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The 1977 Tundra Fires in the Seward Peninsula, Alaska: effects and initial revegetation

by Charles H. Racine
The Center for Northern Studies
Wolcott, Vermont

U.S. Department of the Interior
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16. Abstract (Limit: 200 words) During summer 1977, wildfires burned extensive areas of maritime tundra in the Seward Peninsula. This study was initiated in July 1978 to determine the effects of these fires on tundra soils and vegetation and to establish permanent plots in which to monitor postfire succession. Fifteen 10 m x 1 m permanent belt transects were established at four different burn sites in the Seward Peninsula. Nine of these were located along a topographic transect on a hill where soils and vegetation had been quantitatively sampled in 1973, thereby providing pre-fire comparisons. Two other sample sites were located in a 1971 tundra burn. Soil characteristics and plant density and cover were determined in or near each of the 150 1 m x 1 m quadrats.

Tundra burn patterns were generally patchy, with unburned communities, unburned patches within burned communities, and in most areas of tussock-shrub tundra, less than one half of the accumulated organic soil layer was removed. Except where organics were removed, thaw depths were not greatly increased but unlike the pre-fire situation, after the fire, thaw depths reached into the mineral soils. Frost features were made more conspicuous, if not reactivated, and soil nutrient concentrations (K and P) increased locally. Revegetation in tussock-shrub tundra was rapid, mainly as a result of tussock resprouting, but was much slower in drier low shrub areas where organic soils were largely removed. Some of the implications of these results to vegetation changes, fire management policy, commercial reindeer herding, and off-road vehicle use are discussed.

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by Charles H. Racine
The Center for Northern Studies
Wolcott, Vermont

Final report for Contract #AK-950-CT8-10

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U. S. Department of the Interior
Bureau of Land Management

ALASKA STATE OFFICE

701 C Street, Box 13

Anchorage, Alaska 99513

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Opportunities to study tundra fire effects and post-fire revegetation are generally ephemeral and can't be carefully planned and budgeted to coincide with the event. The Alaska State Office of the Bureau of Land Management (BLM) and Dr. H. William Gabriel made it possible to initiate this study only one year after the 1977 Seward Peninsula tundra fires. The tundra fire study reported here was done as an extension of tundra disturbance studies on the Seward Peninsula conducted during the 1978 field season and supported under contract with the National Park Service (NPS) Alaska Area Office. I therefore gratefully acknowledge support of both the BLM and NPS.

Several other people helped directly and indirectly with the study and I thank them for their cooperation. Dave Scott (BLM-Nome), Keith Woodworth (BLM-Kotzebue), and Roger Bolstad (BLM-Fairbanks) helped in many ways. Clifford Weyiouanna (Shishmaref) provided us with accommodations near Arctic River. Jake Jacobsen (Kotzebue) flew us to Imuruk Lake. Patricia Lillian (BLM-Anchorage) located aerial photos. Larry Johnson (CRREL-Fairbanks) read and commented on the manuscript. Dr. Leslie Viereck (USDA Institute of Northern Forestry, Fairbanks) provided initial encouragement. Tom George (Geophysical Institute, University of Alaska, Fairbanks) obtained helpful remote sensing data. Marilyn M. Racine assisted in all phases of the field work and report preparation.

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SUMMARY

Tundra fires have occurred at short- and long-time intervals on the Seward Peninsula, burning perhaps more frequently and covering more extensive areas than tundra fires elsewhere in Alaska. Peak fire years during warm, dry summers are recorded in old Geological Survey field notes, and since 1956 in Bureau of Land Management (BLM) fire records. During the 1970's, Seward Peninsula tundra fires have been frequent and extensive, with peak outbreaks in 1971 and 1977. The latter fires burned almost one million acres (3600 km^2 or 887,000 acres).

In July 1978, general reconnaissance and quantitative sampling were carried out on burned tundra vegetation, soil organic layers, thaw depths, and frost features at 13 tundra sites which burned in 1977 and one site which burned in 1971 on the Seward Peninsula. Information from the reconnaissance and sampling was used to quantitatively evaluate the effects of fire on different communities, soil characteristics, and processes, and to reconstruct initial revegetation patterns. The most intensive analysis of fire effects was carried out at nine sample sites along a topographic gradient of a gentle hill slope near Imuruk Lake, where soil and vegetation data had been obtained in 1973 and provided prefire information. All 1978 sample sites were permanently marked so that the 150 1 m x 1 m sampling quadrats can be relocated for monitoring future soil and vegetation changes.

Although evidence of burning was found in all types of tundra communities, wet sedge meadow, closed willow shrubland, and open mat and cushion tundra were usually unburned. Closed mat and cushion tundra, however, often burned patchily on drier sites; in one place removal of this vegetation mat revealed archeological remains, not visible before the fire.

Generally, the most frequently burned communities (also the most widespread in the area) had fairly large components of low shrub heaths and dwarf birch. These occur in association with sedge tussocks (sedge tussock-shrub tundra) on moist sites, with single sedge shoots (sedge-shrub tundra) on wetter sites, or alone (birch and ericaceous shrub tundra) on drier sites. Burning was generally less severe in the tussock-shrub and sedge-shrub tundras than in the birch and ericaceous shrub tundra. In sedge tussock-shrub tundra, the thick organic peat layer

remained largely intact, and small unburned patches were common. Here, also, resprouting of tussocks, sedges, and to some extent low shrubs, was already well along one year after the fire, and by seven years, re-establishment of these growth forms appeared to be more or less complete.

On well-drained sites with birch and ericaceous shrub tundra and closed mat and cushion tundra communities (on the brows of hills and the tops of some raised, high-centered polygons), most severe burning occurred; the nearly complete removal of the organic layer there was followed by slow or no first-year resprouting of low shrubs and sedges, but with some establishment of new vascular plants, mosses, and liverworts. Establishment of abundant sedge seedlings (Carex sp. and/or Eriophorum vaginatum) as well as grasses (particularly bluejoint grass, Calamagrostis sp.) was generally common in most burned communities.

The 1977 Seward Peninsula tundra fires tended to accentuate frost features and make them more visible, by burning off the thin plant cover over frost scars and bordering frost contraction cracks. Greater resprouting and flowering of sedge tussock groups on old frost scars than in the adjacent unscarred tussock-shrub tundra also accentuated these features. Whether or not tundra fire leads to stimulation of frost action needs more study, however. In tussock-shrub tundra, enough soil organics burned so that summer thaw reached into the mineral soils, possibly increasing frost action. Nutrient release and increased soil enrichment (over 1973 levels) by extractable potassium and phosphorus were generally restricted to the organic surfaces where charred ash material was abundant.

The short- and long-term role of tundra fires must be studied in relation to the successional changes which tundra vegetation undergoes, both when undisturbed and when disturbed by frost action. Without tundra fires, many areas of tussock-shrub tundra undoubtedly would be converted into birch and ericaceous shrub tundra, with a buildup of organics, mosses, and lichens and with a shallow depth of thaw. There is evidence that this has occurred over extensive areas in the Seward Peninsula during the past 30 years. If tussocks have not died, fire reverses this trend by removing accumulated organics and rejuvenating tussock growth. Following fire, there are changes in the proportions of different growth forms and plant species from those before the fire.

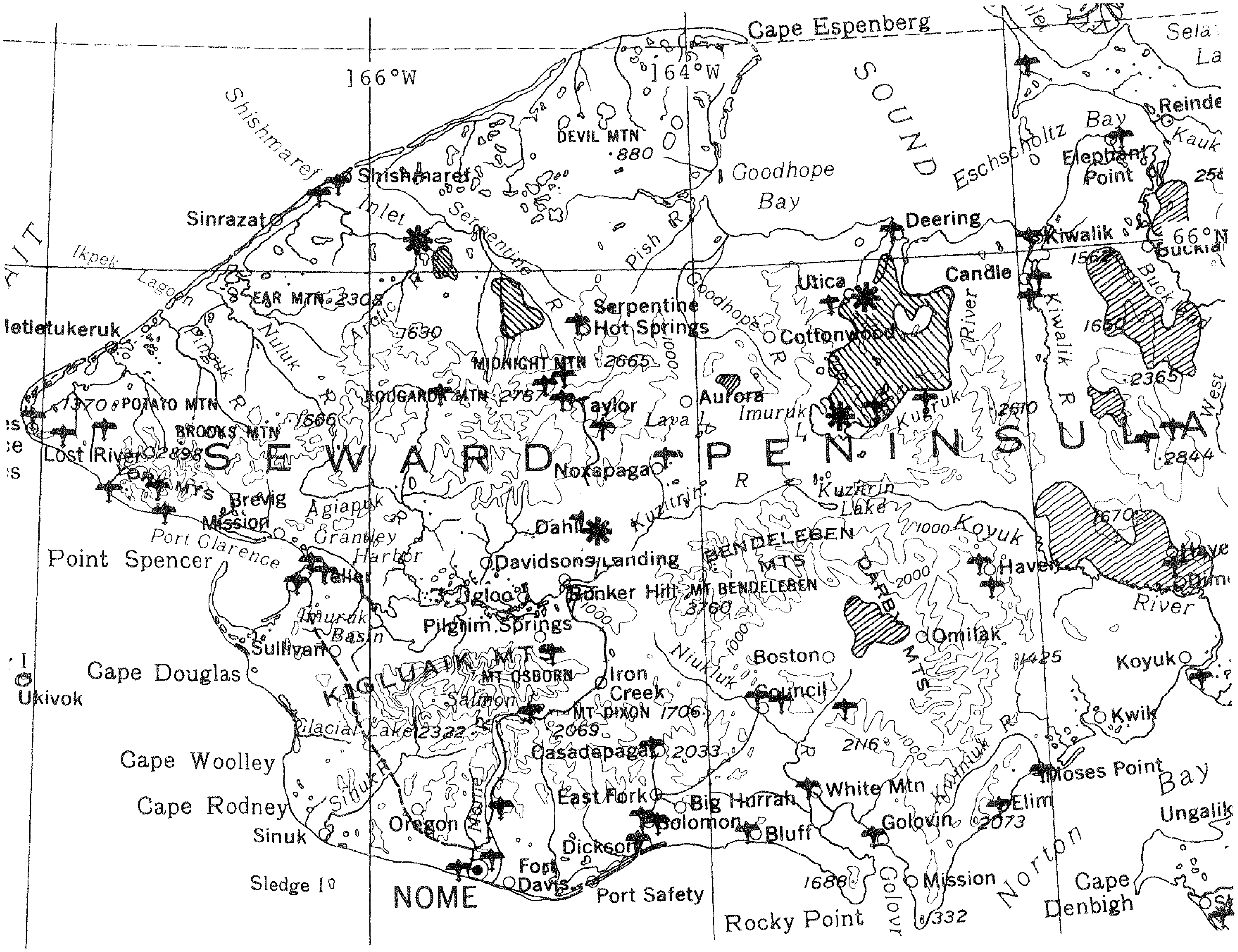

Fig. 1. Map of the Seward Peninsula, Alaska (Scale 1:1,584,000) showing the size and location of 1977 tundra fires. The Deering-Imuruk and Serpentine-Arctic Rivers fires of concern in the present study are indicated [hatched box] *Study sites marked* ✱ .

The implications of some of these results for tundra fire management policy and reindeer herding are discussed. It is also recommended that summer off-road vehicle traffic over recently burned tundra be prohibited. Continued monitoring of the permanent transects established in this study should lead to a better understanding of postfire succession. Some recommendations for additional research are made.

INTRODUCTION

During the summer of 1977, a number of lightning-caused fires burned large areas of tundra on the Seward Peninsula and adjacent regions in northwestern Alaska (Fig. 1). One tundra fire, northeast of Imuruk Lake, covered 958 km^2 (236,000 acres), and altogether almost one million acres burned (3600 km^2 or 887,000 acres). The recent occurrence and large extent of these fires suggest that fire may be much more significant in tundra ecosystems than has been previously acknowledged. Such fires undoubtedly affect the composition, structure, and function of tundra ecosystems, the associated permafrost conditions, and possibly frost action processes.

Changes in tundra brought about by burning may alter the amounts and kinds of food available to native herbivores and commercial reindeer herds. Melchior (1974, 1975) suggests that tundra fires in northwestern Alaska may influence the distribution of certain mammal species there. More immediate impacts of tundra fires include the threats to villages, costs of fighting these fires, reduced atmospheric visibility, and loss of wildlife. The loss of visibility was evident throughout northern Alaska during the 1977 fires.

Despite the unusually large number of fires in tundra on the Seward Peninsula and their possible importance in tundra ecosystems, they have received relatively little attention and study in Alaska. The 1977 Seward Peninsula tundra fires therefore provide a unique research opportunity to initiate studies of postfire burn patterns, early vegetation recovery, and effects on soil-permafrost-frost action processes.

OBJECTIVES

The general purpose of this contract study was to provide analytical assistance to BLM in evaluating the effects of wildfires on tundra ranges. The objectives included: (1) a postfire evaluation of Seward Peninsula fires to provide information on plant communities burned and unburned by fire, (2) evaluation of the utility of visits to older tundra burn areas of known age as means for reconstructing the pattern of succession following fire, and (3) establishment of permanent transects for future reference and monitoring of recovery.

While all the area involved in this study had been public lands administered for many years by BLM, the Imuruk Lake study sites are now within the Bering Land Bridge National Monument, created in December 1978, and administered by the National Park Service.

THE STUDY AREA

Environment

The tundra fire sites chosen for study all are on the Seward Peninsula in northwestern Alaska (Fig. 1), where low arctic tundra vegetation extends south below the Arctic Circle along the west coast of Alaska. Except where mountains run down the spine of the peninsula, the terrain consists of unglaciated rolling uplands and localized coastal lowlands, underlain by continuous permafrost and deep silts or loess deposited during glacial times. The maritime climate of the area varies from east to west and south to north as influence from the Chukchi Sea increases. Mean annual temperature varies between -6°C (20.9°F) (Kotzebue) and -3.6°C (25.6°F) (Nome), with July means of about 10°C (50°F); mean annual precipitation is 222.5 cm (8.76 in) (Kotzebue) and 416.6 cm (19.44 in) (Nome) (U.S. Dept. of Commerce 1973).

During July 1977, temperatures were 5°C above normal and precipitation was 5 percent of normal on the Seward Peninsula, suggesting in part how conditions suitable for tundra fire developed (BLM 1978). The Low Arctic shrub tundra which covers most of the peninsula consists of sedge tussock-shrub and low shrub communities[1] on the gentle

[1]Nomenclature for plant communities is based on Dyrness, C.T., and L.A. Viereck. March 17, 1978 (Third rough draft). A suggested classification for Alaskan vegetation. Mimeo. Institute of North. Forestry, USDA Forest Service, Fairbanks, Alaska.

slopes, wet sedge-grass meadows on flat lowlands, riparian willow shrubland along small drainageways, larger rivers, and streams, and open and closed mat and cushion tundra on dry ridge crests, peaks, and hilltops. Recent attempts to map the vegetation of the Seward Peninsula include George et al. (1977), Nodler, LaPerierre, and Klein (1978), Racine (1977), Anderson, Racine, and Melchior (1974), and Anderson and Belon (1973).

Seward Peninsula tundra fires, with which this report is concerned, are by no means the only form of disturbance to these tundra ecosystems. Gold mining between 1900 and 1940 resulted in the construction of ditches, dams, tractor trails, and even railroads. During the same period, commercial reindeer herds, introduced in the 1890's, increased greatly (up to 400,000 animals by the early 1930's), and intense grazing exerted unknown effects on the vegetation (Palmer and Rouse 1945). Recent evidence for climatic change over the long and short term (last 30 years) exists (Hopkins 1972) and represents still another source of ecosystem change. Even without these external sources of disturbance, sedge tussock-shrub tundra may undergo plant succession which changes the tundra composition and structure and permafrost conditions (Racine 1975). The role of fire in such tundra ecosystems must therefore be evaluated in the context of these other forces affecting ecosystem change.

