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EFFECTS OF WINTER SEISMIC EXPLORATION ON VISUAL RESOURCES, VEGETATION, AND SURFACE STABILITY OF THE COASTAL PLAIN OF THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA, 1985

Nancy A. Felix
M. Torre Jorgenson
Martha K. Raynolds
Robert Lipkin
Deborah L. Blank
Brian K. Lance

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Arctic National Wildlife Refuge
U.S. Fish and Wildlife Serivce
101 12th Avenue
Fairbanks, Alaska 99701

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Effects of winter seismic trails on visual resources, vegetation, and surface stability of the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985.

Nancy A. Felix, M. Torre Jorgenson, Martha K. Raynolds, Robert Lipkin, Deborah L. Blank, and Brian K. Lance. U.S. Fish and Wildlife Service, Arctic National Wildlife Refuge, Fairbanks, Alaska.

Abstract: Winter seismic exploration in 1984 and 1985 left visible trails on the coastal plain of the Arctic National Wildlife Refuge. Thirty-four permanent intensive study plots (30 x 4 m) were established to quantify the effects of this disturbance and to study recovery rates. Sixty-eight photo-trend plots (10 x 4 m) were sampled less intensively to assess a wider variety of sites. Study plots were selected to represent the range of disturbance which occurred in each of 7 major vegetation types. Vegetation type, disturbance levels, and soil profiles were described for each plot. Ice contents in the top 30 cm of permafrost were measured and found to be highly variable within and between plots, ranging from 2 to 58%. The 1 and 2-year-old trails were generally visible in all vegetation types. Visibility improved slightly between 1984 and 1985 on some plots due to weathering of litter and soil to a lighter color, the lack of water on trails in 1985, and an increase in standing dead leaves on trails. Plant cover was generally lower on disturbed plots than on adjacent control plots. Little recovery of plant cover occurred between 1984 and 1985. Disturbance caused only small increases in exposed soil at most plots; statistically significant increases in exposed soil occurred most often on plots with high micro-relief (tussocks, hummocks, and polygon rims). Bare patches were mainly recolonized by vegetative shoots, but seedlings were common at a few plots. Graminoids were the most important recolonizers in most vegetation types, except for riparian shrubland and *Dryas* terrace where shrubs were the most important. Overall, recolonizing shoots made up only a small percentage of ground cover, and bare patches changed little in appearance between 1984 and 1985. Plant productivity, as measured by mass of plants, twig length of shrubs, and number of leaves per sedge plant, was generally higher on disturbed plots than on adjacent controls. Statistically significant changes in nitrogen and phosphorus concentrations occurred in some plant species on disturbed plots. Significantly greater thaw depths were found in nearly half of all study plots. Only 4 plots had increased differences between disturbed and control measurements in 1985 compared to 1984. Measurable track depression (5-12 cm) occurred on 4 plots, which were all on narrow trails in moist sedge-shrub tundra.

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The Alaska National Interest Lands Conservation Act (ANILCA), Section 1002, authorized oil and gas exploration activities on the coastal plain of the Arctic National Wildlife Refuge (ANWR), and required that such exploration occur in a manner which avoids significant adverse effects to fish and wildlife, their habitat, and the environment. Geophysical Service Incorporated (GSI) was authorized to conduct winter seismic exploration January through May 1984 and 1985. In 1984, 2 crews utilizing the drilled shothole technique completed 977 km (607 mi) of seismic line arranged in a 10 x 20 km (6 x 12 mi) grid over the coastal plain (Fig. 1). Another crew in 1984 utilized the vibrator (Vibroseis, a registered trademark of Conoco) technique to complete a series of tie lines extending 5 km (3 mi) inland. In 1985, 2 crews utilizing the vibrator technique completed another 928 km (580 mi) of seismic line, resulting in an approximately 5 x 10 km grid of seismic lines when combined with the 1984 lines. The vibrator technique utilized large trucks (vibrators) as an energy source rather than the buried high explosives (dynamite) used in the shothole technique. Table 1 shows the vehicles used by each crew for the 1984 and 1985 programs.

