WILDFIRE IN THE TAIGA OF ALASKA

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I. INTRODUCTION

The ecological effects of fire in the taiga of Alaska were studied by Harold Lutz in the early 1950's and reported in his much used and quoted paper, "Ecological effects of forest fires in the interior of Alaska" (Lutz 1956). His work has been used as a "bible" by resource managers, and very little effort has been put into continuing fire effects studies. Recently, there has been renewed interest in the effects of fire in Alaska. A bibliography on fire in far northern regions was compiled by Larson in 1969. In 1971, the Alaska Forest Fire Council and the Society of American Foresters sponsored a symposium, "Fire in the Northern Environment" (Slaughter et al. 1971), which brought together a number of research and management personnel and summarized the current status of research and management related to fire in Alaska and parts of northern Canada. My paper draws heavily on the symposium in determining the present status of knowledge on fire effects in the Alaskan taiga. I acknowledge the assistance of several of my colleagues at the USDA

Forest Service, Institute of Northern Forestry, who prepared sections of this paper--specifically Dr. Charles T. Cushwa, Program Leader, the wildlife section; Dr. John C. Zasada, Silviculturist, the autecology section; Roy Beckwith, Principal Entomologist, the section on insects; and Richard J. Barney, Principal Fire Control Scientist, the section on fire history. In addition to a review of the literature, I have included unpublished data and information gathered in several years of research in the Alaskan taiga by the staff of the Institute of Northern Forestry.

A. Vegetation

The northern boreal forest of Alaska is primarily open, slow-growing spruce interspersed with occasional dense, well-developed forest stands and treeless bogs. This type of regional vegetation is referred to by the Russian term "taiga" to differentiate it from the closed, fast-growing forests of the more southerly region of the boreal forest zone. In Alaska the taiga extends from the south slope (Fig. 1) of the Brooks Range southward to its border with the coastal forests, eastward to the border with Canada, and westward to a maritime tree line very close to the Bering and Chukchi Seas. Within this area of 138,510,000 hectares, approximately 32% (43,000,000 hectares) is forested, but only about 7% (9,000,000 hectares) is classified as commercial forest land (Hutchison 1967). The unforested land consists of extensive bogs, brush thickets, grasslands, sedge meadows, and some alpine tundra.

On the warmest, well-drained sites, the forests consist of closed spruce-hardwood stands; white spruce (Picea glauca [Moench] Voss), paper birch (Betula papyrifera Marsh.), and aspen (Populus tremuloides Michx.). On poorly drained sites, including those underlain by permafrost and on north facing slopes, the dominant forest species is black spruce (Picea mariana [Mill.] B.S.P.). In the wettest sites associated with black spruce is the tamarack (Larix laricina [Du Roi] K. Koch). Balsam poplar (Populus balsamifera L.) and its subspecies, black cottonwood (P. balsamifera ssp. trichocarpa [Torr. & Gray] Brayshaw), form extensive stands on the floodplains of the major rivers.

On the broad expanses of the foothills and upland areas are extensive areas of open stands of white spruce and black spruce with willows, resin birch (Betula glandulosa) Michx.), ericaceous shrubs, Cladonia lichens, feather mosses, and sphagnum mosses. Throughout the taiga, the forest stands are interspersed with bogs of many types. These bogs vary from the rich grass and sedge types to the oligotrophic sphagnum bogs. Of great extent is a tussock sedge type with sphagnum mosses, low ericaceous shrubs (especially Ledum groenlandicum Oeder and Chamaedaphne calyculata [L.] Moench). The widely scattered black spruce and tamarack are commonly referred to as "muskeg" (see Drury 1956 for an extensive discussion of the bog types in interior Alaska). Also interspersed throughout the bogs and other low lying areas are numerous small lakes and ponds in various stages of hydrarch succession.

Shrub thickets are common, especially near altitudinal and latitudinal limits of the trees. These are dominated by alder (Alnus crispa [Ait.] Pursh and A. tenuifolia Nutt.), Salix spp., and resin birch. This latter species may form nearly pure stands of extensive areas at tree line.

Grasslands are not common; but in some areas, especially in the foothills, Calamagrostis canadensis (Michx.) Beauv. and Festuca altaica Trin. occur on windy sites. Areas repeatedly burned at lower elevations also sometimes develop into meadows dominated by C. canadensis, Rosa acicularis Lindl., several species of Carex, and many herbaceous species.

The distribution of the various forest, bog, and shrub types is closely related to altitude, slope and drainage, presence or absence of permafrost, and to the past history of forest fires, which apparently have been prevalent throughout the history of the development of the taiga in Alaska.

The forests of interior Alaska represent a nearly natural situation. Before 1900, there was virtually no utilization or disturbance of the resource except by the aboriginal people. With the coming of the gold seekers was the first use of the interior Alaska forest for saw logs and for fuel to heat and run power plants, steamboats, and mining equipment. However, because of the very limited transportation system, this utilization was limited to areas adjacent to the major rivers and to major centers of population and was of short duration in most areas. Since that time, there has been no major development of a forest industry in the taiga of Alaska, and at present, forest utilization is limited to local sawmills that provide only a small percentage of the timber needs of the inhabitants. If one considers fire primarily as a natural phenomenon, then, most of the vegetation of the taiga of Alaska remains relatively undisturbed by man.

B. Environmental Factors

1. Climate

Most of the taiga of Alaska lies within a zone dominated by continental climatic influences (Watson 1959), characterized by extremes of temperatures and low precipitation. Large fluctuations from the mean are common. Funsch (1964) summarized growing season precipitation and temperature data for weather stations within the taiga. At Fort Yukon in the center of the Yukon Basin, temperature extremes varied from -59°C to +37°C. Within the taiga region, daylight varies from 20-24 hours in the summer months to 0-4 hours during the winter. Mean annual temperatures range from -10°C in the northern portions to +2°C in the southwestern regions. Precipitation over most of the area is light, ranging from 165 mm at Fort Yukon in the interior to 750 mm at Illiamna, in the wet southwest portion. The ground is covered by snow from mid-October to mid- or late May, but snowfall accumulation is relatively light, ranging from 75 cm in the Yukon Basin to as much as 250 cm in the coastal areas. Patric and Black (1968) summarized the climatic data for Alaska according to Thornthwaite's (1931) evapotranspiration system and found that most of the taiga fell within zones having a potential evapotranspiration of 14-18 inches (356-457 mm), with a "typical" interior Alaska climate of $D\ C'_2\ dc'_2$; i.e., semi-arid, warm microthermal, little or no rainfall surplus, temperature efficiency normal to warm microthermal. Trigg (1971) calculated values of precipitation effectiveness index (PEI) and temperature effectiveness index (TEI) for the main part of Alaska and combined them into 16 subclasses which he found to be useful for fire weather forecasting.

Regions ranging from hot-arid to warm-dry in his classification scheme are areas of high fire frequency. The growing season over most of the region is short, ranging from 90 days in the interior to 125 frost-free days in the southern coastal area. However, because of the long days, warming is rapid and growing degree days [annual sum of daily mean temperatures above 6°C (43°F)] vary from 940°C (1694°F) for Fairbanks to 620°C (1117°F) for Illiamna at the southwest extreme of the taiga forests (Funsch 1964). High summer temperatures with little night cooling, long periods with little or no precipitation, and frequent lightning storms are three factors that contribute to the high frequency of forest fires.

2. Soils

The soils of the taiga of Alaska have been described in a general way by Kellogg and Nygard (1951) and Lutz (1956). Specific areas in the taiga region have been mapped and the soils described in detail by Rieger (1963) and Rieger et al. (1963). Forest soil types of the Tanana and Yukon valleys have been classified and described by Wilde and Krause (1960). In general, the forest soils are shallow and profiles only poorly developed. Bedrock is primarily a micaceous schist; and most is overlain by loess, sand, outwash, and moraine formed during the Pleistocene, by organic deposits formed in bogs or combined with redeposited loess, or by newly formed river alluvium. Distinct Podzols have developed in the wetter areas south of the Alaska Range, and a Subarctic Brown forest soil is predominant north of the Alaska Range to the latitudinal tree line. Bog soils or Half Bog soils (Wilde and Krause 1960) predominate on wet sites over most of the lowland, and a highmoor peat is common on upland north-facing slopes.

Loess is widespread in a broad band north of the Alaska Range (Péwé 1968) and, consequently, soils are highly erodible when stripped of protective cover. Much of the loess has been transported to lower elevations and mixed with organic material and frozen (Péwé 1957). Permafrost, or permanently frozen ground, is a unique feature of the soils of much of the taiga of Alaska. In the southern sections of the taiga, permafrost is sporadic, found only in the coldest sites and usually only in bogs or on north slopes under thick organic layers. North of the Alaska Range, permafrost is discontinuous, occurring in most of the sites, but lacking on south-facing slopes and in freshly deposited alluvium. In much of the frozen layer, water has been incorporated as wedges or lenses of pure ice. In some soils, this may amount to as much as 50% of the substrate by volume. In other areas, usually in the coarser soils, permafrost contains little or no ice.

In most areas of the taiga, permafrost and vegetation are in a delicate equilibrium. The distribution of vegetation is largely related to the permafrost, or lack of it, and to some extent the distribution of permafrost is related to the presence of vegetation. If the overlying insulating layer of vegetation is disturbed, the permafrost may begin to melt and the active layer (the annual layer of thaw) to thicken. If there are large masses of ice within the permafrost, when these melt, the released water may form ponds, which tend to melt the permafrost along the edges, creating "thaw ponds," a common feature of low lying wet areas in the taiga of Alaska. Another important aspect of terrain underlain by permafrost is thermokarst. If permafrost, heavily laden with ice, is thawed, the surface will subside in a pattern related to the underlying ice, creating a system of deep holes, polygonal trenches, and rounded mounds, a unique landscape termed "thermokarst."