Fire History

Although fire has probably always occurred in the Seward Peninsula tundra ecosystems, there is little information on the frequency and characteristics of past outbreaks (Wein 1977). Melchior (1974) has gathered some information, described here, on the occurrence of fires in the area prior to 1973. The earliest record of such fires on the Seward Peninsula dates from the summer of 1900, when a geological survey and topographic mapping party in the Nome region noted that "the conditions proved very unfavorable for surveying as during the month of July fires raged in every direction and the thick smoke almost prevented the use of telescopic instruments" (Brooks et al. 1901, as quoted in Melchior 1974). A USGS journal entry characterized the climate on the Seward Peninsula for the summer of 1906 as "very warm and dry; tundra fires common; maximum temperature 85°F" (Henshaw and Covert 1908). The summer of 1903 was dry enough so that the work of the survey party was interferred with little by rain or by any climatic

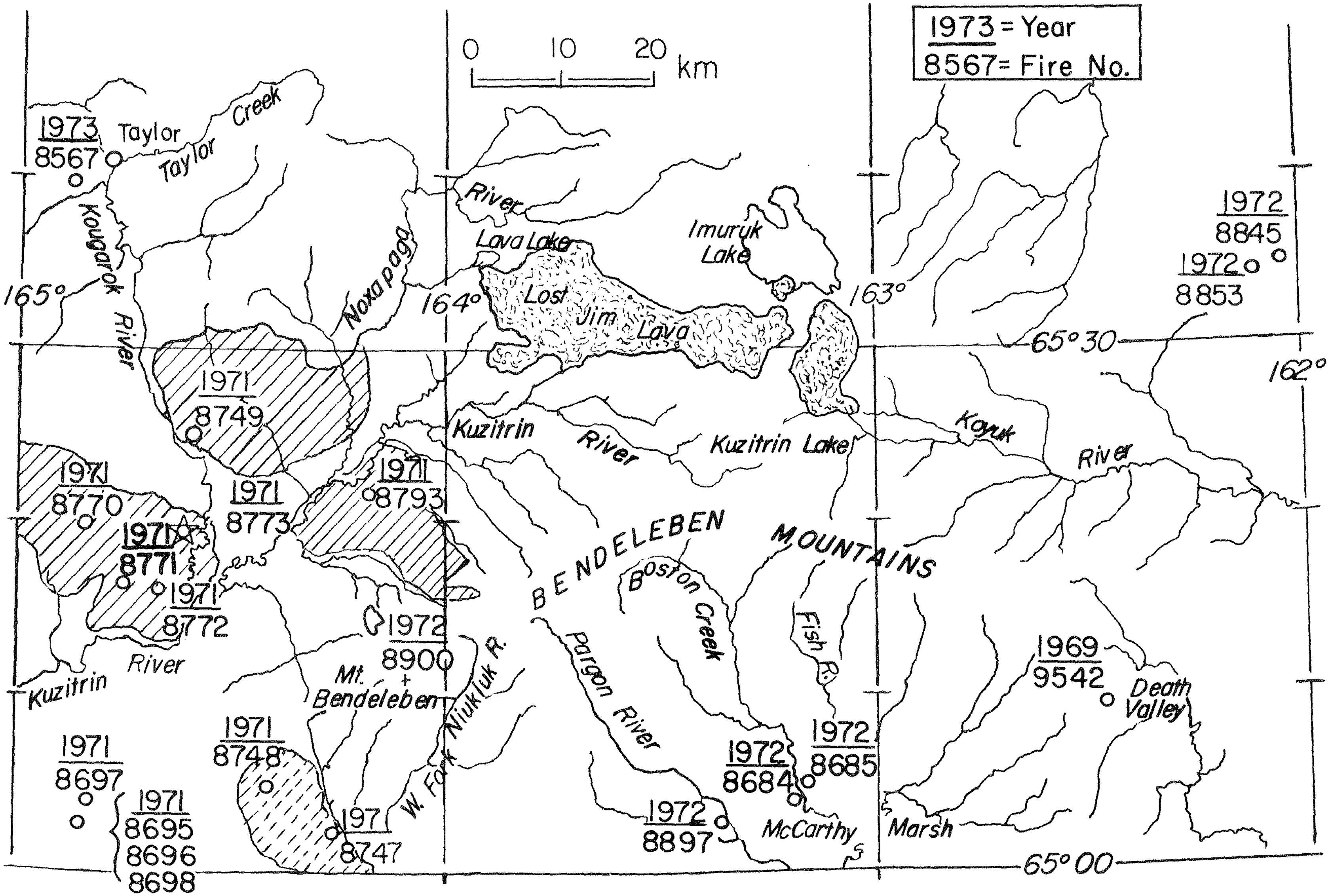

Fig. 2. Map showing the locations and extent of fires between 1969 and 1973 on the central Seward Peninsula. Data from BLM records as reported in Melchior (1974). The 1971 fire site sampled in this 1978 study is marked with a star.

conditions until the early frosts came, although for several days in August smoke from burning tundra made topographic mapping almost impossible (Moffit 1905:72).

There is a gap in the tundra fire record from about 1910 until 1956, when the Bureau of Land Management began keeping records of fires reported within Alaska. It is assumed that fires started by gold mining may have been common during the early half of this period. Palmer (1926) notes that, "Fires are often set by prospectors to clear off the vegetation and thus expose the underlying ground and rock or by Eskimos in an effort to be rid of mosquitoes." Dr. David Hopkins (pers. comm., USGS, Menlo Park, California), who began geological survey work in the Seward Peninsula in the mid-1940's, mentioned that tundra fires may have occurred around Solomon in the early summer of 1947. Melchior (1974) examined BLM fire reports for the period from 1968 to 1973 in the northern Seward Peninsula and found 21 fires reported for this period, of which he mapped the location of several (Fig. 2) and showed that the summers of 1971 and 1972 were peak years. While these pre-1974 fire statistics show that most tundra fires occurred in the east, central, or southern portions of the Seward Peninsula, the 1977 fires burned more northern and western tundras of the peninsula. There is a possibility, however, that a 1977 tundra fire west of the Darby Mountains (Fig. 1) may have reburned parts of a 1972 burn (Fig. 2).

Other records of the occurrence and extent of past tundra fires include those of Wein et al. (1975) and Wein (1977) for western Canada, and Barney and Comiskey (1973) and Hall, Brown, and Johnson (1978) for the Alaskan Arctic Slope. The Seward Peninsula tundra fires appear to be of much larger size and extent than these more northern fires, perhaps because of the increased vegetation biomass on the Seward Peninsula. It is also interesting to note that a large portion (43 percent) of the so-called "forest fires" in interior Alaska actually occur in treeless areas, primarily tundra bogs and fens (Viereck 1975).

Study Sites

During the 1978 field season, tundra fire studies concentrated on two 1977 and one 1971 burns (Figs. 1 and 2). The 1977 Deering-Imuruk Lake fire burned about 940 km^2 between the Inmachuk River on the west and the Kugruk River on the east. The 1977 Serpentine River fires burned three disjunct areas between the Arctic River on the west and the Serpentine River on the east, near to the coastal

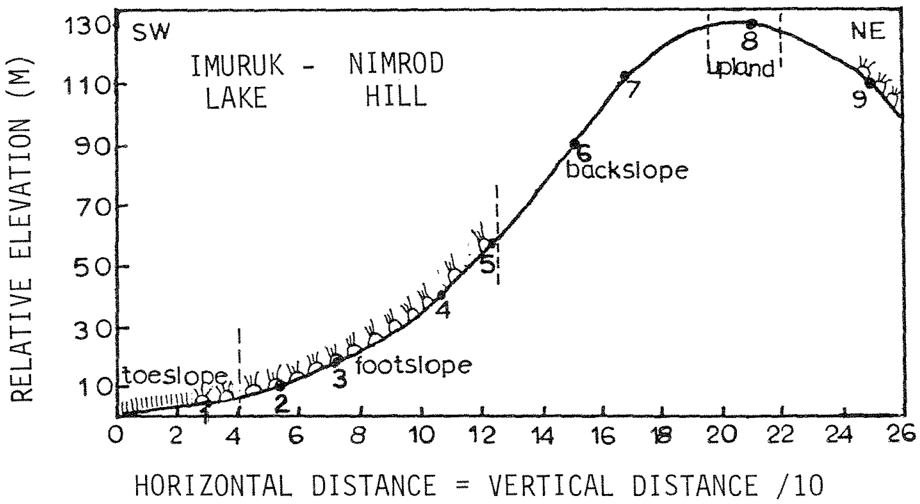

Fig. 3. Scaled topographic profile of Nimrod Hill near the east shore of Imuruk Lake, where quantitative information on prefire (1973) and postfire (1978) vegetation and soils was obtained at the nine sample sites shown. Elevations range from 355 m (1100 ft) at site 1 up to 457 m (1500 ft).

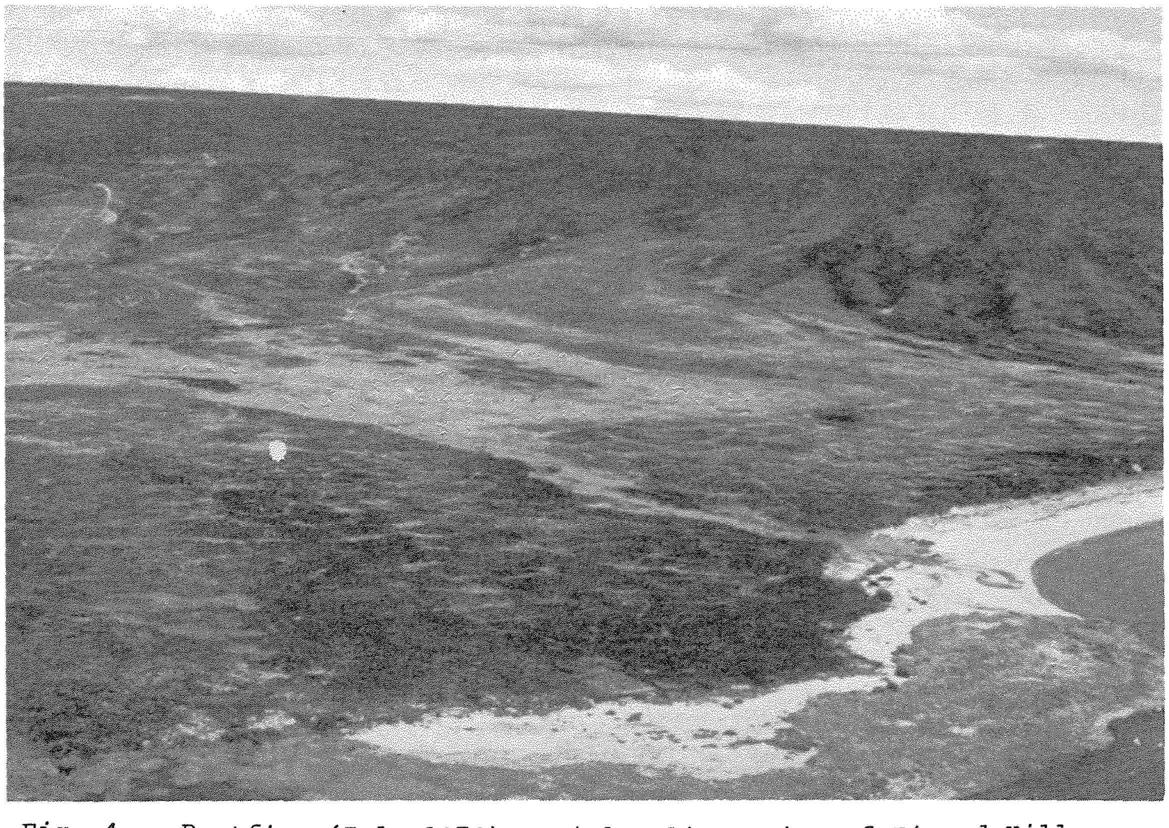

Fig. 4. Postfire (July 1978) aerial oblique view of Nimrod Hill slope, showing the distribution and intensity of burning. Shore of Imuruk Lake is visible in the right foreground.

Shishmaref Inlet-Chukchi Sea region. Finally, the 1971 Kuzitrin River fires covered a large region south of the Bendeleben Mountains and about 100 km north of Nome (Fig. 2).

Two areas were chosen for ground study and the establishment of permanent transects in the Deering-Imuruk Lake fire, one area in the Serpentine-Arctic River fire, and one area of the 1971 Kuzitrin River fire (Figs. 1 and 2). The Deering-Imuruk sites include one at the northern edge of the burn just east of the Inmachuk River near the Utica Creek landing strip, and the other at the southern end of the burn on the east shore of Imuruk Lake. The latter site was chosen because of the availability of prefire, July 1973, quantitative soil and vegetation data obtained by the author (Racine 1974) and soil scientists (Holowaychuk and Smeck 1974) along a topographic transect from the bottom to the top of Nimrod Hill (Figs. 3 and 4). The Arctic River tundra fire site is located on the crest of a small hill covered with high-centered polygons (see Fig. 5) near the mouth of the Arctic River, overlooking Shishmaref Inlet. The fourth study area is located in the 1971 Kuzitrin River burn along the Taylor or Kougarok Road (Fig. 2). Near Coffee Dome, the Taylor Road acted as a firebreak, permitting the comparison of an area not burned with one burned during the 1971 fires. The locations of all four study sites are shown on 1:63,360 scale USGS maps in Appendix 1.

METHODS

Vegetation and soil studies conducted in July 1973 (Racine 1974, 1975; Holowaychuk and Smeck, 1974) on sites which later burned during the 1977 tundra fires provided prefire information for assessing postfire changes. In this way it was possible to avoid the substitution of a space variable (i.e. an adjacent unburned plot) for a time variable. A visit to an older (1971) tundra fire site was also made to help establish postfire successional patterns.

Aerial and ground reconnaissance over each of the burns was done to determine general burn patterns and other features associated with tundra fires. This was followed by more intensive sampling on the ground. A total of 15 permanently marked belt transects 10 m long by 1 m wide were established at the four study sites. The ends of each 10-m-long belt transect were marked with 1.5-m-long wooden lath pushed into the ground for future relocation. These sites were chosen to represent the range of tundra ecosystems and topographic sites burned, with emphasis on the prevailing sedge tussock-shrub tundra. On Nimrod Hill, on the east side of Imuruk Lake, the 1973 vegetation-soils transect was relocated and nine sample sites established as close to the original ones as possible (Figs. 3 and 4). Topographic slope, elevation, and aspect were determined, along with the kinds and extent of various frost features such as mud circles, frost scars, and ice-wedge polygons.

The vegetation in each of the 150 1 m x 1 m quadrats included in these 15 transects was sampled intensively. The transects were oriented in a magnetic north-south direction in case one of the marking laths became lost. A meter tape was stretched tight between the ends of the transect and 10 1 m x 1 m quadrats were positioned on the west side of the tape (see Fig. 17 for transect layout). All species of living plants were recorded for each 1 m x 1m quadrat. The number of green leafy shoots was counted for each species and cover estimates were made. Attempts were made to determine if the origin of these shoots was from seed or vegetative resprouting. The density of cotton-grass tussocks (Eriophorum vaginatum) and the number of seed stalks also were determined in each plot. Later, mean density and cover values were calculated for each species in each set of 10 1 m x 1 m plots of the transect.

Depth from the charred peat surface to frozen ground was measured in each plot and the thickness of the remaining organic mat (depth to mineral soil) was established for the transect. A total of 22 soil samples were collected from the organic and mineral horizons of sample sites along the Nimrod Hill (Imuruk Lake) transect, as close as possible to the sites sampled by Holowaychuk in 1973 (Holowaychuk and Smeck 1974). These were later analyzed for extractable potassium and phosphorus, by the same extraction procedures as those used for the 1973 samples. Photographs of the entire 10 m x 1 m belt transect as well as of selected individual 1 m x 1 m plots were made for future comparison (see Figs. 8 and 15).

RESULTS

Burn Patterns

Aerial and ground reconnaissance of the 1977 tundra fire sites indicated much variation in the extent to which the above-ground vegetation and soil organic layer burned. At the study sites visited, evidence of all intensities of burning can be found, from completely unburned to intensely burned with exposed mineral soils. The pattern is

Table 1. Plant communities within the area of the 1977 Seward Peninsula tundra fires in relation to their probability of burning. Based on 1978 observations.

