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Tundra Fire Effects on Soils and Three Plant Communities Along a Hill-Slope Gradient in the Seward Peninsula, Alaska

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ABSTRACT. During summer 1977, wildfires burned extensive areas of low arctic tundra in the Seward Peninsula, Alaska. The present study was initiated in July 1978 to determine the effects of these fires on tundra soils and vegetation. Nine 10 m × 1 m permanent belt transects were established at regular intervals along the topographic gradient of a burned hill-slope in the central Seward Peninsula near Imuruk Lake. Soil characteristics and plant species density and cover were determined in each of the 90 1-m² plots on this slope during July of both 1978 and 1979.

Soils and vegetation had been quantitatively sampled on this slope in 1973, thereby providing pre-fire comparisons; a sedge tussock-shrub tundra community with mud circles occupied the poorly drained footslope and a birch and ericaceous shrub tundra community with elongate turf-banked frost boils had developed on the moderately well-drained backslope. The broad, poorly-drained summit of this slope was occupied by sedge-shrub tundra with low-centered polygons.

The severity of burning in July 1977 varied along this slope with moderate to heavy burning of the birch and ericaceous shrub tundra and light to moderate burning of the sedge tussock-shrub tundra and sedge-shrub tundra communities. Post-fire (1978 and 1979) changes in plant cover, species composition and soil thaw depths are shown to vary with position on the slope and burning severity. The relationship of these changes to natural succession in the absence of fire is discussed.

RÉSUMÉ. Lors de l'été 1977, les feux spontanés ont brûlé de vastes étendues de toundra dans la péninsule de Seward, en Alaska, dans le bas Arctique. La présente étude débuta en juillet 1978 afin de déterminer les effets de ces feux sur les sols et la végetation de la toundra. Neuf bandes permanentes au transect, mesurant 10 m × 1 m, furent établies à des intervalles réguliers le long du gradient topographique d'un flanc de colline dévasté par le feu près du lac Imuruk dans la partie centrale de la péninsule de Seward. Les caractéristiques du sol, la densité et l'étendue des espèces végétales furent déterminées pour chacun des 90 l - m² de ce versant durant les mois de juillet 1978 et 1979.

Les sols et la végétation de ce versant avaient été échantillonnés d'une façon quantitative en 1973, fournissant ainsi des données comparatives avant le feu. Une toundra d'arbustes et de touffes de cypéracées, avec des mares de boue, occupait le pied du versant mal drainé; une toundra arbustive de bouleaux et d'éricacées avec des dômes de cryoturbation allongés et bordés de tourbe s'était développée sur le versant relativement bien drainé. Le sommet du versant, large et mal drainé, était couvert par la toundra d'arbustes et de cypéracées avec des polygones en creux.

La gravité des dommages causés par le feu de juillet 1977 varie, le long du versant, d'une destruction modérée à presque totale des associations végétales de la toundra arbustive de bouleaux et d'éricacées; d'une destruction légère à modérée de celles de la toundra d'arbustes et de touffes de cypéracées et de la toundra d'arbustes et de cypéracées. Les résultats montrent que les effets du feu (1978 et 1979) sur le couvert végétal, la composition des espèces et la profondeur du dégel du sol varient selon la position sur le versant ainsi que la plus ou moins grande sévérité du feu. Les relations existant entre ces changements causés par le feu et une transformation naturelle sont discutées.

Traduit par Ian Badgley, Université du Québec à Montréal.

Key words: tundra fire, revegetation, post-fire succession, tundra vegetation, tundra soils

INTRODUCTION

Although generalizations about the disturbance and recovery of arctic tundra vegetation and ecosystems have been made (Johnson and Van Cleve, 1976; Webber and Ives, 1978), it is apparent that the responses to a disturbance vary drastically among different ecosystems and different areas. This study describes and compares the effects of fire on soils and permafrost, and describes post-fire revegetation patterns of arctic tundra communities on a hill-slope in the Seward Peninsula of northwestern Alaska.

Widespread lightning-caused tundra fires in July and August 1977 burned over one million acres in northwestern Alaska (Fig. 1). Studies to determine the effects of these fires on vegetation, soils and permafrost were initiated one year later in July 1978 at Imuruk Lake in the Seward Peninsula (Racine and Racine, 1979; Racine, 1979). Permanent plots were established and sampled during the summers of 1978 and 1979. This report describes the results of monitoring post-fire changes in thaw depths and plant species composition and cover in the Seward Peninsula during the 1978 and 1979 growing seasons.

STUDY AREA

The Imuruk Lake area is located in the central Seward Peninsula (65°35′N, 163°20′W; Fig. 1). The rolling, unglaciated landscape here supports low arctic tundra ecosystems dominated by sedge tussock-shrub tundra communities. The only long-term climatic data available for this area come from stations at Nome and Kotzebue, which have maritime conditions in contrast to the more continental climate in the Seward Peninsula interior around Imuruk Lake. Hopkins and Sigafoos (1951) characterize the climate around Imuruk Lake as rigorous and continental with a mean annual temperature of -6.7°C and a mean annual precipitation of around 21 cm of which approximately 25% falls as snow. More than 50% of the annual precipitation occurs during a well-defined rainy season extending from July through September. Subfreezing temperatures predominate from early October to mid-

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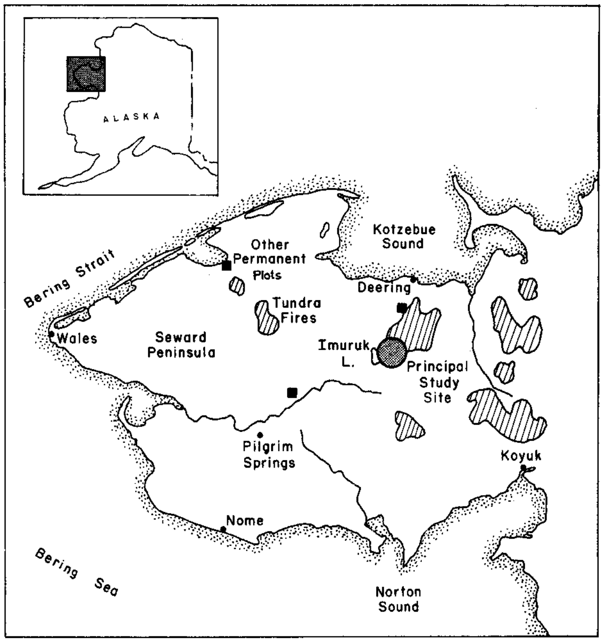

FIG. 1. Map of the Seward Peninsula, Alaska showing size and location of 1977 tundra fires, principal study site, and other sites with permanent plots. Inset map gives location in Alaska.

May. The July mean temperature is near 10°C; however, nocturnal frosts are common during all of the summer months. The treeline approaches to within 25 km of Imuruk Lake.

The most intensive studies were carried out at nine sites along a topographic transect running from the bottom (320 m) to the crest (440 m) of Nimrod Hill, which borders the east side of Imuruk Lake (Figs. 2 and 3). This area was chosen because of pre-fire studies of soils and vegetation carried out along this same transect in 1973 by Holowaychuk and Smeck (1979) and Racine and Anderson (1979). These studies provided a pre-fire control as well as a basis for evaluating the effects of the 1977 tundra fire.

FIG. 2. Post-fire (July 1978) aerial oblique view of Nimrod Hill slope where nine permanent plot study sites were established along a topographic transect. Sandy shore of Imuruk Lake is visible in the lower foreground.

Nimrod Hill (Fig. 2) is located within the lava plateau physiographic region of the Seward Peninsula (Hopkins, 1963). The most conspicuous relief features here are isolated hills with broad, dome-shaped summits and smooth slopes which are rarely steeper than 18%. The transect begins on a Pleistocene terrace adjoining Imuruk Lake and extends up the southwest-facing slope and over the crest onto the northeast-facing side of Nimrod Hill (Fig. 3). The bedrock of Nimrod Hill was shown by Hopkins (1963) to be quartz monzonite which was not buried under the plateau lavas. As depicted in Figure 3, the transect profile is sigmoid in form, starting with a gentle gradient (1-9%) on the footslope, then increasing in steepness on the convex backslope (12-15%) and rising to the broad, level crest. The flexure in slope curvature near site 5 appears to coincide with a fault identified by Hopkins, (1963).

Shallow, weakly expressed, more or less parallel drainage-ways occur at intervals of approximately 100-150 m along the entire southwest-facing slopes of Nimrod Hill (Fig. 2). Low (1-2 m) willow shrub thickets occupy these drainageways. The intervening interfluves are slightly convex, with the sideslopes having a gradient of only a few percent. The transect is located approximately along the axial crest of one of these interfluves.