An important influence of permafrost in Alaska is that of holding ground water near the surface. The permafrost forms an impervious layer, preventing percolation through the soils of surface runoff from precipitation. Thus, the presence of many bogs and extensive wet areas in a region with low precipitation is due, in large part, to the underlying permafrost. However, the statement sometimes encountered that the interior of Alaska would be a desert if it were not for the permafrost is untrue. The best sites for tree growth are on south-facing slopes or on coarse river alluvium where there is no permafrost.

Aspect and slope are of special importance in the distribution of vegetation and soils in interior Alaska. Krause et al. (1959) compared the vegetation and soil on two adjacent stands on north- and south-facing slopes near Fairbanks. They found that with similar parent material, loess over schist, a Subarctic Brown soil had developed on the south-facing slope, whereas on the north-facing slope, there was a Half Bog soil underlain by permafrost. On the south-facing slope was a well-developed white spruce stand (diameters of 25-35 cm) with a moss layer of Hylocomium splendens (Hedw.) B.S.G. On the north-facing slope, there was an open black spruce stand with 8-cm diameter trees and a moss layer of predominantly Sphagnum spp. Both stands were 115-130 years old and were probably established after the same fire. Sharp contrasts in vegetation and soils such as this, related to topography rather than fire history, are common in the taiga of Alaska.

C. Fire

1. History of Past Fires

Limited evidence indicates that aboriginal man was an important cause of wildfires in the northern regions (Lutz 1959). He used fire in camping, hunting, signaling, and combating insects. With the appearance of contemporary man in the northern areas, fire activity increased, especially during the gold rush years at the turn of the century. Fire used for land clearing, as well as from accidental causes, burned considerable acreages during this period.

In the 1940's, with the advent of formal fire control records, more precise measures of the occurrence and magnitude of fires in the taiga became available. Before that, reports were of a more general nature. From 1893 to 1937, 19 fires were reported to have burned in excess of 2,470,000 hectares (6,100,000 acres)(Lutz 1956). During the period of 1898-1940, an estimated 405,000 hectares (1 million acres) of the taiga were burned annually (Lutz 1953). Recently, however, it has been suggested that this early estimate was too low and that an average of from 0.6 to 1.0 million hectares (1.5 to 2.5 million acres) were burned each year between 1900 and 1940 (Barney 1971a).

Based on the compiled wildfire statistics for the period 1940-69, the average annual burn is approximately 400,000 hectares (1 million acres)

(Hardy and Franks 1963; Barney 1969, 1971b). During this 30-year period, over 70% of the fires were man-caused; the rest were caused by lightning. Although man caused the most fires, lightning was responsible for 78% of the acreage burned. Barney (1971a) summarizes the fire records for the 1940-69 period:

> During the decade of the 1940's, 1,138 fires burned 12.4 million acres in the interior of Alaska. The decade of the 1950's saw an increase in the number of fires to 2,583, but burned acreage was reduced to approximately 10.7 million acres. The 10-year fire total for the 1960's was generally similar to the preceding decade with 2,380 fires recorded. Acreage burned during this most recent decade, however, took a significant drop to about 6.4 million acres. This acreage-burned figure was about half of the reported burn of the 1940's. There has also been a decrease in the average size per fire by decade with the 1940's recording 10,906 acres per fire; 1950's, 4,137; and the 1960's, 2,674 . . . .

2. Buildup, Weather, Frequency

In general, the fire season in interior Alaska is defined as April 1-September 30. This time span covers the period of occurrence of the majority of fires. Generally the months of May, June, and July are the most active, coinciding with the major periods of high temperatures and low humidities and precipitation. Precipitation during these 3 months ranges from 1.7 to 107 mm (0.07 to 4.23 inches) at Fairbanks (Hardy and Franks 1963). Longer daylight hours and higher winds also contribute to the increase in fire danger conditions. Buildup indexes generally peak the latter part of June or the first part of July (Barney 1967). The buildup index is essentially a cumulative drying factor and might be compared to a drought index. Periods of severe burning conditions extend for about 4-5 weeks. During this time, the daily fire spread indexes also reach their maximums (Barney 1968). Fires, however, can occur whenever fuels are not covered with snow and are exposed to several hours of warm temperatures and drying winds. Fire and fire danger records have not been kept long enough to ascertain if any cycle exists in fire activity and burning conditions. However, from limited available research, one might infer that a 12- to 17-year fire pattern exists. Certainly, drought situations correlate with general fire activity.

3. Areas and Types Burned

For fire control purposes, the vegetative types of taiga have been broken into five general categories: conifer, conifer-broadleaf, broadleaf, tundra, and other (mostly brush). Although more detailed classes are available, the above classification allows pooling of several sources of data to arrive at some estimate of percentages of cover type burned. Essentially, there are about 90 million hectares (221.6 million acres) classed as potentially burnable in the interior of Alaska. With the exception of a few isolated stands, the vast majority of interior Alaska has been estimated to have been burned over in the last 200-250 years (Barney 1971a). On the basis of recent statistics and the assumption that 25% of the burning is actually reburn and that 0.6 million hectares (1.5 million acres) has burned each year, we can estimate that 22 million hectares (54 million acres or 1/4 the total area), essentially virgin forest has burned since the turn of the century. Table 1 gives an estimate of the area of vegetation types

Table 1.--Estimated areas of vegetation types burned in the taiga of Alaska from 1900 to present (based on Barney, 1971a).

Type	Area (millions of hectares)	Percent of total burn
Conifer	7.9	35.9
Conifer-broadleaf	3.3	15.0
Broadleaf	0.4	1.8
Tundra	9.4	42.7
Other types	1.0	4.6
Total	22.0	100.0

burned since 1900. The special significance of these figures is that, of the total estimate of 22 million hectares burned, 47.3% are in the two treeless classification groups. In a review of cover types burned in fires between 1957 and 1961 (unpublished office report (1964) on file at Pacific Northwest Forest and Range Experiment Station, Juneau), it was determined that of the 5.9 million acres burned, 3.1 million were forested and 2.8 million, non-forested. In the same detailed study of 26 areas burned within that same period, it was found that less than 0.5% of the cover burned could be classified as "commercial" forest land capable of producing at least 1.4 cubic meters of wood per hectare (20 cubic feet per acre) per year. In summarizing the fires on National Forest land in Alaska for the period 1956 to 1967, Noste (1969) found that for the Kenai District of the Chugach National Forest, the only district within the Alaska Taiga Zone, the only large acreage burned was in the non-commercial black spruce type. One fire in this type accounted for more than 60% of all the acreage burned in coastal Alaska during the 11-year period. Thus, it is obvious from these figures that fires in Alaska are primarily in tundra, bog, and non-commercial forest sites and that very little timber of commercial value or land capable of producing commercial timber has been burned.

Man-caused fire activity is centered around population centers. The lightning fires are scattered throughout the taiga. Virtually every acre of vegetation has been touched by fire in the interior, with the possible exception of some floodplain locations, especially islands. The majority of man-caused fires occur in the lower elevations, but more lightning fires occur at higher elevations. The southerly exposures account for the greatest amount of fire activity.

Organized fire control activities began in Alaska in 1939 with the Alaska Fire Control Service (Robinson 1960). This initial effort was soon strengthened, providing additional men and equipment. In 1959, smoke jumpers were used to combat fires in the interior. Aircraft using retardants to "bomb" fires came into use about that same time. Since the 1950's, fire control capabilities have improved. With the advent of increased civilian helicopter use came an increased mobility for the fire fighting organization. Better communications, improved fire detection, fire weather forecasts, new retardants, water dropping, and helitack crews all combine to make a stronger and more effective fire control organization.

In recent years, then, man has made a much greater effort to control fires and is now coming closer to excluding fire completely from the taiga. Statistics show a downward trend in acreage burned, but the number of reported fires increased. The latter is partly because of improved detection; however, fire control efforts are making a considerable impact in reducing the acreage burned. Initial trials are now in progress to seed clouds for both the suppression of lightning and the increase of precipitation in an attempt to lower the hazard as well as extinguish some fires. Obviously, man is ever increasing his ability to get ahead of nature in the control of wildfire.

II. ECOLOGICAL EFFECTS ON VEGETATION

A. Successional Sequence and Relationships

The successional sequence following fire in the Alaska taiga is complex and related to a number of parameters, the most important of which are slope and exposure, presence or absence of permafrost, available seed source, severity of burn, and the autecological relationships of species. Although there are some elements of chance in the successional patterns after an individual forest fire, general patterns recur throughout the Alaska Taiga Zone. These patterns are similar to those found in more temperate regions during early stages of succession; but with later stages, the complexities of permafrost-vegetation relationships create conditions somewhat different from those found in more southern climates. Also, there seems to be more of a tendency for a burned plant community to replace itself directly after fire without going through several intermediate stages. Because of the high frequency and extent in the past of fires, successional stages often burn before a stable situation is reached. It is very difficult to find old, uneven-aged forest stands that one could definitely consider to be climax.

There are two general types of succession that occur in the taiga of Alaska, and each will be described in some detail. They relate in large degree to the presence or absence of permafrost or at least to the presence or absence of poorly drained soils.

1. Dry Sites

On dry sites such as south-facing slopes or coarse river alluvium, the usual forest vegetation is white spruce, paper birch, aspen, balsam poplar, or some combination of these species. Depending upon the severity of the fire, the usual succession is re-invasion by light seeded species such as *Epilobium* and willow shrubs, especially *Salix scouleriana* Barratt and *S. bebbiana* Sarg., and an almost immediate replacement by tree species. Both aspen and birch will regenerate from the original trees by sprouting or root suckers. The herbaceous or shrub stages last only until they are overtopped by the tree species. If a seed source is available, white spruce will also invade within a year or two of the fire, as is evidenced by many even-aged spruce stands. However, in most extensive fires seed is not available; also, white spruce may produce abundant seeds only once in 12 years. Aspen and birch stands dominate most of the south-oriented uplands in the interior of Alaska. Aspen occurs on the driest, warmest sites; these are generally south-southwest facing slopes (Lutz and Caporaso 1958, Gregory and Haack 1965). Balsam poplar and black cottonwood also occur on these sites, but they are primarily found adjacent to rivers (Hutchison 1967, Viereck 1970). The paper birch type occurs on cooler, moister sites than aspen. The aspects upon which this site predominates are those from southeast to northeast and southwest to northwest (Gregory and Haack 1965).