Plant Community Type (Names from Dyrness and Viereck 1978)	Probability of Burning Low---------------High (Unburned)----(Burned)
Tundra	
Sedge-grass	
Wet Sedge-grass	
Wet Sedge Meadow.........................x	
Sedge-shrub	
Sedge-willow..............................x	
Sedge-mat and cushion	
Sedge-Dryas..x	
Tussock	
Sedge tussock-shrub	
Sedge tussock-ericaceous shrub...............................x	
Sedge tussock-mixed shrub....................................x	
Shrub	
Birch and Ericaceous..x	
Willow...x	
Mat and Cushion	
Open mat and cushion.............................x	
Closed mat and cushion..x	
Shrubland	
Tall shrub	
Willow...x	
Low shrub	
Low Willow...x	

undoubtedly related to variations in topography and wind speed and direction, as well as to the composition, moisture content, and soil organic accumulations of the plant communities at the time of the fire.

Within the area of the fire, certain plant communities appear to burn more frequently than others (Table 1). Some of these patterns can be seen in Figs. 4 and 5. Wet sedge-grass meadow often remained unburned on the flats at the base of Nimrod Hill (Fig. 4) and in the bordering troughs of polygons (Fig. 5) as well as in the centers of low-centered polygons. Elsewhere near the Inmachuk River, vegetation in the wettest depressions of old vehicle tracks did not burn, while the surrounding sedge tussock-shrub tundra was charred. Willow shrubland also remained unburned (Fig. 5) except where low willow occupied narrow drainageways along the Nimrod Hill Slope (Fig. 4). Burned areas of low willow shrubs appear as dark stripes on the slope in Fig. 4. Dry and rocky hilltops and ridges generally were unburned where there is open mat and cushion tundra; however, the closed mat and cushion tundra cover on a well-drained hilltop south of Nimrod Hill burned patchily, with some interesting effects on an archeological site as described in Appendix 2.

Smaller patches of unburned tundra, 0.5 m to 3.0 m in diameter, occurred within burned sedge tussock-shrub and low shrub tundra. Frequently, patches (1 m to 2 m in diameter) of Sphagnum moss were found which had not burned but

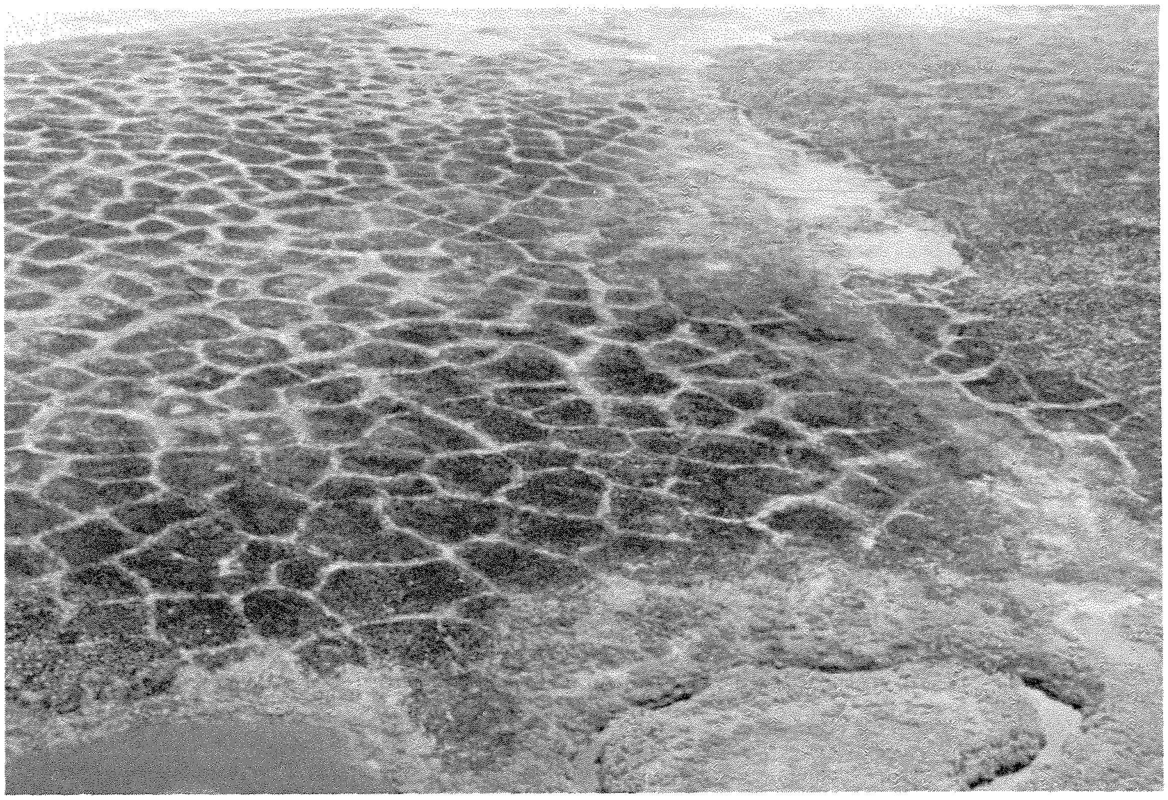

Fig. 5. Aerial oblique view of burn patterns over an area of high-centered polygons near the Serpentine River in the northwestern Seward Peninsula. Note unburned polygon troughs and low willow shrubland along stream in foreground. Also note patches of unburned wet sedge-grass meadow in upper right.

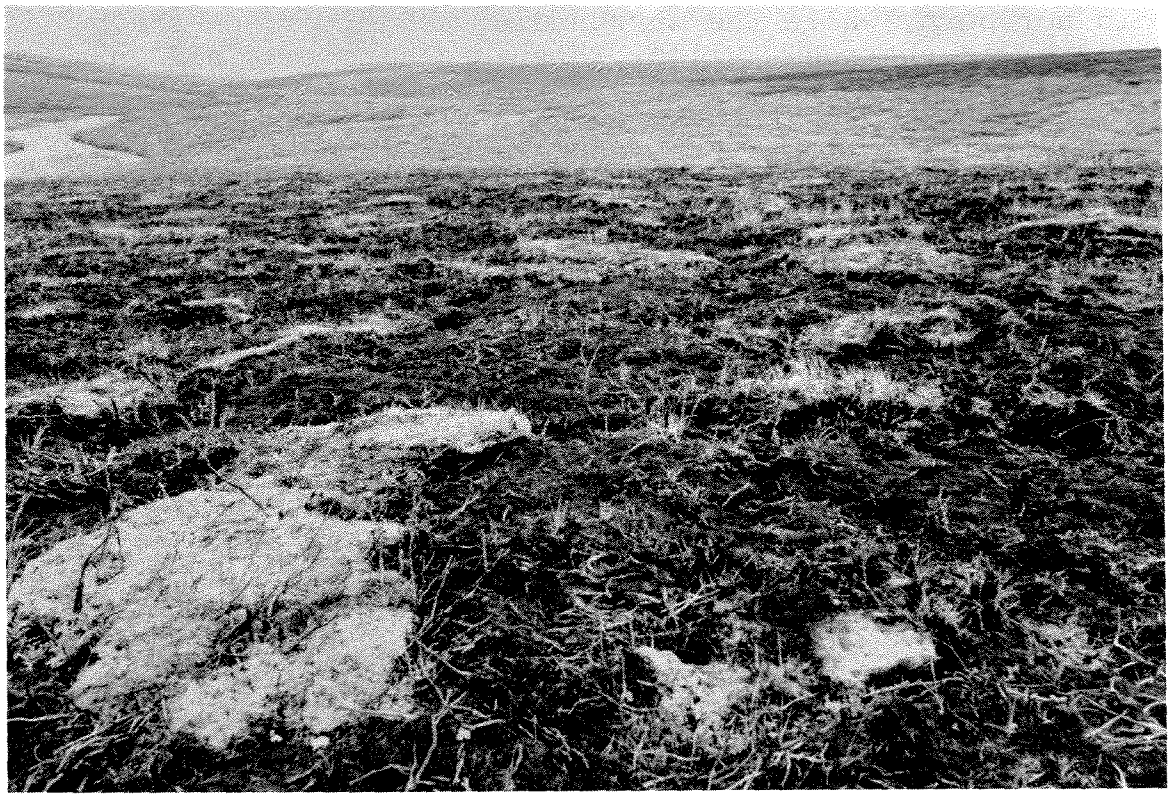

Fig. 6. July 1978 view of 1977 tundra burn on a low shrub slope near the Inmachuk River (left background). Patches of unburned but apparently dead Sphagnum *moss contrast with the charred surface.*

were brown and apparently dead (Fig. 6). While Sphagnum moss may not burn because of its high moisture content, other small and some even fairly large patches of tundra were unburned, for reasons not apparently related to plant species composition or topography (Fig. 7).

Effects on Soils

Soil Organics. The most frequently burned and widespread tundra communities are sedge tussock-shrub and low shrub tundras which occupy gentle slopes. Although most of the aboveground plants except for tussocks are burned off, the degree to which the 0.2-m to 0.3-m-thick organic layer is burned varies greatly (Table 2). Removal of this organic layer would be expected to affect thaw depths, vegetation recovery rates, nutrient levels, and possibly frost action processes. In sedge tussock-shrub tundra, an illusion of deep peat removal is produced by the burning of dwarf shrubs, mosses, tussock leaf bases, and lichens which normally fill the intertussock spaces (Figs. 7 and 8), so that 20 cm to

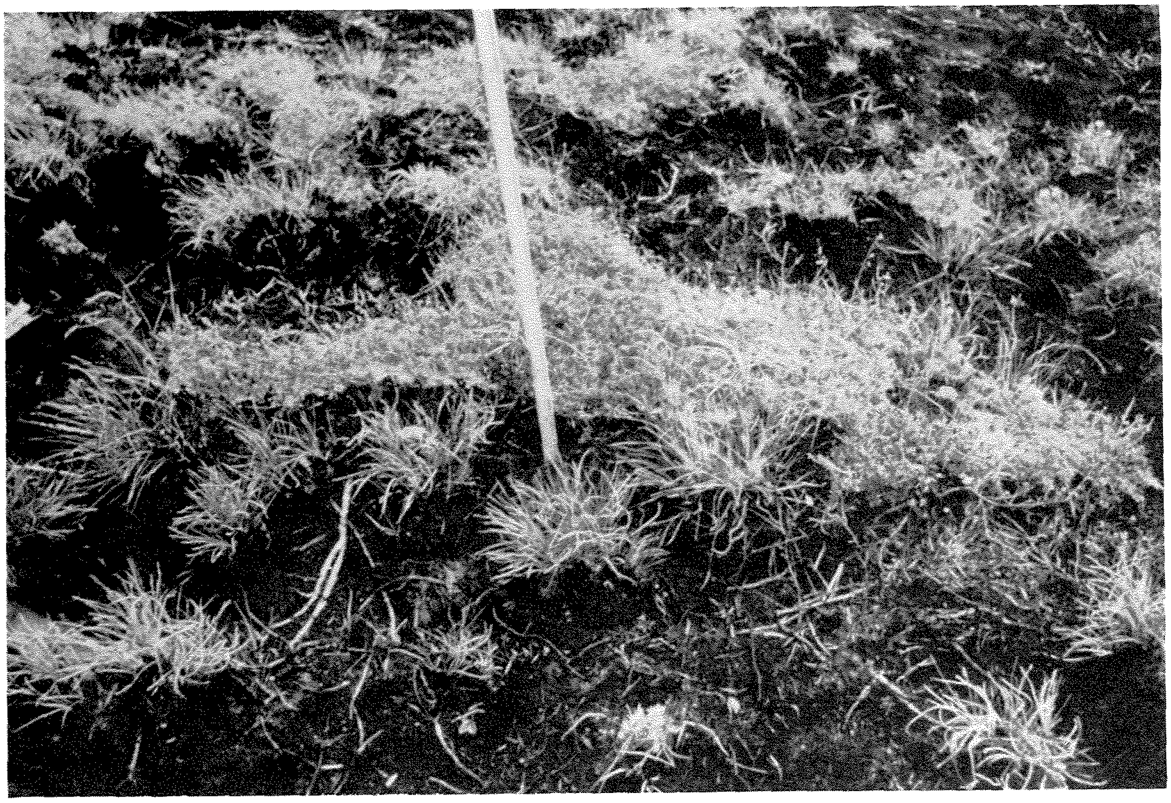

Fig. 7. Patch of unburned tussock-shrub tundra, showing the depth to which the surface burned (beside meter stick) on a 1977 burn near Arctic River-Shishmaref Inlet area.

30 cm of tussock height is exposed. At most sedge tussock-shrub tundra sites, however, the fire did not burn so deeply into this organic layer as to expose mineral soil (Table 2). On the lower slopes of Nimrod Hill, postfire peat thickness was found to be from 24 cm to 30 cm, suggesting a reduction of only 5 cm to 15 cm. Measurements of surface peat removal along the edge of unburned islands (Fig. 7) suggest that less than one half of the organic layer burned. Above these sedge tussock-shrub tundra sites on Nimrod Hill, however, where drainage improves and dwarf shrubs replace tussocks (sites 6 and 7), complete burning of the organic layer was common. Figures 9 and 10 show the well-drained crest of this hill before and after the fire, respectively. It is apparent that most of the aboveground vegetation and organic soil horizon have been removed, particularly where turf-banked frost scars had been covered by a thin layer of mosses (Rhacomitrium sp.), dwarf shrubs including blueberry (Vaccinium uliginosum), lowbush cranberry (V. vitis-idaea), crowberry (Empetrum nigrum), and lichens (Alectoria sp.).

Table 2. Topographic, soil, and permafrost characteristics of sampled tundra burn sites in the Seward Peninsula.

Location	Slope-exposure	Drainage	Soil* type	Frost features* (%) areal extent	Organics 1973*†	Organics 1978*†	Frost depth'73*	Frost depth'78
						cm		(cm)
Imuruk Lake								
Site 1	1%-SW	Poorly Drained (PD)	Histic Pergelic Cryaquepts (HPC)	High-centered polygons (hcp) Mud Circles(1)	25 cm†	15	N.D.††	30(7)/58
Site 2	3%-SW	PD	HPC	Mud Circles(2)	25-30 cm	25	29(7)	30(6)/50
Site 3	5%-SW	PD	HPC	Mud Circles(3)	25-30 cm	25-30	N.D.	31(7)/47
Site 4	9%-SW	PD	HPC	Mud Circles(1)	24(11) cm	10-15	N.D.	34(7)
Site 5	9%-SW	PD	HPC	Mud Circles	28(6) cm	10-15	N.D.	38(4)
Site 6	12%-SW	Somewhat PD	HPC-Pergelic Cryaquepts	Turf-banked Mud Circles(5)	18(9) cm	0-15	25(6)/43§	55(8)
Site 7	15%-SW	Moderately well drained	Pergelic Cryaquepts (PC)	Turf-banked Mud Circles(40)	22(8) cm	0-13	25 cm	55
Site 8	0%	Very poorly drained	Pergelic Cryofibrists	Low-centered polygons	35-43 cm	15-30	23(3) cm	23(3)
Site 9	8%-NE	PD	HPC	Hummocky	20-25 cm	13-15	22(4)	26(3)
Inmachuk R.								
Site 1	3%-W	PD	N.D.	Mud Circles(3)	N.D.	N.D.	N.D.	19(2)/45
Site 2	19%-W	Well drained	N.D.	Frost boils(5)	N.D.	0-10	N.D.	38(9)
Arctic R.								
Site 1	0%	PD	N.D.	hcp	N.D.	0-10	N.D.	31(5)
Site 2	0%	PD	N.D.	hcp	N.D.	0-10	N.D.	36(6)
Coffee Ck.								
1971 Burn	2%-E	PD	N.D.	Mud Circles	N.D.	26(3)	N.D.	32(4)/62
Unburned	2%-E	PD	N.D.	Mud Circles	N.D.	31(2)	N.D.	31(3)/58

* As determined by Dr. N. Holowaychuk (1974) during the Chukchi-Imuruk Survey.
† Organics refers to the thickness of the O horizon in cm.
†† N.D. = not determined.
§ 25(6)/43 is read as 25 cm mean, with a standard deviation of 6 cm outside of mud circles. Depth to frozen ground in mud circles is given to the right of the slash (/) or here 43 cm.