Soil moisture environments along the transect range from moderately well-drained on the southwest backslope (sites 6 and 7) to very poorly drained on the level crest (site 8) of Nimrod Hill (Fig. 3). The footslope between sites 1 and 5 and the northeast-facing backslope are poorly drained. At all sites along the transect, the soil moisture

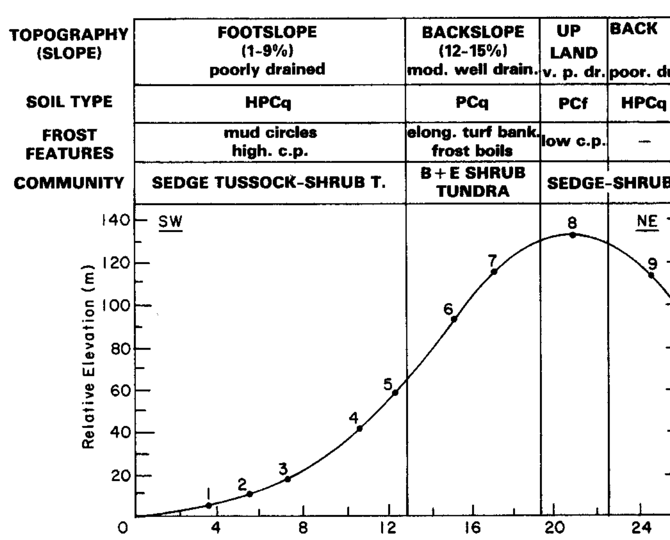

FIG. 3. Scaled topographic profile of Nimrod Hill near the east shore of Imuruk Lake (cf. Fig. 2). Location of nine study sites shown together with topography, slope, drainage, soil types (HPCq- histic pergelic cryaquept; PCq- pergelic cryaquept; PCF- pergelic cryofibrist), frost features (c.p.- centered polygons) and plant community type (B + E – birch and ericaceous). Elevations range from 335 m (1100 ft) at site 1 up to 457 m (1500 ft) at site 8.

environment is well expressed by the color of the mineral soil; a gray gley-soil predominates on poorly drained sites, with a yellowish mottling increasing in extent as drainage improves upslope from site 5 to the level crest (Holowaychuk and Smeck, 1979). The texture of the soil mineral fraction also changes along the transect from a coarse loam on the backslope to a silt clay loam on the colluvial footslope. Soil taxonomic units along the transect correspond with the soil moisture environments (Fig. 3): histic pergelic cryaquepts on the poorly-drained footslope, pergelic cryaquepts on the moderately well-drained backslope, and pergelic cryofibrists on the very poorly-drained level upland.

Various cryogenetic features are evident along the transect (Figs. 2 and 3). Along the nearly level crest of Nimrod Hill, these features consist of low-centered polygons, 10-15 m across. On the upper portion of the backslope, elongate turf-banked, nonsorted frost boils are common. In the vicinity of site 7 these longitudinal features are up to 3 m in diameter and occupy 40% of the area. Although of considerable extent, these frost boils were not very active as of 1973, since patches of lichens and other vegetation covered most of the surface. On the footslope between sites 5 and 1, equidimensional mud circles and some weakly expressed benched solifluction forms represent the main cryogenetic features. These mud circles are usually less than 1 m in diameter, few in number and cover less than 3% of the area. In 1973, their surfaces were covered with a thin mat of fine moss. Along with these mud circles, high-centered polygons occupy the level base of the footslope and terrace at site 1 (Fig. 2).

Corresponding with the above-described changes in topography, soil moisture environments, soil types and cryogenetic features are changes in the plant communities along Nimrod Hill (Fig. 3). These were quantitatively sampled and described before the fire in 1973 and are the basis for the following descriptions; more detailed information on pre-fire communities is provided in the *Results* section (cf. Fig. 4). Nomenclature for plant community names follows Viereck and Dyrness, 1980).

The footslope from site 1 to site 5 is occupied by sedge tussock-shrub tundra dominated by cottongrass tussocks (*Eriophorum vaginatum*); dwarf shrubs such as Labrador tea (*Ledum palustre*), dwarf birch (*Betula nana*), cloudberry (*Rubus chamaemorus*), lingonberry (*Vaccinium vitis-idaea*), blueberry (*V. uliginosum*) and crowberry (*Empetrum nigrum*); the mosses *Sphagnum* spp., *Dicranum elongatum*, *Hypnum pratense* and *Aulocomium palustre*; and lichen species *Cladonia gracilis*, *C. rangiferina*, *Cetraria cuculata*, *C. islandica* and *Peltigera aphthosa*. Nomenclature for vascular plant species follows Hultén (1968); for mosses follows Crum *et al.* (1973); and for lichens follows Hale and Culberson (1970).

Above this sedge tussock-shrub tundra community is a birch and ericaceous shrub tundra community on the better-drained backslope (sites 6 and 7). This community is composed of the same dwarf shrub species as found in the tussock-shrub community (with the exception of cloudberry). Bigelow's sedge (*Carex bigelowii*) replaces cottongrass tussocks here and lichens are more important than mosses. The composition of this community changes slightly on the tops of the elongate frost boils.

On the level crest of Nimrod Hill (site 8) a sedge-shrub tundra community includes sedges of the species *Carex aquatilis* and *Eriophorum scheuchzeri*, as well as cloudberry, dwarf birch, Labrador tea, and lingonberry; *Sphagnum* moss is more important here than in the other communities along the slope. On the northeast-facing backslope of Nimrod Hill (site 9), just below the crest, there is a sedge-shrub tundra community similar to that on the crest except that sedges are less abundant and moss cover more conspicuous. All of the above three plant communities burned during the 1977 tundra fire.

METHODS

To study the effects of tundra fire on a range of ecosystems, a series of permanent plots was established at each of the nine sites along the Nimrod Hill transect in July 1978 (Fig. 3). The transect and sites were located as close as possible to their 1973 positions for comparative purposes. At each of the nine slope positions, two stakes were placed 10 m apart, perpendicular to the contours, and a meter tape stretched between them. Then 10 sample plots, with dimensions of 1 m × 1 m, were positioned between the stakes using the tape as one side. In each of the 90 sample plots on 14-17 July 1978 and 25-29 July 1979, all living plant species were recorded, an estimate of percent cover made, and the number of leafy live shoots or stems counted for each species. Thaw depths were determined by probing the center of each 1 m × 1 m plot while soil pits were dug nearby to determine the thickness of the organic horizon. A comparison of the organic layer thickness before (1973) and after the fire was used to evaluate the severity of burning using the following rating system developed by Viereck *et al.* (1979):

1. Heavily burned — soil organic material completely or nearly consumed to mineral soil, no discernible plant parts remaining.
2. Moderately burned — organic layer partially consumed, parts of woody twigs remaining.
3. Lightly burned — plants charred but original form of mosses and twigs visible.
4. Scorched — moss or other plants brown or yellow but species usually identifiable.
5. Unburned — plant parts green and unchanged.

The patterns of recovery observed at Imuruk Lake were compared with other observations and permanent plots established near Utica Creek on the same 1977 burn, on a different burn near the Arctic River and on an older 1971 tundra fire site about 100 km north of Nome (Fig. 1).

For each site, thaw depths, cover and density values for each species in the 10 sample plots were averaged. Where plots were on frost features, such as mud circles or frost boils, values for these plots were computed separately. Standard deviations were also obtained for the mean values. Paired t-tests (Ostle, 1963), comparing 1978 and 1979 values for each plot, were used to determine significant changes in species cover, density and thaw depths. Since cover values for all species were very low following the fire, shoot density values were generally considered more sensitive indicators of change.

RESULTS

Sedge Tussock-Shrub Tundra (Sites 1, 2, 3, 4, 5)

Soils. On the footslope of Nimrod Hill, the poorly-drained soils on a slope of 1-9% included a pre-fire organic horizon 25-30 cm thick (27.9 ± 5.3 cm; n = 18), overlying frozen colluvial mineral silt clay loam. The measurement of organic horizon thickness in the tussock-shrub tundra in 1978, one year after the fire, suggested removal of only 5 cm or less of this organic horizon and moderate to light burning. Mud circles (0.5-2 m diameter) are common, and in 1973 were usually occupied by groups of vigorous cottongrass tussocks with a thin moss cover over the intertussock mineral soil. This moss mat was completely removed by the 1977 fire.

