). A 1727 burn extending from Frost and Cherokee Lakes east to Winchell Lake supports the oldest remnants of jack pine forest we found (see stand 30, Tables 7 and 8, and Fig. 8). Only six living jack pine were actually found in this age class, but numerous dead and down

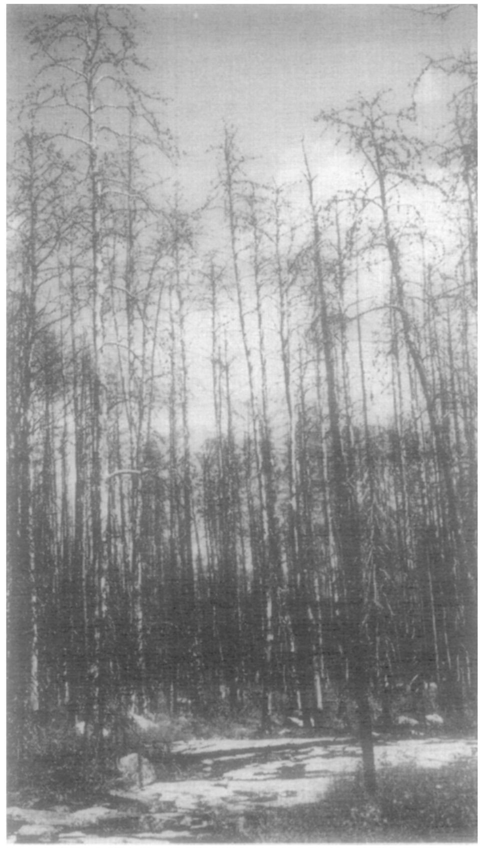

FIG. 4. Jack pine stand of 1864 origin, killed by crown fire in Little Sioux Fire, 1971. (Plot 1, Table 7.) Nearly 40,000 jack pine seedlings per acre present. Light areas in foreground are granite bedrock exposed by burning off lichens (*Cladonia*). About 50 yr are required for lichen regrowth. Photo taken July 1972.

trees show that the species was formerly more abundant. Throughout this locality, scattered red and white pines and white and black spruces of the same age class also exist. The area may not have supported a dense jack pine forest because most of the individuals examined had many low limbs, suggesting that they were open-grown. The stocking of other species of the same age class also seems high. A clear case of succession in a formerly well-stocked jack pine forest is represented by stand 29, located in Sec. 8, T65N, R14W on the south side of the Echo Trail, in a 1755 burn. Succession to fir–spruce–birch was also advanced in this stand, but numerous tall, well-pruned,

FIG. 5. Thirty-three-year-old jack pine stand on the Cherokee Lake Burn of 1936. (Plot 23, Town Lake, Tables 7, 8). Photo taken 1969.

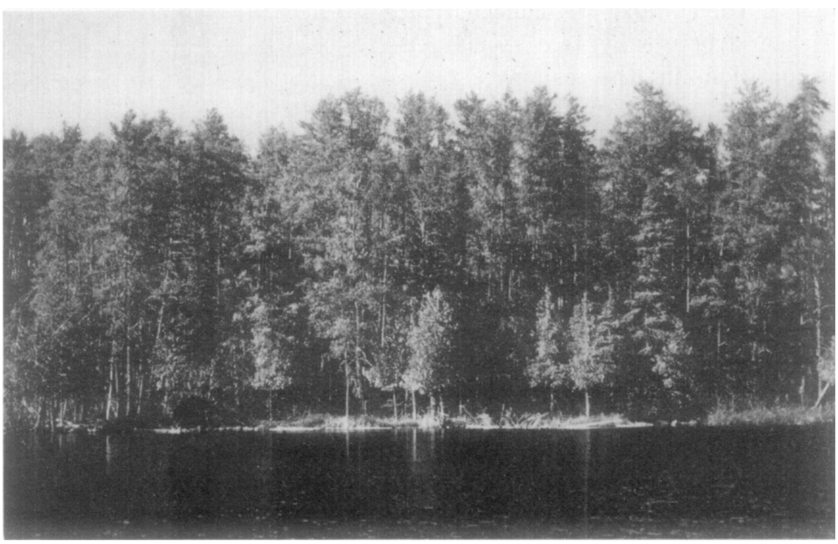

FIG. 6. One-hundred-year-old jack pine stand on an 1864 burn. Little Shell Lake. A few small northern white cedars fringe the lakeshore. Succession not advanced here. Photo taken 1967.

215-yr-old jack pines still remained (Tables 7, 8).

It is clear from our stand data that jack pine can persist as a scattered overstory element in the Canoe Country for at least 210–250 yr without fire. Most present virgin jack pine stands date from 1936, 1910, 1903, 1894, 1875, and 1863–4 burns. If these stands follow the successional trends shown, some jack pine forest would persist at least another 200 yr with continued fire exclusion. However, large-scale successions to fir–spruce–birch and black spruce/feather moss communities would begin to reach

FIG. 7. Remnant of old jack pine forest on a 1755 burn near Echo Trail, 20 miles northwest of Ely, Minnesota. (Near Plot 29, Tables 7, 8). The jack pine in foreground was 215 yr old. Note advanced succession to balsam fir, white spruce, and paper birch. Photo taken 1970. This area burned in a crown fire during the Little Sioux Fire, 1971.

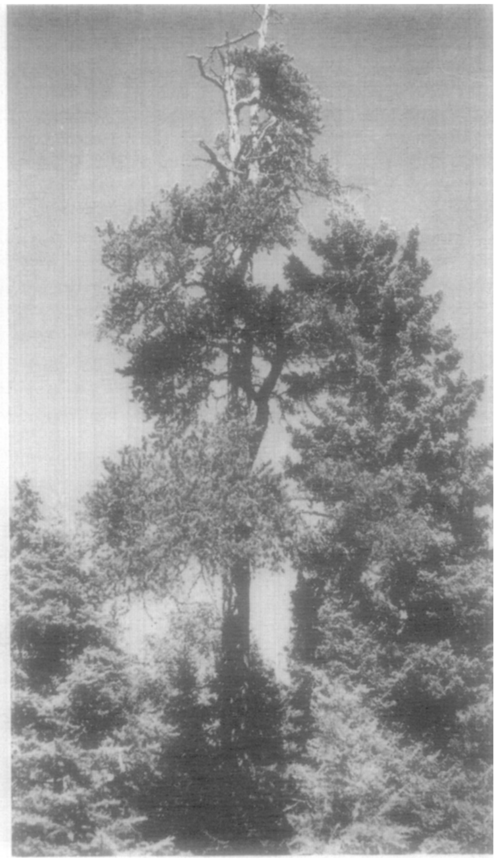

FIG. 8. A 243-yr-old jack pine on Gordon Lake, within a 1727 burn. Succession to fir–spruce–birch is far advanced in this, the oldest former jack pine stand studied. (Plot 30, Tables 7, 8.) Photo taken 1969. This tree, and five others in the same age class, are the oldest known jack pines in the Great Lakes region.

completion in 90–100 yr (2070 A.D.), as the jack pine now present on many 1863–1864 burns reached the limit of its longevity. The final demise of jack pine, now the most conspicuous forest dominant, would come about 2170 A.D. if no more fires occurred.