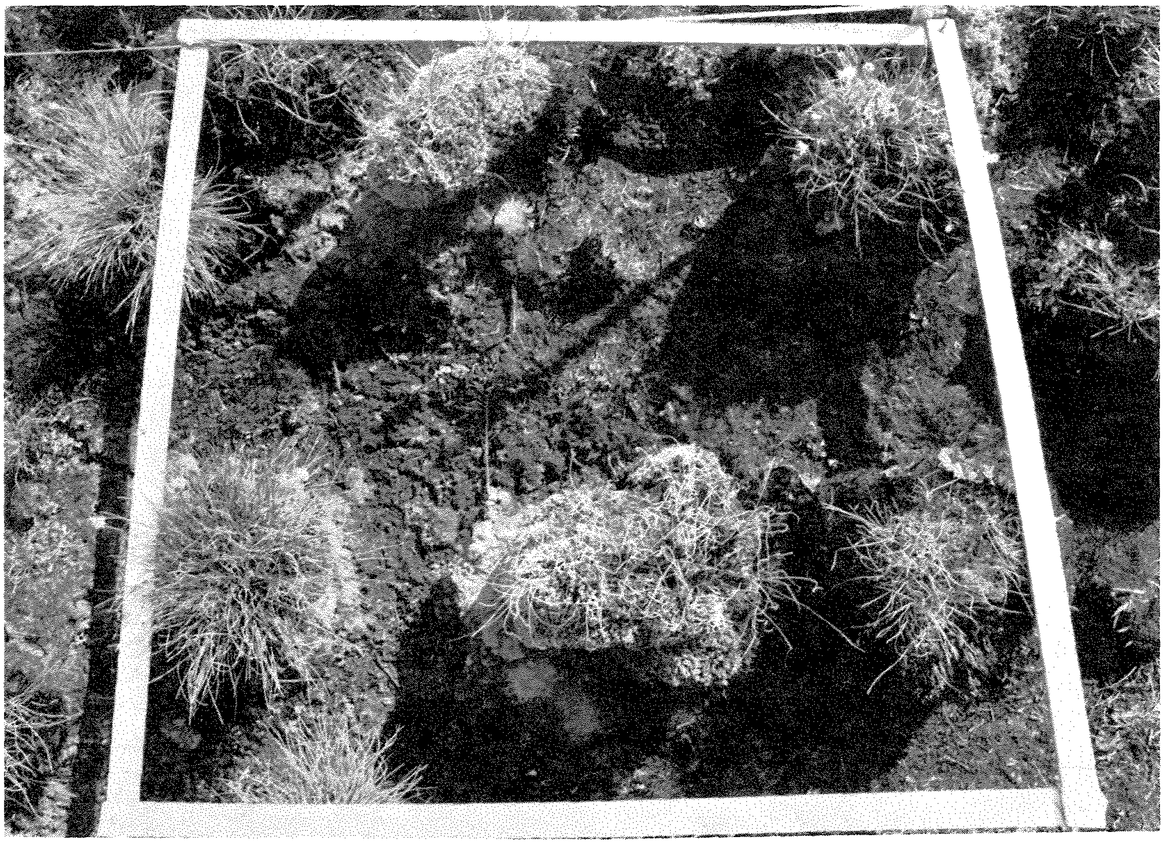

Fig. 8. Vertical view of 1 m x 1 m plot (Sample site 1- Plot 1) on burned tussock-shrub tundra on the lower slope of Nimrod Hill at Imuruk Lake. Photo shows the standing resprouting tussocks and charred intertussock surface.

The organic layer in the burned sedge tussock-shrub tundra on top of the high-centered polygons at Arctic River (Fig. 11) is considerably thinner (0 cm to 10 cm) than that remaining in similar vegetation on Nimrod Hill (10 to 25 cm). The tops of these high-centered polygons appeared to be well-drained, however, so that burning would have been more complete. Peat thickness in the 1971 burned sedge tussock-shrub tundra at Coffee Creek was only slightly less (26 $\pm$ 3 cm) than that (31 $\pm$ 2 cm) on the unburned side of the road.

Soil Thaw Depths. Changes in the depth to frozen ground in burned tundra soils appear to be closely related to the amount of organic horizon removed by the fire. Along the topographic gradient of Nimrod Hill, July 1978 thaw depths increased from values of 30 to 35 cm under burned tussock-shrub tundra on the lower slopes (sites 1-5) to about 55 cm on the steep backslope of burned low shrub communities (Fig. 10), where most of the organic material had been removed (Table 2). At the same time, thaw depths on the crest and northeast-facing side slope of Nimrod Hill were only 23 to 26 cm (sites 8 and 9) where peat hummocks and Sphagnum patches are common (see Fig. 17). Thaw depths at other sedge tussock-shrub sites were generally similar to those at Nimrod Hill, about 30 to 35 cm, except on the hill above the Inmachuk River where thaw depths were only 20 to 25 cm; however, this determination was made earlier in the season (June 26, 1978) than were measurements at other sites in mid-July.

Except where the organic horizon was completely burned, as at sites 6 and 7 on Nimrod Hill (Fig. 10), increased thaw depths are difficult to detect. Prefire 1973 measurements of thaw depths on Nimrod Hill are about the same as

Fig. 9. Prefire (1973) view downslope from the backslope on Nimrod Hill (near sample sites 6 and 7) looking southwest toward Imuruk Lake and the far shore (background).

the 1978 depths in Table 2; however, frost depths in small unburned islands and moss patches in 1978 (Figs. 6 and 7) were 20 to 25 cm, while adjacent burned areas were thawed 30 to 35 cm. Summer 1978 was relatively warm, dry, and early, however, compared with cold, wet conditions in 1973, so that the drying of the burned upper peat layers in 1978 would actually have increased the insulating effectiveness and reduced thaw depths (Bunnell et al. 1975). Although the thaw depth measurements do not show striking changes, postfire thawing is actually much deeper relative to the original prefire peat surface, 5 to 10 cm of which was removed by the fire. Hence, in most burned sites, thawing reaches into the mineral horizon 10 to 25 cm below the burned surface. In prefire 1973 soil profiles at Imuruk Lake, only about one quarter (25 percent) of 100 probes reached into the mineral soil beneath tussock-shrub tundra (Hollowaychuk and Smeck 1974:168). Thawing into the mineral soil may affect several belowground processes, including frost action.

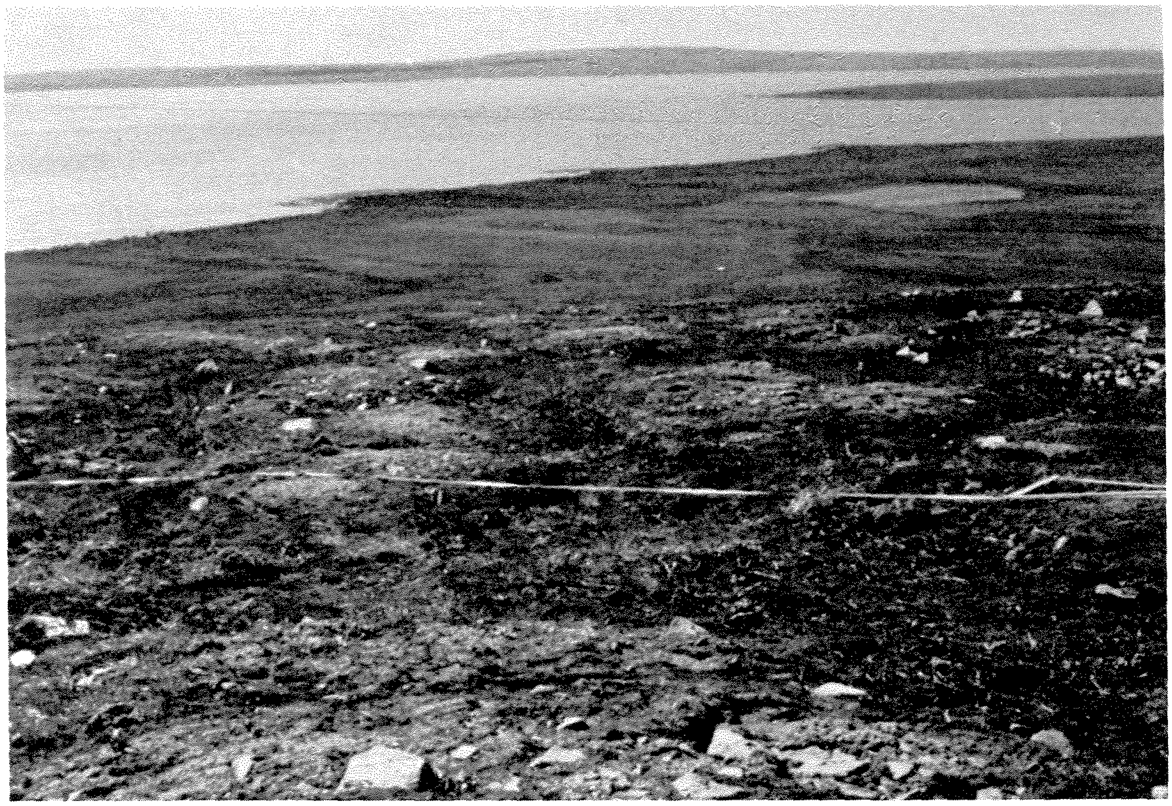

Fig. 10. Postfire (1978) view downslope on Nimrod Hill from the same position as in Fig. 9. Photos show the effects of 1977 tundra fire on vegetation and organic soil cover over frost scars near sites 6 and 7.

Fig. 11. Only a thin organic layer (5 cm thick) remains over mineral soil horizon on burned sedge tussock-shrub tundra on high-centered polygons near Arctic River.

Soil Frost Features. Frost features resulting from soil freeze-thaw cycles become much more conspicuous after overlying soil organics and/or vegetation are burned. The thin moss, lichen, or dwarf shrub cover over inactive frost scars on Nimrod Hill in 1973 was burned off by the fire, exposing a bare soil surface (Figs. 10 and 12). Apparent churning of this exposed surface suggests that postfire frost action took place (see Figs. 9 and 10). Contraction cracks on the flat crest of Nimrod Hill were never seen in 1973 (although we noted low-centered polygons there), but in 1978 these were quite conspicuous (Fig. 13), suggesting that the covering vegetation burned or renewed frost activity took place. Old frost scars or mud circles 1 to 2 m in diameter in sedge tussock-shrub tundra are particularly conspicuous after tundra fire, because of more intense burning in the surrounding tundra and the greater density, resprouting, and flowering vigor of the tussocks on each frost scar.

Soil Nutrients. Burning of the organic layer and deeper thawing into the mineral soil might be expected to release

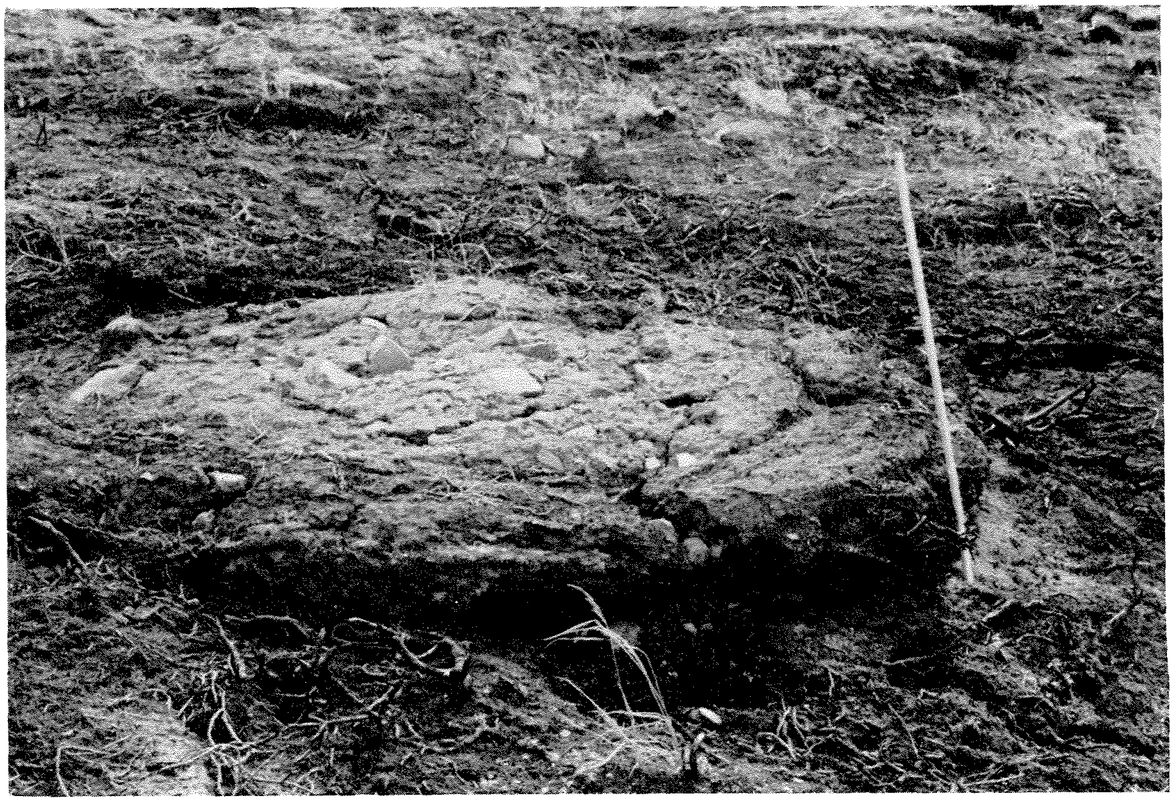

Fig. 12. Postfire turf-banked frost boil on the backslope of Nimrod Hill, near sites 6 and 7 where the 1977 fire burned off vegetation and organics which formerly covered boil.

nutrients or make them more available to plants. Wein and Bliss (1973) found generally higher plant tissue levels of nitrogen, phosphorus, and potassium in burned than in unburned sedge tussock-shrub tundra. Comparison of soil extractable phosphorus and potassium from the same prefire (1973) and postfire (1978) sites on Nimrod Hill (Table 3) suggests postfire increases, at least in the burned surface organic horizons. The variation is greater, however, and the difference between pre- and postfire levels is generally nonsignificant (t = 1.25 for potassium in organics and t = 1.00 for phosphorus in organics). Several high values for both extractable potassium and phosphorus were obtained in surface organics containing charred or ash materials in Table 3. The release of nutrients and possible runoff in water are suggested by the occurrence of small patches of a white precipitate (Fig. 14).

Fig. 13. Conspicuous frost contraction crack on the flat upland of Nimrod Hill in sedge-shrub tundra. Such cracks were not visible here before the fire. Note patchy burning here.

Revegetation and Succession

The results of sampling total vascular plant cover on the study sites one year after fire show that sedge tussock-shrub tundra has the fastest revegetation rates, with about 20 to 25 percent cover (Table 4, Fig. 15). Cover values of only 4 to 7 percent were found on burned drier sites with low shrub communities (Table 4, Fig. 16). Similar cover values of 5 to 7 percent occurred on wetter sites with sedge-shrub tundra communities without tussocks (Fig. 17). Living plant cover, one year after the 1977 fire, is produced by one or more of the following: 1. the resprouting of sedges and dwarf shrubs; 2. seed germination and seedling establishment mainly by graminoids (sedges and grasses) but also by forbs; and 3. colonization by mosses and liverworts. In addition, a small amount of living plant cover one year after fire was of individuals that escaped burning. The proportional contribution of different plant growth

Fig. 14. A white precipitate deposit on burned and charred soil surface bordering an old mud circle (marked by the group of 8 or 9 dead tussocks). These mud circles were not visible before the fire and are undoubtedly relic features.

forms to total plant cover both before and one year after fire on Nimrod Hill is shown in Fig. 18.

Resprouting of cottongrass (E. vaginatum) tussocks accounts for about 15 to 20 percent cover in sedge tussock-shrub tundra one year after fire (Figs. 15 and 18c). Some tussock resprouting undoubtedly also occurred immediately following the fire in 1977 (cf Hall, Brown, and Johnson 1978). Resprouting of dwarf shrubs and cloudberry (Rubus chamaemorus) together with unburned and new moss cover accounts for the remaining cover in this community.

On better drained sites with low shrub (Dyrness and Viereck 1978, third draft) or birch and ericaceous shrub tundra (L. A. Viereck, written comm., Jan. 17, 1979), the low shrub cover and organics had burned off to expose mineral soil (Figs. 16 and 19). On such sites (sites 6 and 7 on

Table 3. Soil texture, prefire (1973) and postfire (1978) potassium and phosphorous nutrient levels in soils along a topographic gradient from the bottom to top of Nimrod Hill on the east side of Imuruk Lake. Asterisk (*) indicates presence of charred organics; minus sign (-) means no determination.