Eventually these stands are replaced by spruce, but the process is usually a slow one. Spruce seed is often limited, distribution is not great over large areas, and seedbed conditions are not optimum for white spruce regeneration. Also, Gregory (1966) has shown that it is difficult for seedlings to become established because of the smothering effect of the birch litter. On the south-facing slopes, aspen is gradually replaced by white spruce--few aspen stands are over 100 years old and these usually have an understory of white spruce. Paper birch is replaced by either black spruce or white spruce. Mixed stands of birch and spruce of up to 150 years of age are common in the uplands.

Because of the frequency of fire in the uplands, what happens to the older spruce stands is not entirely known. Older white spruce stands exist only on the islands of floodplains where they are protected from fire by the river. Here, 350-year-old white spruce stands have been found. These river bottom spruce stands may persist as a result of flooding that periodically eliminates the moss layer, preventing the development of permafrost layers (Viereck 1971). Normally on the floodplain, the successional sequence is from white spruce to black spruce and bog as the permafrost layer develops in the spruce stands (Drury 1956, Viereck 1971). It has been suggested that, even on the upland, old white spruce stands may be replaced by black spruce and bog. Wilde and Krause (1960) have stated, "The poor regeneration of white spruce on these moss-covered soils casts doubt on the climax nature of this species in the subarctic environment. A wide opening in the canopy is likely to cause invasion by Sphagnum spp. and black spruce, an association which would preclude the regeneration of white spruce." This is in contrast to more southern areas of the boreal forest where it is considered that white spruce would be the prevailing vegetation if it were not for repeated forest fires (Raup and Denny 1950, Rowe 1971).

Occasionally, where black spruce stands have developed on coarse alluvium or outwash, or on thin rocky soils, a severe fire may result in the replacement of black spruce stands by aspen which are established as seedlings or by root suckers. Often in these stands, black spruce may reseed at the same time as the aspen; but because of the rapid growth of aspen and the slow growth of black spruce, these stands develop into dense aspen stands with a low understory of black spruce. Thus, black spruce may occur on these temporarily dry sites, but with the development of the black spruce and moss and an impervious frozen layer, these sites will revert to more mesic conditions.

2. Wet Sites

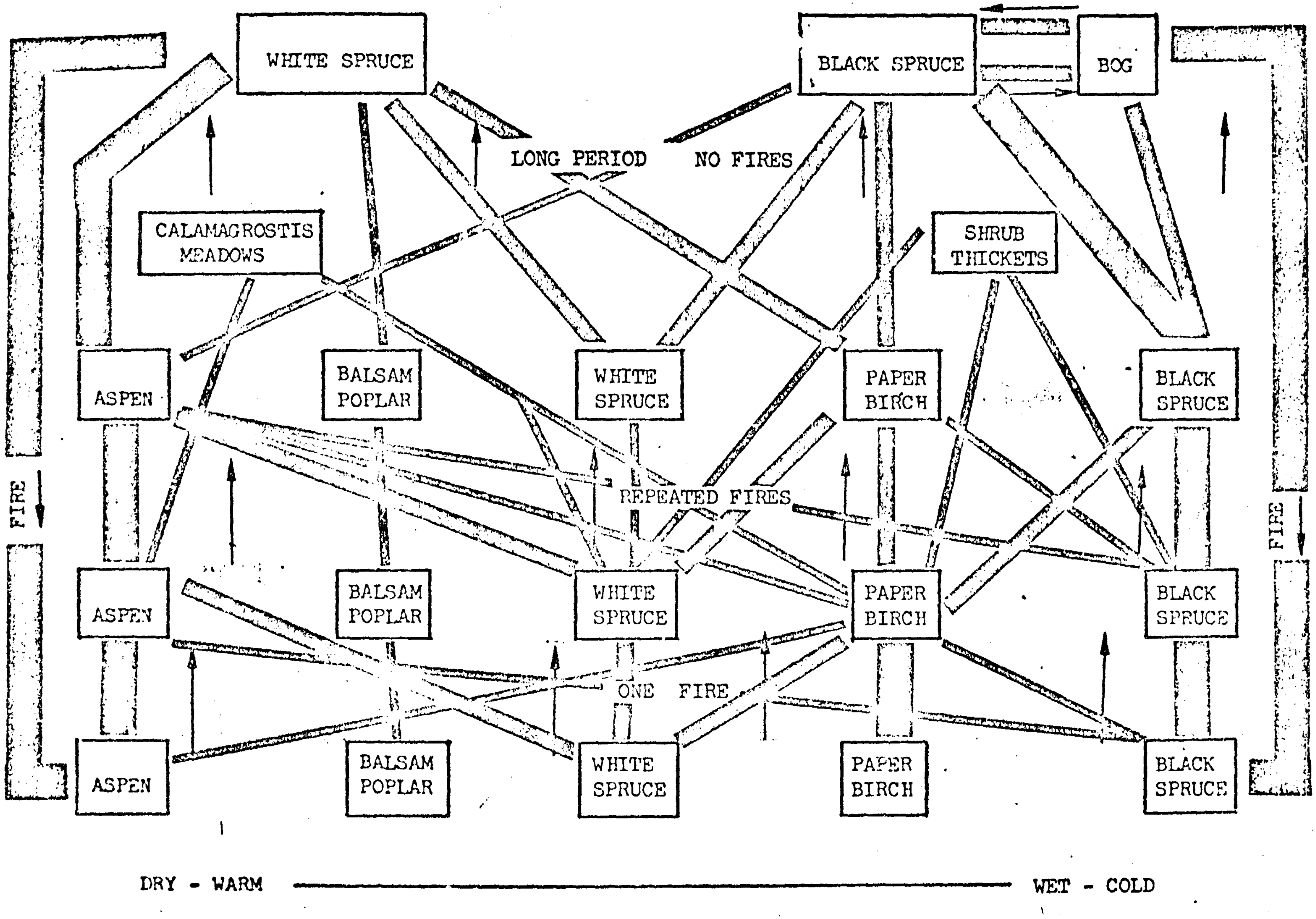
The forest succession on wet sites, poorly drained sites, and permafrost sites follows a somewhat different sequence. These sites, occupied primarily by black spruce stands, muskegs, and bogs, are the most widespread in interior Alaska and are the most frequently burned. Because of the presence of a permafrost layer close to the surface of the ground, fire does not penetrate deeply, even though it is hot enough to kill the trees. Recovery is rapid in these stands and occurs mostly from vegetative reproduction of the shrubs, sedges, and grasses that existed in the stands before the fire. Thus, within 3 or 5 years after the fire, the burned areas may have a nearly continuous cover of Eriophorum spp. and grasses, primarily Calamagrostis and Arctagrostis. At the same time, shoots from the roots of Salix spp., Vaccinium uliginosum L., and Ledum spp. develop rapidly. If Betula papyrifera was growing in the original stand, it often will develop from stump sprouts. Recovery of mosses, especially the sphagnum mosses, is slower, and pioneer mosses and liverworts such as Polytrichum spp., Ceratodon purpureus (Hedw.) Brid., and Marchantia polymorpha L. may dominate the moss layers for many years.

Recovery of the lichen layer, especially that of the climax species of Cladonia, is very slow; and estimates of 50-150 years for recovery of the full lichen mat following fire are common in the literature. However, few data actually exist to document the time required for lichen recovery after fire in Alaska.

Because of the semi-serotinous cones on the black spruce, tremendous quantities of spruce seed drop to the ground during the first and second summer after a fire. These quickly germinate and the pattern is that of rapid replacement of the black spruce type by another very dense black spruce stand. This is the most common pattern seen in the fire succession in the forests of Alaska. In later stages of black spruce development, if fire is not repeated, there is often a development of a thick sphagnum mat, paludification of the site, and eventually the development of open black spruce/sphagnum stands or, in some cases, open bogs with scattered black spruce, tamarack, and birch, the locally termed "muskeg."

If fire is repeated on the same site, a nearly permanent grassland of Calamagrostis canadensis and herbaceous species such as Epilobium angustifolium L. and Delphinium glaucum S. Wats. may result on drier sites. Near tree line, and in some of the wetter sites, repeated fires may result in a shrub thicket of Alnus crispa, Salix spp., and Betula glandulosa.

Figure 2, modified from Lutz (1956), indicates the successional sequence usually followed after a fire in Alaska.



WHITE SPRUCE
BLACK SPRUCE
BOG
LONG PERIOD
NO FIRES
CALAMAGROSTIS MEADOWS
SHRUB THICKETS
ASPEN
BALSAM POPLAR
WHITE SPRUCE
PAPER BIRCH
BLACK SPRUCE
REPEATED FIRES
ASPEN
BALSAM POPLAR
WHITE SPRUCE
PAPER BIRCH
BLACK SPRUCE
ONE FIRE
ASPEN
BALSAM POPLAR
WHITE SPRUCE
PAPER BIRCH
BLACK SPRUCE
FIRE
FIRE
DRY - WARM
WET - COLD

B. Present Mosaic of Vegetation

The successional sequence described in the above section and the relative frequency of fires in the last 200 years have resulted in a mosaic of vegetation in the interior of Alaska that is closely related to past fire history. Old fire boundaries are apparent when scanning the hillsides or when studying aerial photographs. Nearly all of the stands are less than 150 years old, and most represent earlier stages of fire succession. Thus, paper birch and aspen cover large areas of the drier sites in the upland, whereas dense young stands of black spruce are common in poorly drained upland sites and in the lowlands. At present, there are no accurate figures as to the relative percentage of area covered by each of the major types within the taiga. According to Hutchison (1967), of the 43 million hectares of forested land within the taiga, 79% is of non-commercial forests, primarily black spruce and open white spruce stands near tree line. Of the area classified as commercial, which totals 10.5 million hectares, white spruce accounts for 57%; paper birch, 23%; aspen, 11%; and balsam poplar and cottonwood, 9%.