We could not obtain comparable data for the important aspen–birch types because of problems in getting countable increment cores from old aspens. However, these communities are often intermingled with jack pine types of the same age class, and their age structures are similar, although quaking aspen may have a maximum longevity closer to 200 yr. Succession to fir–spruce–birch and cedar should thus proceed on a slightly faster timescale than for jack pine (Fig. 9).

No red pine stands studied in detail had escaped fire longer than 202 yr at the time of our research. The main red pine overstory in our Boulder Bay stand (A-8, located in Sec. 32, T67N, R13W, Lac LaCroix Natural Area) dated from a 1681 burn, but the stand had been partially burned through in 1755 and 1767 (Table 9). The oldest red pine bored here was 283 yr old. Scattered white pines and white and black spruce 30–150 yr old were present in the

TABLE 7

STOCKING OF JACK PINE-DOMINATED VIRGIN FORESTS BY SPECIES AND TIME SINCE STAND ESTABLISHMENT AFTER FIRE, BOUNDARY WATERS CANOE AREA. (DATA INCLUDE ALL TREES 1 IN. OR LARGER, D.B.H.)[a]

Location	Plot number	Year of last fire	Years since establishment	Jack pine	Red pine	Black spruce	Paper birch	White spruce	Balsam fir	White cedar	Other species	Total
		Date	No.	Numbers of trees per acre								Trees/ac
Little Sioux	1	1971	1	39,910			250				20,720	60,880
Little Sioux	2	1971	1	12,460			2170				6770	21,400
Town L.	23	1936	33	3400		100	700					4200
Cherokee L.	31	1936	34	1920		360	1260	340				3880
L. of Clouds	12	1910	59	450		330	290	50	280		10	1,410
L. of Clouds	13	1910	59	530		1690	440	130	140			2930
Cummings L.	20	1910	59	740			110					850
Saganaga L.	16	1903	66	190	5	320	20		35		105	675
Turtle L.	17	1903	66	380		170	250	10	310			1120
Ester L.	14	1894	75	290		180			260	80		810
Cummings L.	19	1894	75	380	195	5	320				10	910
Moose R., S.	2	1894	75	290		260	30					580
Ada Cr.	33	1875	95	70		240	95				25	430
Moose R., S.	3	1864	105	105		160	15		45		145	470
Ester L.	15	1864	105	210	10	370	90		30			710
Insula L.	25	1864	105	140		50	200		20			410
Keeley Cr.	27	1854	116	80		45	45	20	135		30	355
Cash L.	32	1846	124	60		230	85	15	265	5	5	665
Amoeber L.	11	1827	142	200		210	30		110	140	10	700
N. Hegman L.	28	1822	148	80		585	55					720
Seagull L.	6	1801	168	30	10	300	185	5	485	5	20	1040
Seagull L.	7	1801	168	40		585	155	25	45	10	5	865
Echo Trail	29	1755	215	20		80	65	20	470			655
Gordon L.	30	1727	243	5		25	245	10	800		25	1110

[a] Basis: One measured circular plot in each stand (plot sizes range from 1/5 to 1/50 acre, depending on stand density and age). "Other species" includes quaking and large-tooth aspen, white pine, red maple, and mountain ash. Data from Little Sioux Burn are for 1-yr-old seedlings based on 100 mil-acre quadrats per stand.

understory. Succession to fir–spruce–birch was not advanced, and all the fir and birch understory trees aged were 60 yr or less old. The oldest individual red pines cored are now 378 yr old (the Three Mile Island stand on Seagull Lake). Succession to fir–spruce–birch and cedar certainly is occurring in most old red pine stands, and I estimate that without fire the last red pine overstory elements would disappear 400–450 yr after stand establishment (Fig. 10). The youngest virgin stands are now 30–60 yr old. Thus total fire exclusion could cause the virtual elimination of red pine from the Canoe Country by about 2350 A.D. The species might persist on cliffs, steep rocky slopes, and barren islands, but the stately groves of large old red pines now so characteristic of many areas would be gone.

The oldest white pine-dominated community studied was found east of Larsen Lake on a narrow stretch of land between Gaskin and Winchell Lakes, just northeast of a series of ponds and wetlands. This physiographic location had evidently pro-

TABLE 8

BASAL AREA OF JACK PINE-DOMINATED VIRGIN FORESTS BY SPECIES AND TIME SINCE STAND ESTABLISHMENT AFTER FIRE, BOUNDARY WATERS CANOE AREA. (DATA INCLUDE ALL TREES 1 INCH OR LARGER, D.B.H.)[a]

Location	Plot number	Year of last fire	Years since establishment	Jack pine	Red pine	Black spruce	Paper birch	White spruce	Balsam fir	White cedar	Other species	Total
		Date	No.		Basal area—sq ft per acre							Sq ft/ac
Town L.	23	1936	33	118		1	7					126
Cherokee L.	31	1936	34	142		4	21	5				172
L. of Clouds	12	1910	59	78		22	11	4	12		1	127
L. of Clouds	13	1910	59	67		80	10	10	10			177
Cummings L.	20	1910	59	104			1					105
Saganaga L.	16	1903	66	75	1	36	1		3		21	137
Turtle L.	17	1903	66	97		21	31	1	8			158
Ester L.	14	1894	75	102		15			7	2		126
Cummings L.	19	1894	75	123	38	1	4				1	166
Moose R., S.	2	1894	75	81		45	2					128
Ada Cr.	33	1875	95	56		64	13				4	137
Moose R., S.	3	1864	105	72		25	1		3		6	107
Ester L.	15	1864	105	68	5	55	1		2			131
Insula L.	25	1864	105	99		10	43		1			153
Keeley Cr.	27	1854	116	51		4	8	6	22		2	93
Cash L.	32	1846	124	41		49	10	2	21	1		124
Amoeber L.	11	1827	142	96		32	12		7	7	1	155
N. Hegman L.	28	1822	148	56		42	2					100
Seagull L.	6	1801	168	24	19	17	5	1	29	4	1	100
Seagull L.	7	1801	168	32		31	15	4	3	1	1	87
Echo Trail	29	1755	215	30		11	24	7	30			102
Gordon L.	30	1727	243	6		6	37	17	82		1	149

[a] Basis: One measured circular plot in each stand (plot size ranges from 1/5 to 1/50 acre, depending on stand density and age). "Other species" includes quaking and large-tooth aspen, white pine, red maple, and mountain ash.