Location	Texture Mineral Soil[1]	1973 Extractable K (ppm)[1]	1978 Extractable K (ppm)[2]	Change K (ppm)	1973 Extractable P (ppm)[1]	1978 Extractable P (ppm)[2]	Change P (ppm)
Site 1							
Mud Circle	silt-clay	4	15	+11	0.6	2.9	+2.3
Mud Circle		-	71	-	-	1.1	-
Site 2							
0_e 25-0 cm		45	49	+ 4	7.0	4.0	-3.0
0_e 25-0 cm		-	36	-	-	1.4	-
Cgf 0-15	silt	24	21	- 3	1.5	6.9	+5.4
Mud Circle	silt	25	18	- 7	0.8	1.4	+0.6
Site 3							
Mud Circle	loam	7	9	+ 2	0.7	1.5	+0.8
Mud Circle		25	-	-	1.3	-	-
Site 4							
Mud Circle	loam	17	-	-	1.5	-	-
Site 5							
Mud Circle	Cosl	25	-	-	1.0	-	-
Site 6							
*0_e 10-0		40	104	+64	4.7	1.0	-3.7
C_f 0-25	Cosl	18	17	- 1	0.8	1.6	+0.8
Mud Circle		30	115	+85	1.0	1.6	+0.6
Site 7							
Mud Circle	Cosl	40	62	+22	0.7	4.8	+4.1
Site 8							
*0 15-10 cm		72	129	+57	10.0	27.0	+17.0
0 7-0		45	5	-40	5.6	1.6	- 4.0
C 0-5	Cosl	4	4	0	0.8	0.5	- 0.3
*0 Surface		-	67	-	-	9.0	-
0 15-25 cm		-	14	-	-	2.2	-
C 30-31		-	12	-	-	4.5	-
Site 9							
*0_1 23-13 cm	Sphag.	71	247	+176	4.6	5.7	+ 1.1
*0 11-10	Sphag.	42	121	+ 79	1.9	38.4	+36.5
0_e^1 10-5		-	33	-	-	1.6	-
0_e^2 5-0		103	34	- 69	4.6	1.6	- 3.0
0 0-5	Cosl	12	14	+ 2	2.6	4.0	+ 1.4
Mean - Organics		60(23)	76(71)	+38.7	5.5(2.5)	8.5(12)	+6.0
Mean - Mineral		19(11)	14(6)	- 0.5	1.1(.6)	2.8(2)	+1.8
Mean - Mud Circles		22(12)	48(42)	+22.6	1.0	2.2(1.4)	+1.9

[1]Determined at the Ohio State University Soil Testing Lab as reported by Holowaychuk and Smeck 1974; P analysis by Bray's P-1 test; K by Pratt NH_4 Acetate at pH 7.0.
[2]Determined at the University of Vermont Soil Testing Lab by above methods.

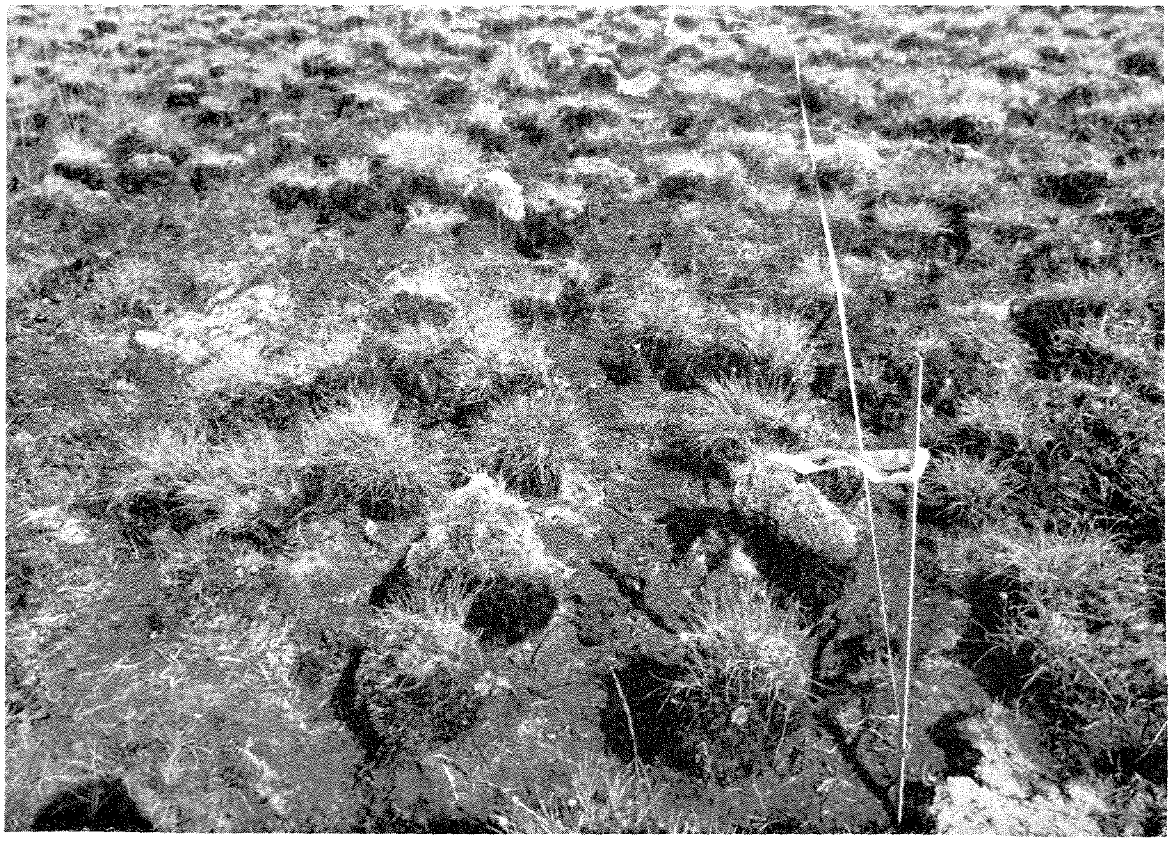

Fig. 15. Sedge tussock-shrub tundra in July 1978, one year after fire on the lower slope of Nimrod Hill (site 3 transect). Re-sprouting of cottongrass tussocks is evident.

Nimrod Hill, tops of high-centered polygons near Arctic River in Fig. 11), colonization by new vascular forb and graminoid seedlings, mosses, and liverworts made up the small percent cover (Fig. 18b). Few or no dwarf shrub shoots were found on these drier burn sites, even though they were important in the prefire vegetation.

On wetter sites with sedge-shrub tundra communities, there is a buildup of mosses and deep organics in the unburned vegetation (sites 8 and 9 on Nimrod Hill, Figs. 17 and 18a). Here, one year after the fire, resprouting of single-stemmed (as opposed to tussock-forming) sedges (Carex aquatilis) was locally important. Resprouting of dwarf shrubs and cloudberry accounted for the remaining revegetation, although unburned patches of Sphagnum also were common (Fig. 17).

Resprouting of dwarf shrubs involved several species which together made only a small contribution to total cover

Table 4. Density (shoots per 1 m^2) and cover (percent) for plant species growing on tundra burn sites. Includes some 1973 prefire values.

SPECIES (No.shoot $1m^2$/cover %)	Sedge-Shrub Tundra ← W E T → 1978 Nimrod Site 8	1973 Nimrod Site 8	1978 Nimrod Site 9	1973 Nimrod Site 9	Sedge Tussock-Shrub Tundra ← M O I S T → 1978 Nimrod Site 1	1978 Nimrod Site 2	1973 Nimrod Site 2	1978 Nimrod Site 3	1978 Nimrod Site 4	1978 Nimrod Site 5	1978 Inmach Site 1	1978 Arc.R. Site 1	1978 Arc.R. Site 2	Coffee 1971	Coffee Creek	Shrub Tundra ← D R Y → 1978 Inmach Site 2	1978 Nimrod Site 6	1973 Nimrod Site 6	1978 Nimrod Site 7
Gaminoids																			
Eriophorum vaginatum	/1	0	0	0	4.5/19	4.5/17	4.3/34	4.2/19	3.2/8	4.0/15	3.7/16	2.5/0	.2/3	4.2/20	/23	0	/1	0	0
Carex sp.	63/4	30 %	6/.5	13 %	52/6	13/1	9 %	7/.5	3/.2	2/.3	3/.5	34/3	7/1	58/4	0	7/.4	0	10 %	0
Calamagrostis sp.	15/.6	0	0	0	16/2	6/.3	0	6/.5	0	1/.2	1/.5	10/1	6/.5	7/.5	55/2	13/2	1/.5	0	20/3
Carex seedlings	2/.5	0	0	0	22/.5	2/.3	0	6/.5	28/.5	1/.1	26/.5	39/1	7/.5	0	0	5/.2	32/.5	0	19/1
E. vaginatum seedlings	1/.2	0	0	0	45/.5	54/.5	0	21/.5	60/.5	15/.5		0	0	0	0	0	22/.5	0	30/.5
" " fruit heads	0	0	0	0	4.5	4.5	N.D.	5.3	2.0	6.8	N.D.	0	0	10.5	0	0	0	0	0
Dwarf Shrubs																			
Ledum palustre	4/.3	4 %	4/.4	12 %	85/6	59/1.2	9 %	41/3	20/1	10/.5	4/.5	3/.5	1/.1	540/16	465/11	1/.1	0	6 %	-
Vaccinium uliginosum	6/.2	-	10/.5	4 %	0	2/.1	10 %	4/.2	16/1	9/.5	4/.3	0	0	269/5	310/7	2/.1	0	18 %	-
Vaccinium vitis-idaea	2/.5	3 %	4/.3	16 %	191/6	43/1	7 %	25/1	12/.6	14/.5	6/.5	0	0	400/6	521/9	-	0	7 %	0
Betula nana	-	6 %	-	11 %	3/.4	1/.2	6 %	2/.2	1/.2	1/.2	-	0	0	27/2	58/5	2/.2	0	8 %	0
Arctostaphylos alpina	0	0	0	0	1/.3	-	1 %	1/.1	0	0	0	0	0	0	0	0	0	0	0
Empetrum nigrum	0	1 %	0	1 %	0	0	2	0	0	0	0	0	0	40/.5	132/3	0	0	5 %	0
Salix pulchra	0	0	0	-	0	0	2	0	-	1/.2	0	0	0	0	0	-	0	2 %	1/.5
Spirea Beauverdiana	0	0	0	0	0	0	0	0	0	0	0	4/.4	2/.2	0	0	0	0	0	0
Rubus chamaemorus	24/2	3 %	52/3	13 %	6/1	50/2	1	16/2	51/5	23/2	39/5	7/.6	1/.3	41/3	52/5	1/.5	0	1 %	-
Herbaceous Dicots																			
Epilobium angustifolium	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7/1	1/.5	0	1/.5
Petasites frigidus	0	0	-	0	0	0	-	0	0	0	0	8/1	3/.5	0	0	0	0	2 %	-
Artemisia Tilesii	0	0	0	0	0	0	0	0	0	0	0	1/.2	0	0	0	0	0	0	0
Polemonium boreale	0	0	0	0	0	0	0	0	0	0	0	2/.4	1/.2	0	0	0	0	0	0
Saxifraga punctata	0	0	0	0	0	0	0	0	0	0	0	0	1/.1	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	4/.4	0	0	0	0	0	0
Vascular Plant (Total)	7 %	47 %	5 %	69 %	42 %	24 %	84 %	28 %	17 %	18 %	24 %	6 %	7 %	56 %	65 %	4 %	3 %	57 %	6 %
Mosses and Liverworts																			
Marchantia polymorpha	12/1	0	0	0	8/.5	-	0	2/.2	3/.4	-	0	2/.3	15/1	0	0	12/1	24/1	0	16/1
Polytrichum sp.	13/.6	0	0	0	7/.4	81/1	0	5/.4	0	0	29/1	16/.4	1/.3	324/2	54/.5	34/1	0	0	2/.5
Ceratodon purpureus	1 %	-	0	0	1 %	0	0	-	2 %	0	0	4 %	18 %	2 %	.5 %	0	11 %	0	6 %
Sphag. sp. (unburned)	26 %	25 %	44 %	13 %	7 %	12 %	1 %	12 %	14 %	13 %	0	6 %	1 %	6 %	17 %	0	0	1 %	0
Sphag. sp. (1t. burn)	16 %	0	30	0	0	0	0	4 %	9 %	0	0	0	0	0	0	0	0	0	0
Lichens	0	13 %	0	8 %	-	2 %	0	-	0	0	0	2	1	2	10	0	0	14 %	0
Cetraria cuculata	0	3 %	0	1 %	-	1	0	-	0	0	0	1	1	.5	.4 %	0	0	5 %	0
C. islandica	0	1 %	0	1 %	-	0	0	0	0	0	0	0	0	.5	4 %	0	0	4 %	0
Cladonia sp.	0	9 %	0	6 %	-	-	0	-	0	0	0	1	0	.5	5 %	0	0	5 %	0

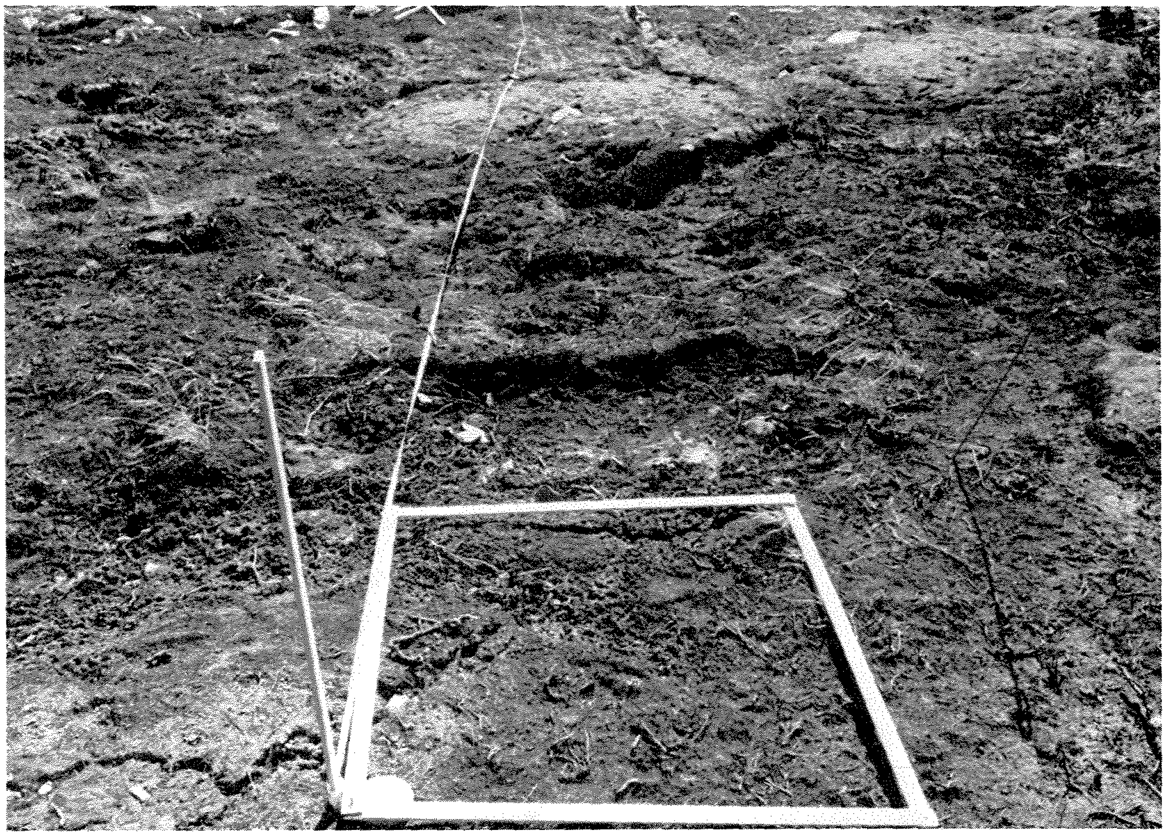

Fig. 16. Burned low shrub tundra on the well-drained backslope of Nimrod Hill (site 7) where vegetation and soil organics have burned off revealing frost scars and little or no resprouting has occurred.