Mid-July thaw depths in tussock-shrub tundra did not appear to be significantly greater one year after the fire (28.5 cm) than before the fire (27.6 cm) at site 2 (Table 1). However, from 1978 to 1979 thaw depths increased significantly at all five tussock-shrub tundra sites; by 30-45% in non-mud-circle areas, and by 12-20% on mud circles (Table 1). There is evidence, obtained during July 1979, to support the idea that this increase in thaw depth is due to fire effects rather than to yearly climatic fluctuations. This evidence includes: 1) measurements of thaw depth in an area of unburned tussock-shrub tundra near Nimrod Hill in July 1979 (28.9 ± 7.6 cm) which were significantly less than on the nearby burned tussock-shrub tundra (35.8-49.0 cm, Table 1); and 2) a bulldozed firebreak which had been cut through tussock-shrub tundra during the 1977 fire north of Imuruk Lake, where thaw depths were 40% deeper on the burned side (53.3 ± 5.8 cm) than on the unburned side (38.0 ± 5.8 cm). (In the bulldozed fireline, thaw depths in July 1979 were 46.3 ± 5.6 cm.) In mid-July of both 1978 and 1979, the upper mineral soil horizons were thawed at most tussock-shrub tundra sites sampled. This condition was rare or unknown in 1973 (Holowaychuk and Smeck, 1979) and is attributed to the cumulative effects of

TABLE 1. Mean thaw depths (cm) in frost-scarred (mud circles, frost boils) and non-frost scarred plots established at nine sites (three communities) along the topographic gradient of Nimrod Hill before and after a 1977 tundra fire

	Thaw depth*								Increase in thaw depth			
	Prefire (1973)		1 yr after (1978)		2 yrs after (1979)		1973-78		1978-79		1973-79	
Site	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	(cm)	(%)	(cm)	(%)	(cm)	%
Sedge Tussock-Shrub Tundra												
Site 1												
Non-mud circle	ND		29.5	6.7	38.2	8.6	ND		+8.7	29	ND	
Mud circle	ND		57.5	3.5	69.0	1.4	ND		+11.5	20	ND	
Site 2												
Non-mud circle	27.6	5.6	28.5	4.7	41.2	5.8	+0.9	3	+12.7	45	+13.6	49
Mud circle	44.5		45.0	6.1	50.5	6.4	+0.5	1	+5.5	12	+6.0	13
Site 3												
Non-mud circle	ND		27.2	3.8	35.8	3.8	ND		+8.6	32	ND	
Mud circle	ND		44.4	6.3	52.8	4.5	ND		+8.4	19	ND	
Site 4												
Non-mud circle	ND		32.4	6.1	44.8	5.5	ND		+12.4	38	ND	
Site 5												
Non-mud circle	ND		37.7	4.0	49.0	4.5	ND		+11.3	30	ND	
Birch and Ericaceous Shrub Tundra												
Site 6												
Non-frost boil	24.6	5.7	53.8	4.5	68.0	9.8	+29.2	119	+14.2	26	+43.4	81
Frost boil	43.2	9.9	65.0		Rock		+21.8	50	Rock		Rock	
Site 7												
Non-frost boil	ND		60.0		Rock		+35.4	114	Rock		Rock	
Frost boil	ND		Rock		Rock		Rock		Rock		Rock	
Sedge-Shrub Tundra												
Site 8												
Non-frost scar	23.5	2.9	31.1	2.9	42.6	1.9	+7.6	32	+11.5	37	+19.1	81
Site 9												
Non-frost scar	21.9	3.7	25.9	2.9	37.5	4.6	+4.0	18	+11.6	45	+15.6	71

*For one to ten 1-m^2 plots at each site
ND = No determination

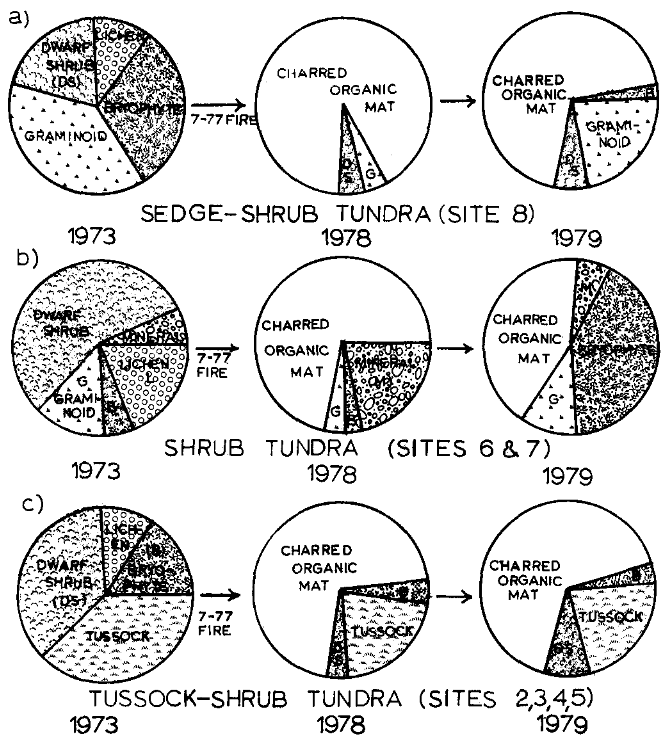

FIG. 4. Contributions of different plant growth forms to total ground cover (whole circle = 100%) before the 1977 tundra fire on Nimrod Hill in July 1973 (left side), one year after the fire in July 1978 (middle) and two years after the fire in July 1979 (right side). Shown for three communities positioned at the top (a), middle (b), and bottom (c) of Nimrod Hill. DS- Dwarf Shrub; G- Graminoid; B- Bryophyte; M- Mineral or bare soil surface.

burning, such as the reduction in the thickness of the organic mat.

Vegetation. Living plant cover was drastically reduced by the 1977 fire; however, small patches of unburned or scorched vegetation were common, particularly on the lower slope at sites 1, 2 and 3 (Table 2). One year later, in July 1978, a ~23% living plant cover was reestablished in this community (Table 2, Fig. 4). This rapid recovery is mainly due to the resprouting of cottongrass tussocks within one year following the fire (Figs. 4, 5 and 7). Dwarf shrubs were slower to resprout, reaching cover values of only 3 to 7% in 1978 (Fig. 4). Colonization of the intertussock spaces by bryophytes and graminoid seedlings also contributed small amounts of living plant cover to the first year recovery (Fig. 4).

FIG. 5. Burned sedge tussock-shrub tundra on the footslope of Nimrod Hill, in July 1978, one year after a tundra fire burned the entire slope (crest of slope on horizon). Site 1 is marked by stakes and tape in mid-foreground. Note resprouting tops of burned tussocks.

Between the first and second years following the fire, total plant cover increased slightly by 8-10% at three of the five tussock-shrub tundra sites (Table 2, Figs. 4, 6 and 8). This increase was mainly due to additional resprouting of dwarf shrubs rather than cottongrass tussocks (Fig. 4). During the second year there was also a small increase in bryophyte cover while sedge seedlings remained abundant. No lichen recovery was observed at any tussock-shrub tundra site although small unburned patches were common at site 1.

Post-fire contributions to cover and shoot density varied among several species which were generally important in the tussock-shrub community before the fire (Table 3) and colonizers not seen at these sites before the fire. These colonizers included bluejoint grass (*Calamagrostis canadensis*), fireweed (*Epilobium angustifolium*) and the bryophytes, *Marchantia polymorpha*, *Ceratodon purpureus* and *Polytrichum juniperinum*. However, none of these colonizers reached high cover values during the first or second years following fire. Of the graminoid species, cottongrass tussocks were clearly the most vigorous resprouter. Resprouting shoots of *Carex bigelowii* and/or *C. aquatilis* were always present but scattered. Bluejoint grass formed small localized colonies and made significant increases in density from 1978 to 1979 at site 3 (Table 3). Seedlings of both *Carex bigelowii* and *Eriophorum vaginatum* were fairly abundant in intertussock spaces during both 1978 and 1979; however, two-year-old tillering seedlings

FIG. 6. Burned sedge tussock-shrub tundra on the footslope of Nimrod Hill, in July 1979, two years after a tundra fire. View upslope from the same position as that pictured in Figure 5 above. Note abundant fruiting heads of *Eriphorum vaginatum* tussocks.