tected the area from fire for some 360 yr—longer than any other site investigated. Our plot (A-5) was taken 200 ft from the west shore of Gaskin Lake, about 1/8 mile northwest of the portage to Winchell Lake (Sec. 26, T64N, R1W) (Table 10, Fig. 11). A sparse supercanopy of very large white pines gives the stand the appearance of still being a pine forest, but the vegetation otherwise is more advanced successionally than any other stand we visited. The largest white pine measured was 41 in. in diameter and more than 100 ft tall. The five pines bored for ages all had rotten centers, but all yielded estimates between 323 and 368 yr. The stand is thus even-aged and undoubtedly of postfire origin. Charcoal was found at the base of the humus layer at all four sites checked. No trees had detectable fire scars. The time of the last significant fire was between about 1610 and 1595 A.D., but a light surface fire might have occurred about 1670, because all of the old pines had center rot beyond that time, and none of the trees other than the pines apparently originated before 1670. The main canopy consists of white cedars up to 296 yr old and 22 in. in diameter, white spruce up to 185 yr old and 25 in. in diameter, and paper birch up to 162 yr old and 16 in. in diameter. The understory is chiefly fir, up to 13 in. in diameter and

FIG. 9. This 106-yr-old quaking aspen stand was totally killed by a crown fire that consumed a budworm-damaged fir–spruce understory during the Little Sioux Fire of May, 1971. The killed stand originated after an 1864 burn. Photo taken October 1971. At this time there were 77,000 new aspen suckers and 2360 aspen seedlings per acre.

121 yr old. Some cedar saplings as small as 2 in. in diameter are also present, some of layer origin. New seedlings of fir and cedar are abundant, and a few white spruce seedlings were found. Some seedlings of paper birch occur on rotten logs. Spruce budworm damage to the fir understory is only moderate. A moderate tall shrub layer consists largely of *Acer spicatum* and *Corylus cornuta*. The most abundant herbs are *Cornus canadensis, Aralis nudicaulis, Linneae borealis, Mitella nuda, Galium*

TABLE 9

STAND STRUCTURE BY SPECIES AND AGE RANGES FOR A 283-YR-OLD RED PINE STAND ORIGINATING AFTER A FIRE IN 1681. GROUND FIRES BURNED THROUGH STAND IN 1755 AND 1767—NO EVIDENCE OF FIRE SINCE (STAND A-8, BOULDER BAY, LAC LA CROIX, BOUNDARY WATERS CANOE AREA. DATA TAKEN 1969, INCLUDES ALL TREES OVER 1 IN. D.B.H.)

Species	Diameter range	Trees/acre	Basal area per acre	Sample tree ages by crown position class			
				Dominant	Codominant	Intermediate	Suppressed
	Inches	No.	Sq ft	Years	Years	Years	Years
Red pine	2–22	155	180	283	278	280	106–266
White pine	1–14	285	20	—	—	153	32–142
Black spruce	1–6	90	6	—	—	103	56–96
White spruce	1–10	10	3	—	—	156	—
Balsam fir	1–4	90	3	—	—	—	30–44
Paper birch	1–4	175	3	—	—	—	21–60
Total	1–22	805	215	283	278	103–280	21–266

FIG. 10. Interior of a 280-yr-old red pine stand on Ramshead Lake. Note stand deterioration from wind breakage, and advanced succession to fir–spruce–birch. This stand originated after a fire in 1681. Photo taken 1966. Portions of this forest burned in crown fires and surface fires in the Little Sioux Fire, 1971. (Stand A-8, Table 9, (not shown) lacked a dense understory, and had not yet been wind-damged.)

triflorum, Maianthemum canadense, Trientalis borealis, and *Aster macrophyllus. Lycopodium annotium* and *L. clavatum* are also common. Mosses are abundant, both on the ground and on rotten logs; the more common species are: *Pleurozium schreberi, Hylocomium splenders, Hypnum cristacastrensis, Dicranum rugosum, Polytri-*

TABLE 10

STAND STRUCTURE BY SPECIES AND AGE RANGES FOR A 360-YR-OLD WHITE PINE STAND SHOWING ADVANCED SUCCESSION TO FIR–SPRUCE–CEDAR–BIRCH. (STAND A-5, GASKIN LAKE, BOUNDARY WATERS CANOE AREA. THIS STAND ESCAPED FIRE LONGER THAN ANY OTHER STUDIED—LAST SIGNIFICANT FIRE 1595 TO 1610 A.D. DATA TAKEN 1969, INCLUDES ALL TREES OVER 1 IN. D.B.H.)

Species	Diameter range	Trees/acre	Basal area per acre	Sample tree ages by crown position class			
				Dominant	Codominant	Intermediate	Suppressed
	Inches	No.	Sq ft	Years	Years	Years	Years
White pine	33–41	5	33	323–368	—	—	—
White spruce	18–25	10	26	178–185	—	—	—
White cedar	1–22	30	28	—	250–296	—	37–96
Balsam fir	1–13	675	69	—	99	95–121	38–85
Paper birch	10–16	20	22	—	160–162	96	—
Total	1–41	740	178	178–368	99–296	95–121	37–96

FIG. 11. Remnant super-canopy of 360-yr-old white pine, with advanced succession to fir–spruce–cedar–birch in main canopy and understory. Stand A-5, Gaskin Lake, Table 10. This area, which may have escaped fire since about 1610 A.D., supports the most successionally advanced stand studied. Photo taken 1969.

chum commune, Mnium punctatum, and *Mnium affine.* The litter-plus-humus layer ranges from 1 to 4 in. in depth, 2 or 3 in. being typical. This stand was clearly once part of a well-stocked white pine forest. Many individuals had died or been windbroken within the past 50–100 yr—the ground was criss-crossed with their old rotting, moss-covered trunks. Probably few if any of the old pines will survive more than another 100 yr, and there are no understory pines to replace them. Thus, at about 460 yr after fire, succession to fir–cedar–white spruce and birch will be complete. The fir understory now present is probably at least the second or third generation of that species to grow beneath these old pines.

TABLE 11

STAND STRUCTURE BY SPECIES AND AGE RANGES FOR AN EARLY POSTFIRE SPRUCE–FIR–CEDAR–BIRCH STAND, BOUNDARY WATERS CANOE AREA (STAND A-24, LONG ISLAND RIVER, WITHIN THE FROST LAKE BURN OF 1936. DATA TAKEN 1969, INCLUDES ALL TREES OVER 1 IN. D.B.H. ALL SPECIES REPRODUCED SOON AFTER FIRE)

Species	Diameter range (in.)	Trees per acre (no.)	Basal area per acre (sq ft)	Sample tree ages (yr)
White spruce	1–5	1450	55	26–31
Black spruce	1–4	450	24	27–32
Balsam fir	1–4	450	14	24–30
White cedar	1–2	550	4	25–31
Paper birch	1	300	2	19–22
White pine	2–3	100	3	26–27
Jack pine	5	50	7	26
Total	1–5	3350	109	19–32

Many spruce–fir–birch and cedar stands are really of direct postfire origin. An example was studied on the east side of the Long Island River, in a 1936 burn (Plot A-24, Sec. 24, T64N, R4W, Table 11). The fire occurred 33 yr before our plot study, but the age range among all trees sampled was only 19–32 yr. Most trees of all species, including the "climax" species white spruce, northern white cedar, and fir, had originated within 5 yr after the fire. The seed source was apparently an unburned 1727-origin mixed-conifer forest across the river.

