AN ANALYSIS OF PLANT SUCCESSION ON FROST SCARS 1961-1980

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Plant succession on frost scars was studied at Ogotoruk Creek, Alaska. In 1961, 326 frost scars were marked for long-term study. The initial physical and biological measurements were repeated several times. In 1965, four transects were established and later revisited to learn if new frost disturbance is occurring. Frost scars at Ogotoruk Creek are convex, primarily oval areas of fine-grained soil with a modal size of about 1 m in diameter. They occur on surfaces of from 1-3^{o} and cover up to 50% of the ground surface. Many frost scars show surface activity due to frost action, but repeated mapping of them indicates that they neither expand nor contract laterally. Repeated measurements along fixed lines suggest that new frost scars are not being formed at present. Plants invade bare areas at Ogotoruk Creek by seeds or vegetative reproduction. Plants growing on frost scars are subject to frost heaving, uplift and disruption from needle ice formation, and wind erosion and desiccation. A direct relationship exists between plant cover on frost scars and soil moisture surrounding the scar. During the 20 years of the study both positive and negative changes in plant cover were recorded. A consistent pattern of plant succession was not detected.

INTRODUCTION

On the wet, relatively flat bottomlands of the Ogotoruk Creek Valley, northwest Alaska (68^{o}06'N, 165^{o}46'W), two major kinds of tundra vegetation occur. On the wettest soils, sedge meadow vegetation consisting primarily of two species, *Carex aquatilis* var. *stans* (Drejer) Boott and *Eriophorum angustifolium* Honck, occurs. On better drained soils a sedge tussock meadow consisting mostly of *Eriophorum vaginatum* L. is extensive. The two types are often mixed where microtopographic differences produce a mosaic of moisture conditions. The two kinds of vegetation occupy approximately 55% of the Ogotoruk Creek watershed (Johnson et al. 1966), an area of about 100 km^{2}. The two vegetation types at Ogotoruk Creek are described more completely in Johnson et al. (1966).

A third kind of vegetation occurs between the upland vegetation of the slopes and the vegetation types of the valley floor. *Carex bigelowii* Torr & Schwein. is the most characteristic plant of several diverse communities which all together comprise about 4.6% of the area, or 458 h. In Johnson et al. (1966) they are referred to as "ecotone communities."

Scattered on the surface in these vegetation types are predominantly oval areas of frost disturbed soil commonly called frost scars or frost boils, or in the formal classification of Washburn (1956), nonsorted circles. They are common in the Ogotoruk Creek Valley, especially in sedge tussock tundra, where up to 50% of the surface may be covered by this patterned ground feature. Frost scars typically measure 1-3 m in diameter; their centers are usually convex, but they may be flat or depressed. Permafrost is deepest under the center of the scar and shallowest at its margins. They are sometimes covered by plants; but in the majority of cases they are sparsely covered or are nearly bare.

At Ogotoruk Creek, frost features are important landscape features and probably play an important role in the dynamics of the plant communities. Nonsorted circles of this type are known from other areas of the Arctic (see especially Hopkins and Sigafoos 1951). Because of the absence of long-term observations, relatively little is known of their genesis, growth, activity, relationship to environmental variables, or other details of their history or future. The colonization of frost scars by plants has been observed, but not followed long enough to determine if plant succession in the traditional sense occurs. Inasmuch as the usual longitudinal method utilized in successional studies does not work well in conditions of soil instability, it was decided to engage in a long-term study of frost scars and their vegetation in order to investigate the following questions:

1. Are frost scars forming under the present climate?
2. Do frost scars exhibit cycles of activity, i.e., initiation, growth, equilibrium, and senescence?
3. Does plant succession on frost scars follow regular and predictable courses?

Preliminary studies were conducted by Johnson (1960) who listed the kinds of patterned ground features present in the Ogotoruk Creek Valley and described the relationships between vegetation and frost features, emphasizing the three vegetation types in which frost action is most important.

In 1961, Neiland permanently marked 326 frost scars located in 24 one acre plots that had been previously established for the study of the vegetation of the Ogotoruk Creek Valley (Neiland et al.

1962, Johnson et al. 1966). She documented the physical details of each scar, mapped its dimensions on a 2 m grid, and described the kinds, amounts, and locations of plants on each scar. Each scar was photographed from a fixed point for future reference.

In 1962, 1963, and 1965, Johnson rephotographed 240, 242, and 299, respectively, of the scars established by Neiland. In 1965, 60 of the scars in 4 plots were remapped in order to determine if physical changes in the scars were detectable. In 1972, 15 of the plots were redescribed, mapped, and photographed, and in 1980 this was repeated for 13 of the plots.