Table 1. Vehicles used by 1984 dynamite crew and 1985 vibrator crew on coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

1984 dynamite crew		1985 vibrator crew	
8	drills on FN-110 tracked vehicles (2.8 psi)	5	tracked vibrator units (4.5 psi)
1	preload vehicle-FN110 (2.8 psi)	1	Chieftain tracked vibrator tender (3.5 psi)
1	Chieftain tracked recording vehicle (3.5 psi)	1	Chieftain tracked recording vehicle (3.5 psi)
4	geophone carriers-FN110 (2.8 psi)	4	geophone carriers-FN110 (2.8 psi)
		1	drill on FN-110 tracked vehicle (2.8 psi)
9	bombardiers (1.3 psi)	8	bombardiers (1.3 psi)
1	camp FN-110 with crane (2.8 psi)	1	camp FN-110 with crane (2.8 psi)
6	Caterpillar D-7 tractors (10.5 psi)	6	Caterpillar D-7 tractors (10.5 psi)
14	camp sleighs (6.0 psi) [2 strings of 5, 1 string of 4]	12	camp sleighs (6.0 psi) [3 strings of 4]
3	6000 gallon fuel sleighs (6.0 psi)	4	6000 gallon fuel sleighs (6.0 psi)
1	dynamite magazine (8.0 psi)	1	sleigh mounted survival unit for remote deployment (on 1 crew)
1	magazine for detonators (less than 1.0 psi)		

Drills, bombardiers, geophone carriers and the recording vehicle made multiple passes on each seismic line. The vibrator units used in 1985 made single trails parallel to each other along the seismic line. Ski-mounted camps pulled by Caterpiller D-7 tractors (cat-trains) occasionally followed the seismic line, but often followed separate routes through areas of deeper snow