If such a stand were sampled 150–200 yr after its origin, it might easily be mistaken for a climax forest simply because a second generation of fir, cedar, and spruce was developing as an understory beneath the first generation of postfire trees. A similar situation exists with black spruce/feather moss communities, which apparently could develop through succession, but most actually have first generation postfire overstories, both on uplands and peatlands (LeBarron, 1939; Heinselman, 1957, 1963).

A possible problem with past studies of succession emphasized by our age-structure work is that much of what appears visually to be succession is really just suppression. The "sapling" understories of many stands were nearly as old as the overstory! This is particularly true of black spruce beneath jack pine. Black spruce often seeds-in well following fire, but regeneration may come in for several years. Spruce seedlings also grow more slowly than the pines in their first few years. Once in a subcanopy position, such trees may survive more than a century in a suppressed condition. For example, in an 1864 burn on Lake Insula we found the dominant jack pines to be 102–105 yr old and up to 15 in. in diameter, while a suppressed black spruce in the same stand was only 5 in. in diameter but 97 yr old. On a 1936 burn on Cherokee Lake the dominant jack pines were 4–6 in. in diameter and 33–34 yr old, while all the black spruce were already suppressed and only 1–3 in. in diameter, but their ages ranged from 28 to 32 yr. These are not isolated cases—we found the same situation on virtually all plots in jack pine/black spruce stands. The same situation exists to a lesser degree with white spruce and northern white cedar. The only two understory species that are commonly much younger than the overstory are balsam fir and paper birch. These poor correlations between diameter and age should make one cautious in generalizing about succession based on size-class analyses alone.

With this background on the present status of succession, let us return to the interrelationships between succession, species diversity, community stability, and productivity. The data that Swain and I assembled, and those of Ohmann and Ream (1971b) suggest that the species diversity of many individual stands increases with succession following fire for at least 100–250 yr. Certainly this is so for the tree stratum, where maximum diversity comes in the midsuccession years when both pioneer and shade-tolerant invaders are present. But if succession proceeds for 300–500 yr, most areas would then show a decline in diversity as the pioneers disappear.

If the unit of concern is a large region like the Canoe Area, however, and not just individual stands, then diversity for the whole ecosystem is a function of both the composition of individual communities and their relative abundance and arrangement on the landscape. Maximum diversity here is attained with a full spectrum of successional stages and community types patterning the landscape, arranged like patches on a quilt. There would be new burns, early postfire successions, maturing pioneer forests, midlife stands showing invasion of shade-tolerant species, and very old communities. The scene, over time, would be like a slowly changing kaleidoscope. This is clearly the way it was in the primeval ecosystem. Diversity for the system as a whole could only be described if hundreds of square miles were studied and mapped simultaneously—as on Earth Resources Satellite imagery.

If, through fire exclusion, system-wide successions eliminate this patterning, then the diversity of the total system would be reduced. Within 200–300 yr fir–spruce–cedar–birch and black spruce/feather moss forests might occupy essentially all upland sites, and the pines and aspens might disappear. So might much of the shrub, herb, and ground vegetation now characteristic of pioneer forests. Indeed, over most of the area the really early postfire successions are already missing because there have been no large burns since 1936, save the Little Sioux Fire of 1971. But these changes are not yet permanent, because the root systems and seed sources of the pioneer species are still present and capable of resurgence if fires recur. Permanent fire exclusion is another matter, however. For if fire could be kept out of the system indefinitely, such characteristic species as jack pine, aspen, red pine, white pine, blueberry, pincherry, and many more might be virtually lost from the system.

Whether "climax" vegetation, presumably fir–spruce–cedar–birch forest, would be more stable than the heterogeneous vegetation mosaic produced by periodic fires should also be considered. There are several reasons to think it would not. First, extensive mature fir/white spruce stands are highly susceptible to the spruce budworm (Batzer, 1969; Van Raalte, 1972). Succession to fir–spruce on the scale expected with fire exclusion would produce ideal conditions for repeated outbreaks by this native insect, which is capable of killing most of the balsam fir over large regions. Just such an outbreak has been in progress in the Canoe Area since about 1956, perhaps sustained by the unnaturally extensive successions to fir throughout northeastern North America caused by fire protection. Such outbreaks do not eliminate fir, however. Enough new seedlings are always present to regenerate the species. Mature white spruce often survives. But the mature and sapling fir component of most stands is killed over large areas, and vast concentrations of dead wood are generated, both standing and down. Tree lichens (*Usnea* spp. and *Alectoria* spp.) make these areas extremely flammable. The probability of lightning or man-caused ignition of such areas therefore becomes a factor in the stability of such an ecosystem. One might argue that the budworm could become the agent for recycling the ecosystem instead of fire, but this cycling is certainly incomplete (Grigal and Ohmann, 1973.) And since the budworm does not consume either dead wood or soil organic layers, it creates a highly fire-susceptible forest that usually does not directly regenerate itself following fire.

A second reason to doubt the stability of extensive fir–spruce–cedar–birch forests is the susceptibility of mature fir and spruce to wind breakage and uprooting. If large areas were covered with mature stands, extensive blowdowns, generating fuel concentrations that would add to fire intensity can be foreseen.

Without fire, black spruce–dwarf mistletoe could ravage many black spruce–feather moss forests—another type that might increase on both uplands and peatlands with continued succession (Anderson and Kaufert, 1959). Fire was apparently the natural check on this parasitic plant, and mistletoe-killed or injured stands are very flammable (Irving and French, 1971). The stability of this type too is therefore suspect. Unlike fir–spruce–birch, however, fire aids the direct regeneration of black spruce communities.

The mean annual production of the "climax" forests would probably also fall short of that in the natural fire-dependent system because of partial blocking of nutrient cycles and energy flow. In nature, fire was the agent that periodically reduced the litter and humus accumulations of upland sites, and peat accumulations on wetlands. It not only reduced these layers physically, thus influencing soil temperature, soil moisture, and other factors, but it also recycled the mineral elements and carbon they contained. Both kinds of recycling are important in maintaining the long-term productivity of northern forests, although good data on these questions are only now being accumulated. The detritus food chain becomes the major energy pathway in the absence of fire, but it is doubtful that it is as effective in recycling nutrients in northern conifer forests.