TABLE 2. Cover values* for plant growth forms at eight sample sites along the topographic gradient of Nimrod Hill in the Seward Peninsula, Alaska, before and after a 1977 tundra fire on this slope

Plant growth form	Prefire (1973) Cover (%)	Prefire (1973) ±1 std. dev.	1 yr after (1978) Cover (%)	1 yr after (1978) ±1 std. dev.	2 yrs after (1979) Cover (%)	2 yrs after (1979) ±1 std. dev.	Diff. between 1978 and 1979 average cover values†
Sedge Tussock-Shrub Tundra							
Site 2							
Graminoid	43.2	17.7	18.7	8.0	21.5	10.8	2.8
Dwarf shrub	39.4	20.9	3.3	1.3	9.3	3.3	$6.0^{.001}$
Bryophyte	2.8	4.7	1.0	0.2	2.7	1.7	$1.7^{.01}$
Lichen	5.5	4.1	0.0		0.0		
Total	90.9		23.3		32.2		$8.9^{.01}$
Site 3							
Graminoid			21.1	17.7	21.4	20.5	0.3
Dwarf shrub			5.7	3.3	6.2	3.4	0.5
Bryophyte			1.0	0.5	2.5	1.4	$1.5^{.01}$
Lichen			0.0		0.0		0.0
Total			27.8		30.1		2.3
Site 4							
Graminoid			9.7	6.0	10.1	6.9	$4.8^{.001}$
Dwarf shrub			7.0	3.2	11.4	2.5	$4.4^{.01}$
Bryophyte			1.8	2.6	5.2	5.8	$3.4^{.05}$
Lichen			0.0		0.0		0.0
Total			18.5		26.7		$8.2^{.01}$
Site 5							
Graminoid			15.6	9.5	20.4	10.2	$4.8^{.001}$
Dwarf shrub			4.0	2.7	8.3	3.4	$4.3^{.01}$
Bryophyte			0.1		0.6		0.5
Lichen			0.0		0.0		0.0
Total			19.6		28.7		$9.1^{.01}$
Birch and Ericaceous Shrub Tundra							
Site 6							
Graminoid	10.0		1.1	3.7	4.6	0.3	$3.5^{.05}$
Dwarf shrub	43.0		0.0		0.0		0.0
Bryophyte	3.0		12.2	25.5	51.7	8.5	$39.5^{.01}$
Lichen	14.0		0.0		0.0		0.0
Total	70.0		13.4		56.7		$43.3^{.01}$
Site 7							
Graminoid			4.0	6.0	14.2	19.6	$10.2^{.05}$
Dwarf shrub			0.0		0.6		
Bryophyte			6.8	5.2	38.1	28.9	$31.3^{.01}$
Lichen			0.0		0.0		
Total			12.1		54.9		$42.8^{.01}$
Sedge-Shrub Tundra							
Site 8							
Graminoid	30.0	11.5	4.6	2.1	22.3	10.4	$17.7^{.001}$
Dwarf shrub	17.2	10.1	2.0	3.5	5.0	1.4	$3.0^{.05}$
Bryophyte	24.6	21.3	2.1	3.8	5.9	1.6	$3.8^{.01}$
Lichen	12.6	9.9	0.0		0.0		0.0
Total	84.4		8.7		33.2		$24.5^{.001}$
Site 9							
Graminoid	13.2	11.8	1.0		1.5		0.5
Dwarf shrub	56.7	8.0	3.4	8.0	14.8	3.1	$11.4^{.01}$
Bryophyte	14.1	10.3	0.0		2.6	2.3	$2.6^{.01}$
Lichen	7.5	8.9	0.0		0.0		0.0
Total	91.5		4.4		18.9		$14.5^{.001}$

*At each site cover was estimated in ten 1-m^2 permanent plots.
†t statistic for paired t-test comparing 1978 and 1979 cover values with level of significance indicated

of these species were found only occasionally in 1979, suggesting low seedling survival from the first to the second year following the fire.

Of the resprouting dwarf shrubs in Table 3, the species which showed the greatest increase in cover and/or density during the first two years following the fire were, in

TABLE 3. Values for selected species sampled at four sedge tussock-shrub tundra sites on the footslope of Nimrod Hill in the Seward Peninsula

	Frequency (no. of plots)*				Cover (%)				Density (shoots/m²)			Seedlings				Tillers			
	1973	1978	1979	Diff.†	1973	1978	1979	Diff.	1978	1979	Diff.	1973	1978	1979	Diff.	1973	1978	1979	Diff.
Site 2																			
Dwarf shrubs																			
Rubus chamaemorus	4	10	10	0	0.9	1.6	4.1	2.6	50	163	113$^{.01}$								
Ledum palustre	10	10	10	0	9.3	1.2	3.4	2.2$^{.01}$	59	90	31$^{.01}$								
Vaccinium uliginosum	10	1	1	0	9.8	0.1	0.1	0	2	2	0								
Vaccinium vitis-idaea	10	10	10	0	6.9	0.8	1.3	0.6$^{.01}$	43	126	83$^{.01}$								
Betula nana	9	3	5	2	6.3	0.1	0.1	0	1	2	1								
Graminoids																			
Eriophorum vaginatum	10	10	10	0	34	17	20	3	4.5	5.2	0.7	ND	54	57	3	ND	0	0	0
Carex bigelowii	9	9	10	1	9.2	0.6	1.0	0.4	13	18	5	ND	2	4	2	ND	0	0	0
Calamagrostis canadensis	0	5	5	0	0	0.3	0.7	0.4	6	15	9								
Site 3																			
Dwarf shrubs																			
Rubus chamaemorus		9	9	0		1.6	2.5	0.9	16	68	52$^{.01}$								
Ledum palustre		10	10	0		2.8	2.8	0.0	41	56	15								
Vaccinium uliginosum		6	7	1		0.5	0.5	0	4	13	9								
Vaccinium vitis-idaea		10	10	0		0.5	0.5	0	25	43	18$^{.01}$								
Betula nana		4	4	0		0.2	0.3	0.1	2	3	1								
Graminoids																			
Eriophorum vaginatum		10	10	0		19	20	1	4.2	4.8	0.6		22	32	10$^{.01}$		0	23	23$^{.01}$
Carex bigelowii		7	7	0		0.5	0.5	0	7	11	4		6	2	-4		0	0	0
Calamagrostis canadensis		7	9	2		0.4	0.8	0.4	0.4	18	11$^{.01}$								
Site 4																			
Dwarf Shrubs																			
Rubus chamaemorus		10	10	0		4.8	7.9	3.1$^{.01}$	51	162	111$^{.01}$								
Ledum palustre		10	10	0		0.6	1.3	0.7$^{.01}$	20	24	4								
Vaccinium uliginosum		10	10	0		0.5	1.1	0.6$^{.01}$	16	24	8$^{.01}$								
Vaccinium vitis-idaea		10	10	0		0.5	0.5	0	12	16	4								
Betula nana		4	6	2		0.2	0.2	0	1	2	1								
Graminoids																			
Eriophorum vaginatum		10	10	0		8	8	0	3.2	3.5	0.3		60	35	-25		0	14	14$^{.01}$
Carex bigelowii		4	4	0		0.3	0.6	0.3	3	5	2		28	73	45		0	41	41
Calamagrostis canadensis		0	0	0		0	0	0	0	0	0								
Site 5																			
Dwarf shrubs																			
Rubus chamaemorus		10	10	0		1.7	3.9	2.2$^{.01}$	23	48	25$^{.01}$								
Ledum palustre		8	10	2		0.5	1.1	0.6$^{.01}$	10	21	11$^{.01}$								
Vaccinium uliginosum		10	10	0		0.5	1.2	0.7$^{.01}$	8	23	16$^{.01}$								
Vaccinium vitis-idaea		9	9	0		0.5	0.5	0	14	23	9								
Betula nana		5	5	1		0.2	0.2	0	1	2	1								
Graminoids																			
Eriophorum vaginatum		10	10	0		14	19	5	4.0	4.4	0.4		15	18	3		0	17	17$^{.01}$
Carex bigelowii		7	8	1		7	0.4	0.1	2	5	3		1	5	4		0	0	0
Calamagrostis canadensis		2	2	0		2	0.1	0	1	1	0								

*Number of 1-m² plots in which species occurs (ten plots sampled)
† Comparing 1978 and 1979 values with level of significance indicated
ND — No determination

order of importance: cloudberry, Labrador tea, lingonberry, blueberry, dwarf birch, willow and crowberry (Table 3). Because of its semi-woody base, cloudberry is included in the dwarf shrub category although it is considered by some to be herbaceous. Cloudberry shoot density increased by an average of 34 shoots/m² (200%) between 1978 and 1979 at four of the five tussock-shrub tundra sites. Labrador tea shoot density also increased significantly at four out of five sites by an average of 49 shoots/m² (65%). Lingonberry shoot density increased significantly

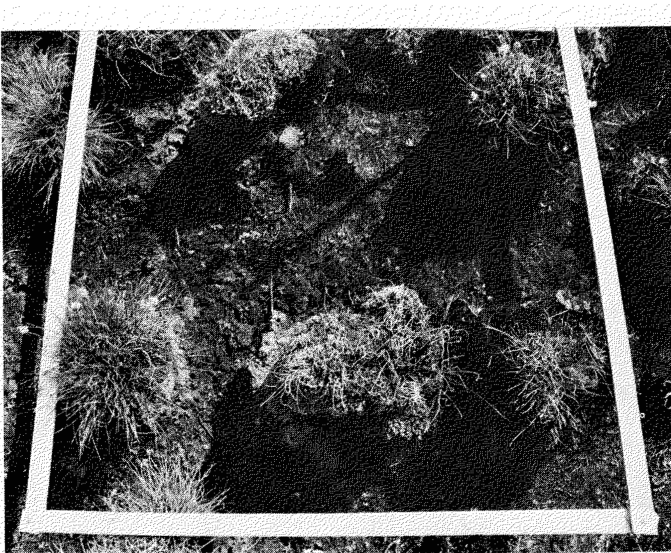

FIG. 7. Vertical close-up view of 1-m² plot at site 1 in burned sedge tussock-shrub tundra on Nimrod Hill, one year after a 1977 tundra fire in July 1978. Note resprouting tops of *Eriophorum* tussocks.