one year after fire. Sprouts were typically small and short and their detection required close observation (Fig. 20, Table 4). In general, dwarf shrubs resprouted most vigorously from the top or sides of burned tussocks or from organic layers where their buried stems escaped burning. Labrador tea (Ledum palustre) shoots appear to be the most common of the dwarf shrubs one year after fire (Fig. 20). Seven years after fire in sedge tussock-shrub tundra at Coffee Creek, Labrador tea cover and density exceeded those in an adjacent unburned area (Table 4). Two other resprouting ericaceous shrubs were lowbush cranberry and blueberry. Shoots of dwarf birch (Betula nana) were generally less abundant than those of the three ericaceous shrubs, even though dwarf birch was frequently of equal or greater importance in the prefire vegetation (Table 4). Sprouts of willow (Salix pulchra) were generally rare in burned areas. Crowberry (Empetrum nigrum) was not found to resprout at any of the 1977 tundra fire sites, although it was present in small amounts before the fire (Table 4). On the 7-year-

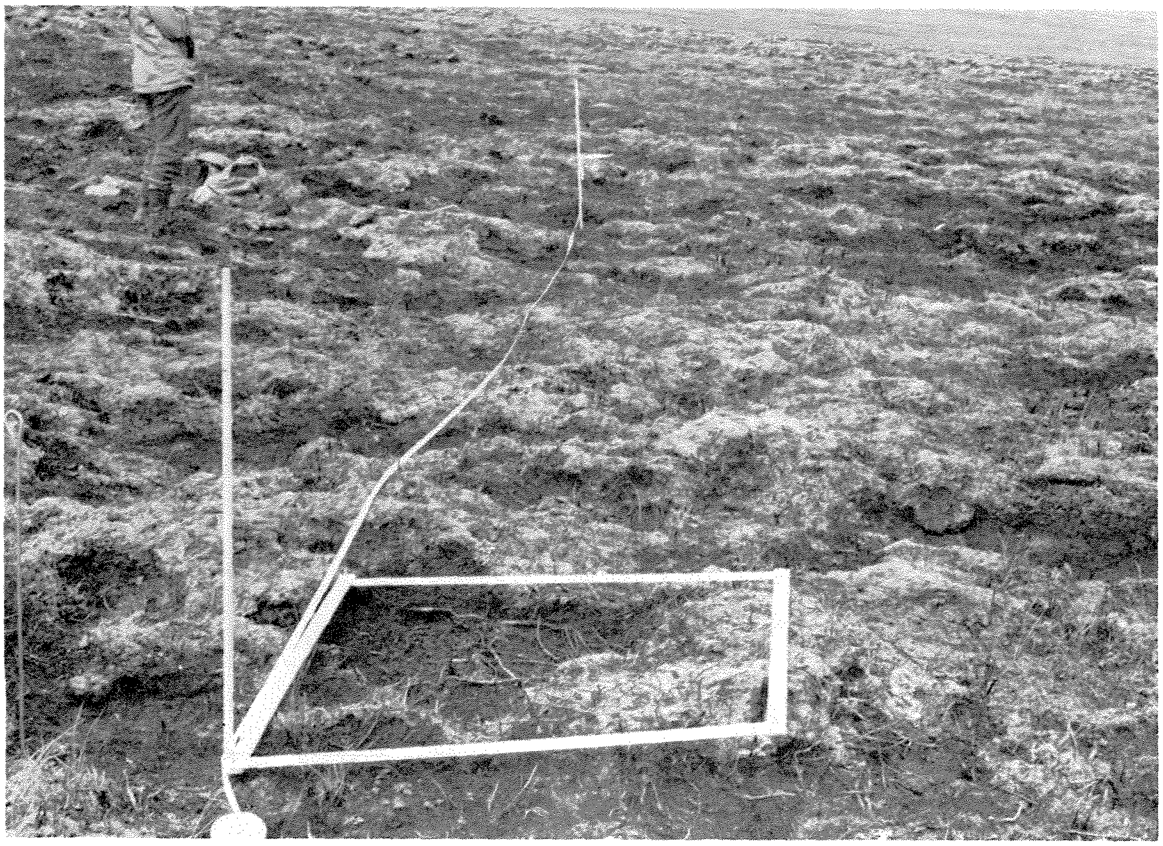

Fig. 17. Burned sedge-shrub tundra on the upper northeast-facing slope of Nimrod Hill (site 9), showing patches of unburned Sphagnum *moss and burned dwarf shrub stems.*

old burn at Coffee Creek, a few crowberry shoots were sampled, but levels were far below values in the adjacent unburned tundra.

Although not strictly a dwarf shrub, cloudberry (Rubus chamaemorus) was the most prolific early resprouter except cottongrass (E. vaginatum) tussocks, and in places it appears to have been stimulated by fire (Fig. 21), reaching densities of 50 leaves/m^2 and cover values equaling or exceeding prefire levels one year after fire. Concentrations of cloudberry leaves were locally abundant 7 years after fire near Coffee Creek (Fig. 22). Two other herbaceous species, which occasionally were found to resprout vigorously after fire (occurring on the burned tops of high-centered polygons at Arctic River), were coltsfoot (Petasites frigidus) and cordate-leaved saxifrage (Saxifraga punctata).

Colonization of the burned tundra surface by seedlings and by mosses and liverworts varied greatly from one site to

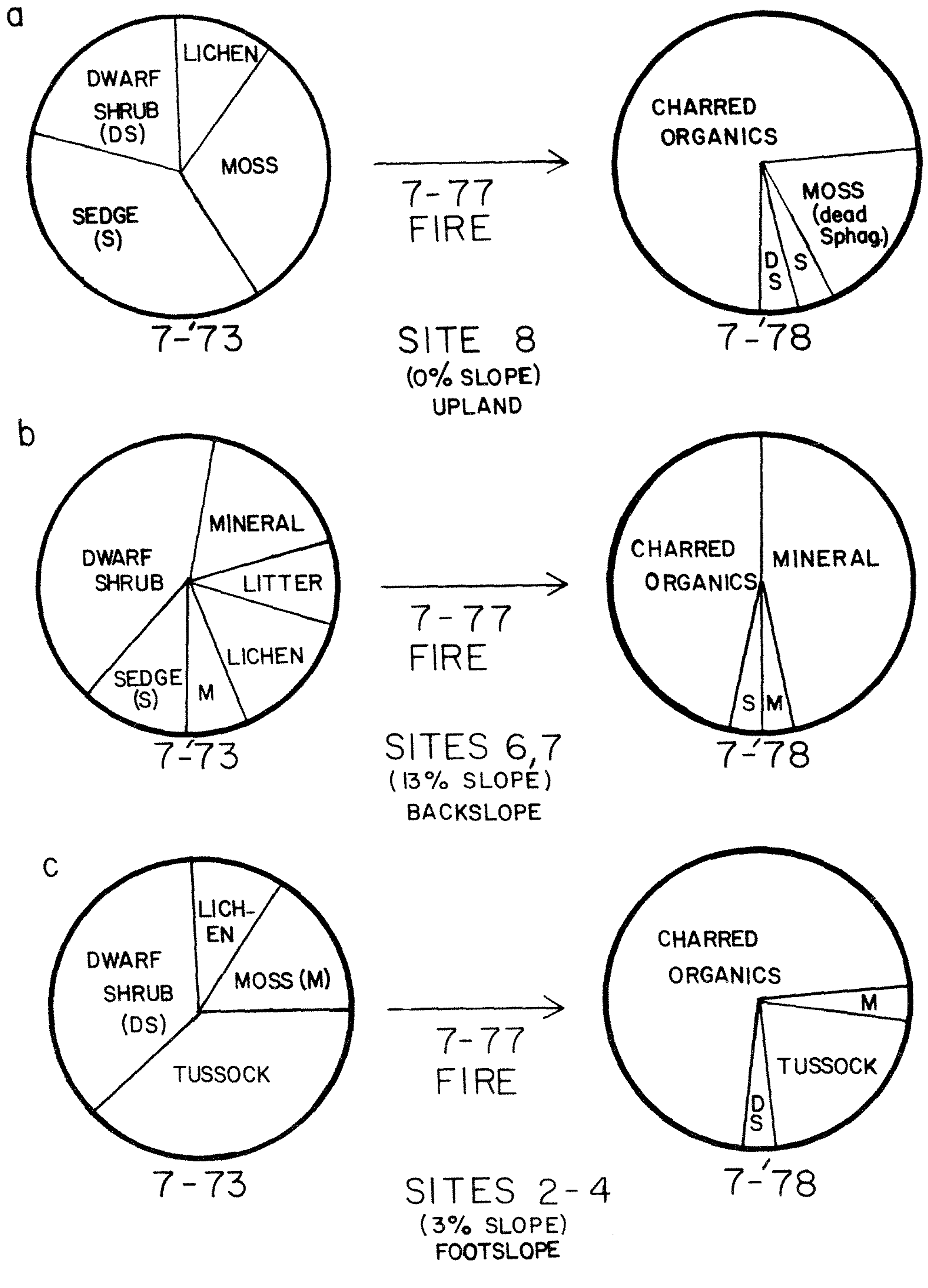

Fig. 18. Contributions of different plant growth forms to total ground cover (whole circle = 100 percent) before the 1977 tundra fire on Nimrod Hill in July 1973 (left side of arrow) and after the fire in July 1978 (right side of arrow). Shown for three positions on the Nimrod Hill slope (a-top or crest, b-middle, c-bottom).

Fig. 19. Vertical view of 1 m x 1 m plot on burned low shrub tundra on a slope near the Inmachuk River (site 2-plot 7), showing burned shrub stems, charred surface with patches of Marchantia polymorpha *liverwort (lower middle) and several fireweed (*Epilobium angustifolium*) rosettes (upper).*

the next. Seedlings of the sedges, Carex sp. and E. vaginatum, and bluejoint grass (Calamagrostis sp.) were generally common and locally abundant. Young shoots of bluejoint grass were found on 11 of the 13 sample sites (Table 4), reaching the highest density on the exposed mineral soil of turf-banked frost scars at site 7 on Nimrod Hill. The highest seedling densities (more than $100/m^2$) were attained by sedges of the genera Carex and Eriophorum. Positive identification of these seedlings was difficult because of their small size (less than 1 cm tall). These sedge seedlings were found most often on the charred peat surface between tussocks, but also were found on tussocks and on drier sites with thin peat layers or exposed mineral soil (sites 6 and 7 on Nimrod Hill). Wein and Bliss (1973) similarly found cottongrass (E. vaginatum) to be the most striking seedling colonizer ($198 \pm 28/m^2$) on the burned peat between tussocks one year after tundra fires in interior

Fig. 20. Sprouts of Labrador tea (Ledum palustre) *from a buried stem section, one year after fire in tussock-shrub tundra near the Inmachuk River.*

Alaska and western Canada. They felt that few of these survived until the second autumn, however. In contrast with the abundance of sedge seedlings found by Wein and Bliss (1973) and by the present study on the Seward Peninsula, Larry Johnson (U.S. Army-CRREL, Fairbanks, Alaska, pers. comm.) found no sedge seedlings in burned sedge tussock-shrub tundra one year after the 1977 fire at the Kokolik River on the Arctic Slope.

On better drained sites with low shrub and birch and ericaceous shrub tundra, the organic peat had frequently burned off, exposing mineral soil; here, seedlings of several nongraminoid species were found growing (Fig. 19). These included fireweed (Epilobium angustifolium), Jacob's ladder (Polemonium boreale), lizard's tail (Saussurea angustifolia), wormwood (Artemisia Tilesii), chickweed (Stellaria monantha), and horsetail (Equisetum arvense). Their occurrence was sporadic and never of high density. Chickweed was common on the tops of turf-banked frost scars at site 7 on Nimrod Hill

Fig. 21. Vegetative resprouting of leaves of cloudberry (Rubus chamaemorus) *in burned tussock-shrub tundra near Arctic River. Burned dwarf shrub stems and sedge rhizomes are visible.*

(Fig. 12), while wormwood, Jacob's ladder, and horsetail occurred on the polygon centers at Arctic River (Table 4).

Like the above seedling species, mosses and the liverwort, Marchantia polymorpha, were most abundant in burned areas where bare soil had been exposed (Fig. 19). Frequently occurring with Marchantia is a thin layer of the moss, Ceratodon purpureus, a common colonizer of disturbed soils. Polytrichum juniperinum was frequently abundant on charred peat surfaces and with other species of Polytrichum, was abundant on the older Coffee Creek burn (Table 4).

In sedge tussock-shrub tundra and sedge-shrub tundra communities, other species of mosses as well as lichens appeared in plot samples, mainly because they survived the fire in small unburned patches. Moss species there included Rhytidium rugosum, Dicranum sp., and Aulocomium sp. The occurrence of large but dead patches of unburned Sphagnum moss was described above. Unburned lichens frequently occurred in less severely burned tussock-shrub tundra and

Fig. 22. Local concentrations and high densities of cloudberry (Rubus chamaemorus) *leaves in sedge-tussock tundra 7 years after a 1971 tundra fire near the Kuzitrin River.*

included species such as Cetraria cuculata, C. islandica, Cladonia gracilis, and Cladina rangiferina. No new colonization by lichens was visible; however, unburned lichen cover reached values of 2 percent in places as compared with prefire (1973) lichen cover of 8 to 15 percent (Table 4, Fig. 18).

DISCUSSION AND CONCLUSIONS

Tundra fires have occurred and will occur in the Low Arctic tundras of the Seward Peninsula during infrequent summers of low rainfall and high temperatures. Seward Peninsula tundra fires appear to burn larger areas than tundra fires elsewhere on the Arctic Slope, in Interior Alaska, and in northwestern Canada. Within these burns, however, are many completely unburned or lightly burned "islands," and over much of the burned area, organic soil horizons remain largely intact so that there is little or no soil erosion. Unburned communities include tall willow shrubland, wet sedge-grass tundra, and open mat and cushion tundra. Sedge tussock-shrub tundra is the most extensively burned community type over much of the area although other communities with abundant dwarf shrubs (sedge-shrub, mat and cushion, and shrub tundra) also burn.

Resprouting of established tussocks and dwarf shrub species begins immediately after fire so that revegetation rates in sedge tussock-shrub tundra are quite rapid. After 7 years, evidence of tundra fire is difficult to detect in sedge tussock-shrub tundra, although relative proportions of different species have been altered. On better drained sites with birch and ericaceous shrub tundra, dwarf shrubs and the organic horizon may be more completely burned and recovery of the plant cover slow. At this time it is not possible to reconstruct or suggest the recovery sequence there, although seed germination and seedling establishment appear to be more important than in sedge tussock-shrub tundra.

While the importance of fire in boreal forest or taiga ecosystems is well documented (Viereck 1973, Rowe and Scotter 1973), the role of fire in northern tundra ecosystems remains poorly understood. Only by careful reconstruction of the postfire recovery sequence and rates for different tundra communities can the role of tundra fires be defined. The study reported here provides some of the necessary background information, first-year revegetation patterns, and permanent plots for monitoring future recovery. A visit to the 7-year-old sedge tussock-shrub tundra burn also showed the value of locating and sampling different-aged burns.

Based on the results of the present study as well as prefire studies by Racine (1974, 1975), one hypothesis for a role of fire in sedge tussock-shrub tundra may be proposed. Without disturbance by frost action, fire, or perhaps intense grazing, sedge tussock-shrub tundra communities undergo a series of autogenic successional changes. These changes involve the accumulation of peat and burial or submergence of tussocks by growing dwarf shrubs, mosses, and lichens. They result in raised permafrost levels, reduced frost action, and the deterioration and senescence of tussocks. Frost action prevents such changes by stirring the soils, incorporating organics, and preventing the buildup of dwarf shrubs, mosses, and lichens. Small groups of vigorous sedge tussocks grow on these frost scars and are conspicuous because of their abundant seed stalks. As succession proceeds and the organic horizon thickens, summer thawing does not reach into the mineral soils, and frequency of frost action is reduced. Fire would reverse these successional trends by reducing the buildup of soil organics, dwarf shrubs, mosses, and lichens around and on tussocks and burning off the accumulated leaf bases. Rejuvenation in tussock growth would follow unless succession had progressed so far and/or fire burned so hot that there is no tussock recovery. Frost action processes might also be renewed if enough organics were burned off so that thaw depths reached into the mineral soils. Some of these successional relationships are hypothetically graphed in Figure 23, based on sampling of burned tussock-shrub tundra one year and 7 years following fire.