For the case of fire exclusion it is hazardous to project either changes in stand composition or environmental interactions very far into the future, because fire exclusion would cause changes in ecosystem processes that have not occurred for at least 9300 yr. The entire system evolved in an environment that *did* include periodic fire. There are so many interactions conditioned by this history that the effect of eliminating fire can hardly be predicted with our present knowledge of the system. Even the possibility of excluding fire must be questioned. Lightning ignitions at times when control cannot be quickly achieved seem guaranteed by long-term fuel accumulations or periodic fuel peaks. The climatic history of the region makes it clear that severe drouths will recur. When they do, the probability of large fires seems high. It is interesting, too, that the maximum longevity of most pioneer trees is far longer than the natural fire rotations for the vegetation types they dominate. The possibility of excluding fire long enough to eliminate these species seems remote.

In much ecological literature as well as the popular press, fire has been viewed as unnatural, man-caused, and a "disturbance" somehow not part of the ecosystem. But for the Canoe Area at least, it must now be seen as just a perturbation within the system. It was an essential factor in maintaining the kind of long-term stability and diversity recorded in the pollen and charcoal diagrams of Craig (1972) and Swain (1972, and this symposium). The composition, structure, and dynamics of the virgin forests can best be understood if we concentrate on understanding how the system functions with fire as part of that system. Rigorous studies of the interrelationships between fire periodicity, succession, and the species diversity, stability, and productivity of this fire-dependent ecosystem are now possible and should be pursued. Much of the needed data are available and this opportunity to construct an ecosystem model of a real-world, fire-dependent system should not be missed. The search for stable communities that might develop in the absence of fire is futile, and it avoids the real challenge of understanding nature on her own terms.

WILDLIFE HABITAT AND FIRE

An understanding of the role of fire in the Canoe Area's ecosystem requires at least a brief look at the interactions between vegetative successions and wildlife habitat. Most native mammals and birds have habitat requirements that correspond with niches in various postfire successional stages. Inasmuch as all the natives found niches in a fire-created vegetative mosaic in primeval times, this is not surprising. Some examples are:

Moose. Large quantities of nutritious browse are required in winter, but this animal, if well fed, is large enough to cope with snow at least 20 in. deep. Aspen, birch, willow, red maple, and pincherry, all common postfire sprouters, are heavily used (Krefting, 1951; Peek, 1972). Large burns are therefore suitable feeding areas, unless the snow is too deep. Two or three years after fire the regrowth protrudes above the deepest snows, and moose can then forage most of the winter. Yearlings may be an important factor in populating new burns (Peek, 1972). Moose also benefit from the overhead cover of conifer forests on cold winter nights and can browse the foliage of sapling fir. Thus a combination of recent burns and adjacent maturing forest (near waterways for summer range) should make a productive habitat complex. Moose are now abundant in certain recently logged or burned sections of the Canoe Area, but less common in large areas of mature forest.

Beaver. Stands of deciduous trees within a few hundred feet of lakes and streams are required. Aspen, paper birch, and willow are favored. Cuttings from these trees are used for dams, lodges, and winter food caches. In the primeval system these trees were found on burns, but within 70–100 yr after a fire beaver often fell all of the aspen and birch within reach of waterways. They must then move on to a newer burn. Fire exclusion is now preventing the regrowth of aspen–birch stands, and a high percentage of the available stands have been cut by beaver. A population decline can be expected.

Snowshoe hare. In natural ecosystems hares attain peak populations in young postfire stands, especially of aspen and birch, because of their need for thin-barked woody stems for winter food. Five to thirty years after fire are probably the best years (Grange, 1965). In recent decades hares have not been abundant except on recently burned or cutover areas.

White-tailed deer. This deer was uncommon in northeastern Minnesota in primeval times, but a large population increase came with the logging and burning of the mature white and red pine forests. Peak populations came between 1930 and 1950. With decreased timber cutting, plus fire exclusion, deer have since declined sharply. Many favored browse plants occur on recent burns, but deer perhaps cannot use large burns effectively because of deep snow and predation (Peek, 1972). Vogl and Beck (1970) have documented the prompt response of deer to fire in northwestern Wisconsin.

Woodland caribou. Caribou were common in the Canoe Country until 1900 but disappeared about 1925, and from Minnesota entirely by 1942 (Gunderson and Beer, 1953; Cringan, 1957). In winter these animals must have subsisted on a combined diet of tree lichens (*Usnea* and *Alectoria*), ground lichens (*Cladonia rangiferina, C. alpestris,* etc.), and browse. The relative importance of browse and lichens is still not clear, but existing caribou populations in Ontario, within 200 miles of the Canoe Area, use both (Cringan, 1957; Ahti and Hepburn, 1967). There is speculation that caribou disappeared from Minnesota because logging and fires between 1870 and 1930 eliminated the old forests and their associated lichen crops. This is tenable for northern Minnesota as a whole, but for the remaining virgin forests of the Quetico-Superior country it is too simplistic an explanation, because there was no logging, and there clearly has been less fire since 1910 than in the preceding 250 yr when caribou were present. For example, caribou were abundant for at least 30 yr after the fires of 1864, which burned some 44% of the virgin forest. And several hundred thousand acres of contiguous virgin forest with a similar fire history remain in Quetico Provincial Park just to the north. But when the caribou disappeared, much of the virgin forest of both the Canoe Area and Quetico consisted of stands 10–60 yr old, dating from the burns of 1864, 1875, 1894, and 1910; and logging had just eliminated most of the old white and red pine forests from adjacent land. In the Canoe Area today tree lichens are found largely on the lower limbs of old fir and spruce, and on dead fir killed by the budworm. Ground lichens are most abundant on open bedrock ridges, which become well covered by lichens 60–100 yr after fire. Some browse plants used by caribou are found in old forests as well as on burns (*Acer spicatum, Pyrus americana, Cornus stolonifera, Salix* spp., and *Viburnum rafinesquianum*). Sedges and some wintergreen herbs are also used. I believe the main habitat change working against caribou was a regional decrease in the proportion of old stands supporting tree lichens and perhaps in the proportion of open ridges supporting a good growth of *Cladonia.* But several areas with these characteristics did exist at the time caribou disappeared, and habitat changes could have been responsible for their extirpation only if very extensive areas with a significant proportion of lichen-bearing stands are essential. The persistence of a small herd on the Slate Islands in Lake Superior (Cringan, 1957) suggests that such vast areas are not essential to survival, although they may be necessary to support a significant regional population. Probably both excessive hunting and regional habitat changes were involved in the elimination of caribou. In any case, the forests of much of the region are now 60–150 yr old, ground and tree lichens are abundant, and there is reason to believe the area could again sustain caribou. Restocking probably is necessary.

Eastern timber wolf. This endangered subspecies is the largest carnivore in the Canoe Country's ecosystem. Its principal prey are the deer, moose, beaver, and formerly caribou. This strongly social and highly territorial animal has pack territories that may encompass 50–125 sq miles. Packs are family groups and typically contain 3–15 individuals (Mech, 1970; Mech and Frenzel, 1971). Enough area of early postfire or postlogging plant communities must exist within a pack's territory to sustain a surplus of the prey species that depend on such communities (deer, moose, beaver). Formerly caribou may have been common in mature forests too, giving the wolf available prey in both old and young forests. But today, old stands contain few prey animals, and the wolf is not common there. Pack sizes may be decreasing (Mech, in press). Further declines in populations can be expected if fire exclusion continues, especially if caribou are not reestablished.