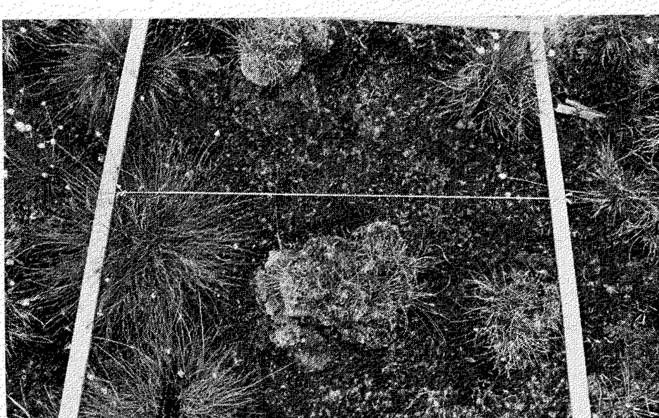

FIG. 8. Close-up view of same 1-m² plot as pictured in Figure 7 above, two years after a 1977 tundra fire in July 1979. Note increased resprouting and fruiting of *Eriophorum* tussocks. Small white dots in the inter-tussock space are *Eriophorum* fruits.

at two out of four sites from 43 shoots/m² to 126 shoots/m² in 1979 at site 2 and from 26 shoots/m² to 43 shoots/m² at site 3. Significant increases in blueberry shoot density occurred only at the two better-drained tussock-shrub tundra sites: 4 and 5. Resprouting dwarf birch occurred sporadically, usually at a frequency of less than 50%. However, during 1979 dwarf birch resprouts appeared in plots where they were not present in 1978, unlike the other dwarf shrub species which had appeared in most plots during the first year following the fire, although dwarf birch was common in the pre-fire tussock-shrub tundra in 1973.

The most striking visual change in tussock-shrub communities between 1978 and 1979 was the increased density of fruiting stalks of cottongrass tussocks (Table 4, Figs. 6 and 8). In 1978, cottongrass fruiting stalk density was about 2-6/m², but one year later in the same plots, densities had increased by ten times (20-60/m²).

TABLE 4. Mean density values* (stalks/m²) of flowering and/or fruiting heads of cottongrass tussocks (*Eriophorum vaginatum*) and bluejoint grass (*Calamagrostis canadensis*) in mid-July 1978 and 1979 following a July 1977 tundra fire in the Seward Peninsula

	1978		1979		Diff. between	Level of
	Mean	Std. dev.	Mean	Std. dev.	1978 and 1979	significance †
Eriophorum vaginatum						
Site 1	4.5	4.1	59.6	37.6	55.1	0.001
Site 2	4.5	4.9	44.9	54.9	40.4	0.05
Site 3	5.3	4.7	22.4	35.7	17.1	0.2
Site 4	2.0	2.6	22.1	20.5	20.1	0.01
Site 5	6.8	8.2	38.5	25.7	31.7	0.01
Calamagrostis canadensis						
Site 1	0.0		8.0	8.9	8.0	
Site 2	0.0		3.3		3.3	
Site 3	0.0		4.6		4.6	
Site 6	0.0		5.1		5.1	
Site 7	0.0		74.2	94.1	74.2	

* Mean values for ten 1-m² plots at each of nine sites along the topographic gradient of Nimrod Hill near Imuruk Lake

† Tests of significant differences made using a paired *t*-test indicated by probability levels

Birch and Ericaceous Shrub Tundra (Sites 6 and 7)

Soils. In 1973, the steeper, moderately well-drained backslope of Nimrod Hill was occupied by a birch and ericaceous shrub tundra community with well-vegetated, elongate, turf-banked frost boils 1-2 m in diameter. Organic horizons were thin (0-5 cm) over these frost boils, but thicker (18-20 cm) in the surrounding unscarred area. One year after the 1977 fire, it was apparent that the fire had removed all of the vegetation and soil organic matter from these frost boils. In the surrounding birch and ericaceous shrub tundra, all of the aboveground vegetation and about 50% of the organic mat had burned, leaving an 8-10 cm organic horizon. Hence, the severity of burning was heavy on the frost boils and moderate to heavy in the surrounding area. The absence of resprouting tussocks, the exposed mineral soil surface on the frost boils (occupying up to 40% of the area), and the blackened/charred organic mat indicated in 1978 that this backslope area had been the most severely burned part of the transect (Fig. 2).

Pre-fire thaw depths in mid-July 1973 on the backslope were about 24.6 ± 5.7 cm in the non-frost-boil areas and 43.2 ± 11.3 cm on the elongate, turf-banked frost boils (Table 1). In July 1978, thaw depths had increased by about 123% (to 54.8 ± 7.0 cm) in the non-frost-boil areas and by 50% (to 65 cm) in the exposed frost boils; however, rock was encountered before thaw depth measurements could be made in many plots. By July 1979, it was almost impossible to obtain thaw depth measurements because of rock. In addition, there was apparent subsidence of the ground surface, probably due to the melting of ground ice, which when it occurred around supporting rock columns resulted in mounds and hummocks up to 1 m high (Fig. 9), having the appearance of frost-heaved rocks.

Groundwater movement downslope, possibly from melting ice on the backslope, was suggested by observa-

FIG. 9. Small (0.5 m diameter and 0.7 m high) mound in birch and ericaceous shrub tundra community on the backslope of Nimrod Hill in July 1979, probably resulting from subsidence of ground surface around rocks. Note tearing of the mat and abundant fireweed and bluejoint grass (background) and sedge seedlings (foreground).

tions made in July 1979 of 1) coarse mineral soil of a color and texture suggesting an origin on the backslope which has issued from the footslope in several areas, and 2) shallow V-shaped channels which were beginning to form on the footslope through surface subsidence. According to Chapin *et al.* (1979), the bright green color of the cottongrass tussocks in these new drainages suggests groundwater movement.

Vegetation. Prior to the 1977 fire, the birch and ericaceous shrub tundra community on the Nimrod Hill backslope (sites 6 and 7) was dominated by dwarf shrubs such as blueberry, dwarf birch, lingonberry and Labrador tea; by *Carex bigelowii*; and by lichens such as *Cetraria cucullata*, *C. islandica*, *Cladonia gracilis* and *C. rangiferina* (Table 5). On the tops of the well-vegetated turf-banked frost boils within this community, the dwarf shrubs, alpine bearberry (*Arctostaphylos alpina*), crowberry and netted willow (*Salix reticulata*) were dominant. Exposed rocks on these frost boils were covered with the lichens *Alectoria nigricans*, *Cetraria cucullata* and *Cladonia gracilis* and the moss *Rhacomitrium lanuginosum* (Table 5).

The 1977 fire severely burned this birch and ericaceous shrub tundra community. Little or no resprouting of species which were present before the fire occurred during the following two years. Virtually all vegetation recovery has resulted from colonizing bryophytes, graminoids and forbs (Fig. 4). One year after the fire the total living plant cover was about 14% and was composed mainly of seedling graminoids (*Carex bigelowii* and *Eriophorum vaginatum*) and bryophytes (*Marchantia polymorpha* and *Ceratodon purpureus*) (Table 5, Fig. 11). In addition, there were small colonies of nonflowering and short-stemmed bluejoint grass and some scattered individuals of fireweed. The tops of the elongate, turf-banked frost boils remained completely unvegetated, with conspicuous cracks and exposed mineral soil and rocks which appeared to have been frost churned (Fig. 11). The only plants on the surfaces of these boils were a few individuals of chickweed (*Stellaria longipes*), *Minuartia rossii* and bluejoint grass at site 7 (Table 5).