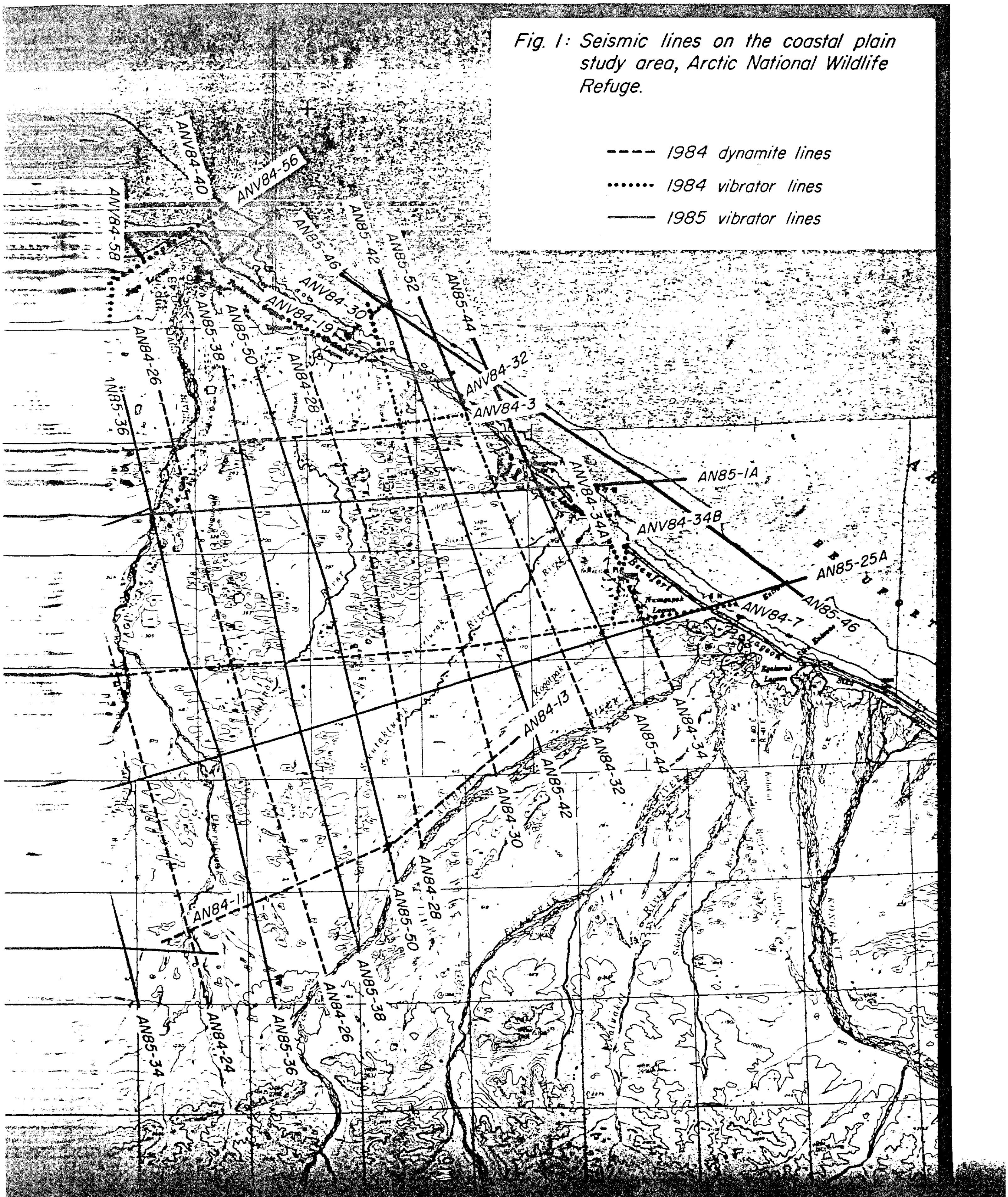


Fig. 1: Seismic lines on the coastal plain study area, Arctic National Wildlife Refuge.

and around areas of sensitive vegetation types to minimize surface disturbance. Resupply of fuel and explosives (1984) were pulled overland in ski-mounted tanks and magazines by D-7 Caterpillar tractors from the coast. Other supplies and personnel were flown in by turbine beaver or twin otter aircraft, which landed on frozen lakes or snow-covered tundra near camps. More specific information on the 1984 and 1985 winter seismic programs can be obtained from GSI's exploration plan and plan of operations (Geophysical Service Inc. 1983a, 1983b, 1984).

Seismic lines and camp moves left visible trails across the tundra (Plate 1). The U.S. Fish and Wildlife Service (FWS) established study plots on seismic trails in 1984 to evaluate the impacts of vehicle traffic and to obtain data for long-term recovery studies (Felix and Jorgenson 1985). In 1985, we revisited these plots and established additional plots on the 1985 trails. This report summarizes data collected during the first 2 years of an on-going study. The objectives of this study are:

1. Evaluate the impacts of winter seismic exploration on visual resources, vegetation, and surface stability.

2. Determine recovery rates of disturbance due to the 1984 and 1985 exploration programs.

Methods

The study area is an irregularly shaped portion of the northern coastal plain and foothills of ANWR, lying between 142°W and 147°W and north of 69°34'N, covering approximately 630,000 ha. It is bordered by the Brooks Range on the south and by the Beaufort Sea on the north. The Aichilik and Canning Rivers provide the eastern and western boundaries, respectively. Land cover of the entire coastal plain lies within the tundra formation. The land is mostly continuously vegetated with low-growing plants, including sedges, grasses, mosses, lichens, forbs, and dwarf shrubs. Taller shrubs are generally restricted to drainages. Shallow soils are underlain with permafrost, and the ground surface remains frozen from about mid-September to mid-May. Snow is usually present by mid-September and remains until early June. Snow cover accumulates in patches and strips due to macroscale and microscale terrain features. A detailed description of the study area, including geology, climate, soils, vegetation, and wildlife can be found in the Baseline Study of the Fish, Wildlife, and their Habitats (U.S. Fish and Wildlife Service 1982).

Intensive study plots and photo-trend plots were established to evaluate the short and long-term impacts of winter vehicle traffic on tundra vegetation. These plots were selected to represent all major vegetation types on the coastal plain and the range of disturbance which occurred in each type. Thirty-four intensive study plots were established in the following 6 areas across the coastal plain: near Camden Bay, 5 km inland on Marsh Creek; on Marsh Creek, 25 km inland; on the Sadlerochit River, 35 km inland; on the Hulahula River, several places 15-50 km inland; on the Okpilak River, 10 and 30 km inland; and east of the Niguanak River, 15 km inland. These plots were sampled in detail to quantify the effects of disturbance and rate of recovery. Sixty-eight photo-trend plots were located throughout the coastal plain and provided a less intensive means of assessing a wider variety of sites.