That extensive areas of sedge tussock-shrub tundra have undergone the above described changes is suggested by comparisons of vegetation-soil studies in the late 1940's (Hopkins and Sigafoos 1951) and more recent studies (Racine 1974, 1975) in the Seward Peninsula. While soil frost features were common, summer thaw depths deeper (38 to 90 cm), and tussocks generally vigorous in the late 1940's, in 1973 we found that many of the same areas had few frost scars, shallower thaw depths (30 to 40 cm), and tussocks which were senescent or buried beneath a matrix of dwarf shrubs, mosses, and lichens. Whether or not such changes during the past 30 to 40 years on the Seward Peninsula were due to changing climate, time since fire, or perhaps reduced reindeer grazing is conjectural (Hopkins 1972). The 1977 burning of many of these areas where autogenic succession has proceeded without disturbance should permit a test of the above hypothesis.

Several other consequences and roles of fire in the Seward Peninsula tundra should be mentioned and discussed. These include postfire changes in the relative importance of component sedge tussock-shrub tundra species, postfire susceptibility to disturbance by off-road vehicles and grazing, and the effects of fire on commercial reindeer herding.

Following fire in tussock-shrub tundra, there are changes in the relative importance of different dwarf shrub and other species as a result of differential resprouting. Such resprouting appears to occur one year after fire only where there are tussocks and/or unburned organics in which dwarf shrub stems may escape burning. Labrador tea appears to resprout at the highest density, followed by lowbush cranberry, blueberry, dwarf birch, and finally crowberry. Vegetative resprouting of cloudberry also appears to be stimulated by fire, although it is not known how berry production is affected. The occurrence of abundant sedge seedlings of *Carex* sp. and *Eriophorum vaginatum* on the charred peat surface suggests future increases in these graminoids. Monitoring of the permanent transects in future years should show how proportions of different species continue to change.

Fire may increase the susceptibility of tundra to disturbance by off-road vehicle traffic. During the spring of 1978 following the 1977 tundra fires, vehicles (tracked bulldozer and wheeled road grader) were driven from Chicago Creek west across the Deering-Imuruk Lake burn to the Inmachuk River, leaving deep ruts and tracks over the burned tundra surface. Although it was not possible to compare the impact on adjacent burned and unburned tundra, the depth of the ruts (up to 25 cm) and exposure of mineral soil suggest that the burned tundra was particularly susceptible to such disturbance at that time. The reduced thickness of the organic horizon and possibly higher water content might increase the depths of ruts. Wein et al. (1975) suggest that vehicular traffic should avoid burned tundra areas in the summer but should use them in the winter because the additional disturbance does not deepen the active layer as much as does traffic in unburned areas.

The effects of tundra fire on reindeer grazing potential are of great concern to commercial herders on the Seward Peninsula (Stern et al. 1977), and must ultimately be determined by the short- and long-term effects of fire on the tundra plant communities. As discussed above, the relative proportions of each species may be altered by tundra fire so that there are changes in the plant species available to the reindeer. Additional studies are needed to correlate the revegetation pattern with reindeer feeding behavior (Palmer 1926).

Although tussock and dwarf shrub resprouting appear to be rapid, so that summer forage becomes quickly available following fire, the prefire lichen cover of 10 to 20 percent in sedge tussock-shrub tundra may require a much longer period of time to recover. Prefire vegetation sampling suggests that lichen cover also increases with time and organic buildup (Fig. 23), so that old, undisturbed tussock-shrub tundra may have the greatest winter forage value. The entire question of reindeer-lichen-fire interactions in the tundra is undoubtedly complex, as it is in the taiga (Carroll and Bliss 1978). There are suggestions (Klein as quoted in Stern et al. 1977, Wein and Bliss 1973) that tundra fires may provide short- and long-term benefits to

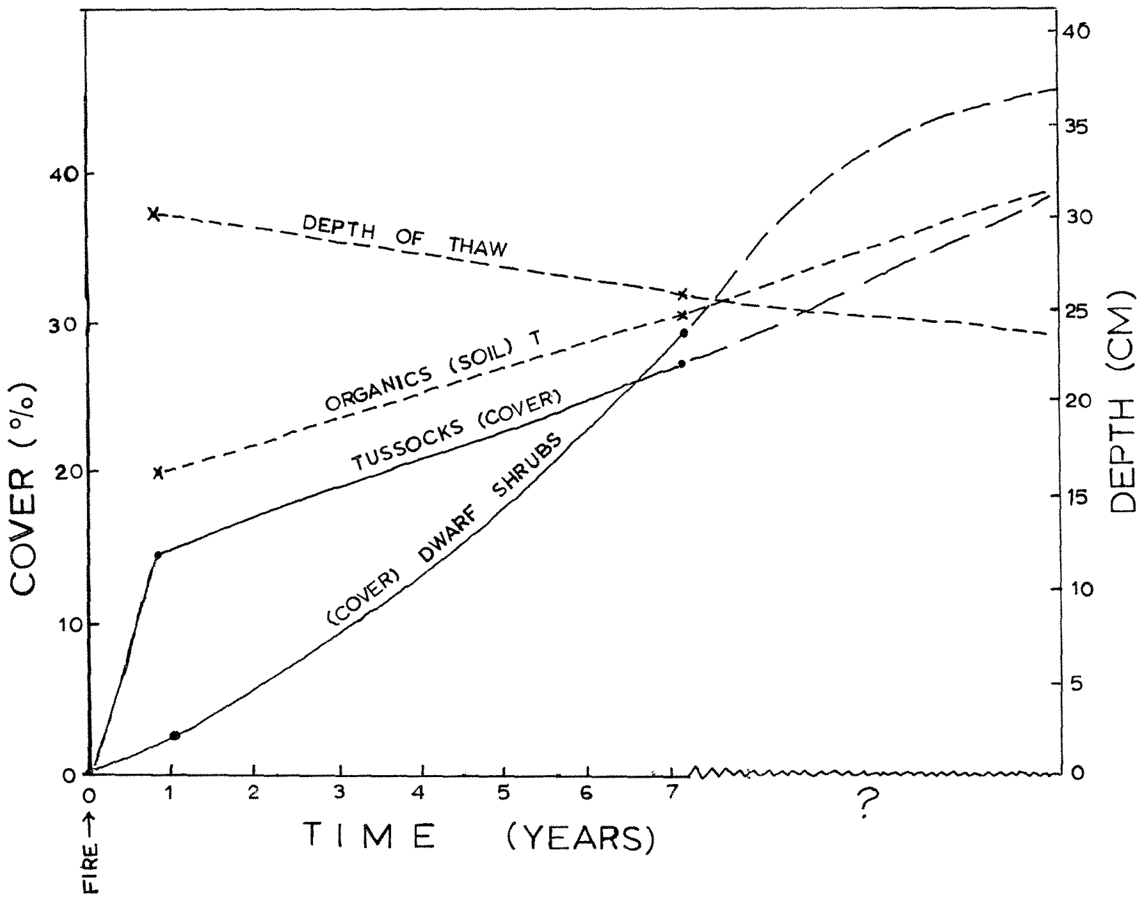

Fig. 23. Hypothetical changes in dwarf shrub and sedge tussock cover in relation to soil organic layer thickness and thaw depths following fire in sedge tussock-shrub tundra. Values for cover, thickness, and depths after 1 and 7 years are taken from this report; values after 7 years are estimated only.

the reindeer range by releasing nutrients otherwise tied up in the organics and plant biomass. Higher plant tissue levels of nutrients following fire (Wein and Bliss 1973) presumably would enhance the forage values. During limited soil analyses carried out in this study, however, increased nutrient levels were found only sporadically in charred organics at the surface rather than throughout the whole soil profile. The relatively "light" burning over much of the moist tussock-shrub tundra may not burn enough plant biomass to release large amounts of phosphorus or potassium.

RECOMMENDATIONS

Certain information obtained in this study should be considered in the formulation of policy regarding the control and management of fires in the Seward Peninsula tundra. This information is for the most part preliminary because tundra fire effects and postfire recovery were evaluated after only one year at a small number of burn sites. Continued monitoring of the permanent transects established in this study as well as additional studies recommended below are needed to better understand the effects and role of fire in tundra ecosystems.

I. There is evidence that over a large part of the Seward Peninsula tundra burns, where moist sedge tussock-shrub tundra is predominant, relatively little destruction of soils and vegetation occurred.

   a. After fire in tussock-shrub tundra, the soil organic layer is not completely destroyed and the mineral soil is generally not exposed. Soil erosion is therefore minimized, as are drastic increases in thawing of the permafrost.

   b. Revegetation in burned tussock-shrub tundra on moist sites appears to be relatively rapid, mainly through resprouting of sedge tussocks and low shrubs present before the fire.

   c. Within a tundra burn area, there are unburned communities; within a burned community, there are unburned as well as moderately and severely burned patches.

   d. Fire may "rejuvenate" tussock-shrub tundra by removing accumulated organics, dwarf shrubs, mosses, and sedge leaf bases, and releasing nutrients for plant growth.

   e. Fire may aid archeological studies by uncovering, but not destroying, remains of interest, such as those seen on a rocky hilltop near Imuruk Lake (Appendix 2). There the fire removed closed mat and cushion tundra, revealing abundant bones.

II. Other evidence suggests that tundra fire may result in undesirable consequences and require different fire control policies than those suggested by I(a-e) above.

a. On drier sites with birch and ericaceous shrub tundra, severe burning may remove the organic layer, expose mineral soil, and possibly result in erosion and slower revegetation than on sedge tussock-shrub tundra sites.

b. Nutrients released by burning of the vegetation and organic soils may move in runoff into lakes, ponds, and streams, thereby affecting aquatic ecosystems.

c. The winter grazing potential for commercial reindeer herds may initially be reduced by burning of lichen cover and predicted slow lichen recovery. Changes in proportions of different tussock-shrub community species result from differential ability to resprout and may also influence grazing potential.

d. Off-road vehicle traffic over burned tussock-shrub tundra in the early summer of 1978 appeared to cause greater disturbance than traffic over unburned tundra. Such summer traffic probably should be prohibited.

III. The study reported here was a small and initial attempt to evaluate fire effects and early recovery on tundra. Further research is necessary to understand the role of fire in tundra ecosystems and thereby help to formulate fire control and management policies. The following are some recommendations for future research on fire in tundra sites.

a. Determine the postfire successional sequences for different burned tundra communities in relation to the severity of burning and prefire composition. This objective must be achieved by monitoring of permanent plots, such as those established during the present study, and locating and sampling a series of different-aged burn sites.

b. Study postfire tundra recovery in relation to autogenic succession as well as to changes resulting from other forms of disturbance due to frost action, overgrazing, etc. The role of fire in tundra ecosystem development, conversions of one community into another, and boundaries or ecotones between tundra communities should all be considered.

(continued)

c. Determine the frequency and extent of past fires in the tundras of the Seward Peninsula and northwestern Alaska. A method for determining the fire history of a tundra site would be beneficial.

d. Study postfire changes in plant standing crop biomass and productivity with regard to the overall functioning of the system and wildlife and commercial reindeer herds.

e. Develop a more detailed understanding of how fires affect nutrient relationships in tundra soils, plants, animals, and in particular, aquatic ecosystems.

f. Develop a method for mapping the pattern of burning with regard to detecting burned and unburned communities, different burn intensities, amounts of organics removed, and revegetation rates. Remote sensing techniques may be useful.

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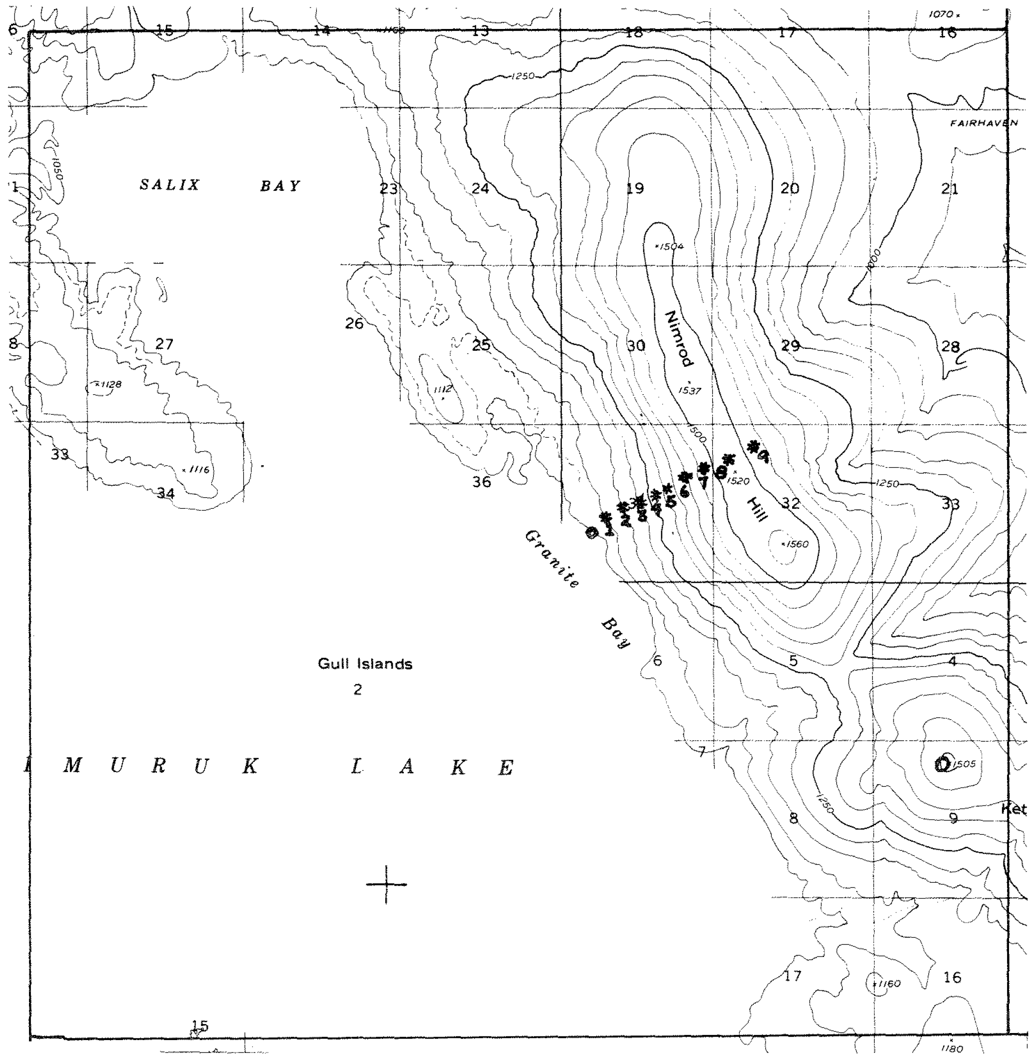
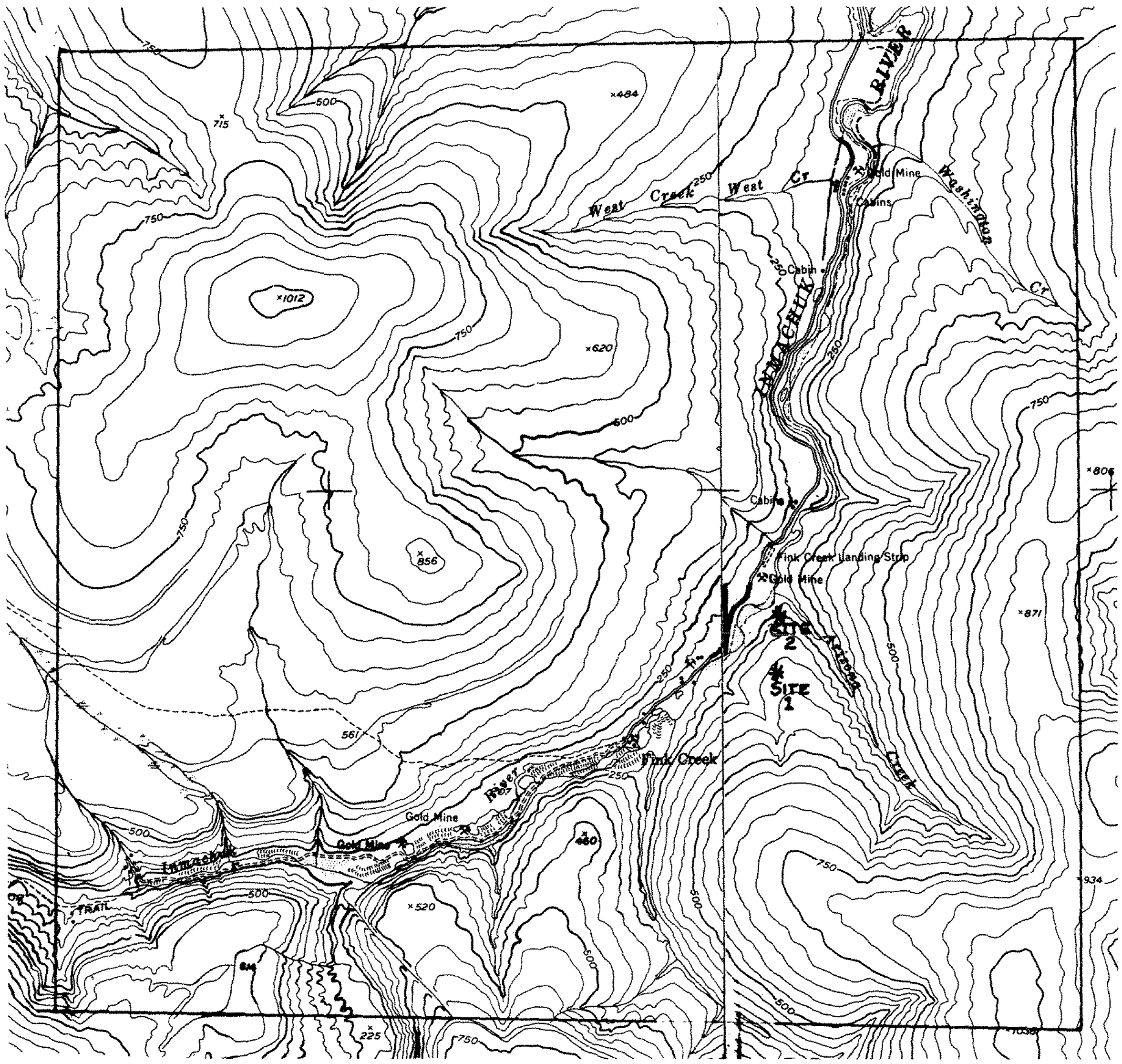
APPENDIX 1. MAPS SHOWING THE LOCATIONS OF TUNDRA FIRE STUDY SITES ON THE SEWARD PENINSULA, ALASKA.