Between the first and second years following the fire, there was a large increase in living plant cover in the non-frost-boil areas: from about 14% cover in 1978 to 55% in 1979 at both backslope sites (Figs. 4, 9, 10 and 12). This increased cover was due almost entirely to the growth and expansion of the species which colonized the site during the first year following the fire (Table 5, Figs. 11 and 12). The moss *Ceratodon purpureus* made a 400% increase from about 8% cover in 1978 to 40% cover in 1979. Expansion, through tillering, of the *Carex bigelowii* seedlings, established in 1978, was also striking (Figs. 9 and 10). There was also a conspicuous increase in the density, cover, height growth and flowering of bluejoint grass. Whereas no flowering and/or fruiting stalks of bluejoint grass were seen in 1978, almost all shoots were reproducing by 1979 (Table 4). Significant increases in the density and flowering of fireweed also occurred during the second year and a few individuals of marsh fleabane (*Senecio congestus*) were present for the first time.

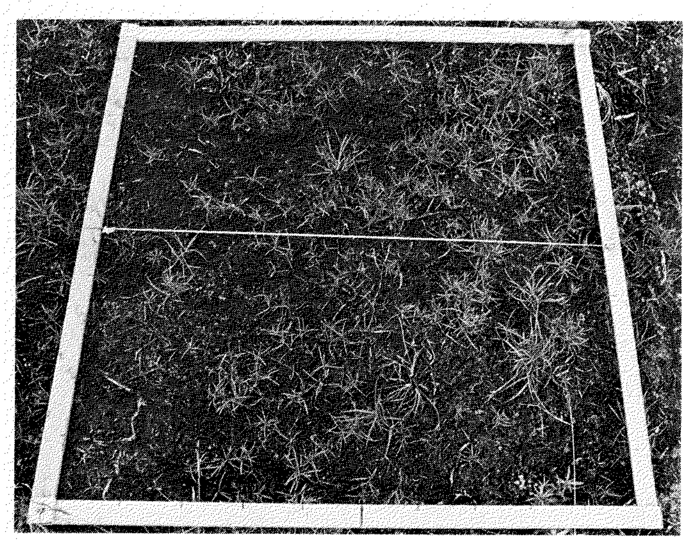

FIG. 10. Vertical close-up view of plot 1 at site 7 in burned birch and ericaceous shrub tundra community on the backslope of Nimrod Hill. Pictured in July 1979, two years after a tundra fire; note abundant tillering seedlings of *Carex* sp.

In 1979, the tops of the frost boils remained bare mineral soil and rock except for slight expansion of the chickweed and *Minuartia rossii* populations at site 7. Only at site 7 (Table 5) was there any evidence of the resprouting of the dwarf shrubs abundant before the fire; here blueberry showed a few resprouting shoots in four plots.

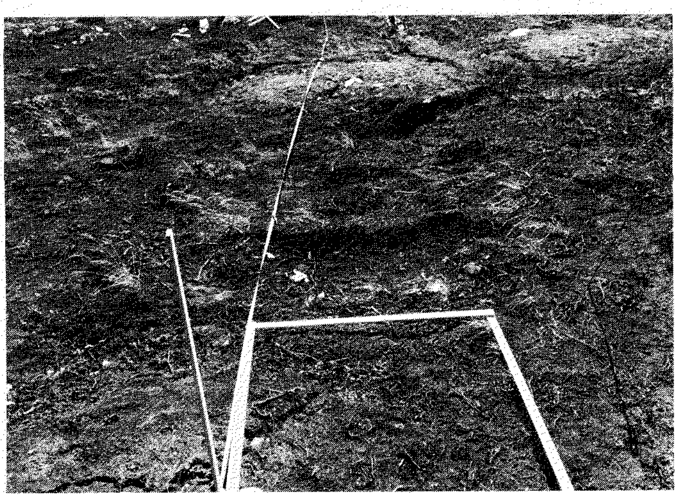

FIG. 11. Burned birch and ericaceous shrub tundra community at site 7, one year after fire in July 1978; turf-banked frost boils from which vegetation and organic mat have been burned off are visible in background. Little or no revegetation has occurred and thaw depths have increased greatly over prefire condition.

Sedge-Shrub Tundra (Sites 8 and 9)

Soils. On the level, upland crest of Nimrod Hill (site 8) and onto the northeast-facing backslope (site 9), the soil moisture environment is very poorly drained. The only frost features at sites 8 and 9 are low-centered polygons on the level hill crest of site 8. In pre-fire 1973, there was a fairly thick accumulation of organic material at both sites, 30-35 cm at site 8 and 20-30 cm at site 9. Much of this thickness was attributed to the buildup of *Sphagnum* moss mats at both sites. Burning at these sites in 1977 was quite patchy (Fig. 13), with the *Sphagnum* moss mats generally remaining unburned but apparently scorched and dead as suggested by their tan color and dryness two years after the fire. At site 9, there were charred and more deeply burned pockets between moss hummocks, where about 13 cm of the organic horizon remained. This suggested that the removal of the top 10 cm of this horizon was probably related to the severe burning of the dwarf shrubs in these pockets. Burning at site 8 was apparently less severe but also uneven. Post-fire determinations of organic horizon thickness varied from 15 to 30 cm, suggesting removal of 5-15 cm.

At site 8 on the level hill crest, thaw depths were found in 1978 to have increased by 7.6 cm (32%) over 1973 depths (Table 1). A further increase in thawing of 11.5 cm (37%) took place at the site during the second year following the 1977 fire. At site 9, on the northeast-facing backslope, little or no increase over pre-fire thaw depths was observed during the first year following the fire. However, an increase of 11.6 cm (47%) occurred during the second year. Rapid post-fire thawing at site 9 may have been inhibited by the large scorched *Sphagnum* mats.

Vegetation. Pre-fire (1973) vegetation at sites 8 and 9 was fairly similar in that dwarf shrubs, sedges and *Sphagnum* mosses were important (Tables 2 and 6). However, the wetter level hilltop (site 8) community was dominated by single-stemmed sedges (*Carex aquatilis* and *Eriophorum scheuchzeri*), while at site 9 dwarf shrubs were clearly dominant (Table 6). The presence of low-centered polygons and the absence of slope drainage at site 8 may account for this shift in dominance. Little vegetation recovery (< 10%) had occurred at either site one year after the fire (Table 2, Fig. 4). Most of the dwarf shrub species present before the fire had started to resprout at both sites, with cloudberry clearly the most prolific (Table 6). *Carex aquatilis* showed limited resprouting at both sites, while both *Ceratodon purpureus* and *Marchantia polymorpha* were occasional at site 8 and rare at site 9.

In contrast with this small first-year recovery, a large (15-25%) increase in plant cover occurred during the second year (1979) as a result of the accelerated resprouting of dwarf shrubs at both sites and of the sedges at site 8. Of the shrubs, cloudberry showed a three-to five-fold

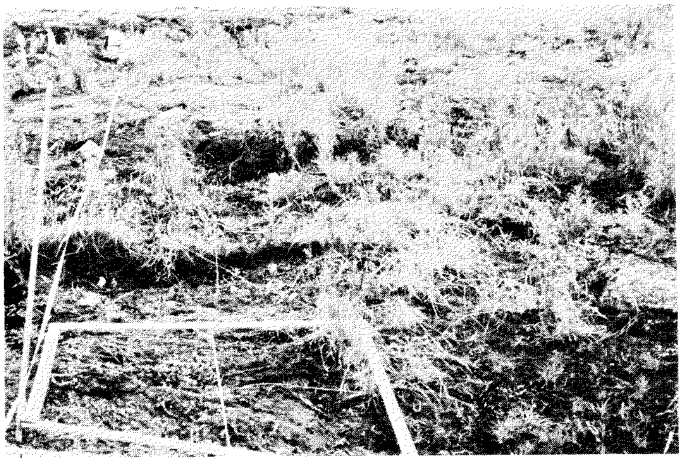

FIG. 12. Same view of burned birch and ericaceous shrub tundra as in Figure 11, two years after a 1977 fire, in July 1979. Note large increase, in vegetation cover due to establishment of bluejoint grass, sedges, mosses, fireweed and marsh fleabane.