In 1965, in an effort to identify any new areas of disturbance that may have occurred, four lines measuring 640, 305, 457, and 213 m, respectively, were established. Along each line, the areas of disturbance intersecting the line were measured and recorded. Two of the four lines were relocated in 1972 and the measurements repeated.

This paper will concentrate on the differences observed in 189 of 326 frost scars between 1961 and 1980. The detailed descriptions of frost scars made in 1961 will not be given here. Rather, changes, if any, in the physical dimesions of the scars and in the kinds and amount of plant cover associated with them will be emphasized.

OCCURRENCE AND SIZE OF FROST SCARS

Are New Frost Scars Forming Today?

The conditions under which frost scars originate are a matter of speculation, but it is assumed by some authors (e.g., Hopkins and Sigafoos 1951) that they do so under the conditions of the existing climate. This belief is difficult to evaluate, because few, if any, studies have demonstrated it. If frost scars are forming today at Ogotoruk Creek, one should expect to find new scars appearing in a 20 year period. This is not the case. In the study plots at Ogotoruk Creek, no new frost scars have been detected from 1961 to 1980. Once formed, frost scars tend to be self perpetuating because of differences between the temperature-moisture relations of the scar and its better insulated surroundings. It is possible, as has been proposed for sorted circles by Ballantyne and Matthews (1982), that following a period of initial activity under somewhat colder, wetter periods than those of today, nonsorted circles became more or less stable.

In an effort to establish an additional baseline against which the occurrence of new frost scars might be measured, four long lines were established in 1965. The areas of bare soil were mapped along each line in order to determine (1) if any new bare areas occurred and (2) if existing bare areas changed in extent. In 1972, two of the lines were again measured (Table 1). Five new bare areas were recorded along transect 3 in 1972, and 78 of the areas of existing bare soil remained essentially unchanged. The transects were not measured in 1980, but they should be examined again to determine if the 1972 observations are measuring errors, represent newly formed bare areas, or are areas on which renewed activity is taking place.

It is also stated in some of the literature on frost scars that they grow or become reduced in area over a period of years. Hopkins and Sigafoos (1951), for example, suggest that a frost scar can be enlarged under favorable years by marginal needle ice formation, and they speak of the "net growth of many scars."

Are Frost Scars Expanding or Contracting Today?

In order to test the idea that frost scars grow (or contract) in one or more directions, maps of frost scar area were compared among 1961, 1965, 1972, and 1980. An example of these comparisons is given for one scar as it was mapped in 1961, 1965, 1972, and 1980 (Figure 1). A potentially significant error occurs in making these determinations. The precise margin of a frost scar is a matter of interpretation--along any edge it may grade into undisturbed tundra without a clear distinction between it and its surroundings.

What is apparent from this example is that over the periods measured, relatively little change in the shape or areal extent of this frost scar has taken place. Of course, the time periods involved are short and the number of frost scars measured is rather small, but all of the data available support a conclusion that the conditions that occurred at Ogotoruk Creek between 1961 and 1980 did not favor the growth or contraction of frost scars.

The belief that new frost scars are arising or growing is encouraged by the appearance of new frost activity within the margins of the scar. At times the combined action of frost heaving due to the presence of subsurface segregated ice and of surface needle ice gives the appearance of intense activity on the scar surface. Neither form of cryogenic activity implies expansion of the areal extent of the scar. Scars that have been inactive for some time may show a burst of renewed surface activity. For example, at several locations along the Trans-Alaska Oil Pipeline haul road, renewed frost scar surface activity occurred where construction activities blocked drainages and apparently increased the amount of soil moisture in the scar surroundings.

PLANT SUCCESSION ON FROST SCARS

Plants invade the bare soils of frost scars by direct seeding and by vegetative growth from their surroundings. A direct relation exists between the degree to which plant invasion is successful and cover established and the average wetness of the site. Scars occurring in sedge meadow vegetation, the wettest of the three being considered here, show the greatest cover of vegetation (Figure 2); those in ecotonal plant communities, the least.

The results of the plant succession study are summarized in Table 2 and in Figure 3. Two major conclusions are apparent. First, the proportion of frost scars showing changes in plant cover between 1961 and 1980 is highest in the sedge meadow vegetation type and lowest in the ecotone communities. This, together with the data summarized in Figure 2, suggests that the availability of moisture may be a controlling factor in frost scar plant succession. Frost scars occurring in the wettest habitats show the greatest degree of change in plant cover--both positively and negatively. The presence of moisture during the growing season favors plant growth but in the cold periods favors the formation of more soil ice which in turn disrupts plants.