Although the distribution and abundance of these types are related in some degree to chance following fire, much is owed to the autecology of the individual species, especially to their regenerative capabilities and their site requirements.

C. Autecological Relationships

The revegetation of a burn in the Alaskan taiga is related to two basic sets of variables. First, the site will set limitations on the plant community and thus the potential number of species available to colonize an area. Second, the success of the species to colonize an area is dependent upon its reproductive characteristics.

Reproduction of the tree species and associated shrubs and herbs is complex owing to the many factors which control this variable, so we will consider seed and vegetative reproduction separately.

1. Seed Reproduction

Obviously, seed supply is of basic importance and, where environmental conditions do not limit germination and seedling growth, it is the factor controlling this type of reproduction. The source can be either seed dispersed onto the burned seed bed or seed stored in the seed bed which is not burned nor rendered nonviable by the temperatures created by the fire.

In the taiga of Alaska, information exists only for seed dispersed into the burn. Zasada (1971) summarized the information for tree species. The most important aspects of his paper and the limited information available on other woody species are summarized below.

(a) Most wildfires occur during the months of June and July. This is approximately at the time (mid-June) of seed ripening and dispersal of aspen and balsam poplar seed, but definitely before ripening of the white spruce seed, and well before the occurrence of significant amounts of paper birch seed. Thus, immediately after a fire, a seed source for aspen and balsam poplar may exist on both living and dead trees within the burn and on trees in adjacent, unburned stands. White spruce and paper birch seed must come from living trees within the burn or stands adjacent to the burn. It is not likely that seeds in cones or catkins would mature after death of the parent tree by fire. Fires also occur prior to black spruce seed maturation. However, because of the semi-serotinous cones of black spruce, there are always some seed available after the burn except in a few exceptional cases, where the burn is hot enough to destroy the cone and its seed. In central Alaska, in one heavily burned black spruce stand with a densicy of 909 dead trees per hectare, based on the seed remaining in 16 trees, it was estimated that the residual seed numbered 8,200,000 per hectare. Germination percentages of this seed for each tree ranged from 8.3 to 75.8 with an average of 41% for 6,400 seed, which meant that there were approximately 3,400,000 viable seeds per hectare left on the trees following a heavy burn.

(b) The periodicity and quantity of seed crops vary significantly between hardwood and coniferous species. Birch, which depends heavily on seed as a means of reproduction (Gregory and Haack 1965), produces vast quantities of viable seed at least once every 4 years (Zasada and Gregory 1972). Although no information is available for aspen and balsam poplar, the quantity and periodicity of seed crops appear similar to birch. The interval between good white spruce seed crops appears to be 10-12 years, and the quantity of seed produced in these good seed years is 10-20% of that produced by birch (Zasada and Viereck 1970). Periodicity of seed crops in black spruce is less important than in other species because some seed is always available in the semi-serotinous cones; however, intervals between good crops are probably roughly the same as for white spruce. At present, no data exist on seed production in black spruce in Alaska.

Another factor to be considered in relation to fire and periodicity of seed crop in white spruce is that of a correlation between bad fire years and increased seed crop the following year. Zasada and Gregory (1969) have shown that one factor of importance in initiation of flower buds in white spruce is a warm, dry period in June and the first half of July. These same conditions also create high fire danger potential. For the brief period of record (1957-71) of seed production, 1958 and 1970 were the best seed years, whereas 1957 and 1969 were the most destructive fire years. A similar correlation has been noted for Pinus sylvestris L. by Uggla (1958), who stated, "There exists a tendency toward a coincidence of hot summers, good seed years, and years with many forest fires." Of course, there are many factors involved, but the correlation between severe fire years followed by heavy seed production needs to be investigated in more detail.

Another aspect of seed crop periodicity which has been documented for white spruce and may also be important for other species is the production of good cone crops containing poor seed. Apparently the seed fail to mature because of climatic conditions. In interior Alaska in 1970, stands above 370-430 meters in elevation had excellent cone crops but very low percentages of viable seed (Zasada, unpublished data on file at Institute of Northern Forestry, Fairbanks, Alaska).

(c) Tree seed dispersal in the taiga is accomplished primarily by wind; unknown and perhaps significant quantities are dispersed over snow and by water, mammals, and birds. Aspen and balsam poplar are dispersed the greatest distance, followed by paper birch, white spruce, and black spruce. The relationship of the number of seeds reaching a given location in a disturbed area and the quantity of seed produced is important and has been considered in detail for birch by Bjorkbom (1971).

Thus, the size and shape of the fire may be important factors in determining the invading tree species. Small burned areas could be colonized by white spruce dispersed from trees around the edge of the fire, whereas invasion of white spruce into large burned areas is an extremely slow process unless pockets of unburned white spruce remain within the burned areas. In a study in the Caribou-Poker Creeks Research Watershed near Fairbanks, Quirk and Sykes (1971) suggested that stringers of mature white spruce are less susceptible to fire than the surrounding successional stands and thus may remain as a seed source when the surrounding stands are burned. Effective dispersal distance for white spruce has been determined to be approximately two tree heights (45-60 m). Extensive fire areas are easily recolonized by black spruce from residual seed, and by aspen, balsam poplar, and birch from long distance transport of seed and from vegetative reproduction. Although Rowe (1971) considers white spruce in Alaska to be a fire-adapted tree, it seems to have no reproductive behavior that is adapted to invasion of large burned areas.

The above discussion has considered only tree seed. No information is available concerning seed production, survival, dispersal, and mobility for shrub and herbaceous species.

Salix is one of the most important groups of shrubs to invade burned areas. Some *Salix* species, such as *Salix alaxensis* (Anderss.) Cov. and and *S. scouleriana*, produce ripe seed as early as the end of May, whereas others, such as *Salix glauca* L., disperse ripe seed from late July until the end of August. *Salix* seed, as with aspen and balsam poplar, are viable only for a few weeks (USDA Forest Service 1948). Therefore, the time of burn may be important in determining which species of willow will colonize the burn the first year.

The second possible source of seed for regeneration following fire is organic matter and soil; longevity of seed stored there and whether or not it is rendered nonviable by the temperatures generated by the fire will determine the availability of this seed. There seem to be two general categories of seed.

Tree, tall shrub (alder, willow), and certain small shrub (e.g., *Vaccinium* spp.) seeds occupy one category. The longevity of these seeds is generally short under natural conditions, lasting from a few weeks (willow) to probably no more than several years (white spruce). In addition, the physical characteristics of these seeds, e.g., thin, soft seed coats and little or no endosperm, seem to provide very little protection to the embryo from high temperatures.

In contrast, the second general category of seeds has relatively thick, hard seed coats and more endosperm surrounding the embryo than short-lived seeds. The longevity of long-lived seeds is not known, but the thick seed coat suggests an impervious nature and perhaps longer period of viability under natural conditions. Although no data are available for Alaska for the effect of fire on seed germination, seeds from elsewhere with similar characteristics are known to be fire resistant; and, in some species, their germination is stimulated by fire (Cushwa et al. 1968). Among others, genera included are Viburnum, Rosa, Cornus, Geocaulon, Corydalis, and Shepherdia. In one burn studied in Alaska, Corydalis sempervirens (L.) Pers. seed germinated within a few weeks after a burn, apparently from residual seed in the burned organic layers.

The environmental factors which regulate temperature and moisture and which affect seed germination and seedling establishment are the next important aspect of seed reproduction. Mineral soil appears to be the most suitable seed bed for germination of all species of Alaska taiga trees and most of the shrubs. Organic seed beds can provide excellent conditions if they remain wet throughout the critical period; however, this probably rarely occurs on most burned sites in Alaska. When seed beds are dry, temperatures as high as 70°C have been recorded at the surface of the unburned moss-organic matter on south slopes. The maximum thickness of organic seed beds which can be tolerated is determined in part by the ability of the radicle to penetrate to a more stable moisture supply such as exists in the mineral soil; general observations show that thicknesses greater than 5-8 cm will prevent rapid establishment of white spruce and most likely all tree species.

Lutz (1956) observed considerable variation in seed bed conditions in burned areas. He reported that an average of 35% of burned areas had exposed mineral soil. However, the variation was extreme (0-100%) and would appear to indicate that each burn must be considered as a separate case. With regard to seed bed conditions, it is probably more realistic to consider the organic matter thickness in the unburned stands. In mature hardwood stands, organic matter thickness averages 7-10 cm. In white spruce stands, moss-organic matter is generally 20-30 cm thick; in black spruce, up to 50 cm or more thick. This, in conjunction with those factors which affect drying of these layers, helps to explain the variation in the amount of mineral soil exposed and observed by Lutz. They also complicate the patterns of revegetation within each burn.

2. Vegetative Reproduction

Vegetative reproduction is important for the following reasons:

(a) The great variability in destruction of the organic layers sets limitations on reproduction by seed.

(b) Reproductive material with an established root system and available supply of stored food is immediately available and not dependent on dispersal into the burned area.

(c) There is a low success ratio of sexual reproduction by some species coupled with an ability to reproduce vegetatively. Aspen stands are mostly the result of vegetative reproduction (Gregory and Haack 1965). Balsam poplar and black cottonwood are known to reproduce vegetatively; however, the importance in stand formation is not known. Birch also reproduces by stump shoots; but although stands with several stems originating from old stumps are not uncommon, most trees appear to be of seed origin. Vegetative reproduction following fire is of little importance to the spruces. Most of the shrub and herbaceous species sprout or sucker vigorously following fire. On a 1971 fire at Wickersham Dome in interior Alaska, revegetation is being studied in detail by the Institute of Northern Forestry. *Populus tremuloides*, *Betula papyrifera*, *Salix scouleriana*, and *Alnus crispa* were observed to produce shoots up to 40 cm long the same summer as the fire, and there were numerous smaller sprouts of *Ledum groenlandicum*, *Rosa acicularis*, and *Vaccinium uliginosum*.