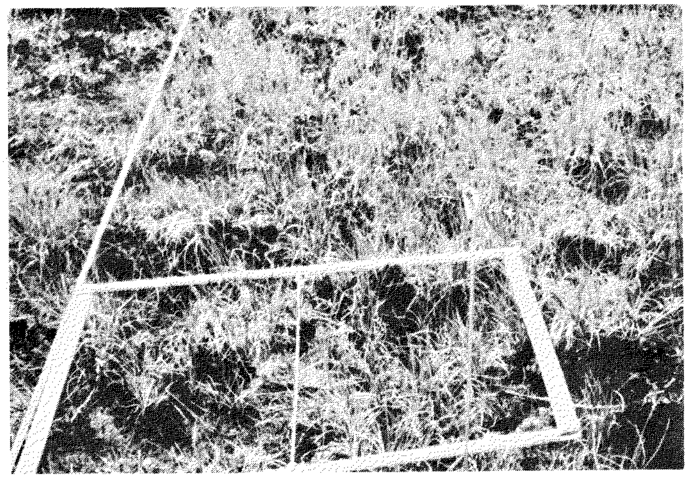

FIG. 13. July 1979 view of sedge-shrub tundra community on the crest of Nimrod Hill (site 8) which burned in July 1977. Note vigorous resprouting of the sedges, *Carex aquatilis* and *Eriophorum scheuchzeri*.

TABLE 5. Values for species sampled in a birch and ericaceous shrub tundra community at site 7 before and after a tundra fire on Nimrod Hill in the Seward Peninsula, Alaska (Values given separately for the tops of elongate turf-banked frost boils and the surrounding tundra)

	Prefire (1973)				One Year after (1978)						2 years after (1979)					
	Non-frost boils		Frost boils		Non-frost boils			Frost boils			Non-frost boils			Frost boils		
Species	Freq.*	Cover (mean %)	Freq.	Cover (mean %)	Freq.	Cover (mean %)	Density (shoots/m²)	Freq.	Cover (mean %)	Density (shoots/m²)	Freq.	Cover (mean %)	Density (shoots/m²)	Freq.	Cover (mean %)	Density (shoots/m²)
Dwarf shrubs																
Betula nana	10	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ledum palustre	9	6	0	0	1	1	1	0	0	0	1	1	1	0	0	0
Vaccinium vitis-idaea	10	7	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Vaccinium uliginosum	10	18	10	8	2	1	1	0	0	0	4	2	0	0	0	0
Arctostaphylos alpina	0	0	6	5	0	0	0	0	0	0	0	0	0	0	0	0
Salix sp.	7	1	7	1	0	0	0	2	1	1	0	0	0	2	1	1
Empetrum nigrum	8	5	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Salix reticulata	0	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0
Graminoids																
Carex bigelowii																
Adult	10	10	6	1	0	0	0	0	0	0	5	1	13	0	0	0
Seedlings	ND		ND		10	1	19	0	0	0	10	3	25	0	0	0
Tillers	ND		ND		0	0	0	0	0	0	10	4	100	0	0	0
Eriophorum vaginatum																
Seedlings	ND		ND		8	1	30	0	0	0	1	1	1	0	0	0
Tillers	ND		ND		0	0	0	0	0	0	0	0	0	0	0	0
Calamagrostis canadensis	0	0	0	0	7	4	28	6	1	9	8	15	117	10	1	19
Forbs																
Petasites frigidus	10	2	10	1	1	1	1	1	1	1	1	1	2	1	1	1
Epilobium angustifolium	0	0	0	0	5	1	1	1	1	1	8	1	8	1	1	2
Senecio congestus	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0
Stellaria	0	0	0	0	0	0	0	6	2	10	0	0	0	6	3	100
Sagina intermidia	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1
Bryophytes																
Ceratodon purpureus	0	0	0	0	10	7	ND	6	3	ND	10	51	ND	8	25	ND
Marchantia polymorpha	0	0	0	0	9	1	ND	4	1	ND	9	1	ND	2	1	ND
Polytrichum spp.	0	0	6	1	1	1	ND	1	1	ND	1	1	ND	1	1	ND
Sphagnum spp.	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhacomitrium lanuginosum	0	0	10	20	0	0	0	0	0	0	0	0	0	0	0	0
Lichens																
Cetraria cucullata	10	5	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Cladonia gracilis	10	9	10	4	0	0	0	0	0	0	0	0	0	0	0	0
Alectoria nigricans	0	0	10	4	0	0	0	0	0	0	0	0	0	0	0	0

*Number of 1-m² quadrats in which species occurs/no. of quadrats sampled on that site × 10
ND — no determination

increase in cover and reached levels equal to those before the fire. Blueberry also showed a more rapid recovery here than at other sites along the transect. However, by far the largest increase in density and cover was made by *Carex aquatilis* (and to a lesser extent *Eriophorum scheuchzeri*) at site 8 (Fig. 13), which reached cover values of about 23%, near the pre-fire level of about 30% (Fig. 4, Table 6). Both dwarf birch and blueberry were fairly important at sites 8 and 9 before the fire but showed little or no resprouting during the following two years. Crowberry was also present at both sites before the fire but showed no sign of post-fire recovery. Few species, with the exception of cloudberry, were seen to resprout out of these mats at site 9. Fireweed is the only vascular plant species at sites 8 and 9 that was not sampled there before the fire.

DISCUSSION AND CONCLUSIONS

It is clear that the 1977 fire had different effects on each of the three tundra communities located along the slope of Nimrod Hill. Although the results are preliminary and based on only two years of post-fire recovery data, some similarities and differences with respect to the effects and role of fire in these three communities can be discussed. Certain of the changes resulting from fire along the gradient of Nimrod Hill are summarized in Figure 14.

The sedge tussock-shrub community on the footslope of Nimrod Hill appears to have been least affected by the fire in terms of the severity of burning, change in thaw depths and post-fire revegetation. The severity of burning here was light to moderate, and thaw depths did not increase by more than 10-15 cm during the following two years (Fig.

TABLE 6. Values for species sampled at two sedge-shrub tundra sites on the crest (site 8) and northeast-facing backslope (site 9) of Nimrod Hill in the Seward Peninsula, Alaska, after a 1977 tundra fire

	Site 8								Site 9							
	Prefire (1973)		1 yr after (1978)			2 yrs after (1979)			Prefire (1973)		1 yr after (1978)			2 yrs after (1979)		
Species	Freq.*	Cover†	Freq.	Cover	Density (shoots/ m²)	Freq.	Cover	Density (shoots/ m²)	Freq.	Cover	Freq.	Cover	Density (shoots/ m²)	Freq.	Cover	Density (shoots/ m²)
Dwarf shrubs																
Rubus chamaemorus	10	3.3	9	1.2	24	9	3.3	45	10	13.1	10	2.6	53	10	12.2	129
Ledum palustre	10	3.9	5	0.4	4	7	0.7	7	10	12.0	7	0.3	4	8	0.6	16
Vaccinium uliginosum	1	0.4	4	0.3	6	5	1.1	21	7	3.7	8	0.5	10	10	1.9	35
Vaccinium vitis-idaea	10	2.8	3	0.2	2	4	0.2	3	10	15.5	6	0.3	2	7	0.3	5
Betula nana	10	5.9	1	0.1	0	2	0.1	0	9	11.3	0	0	0	0	0	0
Graminoids																
Carex aquatilis	10	20.0	10	4.0	63	10	21	136	10	13.2	10	0.4	5	7	0.4	6
Eriophorum scheuchzeri	6	10.0	8	0.6	15	8	1.5	42	0	0.0	0	0	0	0	0	0
Bryophytes																
Ceratodon purpureus	0	0	8	0.9		9	1.2	ND	0	0	0	0	0	10	2.5	0
Marchantia polymorpha	0	0	8	0.7		8	2.5	ND	0	0	0	0	0	4	0.3	0
Polytrichum spp.	0	0	9	0.6	13	10	2.3	ND	0	0	0	0	0	0	0	0
Sphagnum spp.	10	26.0		dead			dead		10	13.0		dead			dead	
Lichens																
Cetraria cucullata	10	3.6	0	0	0	0	0	0	7	1.9	0	0	0	0	0	0
Cladonia gracilis	10	9.0	0	0	0	0	0	0	7	5.4	0	0	0	0	0	0

*Number of 1-m² plots in which the species occurs (ten plots sampled)
†Mean percent cover averaged over 10 plots

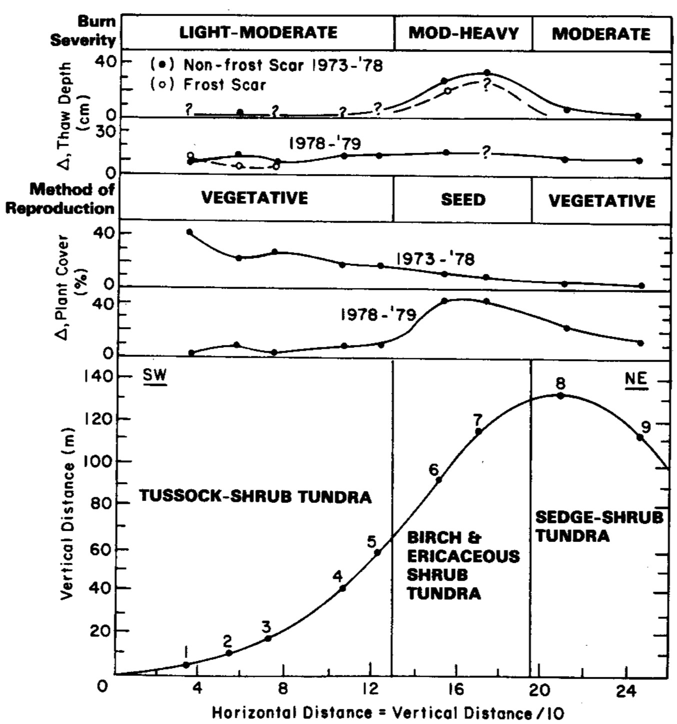

FIG. 14. Summarized fire effects and post-fire recovery during 1978 and 1979 from a 1977 tundra fire along the topographic gradient of Nimrod Hill in the Seward Peninsula, Alaska.