Black bear. The bear is omnivorous and thus can find food in many habitats. But the important berry-producing plants, such as blueberries, raspberry (*Rubus idaeus*), juneberries (*Amelanchier* spp.), and cherries (*Prunus* spp.), are most abundant 2 to perhaps 20 yr after fire or logging. Thus recent burns or cutover areas are important habitats for bear. In primeval times this animal undoubtedly frequented burns during berry season, but today there are few burns, and most berries are found on cutover areas beyond the virgin forests. Raspberries are an exception, because they also abound in openings in budworm-killed fir stands.

Small mammals. Most species native to the Canoe Country seem well adapted to survival during and after fires. Traplines run on the Little Sioux Burn 3 wk after the fire by Milton Stenlund, Minnesota Department of Natural Resources, showed that redback voles, chipmunks, and deer mice were active even in the most severely burned areas (Books, 1972). Apparently they survived the fire underground and reappeared as soon as it had passed. After both the first and second growing seasons traplines yielded nearly a full complement of small mammals: redback vole, woodland deermouse, meadow vole, masked shrew, least chipmunk, and meadow jumping mouse. The red squirrel is temporarily displaced by fire, but its niche is in maturing jack pine, black spruce, and red and white pine stands—all postfire communities.

Ruffed grouse. In northern Minnesota this grouse depends heavily on the buds of aspen for winter food, especially on the staminate flower buds of quaking aspen (Svoboda and Gullion, 1972). A patchwork of aspen stands of different ages, interspersed with conifers, provides good feeding habitat plus winter shelter. This was the character of the primeval forest. Succession due to fire exclusion is now gradually reducing ruffed grouse habitat, although there is still much good habitat in the younger aspen forests.

Other birdlife. The primeval mosaic of forest age classes and successional stages created by fire provided niches for all native land birds. For example, several species of woodpeckers occur sparingly in mature forests, but concentrations of these birds developed on the Little Sioux Burn in the first and second years after fire. They were seeking the abundant larvae of wood-boring beetles and barkbettles in fire-killed or fire-injured trees. Notably abundant were the otherwise uncommon northern three-toed woodpecker (*Piciodes tridactylus*) and the black-backed three-toed woodpecker (*Piciodes arcticus*). In contrast, many warblers seem especially abundant in mature forests with a fir element during outbreaks of the spruce budworm, upon which they feed (MacArthur, 1958). This insect was periodically epidemic in old stands in primeval times as well as now (Blais, 1965).

Clearly the entire biota was adapted to an environment that included periodic fire.

Wholesale succession of the forest due to fire exclusion is now restructuring the entire system, and gradually eliminating the niches of many formerly abundant wildlife species. While some might find their niches expanded in such an ecosystem, for example, warblers or caribou, the removal of fire would apparently cause a significant loss of diversity and an overall decrease in wildlife.

RESTORING FIRE TO THE ECOSYSTEM

Wilderness preservation programs for the Canoe Area and similar regions with fire-dependent ecosystems hinge on the public values and objectives to be served. Many values attributed to wilderness depend on maintenance of the natural system (Brower, 1960; Falls, 1967; Heinselman, 1965a, b, 1970a; Leopold, 1921; Littlejohn and Pimlott, 1971). Those most closely linked to natural ecosystems include:

1. The cultural, aesthetic, and psychological value of experiencing the natural world.
2. The value of rare, endangered, or unique species, plant communities, environments, and ecosystems in maintaining the diversity of the Earth.
3. The scientific value of understanding natural systems—especially large-scale ecosystem processes that require complete systems, well buffered from outside influences.
4. The value of natural ecosystems as check areas for studies of technologically modified systems outside wilderness.
5. The value of wilderness as a reservoir of plant and animal genetic stocks adapted to the natural environment and uninfluenced by the intentional selection or transfer of stocks by man.
6. The educational value of wilderness as an outdoor laboratory for study and research in higher education and as a means to increase the general public's understanding of natural environments and the ecological problems facing mankind.

If the public holds such values for the virgin landscapes of the Canoe Area, and if management is to respond to these values, then the presettlement ecosystem should be maintained or where necessary restored to the maximum extent feasible. A wide-range of vegetation and fire-policy alternatives can be tested against such values and objectives. Four options often considered are:

1. Exclude all fires as far as possible and accept the vegetative and wildlife population changes that ensue (gradual succession to fir–spruce–cedar–birch and black spruce/feathermoss communities with their associated wildlife). Also exclude all mechanical vegetation manipulation. (This has been the practice in the "No-cutting Zones" of the Canoe Area.)
2. Allow all natural forces a free rein, including lightning-caused fires. (One might still control man-caused fires here.) Exclude mechanical manipulation.
3. Create vegetative disturbances similar to those produced by fire with noncommercial tree cutting, where necessary followed by prescribed fire or mechanical soil treatment. Follow treatments with seeding or planting and other cultural measures as needed to simulate the natural vegetation.
4. Reestablish the natural fire regime with prescribed-controlled burning of intact virgin forest communities. Set fires in standing forests to duplicate the ecological effects of natural wildfires. (Carefully identified and monitored lightning fires might also be allowed to burn when considered safe.) Exclude all mechanical manipulation, seeding, and planting.

Obviously there are many possible combinations and variants of these alternatives, and I cannot explore them all here. I have already dealt with the ecological consequences of Fire Exclusion (option 1). It is still policy in most Wilderness Areas, and, to the extent it succeeds, it is the management practice as well. And it has advocates. At the very least it is a defensible "holding action" until better alternatives are ready for application. Some argue that it is the preferred alternative, knowing full well that it is really an ecological experiment on a grand scale. However, it does carry two major risks if pursued indefinitely: 1. Fuels might eventually accumulate to very high levels, and catastrophic wildfires might become inevitable in spite of protective measures. 2. Habitat for many abundant and interesting wildlife species will eventually deteriorate to the point that populations would decline to very low levels.

The second option, allowing most lightning fires to run, carries safety risks for the Canoe Area, but it is a viable option for some mountain wilderness (Kilgore and Briggs, 1972). The problem in the Canoe Area is that some lightning fires will inevitably occur during severe droughts on days with high winds. Once such fires become large, control is difficult, and wind shifts could threaten lives or property outside the wilderness. In this nonmountainous terrain such fires could run many miles and jump large water barriers by spotting. Fires such as these may have accounted for a significant percentage of the burn area in primeval times.

The third option, substitution of mechanical manipulation for natural fire, is technically feasible (at high costs), but it sacrifices most of the values of wilderness associated with natural ecosystems. The problem is that once trees are cut, the seed sources for many species are changed, and the choice of the new plant community rests largely in the manager's hands. The technical skills and tools of forestry then become necessary, even if the operation is noncommercial. The result is a forest managed by silviculture.