The occurrence of the propagating plant parts within the organic matter-soil system is important in vegetative reproduction. This, as with organic matter, varies between sites and with species. In the aspen stands, most of the propagating roots occur within 5-15 cm of the soil surface. In white and black spruce forests, the roots and rhizomes of many of the shrub and herbaceous species occur within 2-5 cm of the mineral soil-organic matter interface. Thus, the intensity and depth of burn may encourage sprouting and suckering under some conditions and prohibit them under others.

III. EFFECTS ON SOIL

A. Permafrost

One of the most important effects of forest fires and the resultant burning of the organic layer in the taiga of Alaska is the increase in the depth of the annual thaw (active layer) of permafrost soils. The thick moss layer of black and white spruce stands acts as an efficient insulator during the summer months, limiting thaw of the soils to depths of 1 meter or less. In a typical black spruce stand on permafrost in interior Alaska, maximum thaw is from 40-75 cm. Bliss and Wein (1971) report active layer thicknesses of 30-48 cm for various vegetation types, including some shrub types, on the north slope of the Brooks Range.

Few data are available for thickness of the active layer under natural vegetation or after burns in the forested stands in Alaska, but it is generally known that the active layer is thicker in the successional stages following fire than it is in unburned black spruce forests (Lutz 1956). In the Mackenzie Delta at Inuvik, Heginbottom (1971) reported that by the second summer after a fire in the black spruce type, thaw was 9 cm deeper in burned than in unburned stands and 35 cm greater on the firelines where the organic layer had been completely removed. For the same fire and area, Mackay (1970) reported a 42% increase in active layer thickness 2 years after the burn. In an extensive fire in eastern Alaska, Lotspeich et al. (1970) found no significant difference in thaw depth 1 year after the fire. Both burned and unburned stands had thawed to about 70 cm by the end of the first summer following the fire.

In some low alpine tundra of _Eriophorum_ tussocks in the taiga of Alaska, Wein (1971) reported a 30-50% increase in the active layer in early summer following a fire the previous year, but only a 15-20% difference by the time of maximum thaw in the fall. The increased thawing depth was most significant during the short growing season of the _Eriophorum_ tussocks.

Heilman (1966) studied soil temperatures, active layer thickness, and nutritional status in black spruce-sphagnum stands on north-facing slopes in interior Alaska. He found that the active layer ranged from 18-25 cm in black spruce-sphagnum stands but was greater than 40 cm in adjacent birch stands. He concluded that on these sites late stages of forest succession after fire resulted in a change from the birch stands to black spruce-sphagnum type and eventually a sphagnum bog with scattered black spruce. As this succession proceeded, there was a degradation of site, brought about primarily by the thickening of the moss mat and the resultant lessening of the depth of thaw.

In our study on Wickersham Dome near Fairbanks, we found no significant difference in the depth of thaw between burned and unburned sites at the end of the same summer as a late June wildfire. In four burned black spruce stands, the results of probing in each stand showed an average depth of 44 cm, whereas in two unburned stands, the active layer depth was 47 cm. However, refreezing of the active layer the following winter was more rapid in the unburned stands than in the burned.

At the northern limits of the forest vegetation, fire may result first in a slight lowering of the permafrost layer, followed in a few years by a significant increase. Kryuchkov (1968) reports that fire first caused a thawing of the active layer, with a resultant release of moisture, creating conditions which stimulate the growth of Eriophorum cover. As a result of the insulating effects of the thicker vegetation mat, the active layer was only 40-45 cm thick a few years after the fire whereas before the fire, it was 50-70 cm. The resultant colder and wetter soils prevented the establishment of tree seedlings and caused large areas of what Kryuchkov termed "pyrogenic tundra." It is quite likely that the same reaction to fire may be occurring in Alaska near the latitudinal and altitudinal tree limit. Wein (1971) studied biomass production on burns in an Eriophorum-heath within the taiga in Alaska. He found that the amount of regrowth was 50% on 1-year burns, 80% on 2-year burns, and that after 4 years, the production was 110% of the control. According to Kryuchkov's report, this increased productivity of the vegetation mat would eventually result in a shallower thaw than before the fire.

One other effect of the lowering of the permafrost table after fire is the formation of thermokarst. In areas heavily underlain by ice wedges, thawing results in a subsidence of areas over the ice wedges, creating a polygonal mound and ditch pattern. These ditches may be 2-3 meters deep and often remain filled with water most of the summer. Active thermokarst, with trees tipping into the ditches and fresh cracks in the mounds, occurs in successional stands of birch at least 40-50 years after the fire. Eventually, with the return of black spruce, these sites may become stabilized, or small thaw ponds may develop and continue in an active cycle of pond and black spruce, as has been described by

Drury (1956).

B. Soil Nutrients

Lutz (1956) has summarized the data on the effects of fire on soil nutrients in Alaska. Although, as stated in Ahlgren and Ahlgren (1960), there is considerable variation in the effects of fire on soil properties as related to various aspects of the site conditions and original soil properties, some generalities may be made which seem to hold true for Alaska and other northern countries. Both Lutz in Alaska and Scotter (1971a) in northern Canada have found an increase in nitrogen, exchangeable calcium, and to a lesser degree, potassium and phosphorus, in the surface soil layers following fire. Coupled with this is a decrease in acidity. Lotspeich et al. (1970) found no significant trends in soil nutrients 1 year after a fire in black spruce stands in eastern Alaska but did note a slight decrease in total cation exchange and an increase in potassium.

Lutz (1956) explains the increase in available nutrients as resulting from their release from the burned portions of the organic layer as well as from increased nitrification by soil organisms and by increased abundance of plants with nitrogen-fixing organisms following fire. Van Cleve (1971), on the other hand, estimated that with a uniform burn consuming the nitrogen in the 0-5 cm layer of the forest floor, 778 kg/ha and 2,026 kg/ha of nitrogen would be lost from a 70- and 170-year-old spruce forest, respectively. This loss would represent a potential supply of N rather than an actual supply of available N at the time of the fire.

However, Heilman (1966, 1968) showed that much of the soil nitrogen, potassium, and calcium is tied up in lower organic layers, which in permafrost soils remain frozen the year around, and is thus unavailable to plants. In the five stages of succession from a birch-alder stand to a sphagnum-black spruce stand, he found that the foliar levels of nitrogen decreased with age of the successional stand and that P and K actually reached deficiency amounts as the nutrients became unavailable in the frozen or cold organic layers. He concluded that the removal of low density and low-nitrogen-containing layers of moss by fire and the deeper thawing of the underlying soil results in a concentration of available nutrients in the warmest portion of the soil profile and helps to explain the large improvement in productivity and available nitrogen following the burning of the sphagnum-black spruce type in Alaska.

Whatever the actual cause, there does seem to be a release of nutrients and a fertilizing effect of fire on the organic soils in Alaska. Lutz (1956) noted that seedlings which become established immediately after fire may grow faster than seedlings of the same age in nursery beds. No data exist for the amount of time that this effect persists under Alaskan conditions. However, in Sweden, Uggla (1968) found that the growth of seedlings on an area of raw humus which had been burned was better than growth on an unburned area for only the first nine years following the fire. After 21 years, tree growth on the unburned area was 65% greater than on the burned area. In Alaska, Heilman (1966) has shown that in the later stages of succession of the black spruce type, the nutrients once again become limiting to tree growth.

IV. EFFECTS ON HYDROLOGY AND SILTATION

Little information is available on the effects of fire on hydrologic relations in Alaska. Lotspeich et al. (1970) studied changes in stream nutrients and fauna in and adjacent to a 100,000-hectare fire in eastern Alaska. They found an increase in the chemical oxygen demand and potassium concentration in streams of the burned area compared with those in the unburned area, but they found no change in the benthic fauna of the streams that could be attributed to the effects of the fire. Lotspeich (1972) also studied the effects of dropping 288,000 liters of fire retardant in a small watershed to control a fire at Wickersham Dome in 1971. He found a slight increase in total phosphate in the stream below the fire compared with that above the fire, but nitrogen concentrations were not affected.

Increased erosion and water runoff as a result of fire seem to be at a minimum in northern areas in contrast to temperate regions, where fire nearly always results in increased runoff and flashy stream flow (Ahlgren and Ahlgren 1960). Both Lutz (1956) and Scotter (1971a,b) point out that the low intensity of summer rainfall, the long periods when the soil is frozen, the high water-holding capacity of the organic layers, and the rapid revegetation of the partially burned organic soils result in very little surface erosion of the burned sites.

However, this is not true of the areas on which firelines were constructed by large tracked vehicles (Figure 3). Lotspeich et al. (1970) pointed out that the fire control methods may cause more long lasting damage to the aquatic ecosystems than does the fire. DeLeonardis (1971) confirms the conclusions of Lotspeich and points out that the erosion effects of constructed firelines may far outlast any effect of the burn. This problem of erosion of firelines is brought about by the nature of the underlying permafrost. These firelines have often been constructed along small watercourses in the valley bottoms where the substrate consists of organic soils underlain by permafrost with large quantities of ice. When the vegetation and organic mat are removed, the permafrost melts, releasing large quantities of water and beginning a series of water-filled depressions. This problem is compounded if a nearby stream is captured by the system so that more water is available for melting the permafrost and for eroding the surrounding silt. The combination of melting ice wedges and water erosion may result in erosion ditches 5-10 meters deep (Figure 4), even on relatively flat terrain. Revegetation of these ditches is slow because of the continuous slumping and erosion--5-10 years after a fire there can still be active erosion even though the surrounding burned area has nearly recovered from the effects of the burn. Considerable effort is now made in Alaska to locate firelines away from low-lying permafrost sites, and quick rehabilitation of firelines by constructing water bars, artificial fertilizing, and seeding is done whenever possible (Bolstad 1971). Still, the siltation of streams and erosion caused by the gullying of firelines on permafrost is one of the most long lasting and serious consequences of forest fires in Alaska today.