13). Initial revegetation following the fire appears to be almost completely due to the vegetative resprouting of the vascular plant species present before the fire. Hence, much of the pre-fire species composition is apparently restored fairly quickly, although little lichen and moss recovery has taken place during these first two years. The

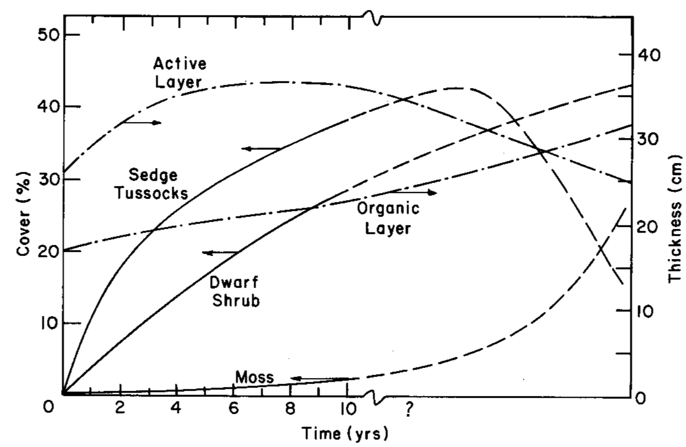

FIG. 15. Hypothetical model showing changes in vegetation (growth forms), soil active layer and organic horizon thickness following fire in tussock-shrub tundra ecosystems. Arrows show to which ordinate axis the curve belongs.

relative importance of graminoid tussocks over dwarf shrubs has significantly increased as a result of the fire. This is due to the almost immediate post-fire resprouting of cottongrass tussocks in contrast with the relatively slow resprouting of dwarf shrubs.

A model showing post-fire successional changes in tussock-shrub tundra is proposed in Figure 15. After some unknown interval of time, the dwarf shrubs and mosses would eventually grow up around the cottongrass tussocks, resulting in the senescence of the tussocks and thinning of the active layer. Such a successional process involving the buildup of the organic mat (paludification) and burial of tussocks has been noted on a large scale in the Seward Peninsula (Hopkins, 1972; Racine and Anderson, 1979; Melchior, 1979). Fire would prevent such conditions from developing in tussock-shrub tundra through removal of some of the vegetation and organic soil from around tussocks.

Frost action, leading to the formation of mud circles in tussock-shrub tundra, would also promote vigorous tussocks by disrupting the organic mat and the mosses as well as the dwarf shrubs growing up around them. Mud circles can serve as a substrate for the establishment of new cottongrass tussocks (Hopkins and Sigafoos, 1951). Evidence obtained on Nimrod Hill suggests that fire may stimulate frost action, leading to mud circle formation; in 1973, extensive probing in the tussock-shrub community suggested that the summer active layer rarely reached into the mineral soil (condition on the right in Fig. 15). However, by 1979, two years after the fire, thawing appeared to extend below the organic horizon into the mineral soil horizons (condition on the left in Fig. 15). This would promote the formation of ice lenses in the mineral soil during freeze/thaw cycles so that the physical movement and churning necessary for frost action would be possible.

The post-fire origin of resprouting dwarf shrubs is presumably stems, roots and/or rhizomes buried in the remaining organic soil layer. Dwarf shrub species showed differential resprouting rates following the fire on Nimrod Hill. These differences may be related to the depth or location of their underground stems or roots in relation to the severity of burning. Dwarf shrubs which penetrate deep into the organic mat or grow into the tussock mass might escape fire and recover faster than those near the surface.

Shaver and Cutler (1979) have determined the vertical distribution of biomass above and belowground for different species in tussock-shrub tundras in various parts of Alaska; they found, for example, that crowberry and lingonberry have most of their belowground biomass located near the surface. In the Seward Peninsula, we found no evidence of recovery of crowberry in two- or seven-year old burns. Lingonberry resprouted abundantly but these sprouts were almost always located on the surface or sides of tussocks (K. Devereaux, pers. comm.), suggesting that they escaped burning within the tussock mass. In the sedge-shrub tundra community at sites 8 and 9 on Nimrod Hill, where there are no tussocks, lingonberry was abundant before the fire but showed little post-fire resprouting. Vigorous post-fire resprouters such as Labrador tea and cloudberry have a high proportion of their biomass in the deeper soil organic layers (Shaver and Cutler, 1979; Flinn and Wein, 1977).

Fire had the most drastic effects on the birch and ericaceous shrub tundra community located on the better-drained backslope of Nimrod Hill. The severity of burning was moderate to heavy, with thaw depths increasing greatly in the first year following the fire; by the second year there was evidence of surface subsidence and the formation of hummocks where there were supporting rock columns. Transport of mineral soil by groundwater moving downslope from this area may result in changes in slope topography. Mackay (1977) reported that a burned hillslope at Inuvik, N.W.T. subsided nearly 50 cm during the eight years following a 1968 fire. Cody (1964) described similar subsidence and formation of hummocky terrain three years after a taiga fire in the Mackenzie Delta.

Vegetation recovery in this burned birch and ericaceous shrub community is different from that in either of the other communities; all regeneration appears to be from seed by species of minor importance in the pre-fire community rather than from the resprouting of species abundant before the fire. The dwarf shrubs which were dominant before the fire have been replaced by graminoid sedges, grasses and several forbs. Successional bryophytes have also played an important role in post-fire vegetation recovery in this backslope community, in contrast to their minor role in the other tussock-shrub and sedge-shrub communities. It might be argued that these differences are due to the greater severity of burning of this particular community on Nimrod Hill. However, observation and aerial reconnaissance over much of the 1977 burn suggest that the birch and ericaceous shrub tundra community consistently burns more severely because of its more xeric topographic position and the absence of fire-resistant tussocks.

Three possible origins of the seed can be suggested for the seedling community: 1) seeds buried in the organic soil layers are exposed by fire; 2) seeds are dispersed onto the burn immediately following fire by plants growing in adjacent unburned tundra; and 3) seeds are produced in the burned area by the abundant flowering stimulated by fire. This third source is discounted as an initial seed source because neither cottongrass tussocks nor bluejoint grass flowered abundantly until the second year following the 1977 fire. We have no data to test the second hypothesis. There is some recent evidence to support the buried seed origin; McGraw (1979) determined that a large, viable seed bank (3367.2 seeds/m^2) was contained in the organic horizon of a tussock-shrub tundra community in interior Alaska. Seeds of *Eriophorum vaginatum* and *Carex bigelowii* composed 60% of this total and these seeds were at depths greater than 15 cm, with *Carex* seed density increasing with depth in the organic mat. Hence, the relatively deeply buried seed bank of these two sedge species would be available for recolonizing even moderately to heavily burned areas such as those on the Nimrod Hill backslope.

In the sedge-shrub community on the crest and northeast-facing backslope of Nimrod Hill, both the severity of burning and the post-fire revegetation were inhibited by the presence of *Sphagnum* moss mats. Although these mats did not burn, they appear to have been killed by the fire. These *Sphagnum* mats have undoubtedly reduced the rate of increase in the thickness of the active layer. Vegetation recovery in the sedge-shrub tundra community has proceeded by vegetative resprouting of species present before the fire, but at a slower rate than in the tussock-shrub tundra community. Few shoots (except for cloudberry) appear to grow out of the dead *Sphagnum* mats. However, as in both of the other burned communities on Nimrod Hill, sedges appear to have been stimulated by the fire, and are resprouting earlier than dwarf shrubs.

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