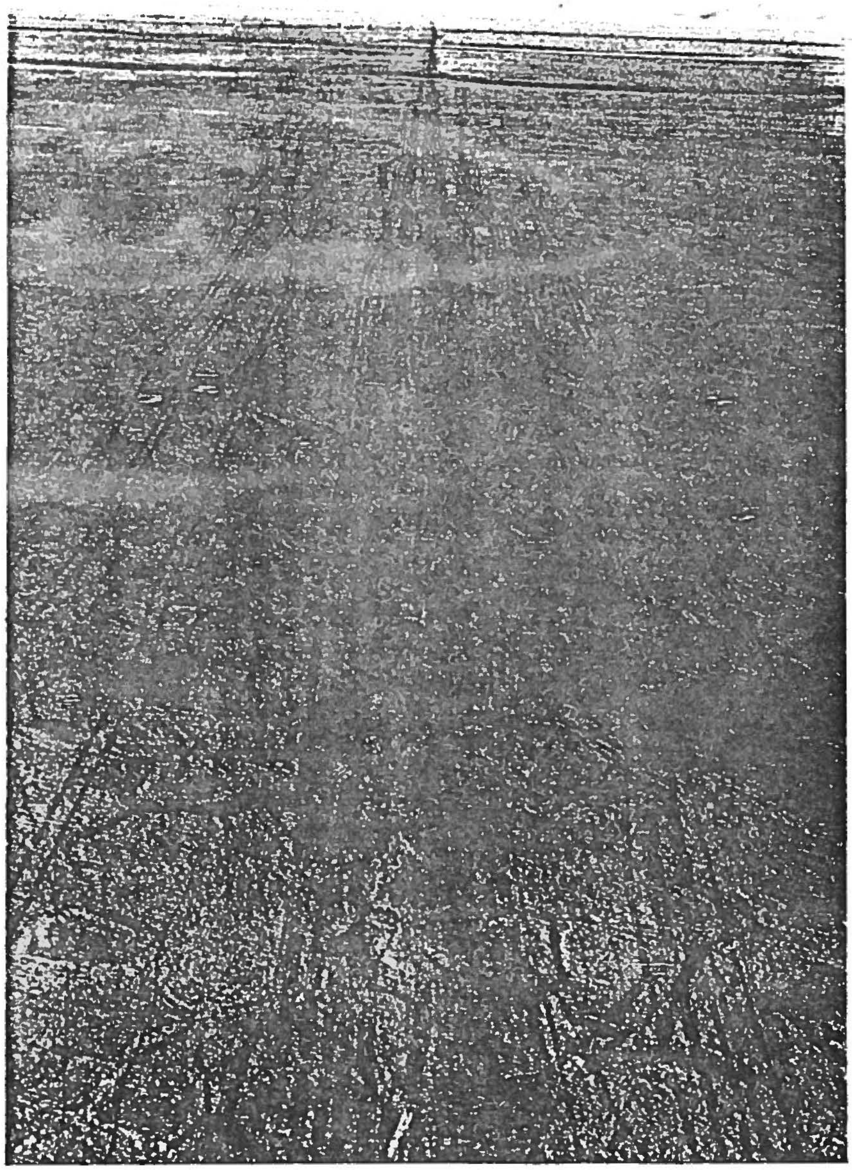


Plate 1. Seismic line through wet and moist sedge tundra, photographed the summer following disturbance.

Sixteen intensive study plots were established in 1984 and 18 additional intensive study plots were established in 1985. Disturbed plots (4 x 30 m) were located on vehicle trails, and control plots were located in adjacent areas with similar habitat characteristics. The size of the disturbed plot varied at a few locations according to the width of the disturbed area, and in some cases consisted of individual tracks. Photo-trend plots were usually 10 m by the width of the disturbance. Each plot was marked with wooden stakes, rebar, aluminum tags, and 15 x 15 cm galvanized plates.

Land cover class, vegetation type, landform, and micro-relief were described for each plot, according to Walker et al. (1982, 1983). Slope was measured with an Abney level, and aspect was recorded. Disturbance type was recorded: trails were classified as seismic lines, camp moves, or all vehicles (overlapping seismic lines and camp moves); and trails were also identified as narrow (less than 2 vehicle widths or at least 2 overlapping cat-train trails) or diffuse. Disturbance types also included fuel spills and craters where chunks of tundra had been blown out during the dynamite explosions. Ocular estimates of decreases in plant cover, increases in soil exposed, structural damage to hummocks or tussocks, and compression of mosses and litter were recorded according to categories adapted from the Muskeg Research Institute (1970). Plots were then classified into the 9 vegetation types and 4 disturbance levels within vegetation types which were described for the study area (Felix and Jorgenson 1985, Felix et al. 1987)

The soils of each intensive study plot were described and sampled from 5 soil pits spaced at 5-m intervals adjacent to the control plot. Soil horizons were measured to the nearest centimeter and their textures described following Bates et al. (1982). Samples for soil moisture and bulk density determinations were taken from the surface horizon, and from those lower horizons in the active layer having uniform texture, using a constant volume sampler (an open cylinder, 3.0 cm deep and 7.0 cm in diameter). Field weight and oven dry weight (105°C for mineral samples, 65° for organic samples) were determined for percent moisture and bulk density calculations.