The fourth option, combining prescribed-controlled fire with carefully selected and monitored lightning fires, is the only alternative for the Canoe Area that responds to the objective of restoring the natural ecosystem with safety (Heinselman, 1971). The application of this alternative to large-scale northern conifer forest ecosystems is new to applied ecology because natural fires in northern conifer forests are different from prescribed fires in the ecosystems in which most burning experience has been gained so far (the southern pines, ponderosa pine, the sequoias, logging slash in the north, grasslands, etc.). Fires in living northern conifer forests are frequently combinations of intense ground fires and running crown fires. Often heavy litter and thick organic-matter accumulations are part of the fuel load. In some plant communities fires burned only at long intervals, perhaps 50–400 yr. Their ecological function was to eliminate the old forest and begin successions anew. We have had little experience with the deliberate use of such fires, but this would be essential if wilderness ecosystems such as those of the Canoe Area are to be restored and maintained. For example, the problems are different from those of restoring fire to the giant sequoias of California (Kilgore, 1972), because of the ecological requirement for frequent crown fires in the Canoe Area.

To restore fire to its natural role in the virgin forests of the Canoe Area a prescribed-fire program might be applied as follows:

1. The objective would be to duplicate the frequency and severity of natural fires by setting carefully prescribed fires in times and places when safety and control can be assured. To the extent that the natural fire regime is achieved, the resulting forest reproduction and age structure, plant-community composition, and wildlife-habitat conditions would be accepted as natural. Direct control of vegetative successions and a planned outcome would not be intended. The results of given burns, whatever they might be, would be neither "good" nor "bad," but simply natural. The emphasis would be on restoring the natural *environment*. There would be no intention of creating specific forest communities or wildlife populations.

2. There would be no seeding or planting of trees, shrubs, or herbs, nor should there be any need, because fire without cutting

is a natural factor. It is expected that a wide-range of vegetative effects would be achieved. Some forest stands would be totally killed. Others might receive only understory removal or light surface fire or be skipped entirely by the vagaries of fire behavior. This too would be considered natural and not a "failure."

3. The area burned per decade, and the timing of repeat burns, would be based on the actual fire history of the virgin forests. The objective would be to duplicate the long-term historic fire pattern as nearly as possible, considering safety and ecosystem size. An average of about 4200 acres per year might be burned in the remaining 420,000 acres of virgin forest of the Canoe Area. This would put the virgin areas on an overall "fire rotation" of 100 yr. Some stands would survive many of these fires, and many areas would be fired at longer or shorter intervals, as they were in nature. In poor fire seasons there might be little or no burning, while in good ones the quota for several years could be burned.

4. Selection of areas to be burned might be based on a combination of the following:

a. Location and incidence of actual lightning-caused fires in the virgin forests over the past few decades.
b. Identification of natural firebreaks (large lakes and streams, swamps, etc.) that limited the spread of past wildfires.
c. Planning of safe ignition sequences so that a whole series of burns could be carried out with maximum safety, using natural firebreaks and previous burns as barriers to escape.
d. Random selection of the order of firing of major units to avoid subjective choices based on other than ecologic, logistic, or safety factors.

5. No cutting of trees or artificial modification of the fuel situation would be done except locally when absolutely essential to ignition or control.

6. No road construction or use of tractors and bulldozed firelines would be allowed. Helicopters and conventional aircraft could be used for water bombing, equipment and crew transport, observation, communications, and related logistical work. Electric or aerial ignition could be used for large units if weather, safety, and ecological considerations required. (The policy on equipment and control measures would be to use only practices that leave no mechanical scars and have minimal unnatural effects.)

7. Both surface fires and crown fires would be set deliberately in standing virgin forest communities of all flammable types. In types such as red pine, where surface fires were common in the past, firing could be done during moderate burning conditions. Combinations of spring, summer, and fall burns might be used, based on lightning fire frequency in these seasons, to safely duplicate the natural regimes of crown, surface, and ground fires.

8. One necessary compromise with the natural regime would be burn size. Burning units could still vary greatly in size as they did in nature, but the occasional very large burns of 100,000 acres or more that occurred in the past could not be tolerated because the Canoe Area is now only a miniature of the primeval wilderness. An upper limit on burn size must be arbitrarily set. Several years' quota might still occasionally be burned in a single fire, if this seemed ecologically desirable, safe, and within tolerable size limits. We do not fully understand the effects of burn size, but it probably is a factor in wildlife habitat, seed sources, and other matters.

9. The burning of virgin forests is possible only during fire weather sufficiently severe to allow fires to move—at least slowly. Expertise must be developed to achieve natural ecological effects without losing control of such fires. Early in the development of a burning program it would be necessary to work conservatively with small units, large and effective natural firebreaks, and moderate weather. This work could build quickly on past research on fire

weather, fuels, and behavior, on prescribed fires for logging-debris reduction and site preparation, and on studies of burning beneath living red pine (Ahlgren, 1959, 1960, 1970; Beaufait, 1962; Buckman, 1964a, b; Haines and Sando, 1969; Johnston, 1971; Sando, 1969; Sando and Haines, 1972; Sando and Wick, 1972; Van Wagner, 1966, 1971; and many more). As the program developed, managers and researchers could jointly define acceptable burning weather, necessary fire barriers, size of units, etc. These questions would need to be decided on both ecological and practical grounds. With experience, some lightning fires probably could be allowed under carefully defined rules and included in burn quotas.

Some of the ecological and social consequences of such a program might be as follows:

1. Only one natural agent, fire, would be used, hence the ecosystem should respond naturally.

2. Nutrient cycling rates and pathways and accumulation rates of organic matter should approximate those of the primeval ecosystem.

3. There would be no mechanical scarring of the landscape, no stumps, no sawn logs or felled trees, no planted trees, and no other obvious signs of man's activities. The psychological, cultural, and aesthetic values of the virgin wilderness should therefore be conserved, because the ecosystem would in fact be as nearly natural as possible. In the words of the Wilderness Act ". . . the earth and its community of life . . ." would be as ". . . untrammeled by man . . ." as we could safely make it under present constraints. The land would retain ". . . its primeval character and influence . . ." and ". . . generally appear to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable. . . ."

4. The vegetation mosaic produced should include all of the virgin plant communities identified by Ohmann, Ream, and Grigal, plus those additional early postfire successional stages now missing because of fire exclusion. Eventually each should occupy a natural proportion of the landscape.

5. Gene pool values would be preserved to the maximum extent still possible.

6. Scientific and educational values for studies of large-scale ecosystem processes would be enhanced. It can be argued that since man would control the times and places of ignition, and the size of the burns, the system would be "unnatural." But there would be no direct control over local fire behavior or effects, over sources of plant propagules, or over other variables that determine vegetative or animal responses. Philosophically man would have some control, but only through conscious reintroduction of the very environmental factor that shaped the primeval vegetation. To the extent that fire frequency, intensity, and timing duplicated the natural regime, the effects should be natural. Major new scientific and educational opportunities would be created because there are now no areas within the Great Lakes conifer forest where a large natural ecosystem that includes fire can be studied. New learning opportunities for the public would also be an important consequence.