Second, the proportion of frost scars in any vegetation type that show changes in plant cover increases with time. In 20 years the direction of change in plant cover has not been consistent on any single scar.

The discussion that follows describes only the gross changes that occur on frost scar surfaces. Detailed and quantitative descriptions are not given here.

The scars of the sedge meadow show the greatest fluctuations in plant cover of any of the three types (Figures 1 and 4). Plant cover on a few of these scars has changed by nearly 100% over the 20 year period. The large changes that occur in this type are nearly always the result of the establishment or the loss of one or two major species, particularly Eriophorum angustifolium or Carex aquatilis. The former is particularly susceptible to being uprooted (or detached from its rhizomes) by the effects of needle ice. At least temporary stability with complete plant cover can occur on scars of this type if they can maintain their cover long enough to produce an organic layer over the base mineral soil.

On scars occurring in Eriophorum tussock vegetation, changes in plant cover generally involve different species than is the case in sedge meadow vegetation. Some of the most noticeable changes on scars of this type involve tussock forming species, especially Eriophorum vaginatum and Deschampsia cespitosa. The latter, especially, seeds into the bare surface of the scar and forms small tussocks. These tend to persist and enlarge over several years, but they eventually decompose and are replaced by other tussocks in different locations on the scar. Eriophorum vaginatum shows the same kind of behavior, but it is not as abundant as an invader as Deschampsia cespitosa (Figure 5). In addition, once established it persists longer and grows to a much larger size. Because the pattern of change on these scars is more like a loss and replacement cycle than an invasion and subsequent elimination, changes in total cover tend to be small. Plant cover in general is lower on these scars than on those in the sedge meadow.

Plant cover on scars of the ecotone is very low, and changes are not obvious. Occasionally plants become established, ususally by seeds, on these base gravelly surfaces, but they do not persist for more than a few years. Invasion of plants from the surroundings of the scar is very slow, if it occurs at all. The surface of these scars tends to be dry, and the substrate coarse and, during the growing season, very hard. Although little evidence of needle ice formation is seen in any of the scars of this type, they show substantial heaving from subsurface ice during the freezeup period. Of the three types of scars, these ecotonal ones as a group show the least changes over the 20 year period.

SUMMARY

This review of a very large number of observations on frost scars at Ogotoruk Creek emphasizes changes that have taken place in the physical and biological characteristics of 188 frost scars between 1961 and 1980. In general, the evidence suggests that the physical dimensions of the scars have changed little in the 20 year period. Although surface activity is high on many frost scars, the lateral dimensions of the scars do not change, at least within our capability of consistent measurement. Neither is there conclusive evidence that new frost scars are forming at present.

Plant succession occurs on frost scars, but not in a directional or progressive sense. Rather it appears that on most frost scars, plant cover waxes and wanes as year-to-year climatic changes occur. Our data and observations suggest that plant cover is likely to be highest on frost scars occurring in the wettest habitats and least on those of the driest habitats. Although high levels of soil moisture encourage plant growth, they also create the most favorable conditions for the formation of soil ice, so it is also true that these frost scars show the greatest and most rapid changes in plant cover. Likewise, frost scars in the driest habitats change least over time. The idea of cycles of frost scar genesis, activity, invasion, and stabilization by plants and ultimate disappearance is not supported by this study. Indeed, the most striking feature of frost scars is their persistence.

The activities on frost scar surfaces involve an interplay of physical and biological phenomena. Only rarely do the biological forces achieve a transient dominance over what are fundamentally the powerful physical effects of the freezing and thawing of soil water.

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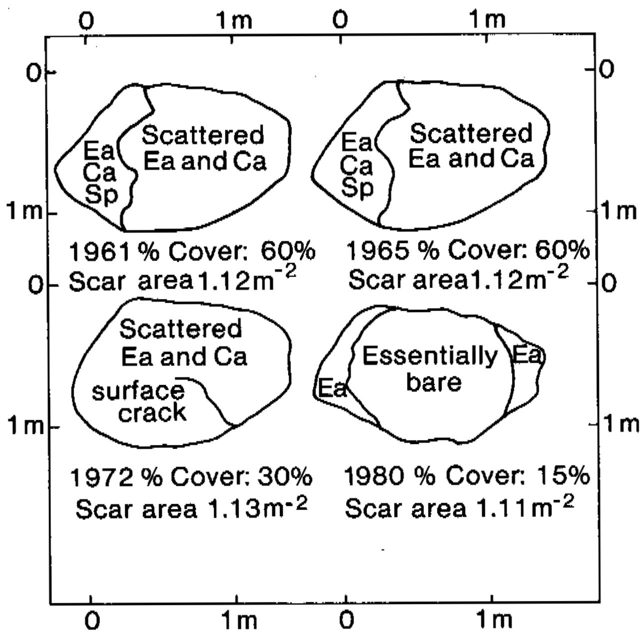