V. EFFECTS ON WILDLIFE

There are numerous writings on the effects of fire on the habits of wildlife in Alaska, but most have resulted from extensive studies of large areas with little quantitative data to support general hypotheses. No doubt, the size of the State, the diversity of wildlife habitats, logistic problems, and cost have all contributed to the general lack of systematic quantification of the effect of fire on wildlife habitat in Alaska.

Gradually, the focus of research is sharpening on the effects of fire on wildlife habitat in the northern forest. Scotter's (1963, 1964, 1967, 1971a, 1971b, and 1972) works in Canada are examples of hypotheses being tested to determine quantitatively the effects of fire on the habitats of some species of wildlife.

In the writings of early naturalists and explorers in Alaska, there are numerous observations on the occurrence of fire and its effects on the habitats and population densities of wildlife. Lutz (1956, 1959) provides an excellent summary of these early writings on fire occurrence and effects on wildlife in Alaska.

A. Caribou (Rangifer)

Much has been written on the effects of fire on the habitat of caribou in North America. There is general agreement that fire destroys the lichen-rich winter range of the caribou and that recovery of cryptogamic flora is slow, often requiring more than 100 years to reach pre-burn levels of production.

Palmer (unpublished data on file at Fairbanks, Alaska, 1941), Lutz (1956), Courtright (1959), Leopold and Darling (1953a, 1953b), Buckley (1958a and b), Sumner (1951), Hanson et al. [Hanson, H., R.F. Scott, R.O. Skoog, R.A. Rausch, and W. Mitter. 1958. Caribou management studies, analysis of Nelchina caribou range. U.S. Dept. Interior, Fish and Wildl. Serv. Job Completion Reports, Project W-3-R-12, Alaska Work Plan B, Job. No. 6, Vol. 12, No. 4. Unpublished report], and others have written on the detrimental effects of fire on caribou habitat in Alaska. A basic assumption underlying all these writings was that during winter, caribou depend heavily on the availability of lichens as a source of food. This assumption was influenced no doubt by research and observations from other parts of the world, especially Canada. Reports by Kelsall (1968), Banfield (1952), Cowan (1951), Edwards (1954), Cody (1964), Scotter (1964, 1967, 1971a, 1971b, 1972), Bergerud (1953), and others have commented on the detrimental effects of fire on caribou winter range by destroying lichens throughout the caribou's range in Canada.

Skoog (1968), in reviewing work done in Canada, felt that the portions of Canada between Hudson Bay and the Mackenzie River were considerably different from arctic Alaska, both in physiography and vegetation. He pointed out that in Canada the tundra merges gradually with the taiga, mountain ranges are absent, and the terrain is generally flat and rocky with relatively few extensive sedge meadows. The most extensively burned sections of Alaska occurred in the lowland areas, which Skoog felt were not commonly used by caribou. The wide interspersion of alpine areas, rivers, lakes, and bogs in Alaska limited both the extent and effect of fire on the main caribou ranges.

Basically, there is no disagreement that fire eliminates much of the lichen forage in spruce forest for considerable periods of time, thereby reducing the potential carrying capacity of the total range. The main point, Skoog stresses, is that, because of the variation in physiography, vegetation, and food habits, the effect of fire on the total caribou habitat in Alaska has not been as pronounced as it has been in other parts of the world, especially Canada. He stated that in much of Alaska, the irregular topography and the interspersion of fire barriers have permitted many areas containing abundant winter forage to escape destruction by fire. This situation is in contrast to northern Canada, where fires can sweep for miles across the continuous spruce forest. Also, Skoog showed through examination of stomach contents that caribou in Alaska do not require lichens, nor should the relative abundance of these plants be used as the indicator to establish the carrying capacity of Alaskan ranges. Based on examination of 91 samples of caribou stomach contents from the Nelchina range, Lensink [Lensink, C.J. 1954. Food requirements and range use, Nelchina caribou herd: Summer food habits. U.S. Dept. Interior Fish and Wildl. Serv. Federal Aid in Wildl. Restoration Proj. W-3R, Quarterly Prog. Rep. Vol. 9, No. 1] found that the fall diet consisted of 31% lichens, 23% grass and sedge, 41% woody plants, primarily willow leaves. Skoog, in examining over 500 caribou rumina from animals killed by hunters in the same area, concluded that during October, November, and December sedge-grass comprised 50% of the diet and lichens, 30%.

Later during the winter, utilization of these foods was estimated to be equal.

In conclusion, Skoog believed fire has destroyed rather large expanses of potential caribou winter range in Alaska. Theoretically, the carrying capacity of the total caribou range in Alaska has been reduced temporarily due to this destruction of winter forage; however, the present population densities are much lower than the maximums dictated by food alone and, hence, the reduction in total range due to losses in winter range by fire becomes less meaningful as a factor limiting the caribou population density in Alaska. "The fact that Alaska caribou are not dependent upon lichen growth in spruce forest and can utilize the extensive sedge forage on the tundra, alpine meadows, bogs, and lake shores greatly mitigates the losses due to fire" (Skoog 1968).

Skoog's work points out the need to avoid sweeping generalities applied to areas with the ecological diversity of Alaska. Each of the six caribou ranges in Alaska has unique features--physiographic, floristic, etc.--and fire affects the capacity of each area to support caribou in varying degrees, depending on many environmental factors. Unfortunately, we have not as yet quantified the floristic response to burning in many of these ranges in Alaska.

Hanson et al. (1958) identified and described the natural plant communities on the Nelchina range, including observations on succession and factors affecting succession, maintenance, and occurrence of plant communities. This is one of the more detailed studies of the ecology of caribou range in Alaska.

Pegau (1972) recently resurveyed many of Hanson's plots and concluded that shrubs were increasing due to a general "drying" of the range and overuse of lichens by caribou. He felt more work was needed to determine the ability of the Nelchina herd to use forage other than lichens during winter.

Courtright (1959) has an excellent summary of literature on the genus Rangifer, including information from Canada, U.S.A., Scandinavia, U.S.S.R., and other northern countries.

Lichen Production.--"The quickened rhythm of fire has in general favored extension of willow-aspen-birch and concommitantly reduced the original stands of lichens...." (Leopold and Darling 1953a). "...up to 50 or even 100 years being required for them to achieve pre-burn levels of production" (Leopold and Darling 1953b). These statements are repeated numerous times in the literature on fire effects on wildlife habitat in Alaska.

Scotter (1971a), working on the winter range of barren-ground caribou in the taiga of Canada, found that the standing crop of lichen following burning varied from 3.4 to 812 kg/ha (3 to 725 pounds/acre) from the youngest to the oldest (1-10 to 120+ years) upland forest and that when mature spruce-lichen forests are burned, major forage lichens usually take 70-100 years or more to recover their pre-burn abundance.

Cody (1964) found no significant recovery of the lichen cover 9 years after a fire in the Mackenzie Delta.

Pegau (1970a) found that, in western Alaska, lichens, disturbed by a number of causes (but not fire) and then protected by fences from grazing reindeer, had not fully recovered after 33 years. He (Pegau 1968) reported annual growth rates for *Cladonia alpestris* L. (Rabenh.) and *C. rangiferina* (L.) Wigg. of 5.0-5.3 and 4.1-4.9 mm/yr, respectively, on the Seward Peninsula, whereas Scotter reported rates of 3-5 mm/yr for major forage lichens in Canada.

B. Moose (*Alces*)

Spencer and Chatelain (1953) found, through observations of burns in south central Alaska, that succession followed a variety of patterns resulting in creation of useful moose winter range for from 0 to 50 years. Under average conditions, stands appeared to furnish good forage for 15-20 years after the fire. They felt that the 127,600-hectare fire in 1947 on the Kenai Peninsula induced an increase in moose population of approximately 400% between 1950 and 1953, with significant forage produced in 3 years following this fire, 96% of which was aspen sucker growth.

Leopold and Darling (1953a and b), Chatelain (1951, 1952), Spencer and Hakala (1964), and Hakala et al. (1971) have written about the effect of fire on moose habitat in the Copper River, Susitna, and Kenai areas of Alaska. General observations are that fire improved the habitat through increased productivity and availability of deciduous woody plants (willow, aspen, birch, cottonwood) and that moose populations in these areas increased in response to improved habitat conditions. Detailed studies continue on the Kenai to evaluate the effect of the 1947 Kenai fire and the 1969 Swanson and Russian River fires on wildlife habitat.

Hakala et al. (1971) felt that during the next 3-5 years, moose browse would regenerate on the Swanson and Russian burns and that browse should continue to improve during the next 20 years, thereby attracting many moose hunters, as did the 1947 Kenai burn.

In general, most writers agree that moose achieve highest densities in forest areas opened by fire or other forms of timber removal, permitting regeneration of willow, birch, and aspen. The moose is definitely an animal that prospers in sub-climax forest conditions.

Buckley (1958a), in summarizing the net effect of fire on wildlife in Alaska, concluded that major disturbance of the landscape (primarily fire) during the first half of this century had created a condition which makes it highly unlikely that there have ever before been so many moose present in Alaska as there are today.

C. Sheep and Goats (Ovis, Oreamnos)

Leopold and Darling (1953b) concluded that sheep and goats were primarily associated with climax vegetation of the alpine type rather than with tundra-taiga types and that fire, because of its infrequent occurrence in this type, had little influence on the habitats of sheep or goats in Alaska. Hjeljord's (1971) investigation of the feeding ecology and habitat preference of the mountain goat in southeastern Alaska and Gross' (1963) study of sheep range on Victoria Mountain and Mount Schwatha in Alberta did not mention the influence of fire on the habitats of these species.