7. There are legitimate questions about our ability to implement this alternative with safety. However, a number of competent foresters and ecologists with fire experience believe the safety problem could be solved within a few years. A conservative approach would be to begin research on small burning units under marginal burning conditions, and then work gradually into better burning conditions and larger units. If the method is rejected without such trials, then the option of maintaining the natural ecosystem would be foreclosed without testing the only ecologically viable alternative that faces the fire-safety question.

8. It would be necessary to alert or evacuate recreational visitors near planned prescribed burns. Closure of burning units might also be required at times. However,

such burns would occur on only a very few days each year, and the area involved in any one year would be a tiny fraction of the Canoe Area (generally less than 1%).

9. If a prescribed fire got out of hand in severe fire weather there would be risk of loss of human lives and serious property damage. It must be realized, however, that present fire-exclusion policies carry the same or greater risks. A solution to the fuels problem in Wilderness Areas is required if this dilemma is to be removed.

10. Eventually many highly flammable budworm-killed fir stands and old jack pine forests would be consumed, and the fuels situation would return to natural levels. Consumption of dead and down wood and of standing dead trees would be good in summer and fall burns. Once fuels were reduced to natural levels, control of wildfires would become easier.

11. Spruce budworm populations should be brought down to natural levels after enough fir–spruce forests were burned to deprive this insect of unnatural concentrations of mature fir. Perhaps understories of old budworm-killed fir in aspen–birch communities were an important fuel source that in nature allowed aspen–birch stands to burn easily, and thus to regenerate. This may be one of those "large-scale ecosystem processes" we do not yet fully understand.

12. Restoring fire to the ecosystem should reestablish fire as a natural check on dwarf-mistletoe. Elimination of the host (black spruce) over large areas is required for short periods to reduce this parasite (Irving and French, 1971).

13. It is often argued that a prescribed burning program would be difficult to execute logistically. Manpower, equipment, and communications must be mobilized quickly, because suitable weather is often of short duration. Suitable weather also involves the possibility that wildfires may occur elsewhere. And sometimes there are only a few good burning days a year, or none at all. However, in the virgin forests there are many vegetation and fuel types, and areas suitable for firing probably could be located somewhere almost every year. Major opportunities to burn large units under extended drought conditions might occur only once in 5–10 yr. When these opportunities arose it would be desirable to capitalize on such weather, just as nature did. This would require assembling a large prescribed-burning team and keeping them on standby through the drought to utilize every good, yet safe, burning day. If burning programs became practice, a resident prescribed-burning specialist and a resident ecologist would be needed.

14. A need for public understanding of the objectives of a prescribed-burning program is obvious. Some say the public would never accept the idea of burning virgin forests in wilderness. New educational programs that maintained the public's concern about wildfire, yet built ecological understanding and acceptance of prescribed fire, would be necessary.

15. Habitat suitable for native mammals, birds, reptiles, insects, and other animal life would be created automatically, without conscious planning. Recent burns would provide browse and fruits for moose, deer, bear, hares, and small mammals. This in turn would assure a food supply for timber wolves and other canivores. Areas of mature forest would supply niches for pine marten, spruce grouse, and woodland caribou. Young aspen–birch forests would provide niches for ruffed grouse and beaver. Similar statements could be made for all other native species. In short, the primeval ecosystem recreated, should assure the full complement of wildlife naturally characteristic of the Canoe Area. Only a lack of some very large burns, or perhaps also of very extensive old forests, might introduce habitat factors on a gross scale not present in the primeval ecosystem.

16. The reintroduction of fire would present an exceptional opportunity for education programs to help visitors understand the complexity of natural ecosystems. Changes in wildlife populations and in

viewing opportunities could be an important aspect of such programs.

Assuming that a program of prescribed-burning and lightning fires such as that just outlined could be implemented, one question remains: How much time is there before the successional changes already initiated by fire exclusion will cause fuel accumulations and ecological changes that might preclude restoration of the natural system? Fortunately succession is slow enough in this near-boreal ecosystem so that 10–20 yr, or perhaps even 50, could elapse before fire exclusion causes irretrievable changes. It is true that unnaturally large areas are developing heavy fuel loads due to stand maturation, succession, budworm epidemics, local blowdowns, and other events related to fire exclusion, but these things are still natural in any given stand. What is unnatural now is mainly the deficiency of those young forests and recent burns that a natural fire regime would have produced in the 60 yr since fire protection became effective. Yet even now, 82% of the virgin forest dates from the fires of 1863–1864 or later (Table 4). Thus most stands are still less than 110 yr old, and large areas are only 60–90 yr old. Such forests are certainly not too old to respond naturally to fire. Research on the Little Sioux burn is already demonstrating this in several vegetation types. Some red and white pine stands may have fir–spruce–cedar understories capable of supporting fires of unnatural intensity, but such understories could still be burned out with carefully prescribed fires. But time *is* slowly running out. Our opportunity to restore this unique ecosystem will not last indefinitely. There is still time for research and administrative trials, but they must begin soon.

THE VALUE OF NATURAL ECOSYSTEMS

The ecological conclusions and management implications discussed here embody an object lesson that should not be missed. For we have not yet learned all that can be gleaned from even rather simple natural history studies in our larger Wilderness Areas, National Parks, and *de facto* natural areas. Some widely applicable concepts, such as the increasing species diversity and stability of maturing ecosystems, still need to be tested against large-scale real-world examples where the natural patterns are still discernible. Without such tests, whole bodies of ecological theory may rest on dubious premises, or fail to account for significant exceptions, and yet go unchallenged. Such tests are already impossible in most of Asia, Europe, and the eastern United States, where only fragments of natural terrestrial ecosystems remain. I suspect our large nature reserves and other relatively unmodified areas of the globe still hold the key to many new ecological principles. And it may be that only here can the full complexity of natural systems ever be worked out, because some processes are visible only at full ecosystem scales. Society can ill afford the further erosion of such areas in either size or diversity until the natural systems of the earth are understood much better than they are today. For if we are to understand the genetic, physiological, and ecological characteristics of organisms, we must have some examples of the ecosystems in which they evolved. In the end such understanding may be no less than the key to human survival.

ACKNOWLEDGMENTS

No field study as extensive as that reported here is conducted without help from many. I gratefully acknowledge all who aided me. My wife, Frances, and Albert Swain deserve special thanks for their help and companionship in the field, without which the data could not have been obtained, and for much other assistance. I also thank the following for help in work planning, general support, technical advice, analyses, and field work: David B. King, James Morgan, Robert Lucas, Charles Cushwa, Lewis Ohmann, Robert Ream, Herbert Wright, Charles Wick, and Edward Stone. Many members of the Superior National Forest have my thanks for sharing their records and for logistical support.

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