FIGURE 1 Plan of frost scar 1-1 in 1961, 1965, 1972 and 1980. Vegetation cover for each year is expressed in percent cover. The area of each frost scar is expressed in m^{-2}.

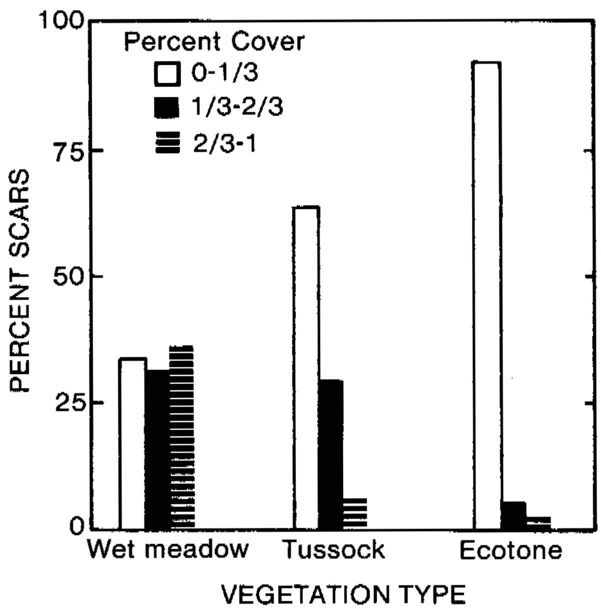

FIGURE 2 Percentage of scars in three vegetation cover classes. Surveyed and staked scars included.

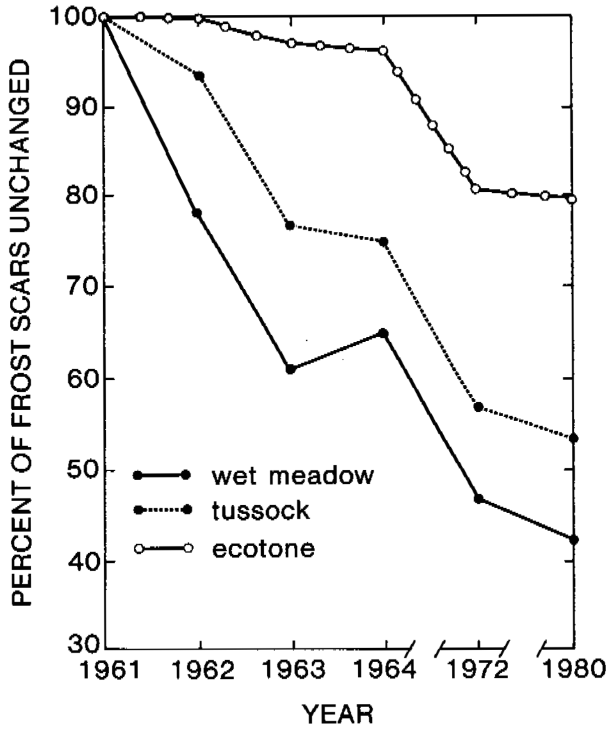

FIGURE 3 Percent frost scars remaining unchanged in percent plant cover from 1961 to indicated year.