On plant succession and wildlife management, Cowan (1951) commented that some sheep ranges and populations in the Canadian Rockies were being reduced by the advance of the forest in areas where fire control was effective. Geist (1971) felt that sheep habitats were being displaced gradually by other plant communities in response to climatic changes and that the stable climax grass communities which comprise major sheep habitats do not vanish within a few decades as do the burned habitats of moose. He did note exceptions where fire has resulted in some grasslands occupied by sheep.

Edwards (1954) stated that in Wells Gray Park, B.C., goats were unaffected by fire because their range was generally above the elevation of fire influence (above 4,000 feet).

Stelfax (1971) stated that fire improved sheep ranges by converting the undesirable coniferous forest into productive grasslands on which sheep in the Canadian Rockies depend for forage. Sheep population in these areas tripled between 1916 and 1936, primarily through improved range conditions resulting from fire.

D. Small Mammals

Hakala et al. (1971) cited an unpublished report by Ellison on file at the Kenai National Moose Range of a study of small mammals on the 1969 Swanson River burn. Hakala et al. stated, "Immediately after the fire, dead voles were found in the smoldering ashes. But a year after the fire, numbers of voles seemed to be nearly equal inside and outside the burn, although numbers of shrews may have been fewer in parts of the burn. The insectivorous diet of shrews might make them more susceptible to habitat disturbance by fire." Ellison felt that location of traps in the burn possibly influenced results; however, there were many islands of unburned habitat throughout the burn.

Guthrie (1967) suggested that the melanism found in the arctic ground squirrel was due to the darker individual being favored when burnt-over areas were invaded. Citellus undulatus osgoodi, a large ground squirrel inhabiting the Yukon Flats basin, relies on seral plants for food. Guthrie felt that the Yukon Flats area, with 166 mm of annual precipitation, is particularly susceptible to fire and by more than coincidence is the area of highest squirrel density. He thought fire increased the number of plants eaten by ground squirrels, but that non-melanistic squirrels were more susceptible to predation, thereby favoring survival of melanistic squirrels in burned areas. He concluded that melanism in ground squirrels of the Yukon Flats appeared to be a polymorphic adaptation which permitted the squirrel to take advantage of a favorable environmental situation. However, as the burned stands develop or mature following fire, non-melanistic squirrels are favored, resulting in a special case of balanced polymorphism. Guthrie's paper is the only reference found which indicated that changes in pelage may be associated with burned forest, and that this adaptation might be a significant survival adaptation for a species whose food is increased by altering succession of vegetation by burning.

E. Fur bearers

Robinson (1952) stated that wildfire destroys habitats of Alaska fur bearers and they must move into new areas or eke out an existence near the burn. He felt "good prime pelts are obtained from unburned, rather than burned areas."

Sumner (1951) commented that fur was the third largest industry in Alaska, but 50 years of forest fires and extensive trapping resulted in a marked decline in this resource.

Hakala (1952), in describing beaver (Castor canadensis) habitat on the Goldstream Creek and Chatanika River, mentioned that where spruce had been burned, poplars and birches were abundant. Murray (1961) studying beaver ecology in the upper Tanana River, commented that when fire makes actual contact with a beaver colony, "damage may be immediate and absolute." The immediate effect of fire is destruction of their food supply; but on a long-term basis, fire renews the aspen-cottonwood forest. He also observed that when pure spruce stands burned, new growth of aspen and cottonwood increased the abundance and availability of beaver food.

Patric and Webb (1953) felt that the high beaver populations of many areas in the northern forest were a direct result of extensive clearcutting and widespread forest fires. They did, however, state that "modern fire control and intensive forest management practices are generally reducing the area of suitable beaver habitat, because the beaver is adapted to the early stages of forest succession, especially post-fire types, which include aspen and willow."

Lensink (1953) and Lensink et al. (1955) found that Cleithrionomys and Microtus comprised 74% and 68% of the diet of marten (Martes americana actuosa) during summer and winter and concluded marten were found in areas dominated by climax spruce forest. The burning of climax spruce forest eliminated fur bearers, such as marten.

Edwards (1954), working in Wells Gray Park, B.C., concluded that fire removed marten for decades and found that decline in caribou restricted the use of forested lowlands by wolverine and grizzly bear.

During a 3-year study (1948-51) in Ontario, DeVos (1951) found that fisher (Martes pennanti pennanti) and marten (Martes americana americana) were practically absent from extensive recently logged or burned areas and that stands of birch and aspen of fire origin were poor habitats. He stated that late stages of succession produced more favorable habitats for fisher and marten.

Koontz (1968), in studying small game and fur bearers of the proposed Rampart Dam impoundment area on the Yukon River in Alaska, concluded that the effects of fire on wildlife populations were not clearly understood but that many people felt uncontrolled fire and certainly repeated fires were not beneficial to some species of wildlife. He thought that fires repeated at "long intervals" may be beneficial to most species of wildlife by creating edge and causing reversion of vegetation into several successive stages.

Murray (1961) stated that in the past, fires were set by Indians in interior Alaska to drive muskrats from their dens, but that this practice had been successfully discouraged.

F. Black Bear (*Ursus americanus*)

Hatler (1972), in his study of food habits of black bear in Alaska, stated that many older burns produced excellent crops of blueberries, which comprised 49% of the fall diet of black bear in his study.

G. Snowshoe Hares (*Lepus americanus*)

Grange (1965) felt that the chance for great abundance of hares in northern coniferous forest was limited to very early successional forest stages not long after the occurrence of fire. He stated that, in Alaska, 9% of the total forested area burned during an 11-year period (1940-50) and that, because of slower succession, fire effects may persist for decades. Generally, Grange felt that fire-habitat-succession relationship to snowshow hare population fluctuations should be studied more thoroughly before dismissing its influence by fire.

During a peak of the hare population (estimate of 150 hares/square km) near Fairbanks, Alaska, in the fall-winter of 1971-72, hares consumed willow sprouts that resulted from a fire during late June of 1971. They also consumed charred black spruce and aspen bark.

H. Waterfowl

Komarek's (1971) comments in a recent symposium on fire in the northern environment adequately describe the situation: "No investigations of any serious nature have been made on the effects of fires upon habitats of the waterfowl that frequent interior Alaska."

Two master of science theses on waterfowl in the Minto Flats area make no mention of the effects of fire on waterfowl populations or habitats (Rowinski 1958, Hooper 1952). Their work was on succession following flooding.

Buckley (1958b) commented that fire removed insulation, lowering permafrost depths and consequently modifying the surface, subsurface drainage, and water-holding capacity of the soils. The lowering of the water table, he postulated, would reduce the amount of waterfowl habitat and thus reduce the total population.

On the other hand, Buckley (1958b) felt that removal of woody vegetation by fire increased the attractiveness of the area to most waterfowl species. He attributed a population increase in the 77,600-hectare (192,000-acre) Selawick burn from 8.1 to 12.8 ducks/square km to the fact that new plant growth started at least 2 weeks earlier in the burn than in nearby unburned portions. In this prime tundra breeding area in northwestern Alaska, early nesting commonly results in higher production than later nesting. This 2-week increase was significant in areas like Selawick, where growing seasons were short.

I. Grouse (Canachites canadensis)

Hakala et al. (1971) cited an unpublished report by Ellison concerning the effect of the 1969 Swanson River fire on spruce grouse. Ellison found only 18 broods on one 10.4 square kilometer (4-square-mile) plot in the burned fraction (1 year after the fire), compared with 41 on the same area in 1969 before the fire. They concluded that the fire reduced the carrying capacity for grouse broods by 56%.

VI. EFFECTS ON INSECTS

A number of insect species have been observed to be prevalent in fire-damaged trees, especially spruce. Buprestids and cerambycids are commonly seen in large numbers within a fire area, possibly attracted to the smoke and heat (Evans 1971) or by some olfactory response to volatile materials. Scolytids attack the damaged trees and the fallen logs that have adequate phloem for brood production.

The wood borers rapidly degrade the logs, making salvage for lumber impractical. They play a major role in breaking down damaged material. Bark beetles are of more importance on the fringe of the fire, in "islands" of slightly scorched trees within the fire perimeter, or in the residual stand. Dendroctonus sp., Ips spp., and Trypodendron spp. have all been found in damaged trees adjacent to burns. The first two genera have the potential to increase their population in the burned material and spread to the live trees outside the burn. Trypodendron bores directly into the wood, causing a "shot hole" appearance. The holes and staining that follow degrade the wood. If the climatic conditions are favorable, the populations of Trypodendron in adjacent unburned stands may cause as much or more damage than the original fire.

Another aspect of fire-insect relationship is that the changes in the composition or age of the forest stands after fire are accompanied by changes in the insect fauna. Where spruce may not have presented an entomological problem, destructive defoliators, such as the large aspen tortrix (Choristoneura conflictana [Wlkr.]), may become widespread in the hardwoods (Beckwith 1968). Often the conversion of a large area to seedlings produces a potential insect problem that does not exist prior to the fire.

Insects can also add to the fire potential in an area. Large areas of trees killed by bark beetles add to the dry fuel supply until the wood breaks down. These trees, when fallen, add to the difficulty in moving men and equipment in fire suppression activities. Bark-beetle-killed timber is present in large quantities in many areas of Alaska.

VII. EFFECTS ON RECREATION AND ESTHETIC VALUES

The prime value of Alaska's taiga lies not in development of commercial forestry, but rather in its use for all types of recreation, such as hunting, fishing, photography, hiking, and scenic viewing from the highways, trails, and waterways. It is essential, then, that some consideration be given to both the positive and negative effects of fire on recreation and esthetics in Alaska.