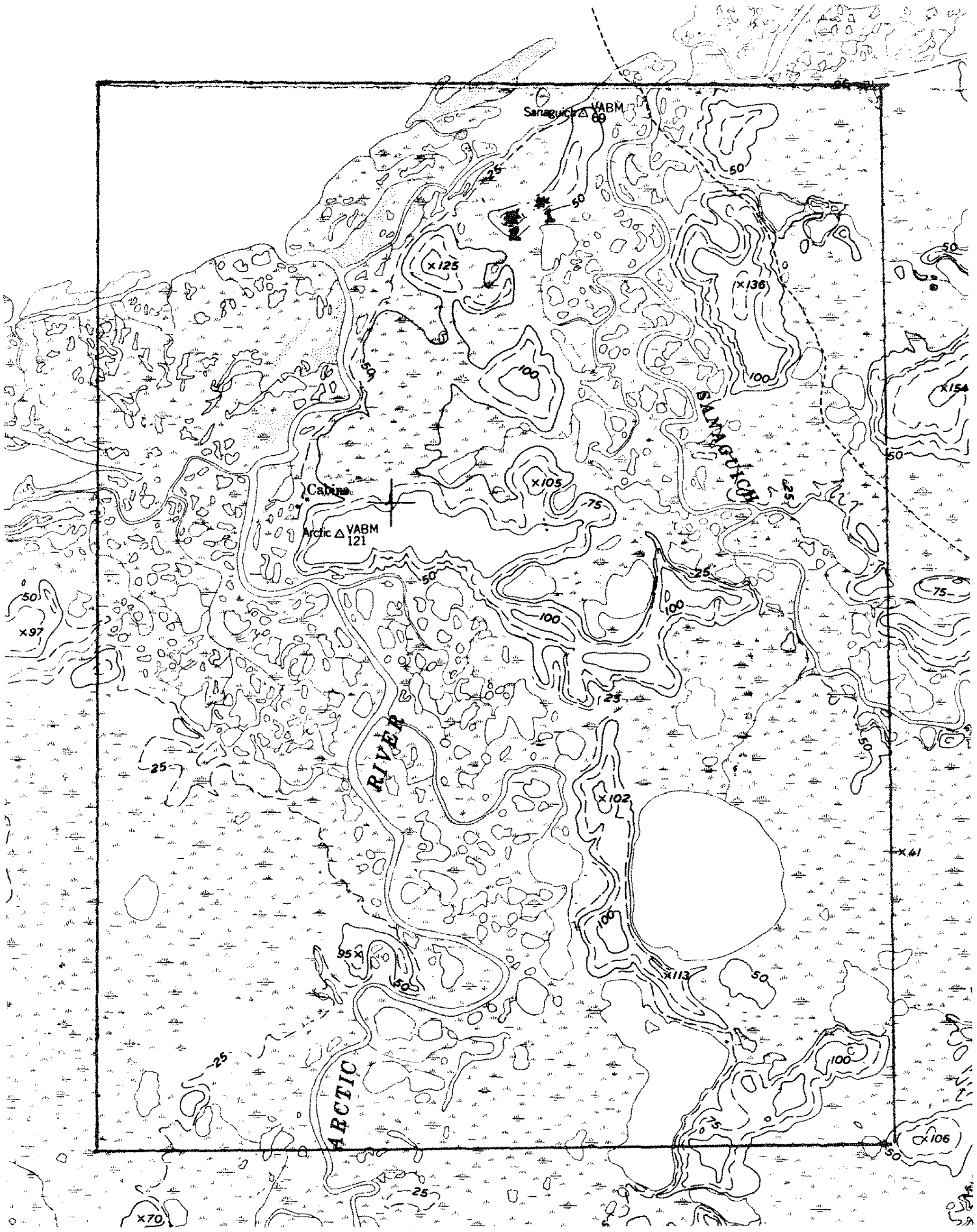
1. East side of Imuruk Lake. USGS topographic map showing part of the Bendeleben C-3 quadrangle. Along a topographic transect from the bottom to top of Nimrod Hill, vegetation and soils were sampled in July 1973 and again in July 1978 following the 1977 tundra fires. Each of the nine sample sites is marked with an asterisk (*). Locations of archeological sites where tundra fire effects are described in Appendix 2 are marked with circles (o). Scale 1:63,360.



2. East side of the Inmachuk River. USGS topographic map showing parts of the Bendeleben D-2 and D-3 quadrangles. The 1977 Deering-Imuruk Lake tundra fire burned much of the tundra shown here to the east of the Inmachuk River. The locations of two permanent transects are marked by asterisks (*). Scale 1:63,360.



3. Mouth of Arctic River. USGS topographic map showing part of the Shishmaref A-3 quadrangle. The 1977 tundra fires on the Seward Peninsula burned the summit of a small hill where two permanent transects were established during July 1978 to study recovery. The site is marked by an asterisk. Scale 1:63,360.



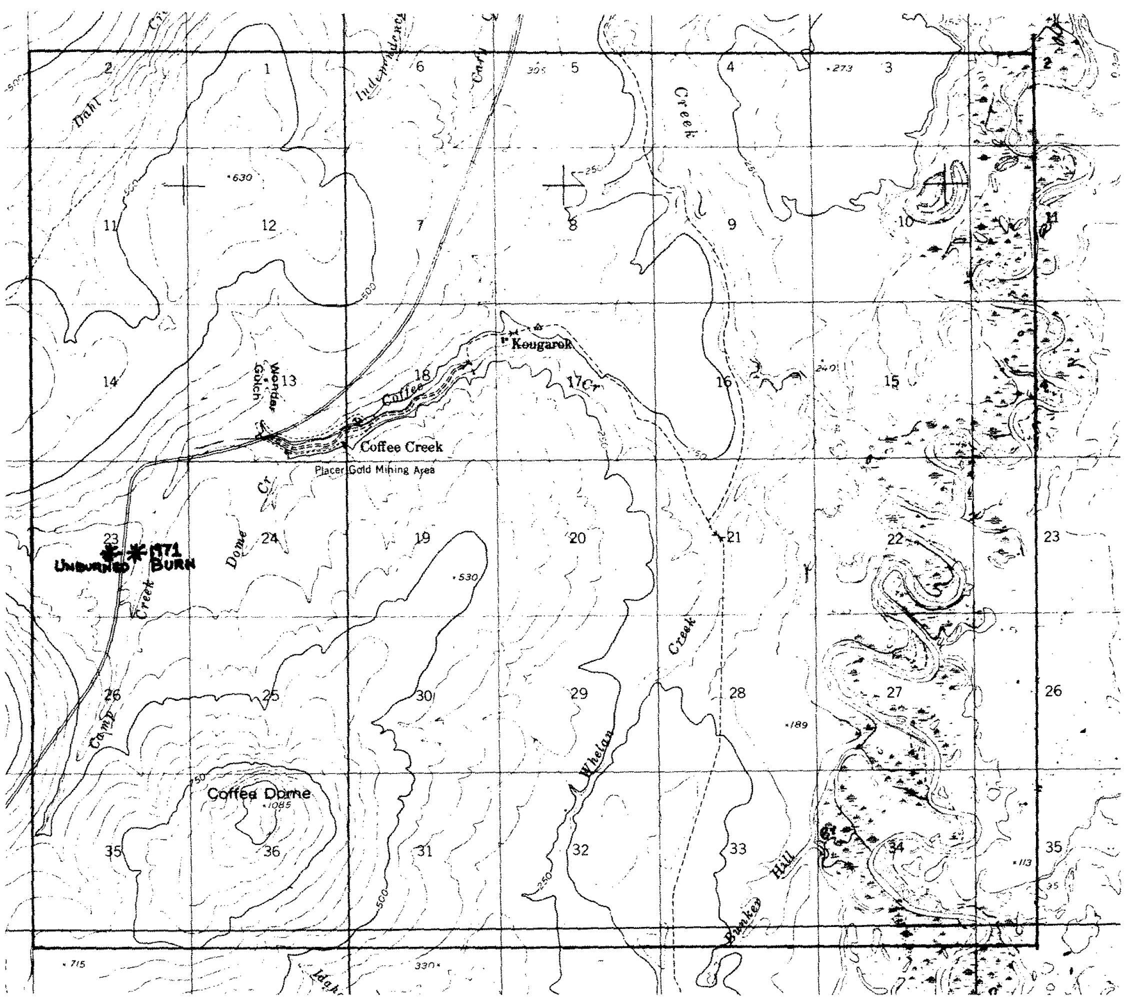
APPENDIX 2. TUNDRA FIRES AND TWO ARCHEOLOGICAL SITES ON THE SEWARD PENINSULA, ALASKA. (A modified copy of a manuscript submitted for publication in Arctic, Journal of the Arctic Institute of North America.)

During a 1973 biological survey of the proposed Bering Land Bridge National Preserve on the Seward Peninsula, Alaska, several archeological sites were found and examined near the east shore of Imuruk Lake[1]. As the botanist for this survey, I (CHR) visited these sites, which included five stone-lined pits or depressions on the top of a rocky knoll 2 km east of and 90 m above Imuruk Lake, and a cache pit dug into an old shoreline bluff just above the sandy beach of Granite Bay. The stone-lined pits were conspicuous, as their margins were outlined by stones projecting above the surrounding boulders. Low willow shrubs bordered the pits and had grown into some of them, while mats of avens (Dryas sp.) and various cushion plants covered much of the surrounding well-drained ground. No test pits were dug in these stone depressions, but we spent several hours searching the ground surface within and surrounding them without finding any bones or artifacts. Melchior and Bennett believe that the stone pits are the remains of dwellings, since no geologic process is known that is likely to have produced such a structure. We found no animal remains or artifacts in the cache pit, even though we removed the overburden in the pit to the depth of frozen ground. High-centered polygons with sedge tussock-dwarf shrub tundra covered the flat bench immediately above the cache pit and no artifacts were found there, either. Without excavation it was not possible to determine more about these sites.

During the summer of 1977, warm, dry weather followed by lightning storms resulted in widespread tundra fires in northwestern Alaska, in particular on the Seward Peninsula. One fire burned about 958 km^2 over a large area south of Deering and north of Imuruk Lake between the Inmachuk and Kugruk Rivers. This same fire burned up to the water's edge along the east shore of Imuruk Lake to the site of the 1973 biological survey base camp.

[1]Melchior, H.R., and R.O. Bennett. 1974. Archaeological Observations. Pages 492-508 in H.R. Melchior ed. Chukchi-Imuruk Biol. Survey- Final Report. Coop. Park Studies Unit, Univ. Alaska, Fairbanks, Ak. 517 pp.

4. Coffee Creek along Taylor Road. USGS topographic map showing part of the Bendeleben B-6 quadrangle. A summer 1971 tundra fire burned large areas in the vicinity of the Kuzitrin River. The Taylor or Kougarok Road acted as a firebreak, however, so that the tundra on the west side of the road remained unburned. During the summer of 1978, permanent transects were established on both sides of the road at Mile 94. These are marked by asterisks. Scale is 1:63,360.



METHODS

In July 1978, we returned to this camp site with the intent of comparing pre- and postfire vegetation and soils in this area. Although the emphasis of this research was the effects of tundra fires on vegetation, soils, and post-fire recovery, we were able to revisit the archeological sites described above and thereby observe the effects of the fire on these sites.

RESULTS

The vegetation mat that covered the ground around the stone-lined pits on top of the knoll had burned during the 1977 fires. Although these mats consisted of a thin and broken layer of matted dwarf shrubs, cushion plants, and lichens over a stony soil, enough organic fuel was apparently present to allow complete burning of large patches. The fire also burned the bordering willows and into the bottom of one stone-lined pit. Where the fire had burned off the vegetation mat in the vicinity of these pits, the ground was littered with large numbers of unburned bones and bone fragments. Most of the bone fragments appeared to be from caribou leg bones, while some whole rib and jaw bones were found beneath large rocks previously covered by vegetation. The only object found in the burned areas which could possibly be an artifact was a flat piece of white quartz with sharpened edges (scraper?). The above objects were not visible during our 1973 visit to these stone-lined pits.

The 1977 tundra fire had also burned the dwarf shrubs and tussock sides which covered the flat bench just above the cache pit dug into the shoreline bluff along Granite Bay. Here, we found an _ulu_ (Eskimo woman's knife) with a slightly charred wooden handle and rusted steel blade, a rusted 1-m length of stovepipe, and a rusted and pitted metal bowl. Although these objects could have been placed there after our 1973 visit, their deteriorating condition suggests that they were there then but hidden by the covering vegetation. Their position immediately above the cache pit also suggests some association with it.

DISCUSSION AND CONCLUSIONS

A 1977 tundra fire in the Seward Peninsula removed the vegetation mats surrounding and covering two archeological sites on the east shore of Imuruk Lake. Bones and artifacts, which had been covered by these vegetation mats and incorporated into them, were strikingly revealed *in situ*. None of these objects were visible or could be found during brief reconnaissance of these sites in 1973 before the tundra fires. Our postfire visit to these sites hence supplied new information concerning these pit structures. Although interpretation is beyond the expertise of the authors and the scope of this paper, we suggest that the postfire observations of these Imuruk Lake sites modifies the original interpretation of these sites; the finding of an *ulu*, metal stovepipe, and bowl adjacent to the cache pit suggests a fairly recent origin or use of this pit. The abundance of animal bones in the vicinity of the stone-lined pits strengthens the original argument that these were dwellings.

Tundra fires appear to be an effective and valuable archeological aid which allows quick reconnaissance of an area to locate potential sites of interest. By removing the tundra vegetation mat, fire performs a type of excavation which may reveal artifacts and/or bones. We wonder whether the same degree of excavating precision, even if feasible, could be achieved by hand removal of the vegetative overburden. Apparently in the cases reviewed here, the tundra fire never burned hot enough at the level of the bones and artifacts to destroy them. This would be the case particularly on dry sites where the organic mat is thin. We suggest that arctic archeologists make an effort to locate and examine archeological sites in areas of relatively recent tundra fires.