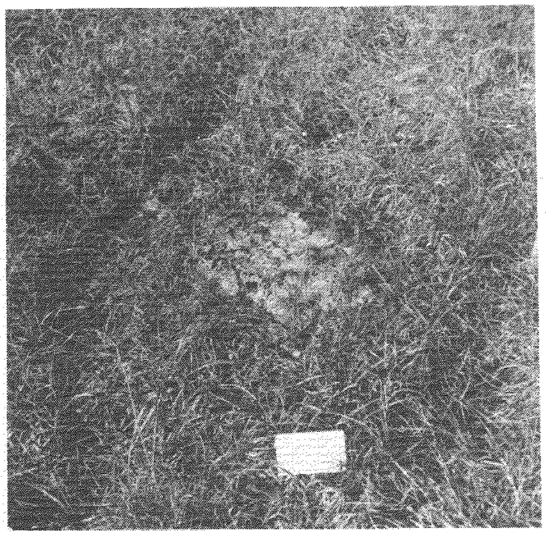

Fig 4a

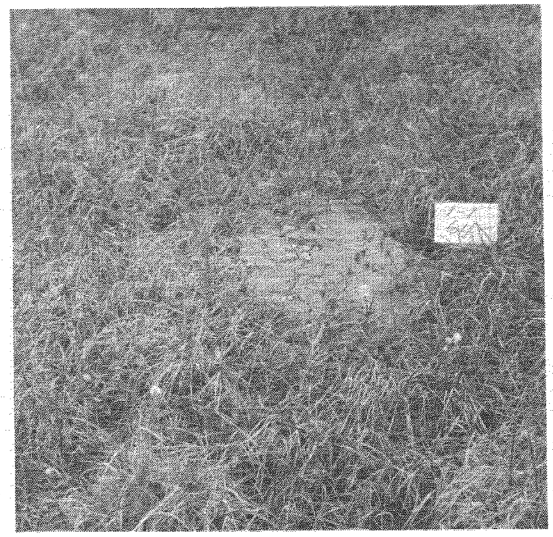

Fig 4b

Fig 4c

Fig 4d

FIGURE 4 Comparison of plant cover of frost scar 1-1 in the years (4a) 1961 (labeled 1-1), (4b) 1964, (4c) 1972, and (4d) 1980. After relatively little change until 1964, the open area present in 1964 expanded in 1972, and by 1980 almost the entire scar surface is bare of plants. Graminoid plants are primarily a mixture of *Eriophorum angustifolium* and *Carex aquatilis*. For comparison see also Figure 1.

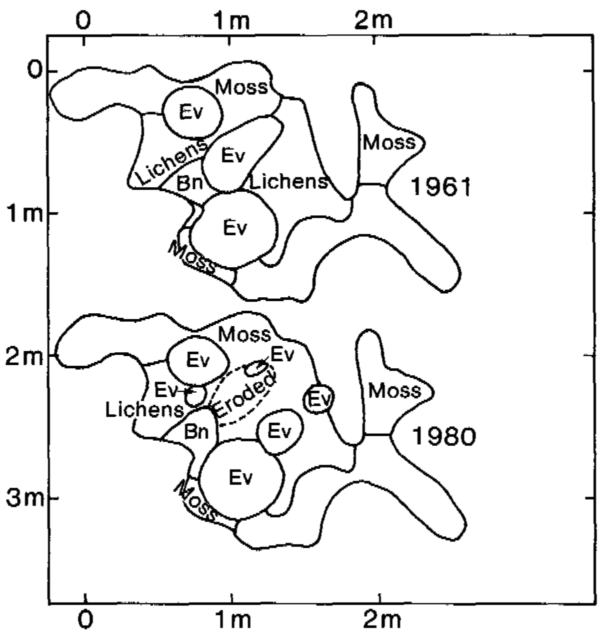

FIGURE 5 Comparison of frost scar 36-7 between 1961 and 1980. One large tussock present in 1961 has almost completely eroded away. Three new tussocks have appeared in 1980. Ev is Eriophorum vaginatum; Bn is Betula nana.

TABLE 1 Comparison of Occurrence of Disturbed Areas Along Two Transects

Transect No.	Length of transect	Number of disturbed Areas along lines in both years.	Areas found in 1965 but not in 1972.	Areas found in 1972 but not in 1965.
1	640 m.	9	1	0
3	457 m.	69	1	5*

*A more detailed examination of these 5 areas suggest that they may be areas of renewed activity, rather than newly formed frost scars.

TABLE 2 Summary of Changes in Plant Cover on Frost Scars of 3 Vegetation Types in the Ogotoruk Creek Valley From 1961 to 1980 (1962) is First Year of Comparison)

	1962					1963					1964					1972					1980				
	N	o	+	-	?	N	o	+	-	?	N	o	+	-	?	N	o	+	-	?	N	o	+	-	?
Wet Meadows	83	65	17	3	4	56	36	17	2	1	102	67	17	16	2	78	37	17	22	2	80	34	10	33	3
Tussock	110	103	2	2	3	115	89	4	12	11	155	116	15	23	1	96	55	21	9	11	78	42	12	17	7
Ecotone	27	27	0	0	0	42	41	1	0	0	54	52	2	0	0	27	22	4	0	1	30	24	0	0	6

NOTE: N = number of scars in sample; o = no change; + = greater plant cover; - = less plant cover; ? = direction of change, if any, uncertain.