From the scenic landscape aspect, a recently burned and blackened area is ugly to many viewers. Any form of hiking or other recreation within the burned area is nearly impossible because of the unpleasantness of the ash and charcoal. Burned spikes of trees, brown needles, and a blackened forest floor are the conspicuous elements of the new burn. However, in Alaska, the area is snow-covered for 7 months of the year; at that time and with low sun angles, it is almost impossible to separate burned from unburned areas. Also, within 2 or 3 years, revegetation of the forest floor is nearly continuous, so there is an almost parklike appearance to the burn, except for the dead spires of the trees. In some areas of Alaska, tree crushers are now being used to rehabilitate burns; and it has been found that with the standing spikes knocked down, the appearance of the old burns is improved (Hakala et al. 1971). Within a few years, the burns are revegetated with shrubs and young trees.

In the Alaskan landscape, the successional vegetation stands out in contrast to the unburned spruce stands. The taiga would be a rather monotonous landscape if it were not for the many vegetational patterns of hardwood and conifer stands that have resulted from past fires.

The negative effects of fire on recreation also may be of rather short duration. Although the burn itself may be an unpleasant place for hiking and hunting for a number of years because of the dead and fallen trees, the firelines provide open avenues for other types of recreation. At the site of the 1971 Wickersham fire, the Bureau of Land Management set up a snow machine recreational area and published maps of the firelines for access. Reaction among snow-mobilers was positive, and the area received some recreational use. As pointed out by Hakala et al. (1971), the recreational use of a burned area for hunting will be greater 20 years after a fire than before because of the increased moose and snowshoe hare populations. They also pointed out that a year after a fire on the Kenai Peninsula, large numbers of people visited the burn in order to harvest a large crop of morel mushrooms.

One aspect of fire that affects tourist and resident alike during bad fire years is that of smoke in the atmosphere. As pointed out by Miller (1971), the scenic attractions of Mount McKinley National Park can be obscured for several weeks at a time, thus preventing the tourist from experiencing a high quality visit to the Park. However, he reported no significant decrease in visitation or tourist activity in 1969, even though the mountains were obscured by smoke for several weeks. One other effect of smoke is to close down airports. When this happens to an airport of a major city, as it has to Fairbanks, it may result in considerable inconvenience to tourist and resident alike.

VIII. DISCUSSION

Land planning in Alaska is presently in a stage of rapid transition, due primarily to pending large shifts in land ownership brought about by the Alaska Native Land Claims Settlement Act of 1971. Consequently, we do not know what the management plan for most areas in Alaska will be. However, we do know that much of Alaska's taiga will be managed as State and National Forests, Wilderness Areas, National Parks, Research Natural Areas, and Wildlife Refuges. In some of these areas the management policy will undoubtedly be to preserve the natural vegetation, with the inevitable question of how to handle the role of fire in the natural system. This question is already being asked by those involved in our National and State Parks (Hoffman 1971; Prasil 1971).

We do not have complete basic quantitative information regarding the ecological effects of fire on vegetation, environment, and wildlife in the taiga, but we can make some recommendations regarding wildfire management based on the available information from Alaska and other northern areas.

Everyone working in resource management in Alaska must realize that fire has always been a part of the taiga environment and that to exclude fire completely will lead to the creation of unnatural conditions. It is also necessary to orient ourselves away from the concept that the prime utilization of the taiga will be for commercial timber production. The main value of the interior Alaska forests may well be its wildlife and recreational values and the best goal for land management that of keeping large areas in successional plant communities. Many millions of dollars are spent controlling fires in Alaska that may do more good than harm if allowed to burn themselves out. But at present it is impossible to recommend letting such uncontrolled fires burn, for they may develop into a fire of a million hectares in extent that destroys houses, threatens villages, and burns valuable commercial timber. On the other hand, if all fires are controlled, it can be predicted that the landscape will become dominated by spruce and bog and the successional species of fauna will be reduced. Fast-growing aspen, birch, and white spruce will be replaced by black spruce and bog in all but the warmest and best drained sites where white spruce will remain. Hardwoods, primarily balsam poplar, will be found only on the floodplains adjacent to the rivers. Moose will not be nearly as abundant as they are now, and there is no guarantee that caribou will be more plentiful.

Heinselman (1971) has suggested six alternative fire policies for the management of Wilderness Areas and parks which might also pertain to the remote areas of Alaska. These are as follows:

"1. Attempt fire exclusion and accept the slow but pervasive changes in plant and animal communities that inevitably follow.

2. Allow "safe" lightning-caused fires to burn; allow also for some other wildfires that cannot be controlled, but extinguish the rest. If this option results in less than the natural fire frequency and burned area, so be it.

3. Allow "safe" lightning fires to burn, allow for some other wildfires that cannot be controlled, but prescribe enough additional controlled fires to assure the natural fire regime.

4. Suppress all wildfires to the extent feasible, and duplicate the natural fire regime with prescribed-controlled fires.

5. Allow all wildfires to burn unchecked unless life or property are directly threatened, and hope that a natural fire regime will result.

6. Abandon the ideal of natural ecosystems and turn to full-scale vegetation and environmental manipulation by mechanical and chemical means, seedling, planting, and so on. Attempt to produce desired vegetation with the tools of applied forestry."

Heinselman recommends either option 3 or 4 for areas where the natural vegetation is to be preserved.

In planning for the management of the wide variety of Alaska's resources, all of the above listed options plus others may eventually be used. Thus, for areas managed primarily for caribou or reindeer winter range, complete fire suppression may be the best policy whereas within areas established primarily for moose management, it may be possible to allow all wildfires to burn unless they endanger life or property or threaten to expand into areas with higher priority for fire suppression. This latter method has worked well in the management of fire-dominated vegetation in some high elevation forests in California (Kilgore and Briggs 1972). In regions surrounding human developments and in those managed for timber production, all wildfires will need to be suppressed and prescribed-controlled fires utilized for vegetative manipulation. In the large remote areas of Alaska, it may be possible to preserve the natural vegetation by allowing most lightning-caused fires to burn.

The Bureau of Land Management, the fire control agency in most of the Alaskan taiga, already has the beginning of such a priority system in effect (Richardson 1971). However, they do not feel that it is yet possible to allow uncontrolled fires in the Alaskan taiga. They have found that all large uncontrolled wildfires eventually become a threat to life, property, or military installation. Regardless of what is burning, the smoke that drifts from them covers high-value areas and stops aerial detection and air attacks on new fires. "We have not been able to identify any area where fires can safely be left to burn without serious consequences and high costs" (Richardson 1971).

However, because of their priority system, in extreme fire years, when BLM's resources cannot possibly cope with all fires, many fires are left to burn uncontrolled, thus allowing for the re-establishment of successional stands over large areas.

In high priority fire suppression areas, Richardson (1971) suggests that prescribed fire will be the management tool needed to replace the natural effects of wildfire.

IX. RECOMMENDATIONS FOR THE FUTURE

To provide better background information for selection of fire suppression options, there is a need to increase the intensity of research on all aspects of fire effects and on techniques of controlled burning. We must build on the work of Lutz and other researchers to gather more detailed quantitative data from the many diverse areas in the Alaskan taiga. Specifically, we need to know:

1. The quantitative changes taking place, with time, in all aspects of the plant community, including biomass and nutrient status. This can be accomplished partially by obtaining information from a number of aged burns, but it will also be necessary to establish permanent plots and continue intensive observations over a period of years.

2. The autecology of the important taiga species, especially those important to wildlife, and how they relate to fire. We have to know the regenerative capabilities and requirements of the tree, shrub, and herb species, the duration of seed viability, and its ability to survive the heat of burning.

3. More detailed information on the effects of fire on the animal inhabitants, not only big game species, but birds, small mammals, insects, and aquatic life. Once the detailed plant succession sequence is determined, it will be easier to conduct specific studies relating to wildlife habitat and fire. Of special importance in Alaska are the problems relating to the effects of fire on caribou and moose populations and on waterfowl. Alaska is one of the main nesting areas of waterfowl in North America, and much of these breeding grounds are within the taiga.

4. The effects of fire on stream hydrology, erosion, landslides, and the siltation and temperature changes in streams as well as on the aquatic populations. The water and fish of Alaska are two of its most important resources, but little is presently known of the effects of large wildfires on stream flow or fish populations.

5. The effects of fire on soil nutrients, soil temperatures, and permafrost, especially the long and short term effects of fire on the depth of annually thawed ground (the active layer) in the various permafrost zones within the taiga. How does fire affect the complete nutrient cycle within the ecosystem?

6. The effects of fire on recreation, both of the tourist and resident population. This will be a difficult problem in that it must involve the esthetic values of the people and the quality of the visitation, intangibles upon which it is impossible to put a dollar value. The increased resident population of the state related to the oil industry must also be considered.

7. The methods and effects of controlled burning in the taiga. If wildfire suppression becomes completely successful, then a means of creating the natural ecosystems must be developed if any of the landscape is to be kept in its natural state.

8. The role of fire in the taiga before the arrival of outsiders. This should be studied now before this history is destroyed by the present encroachment of man into the natural ecosystems.

9. In addition to the specific research needs on the effects of fire on the various aspects of the environment, there is an even greater

need to use a systems approach in determining the effects of fire on all of the resource values of an area. This will enable resource managers to not only plan a fire suppression policy, but also to use fire to their advantage in carrying out management plans.

X. ACTION FOR THE PRESENT

At the USDA Forest Service Institute of Northern Forestry, a new multifunctional research work unit is now operating with the objective of answering some, if not all, of these questions. Coincident with the establishment of this project was a wildfire in late June of 1971, which burned 6,300 hectares conveniently located within 50 km of the Institute. Intensive studies into many aspects of plant succession, micro-environmental changes, mammal and insect populations, nutrient cycling, biomass, and productivity were initiated within the first year after the fire. In addition, a vegetation soil survey is being carried out in a number of areas burned during the past 100 years. It is hoped and planned that a number of additional studies on the effects of wildfire in the taiga will be initiated in the next few years. This project will quantify proposed hypotheses, point out similarities and differences between fire effects in the taiga and those of more southern latitudes, and eventually lead to the basic knowledge needed to understand the role of fire in the natural ecosystems of the Alaskan taiga.

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