Excess ice content of the soils was determined from permafrost cores taken from each soil sampling pit (excluding those with gravelly soils), using a 7.6 cm (3 in) core barrel. Ice wedges were avoided. Soil horizons and textures of the core were described as above, and the ice content of each layer was visually estimated and classified following Pihlainen and Johnston (1963). Average ice contents of the top 10 cm and top 30 cm were calculated from the visual estimates. The upper 30 cm of each core was removed and thawed, and volume of water in excess of soil saturation was measured. The excess ice content (I) was calculated as a percentage of the total core volume:

$$I = V_i/V_c \times 100, \qquad V_i = V_w \times 1.09$$

where V_i = volume of excess ice in the core, V_c = the volume of the core, V_w = the volume of water in excess of soil saturation in the core, and the coefficient of expansion for water to ice = 1.09.

The visibility of disturbance was rated at all plots from the air (at 60 m (200 ft) altitude) and on the ground, following a system adapted from Abele (1976):

- not visible - trail could not be discerned
- barely perceptible - trail could be discerned from disjunct disturbance or from a particular viewpoint
- visible - continuous trail could be discerned from most angles
- easily visible - noticeable color change on trail, obvious contrast with undisturbed area

A series of photographs was taken at each intensive study plot (disturbed and control), and each photo-trend plot to provide a long-term visual record of disturbance (Plate 2). Photographs were taken from both ends of the plots using a 35-mm wide-angle lens (focused at 10 m for intensive plots, and 5 m for photo-trend plots). Two 1-m^2 quadrats were located in areas of typical disturbance in each disturbed plots, and were permanently marked with rebar. We placed a 1-m^2 metal quadrat over these markers, and photographed each quadrat from a 1-m stepladder. A stereo pair of aerial photographs was taken of each plot from a helicopter at an altitude of 60 m (200 ft), using a 50-mm lens. Oblique aerial photos were also taken from the helicopter to aid in locating the plots. These photographs are on file at the ANWR office in Fairbanks. Photographs from 1984 and 1985 were compared to determine if changes had occurred in the visibility of 2-year-old trails.

Plant cover was sampled on the intensive plots using a vertical point frame (Hays et al. 1981). The point frame consisted of a 2-m long rectangular aluminum frame with guideholes at 20-cm intervals through which wire pins (with sharpened tips) could be lowered vertically to sample vegetation (Plate 3). Twenty points (spaced at 20-cm intervals) were sampled on each of 10 transects (spaced at 3-m intervals), for a total of 200 points in each plot. In 1984, the Marsh Creek plots were sampled using a tent stake as a pointer and a string marked with the points to be sampled. Points were grouped into replicates of 100, and 3-6 replicates per plot were sampled. For all plots estimates of percent cover of vascular and nonvascular plant species, litter, organic soil, organic-mineral soil, and mineral soil were obtained by recording the first interception of the pin with each species in the canopy and the ground cover. On riparian willow plots, the height at which each shrub was hit by the pin was recorded.

Multivariate analyses of variance of plant cover by treatment and year were conducted on raw data and transformed data for all life forms with over 3% cover, and all species with over 5% cover (Dixon et al. 1985). Two-way analyses of variance were conducted for vascular, nonvascular, and total plant cover by treatment and year. Cover data were transformed before statistical analyses, because of unequal variances between the treatment/year categories. Comparison of a square root transformation and an angular transformation carried out on a portion of the data indicated that the square root transformation was more effective in reducing variance in the data. There were few differences in the results of the statistical tests for the raw data and transformed data, therefore results for the raw data are presented. The 10 transects were considered replicates for the analysis. The 1985 Marsh Creek data were grouped into 2 replicates of 5 transects each, so that both 1984 and 1985 replicates had 100 points each.

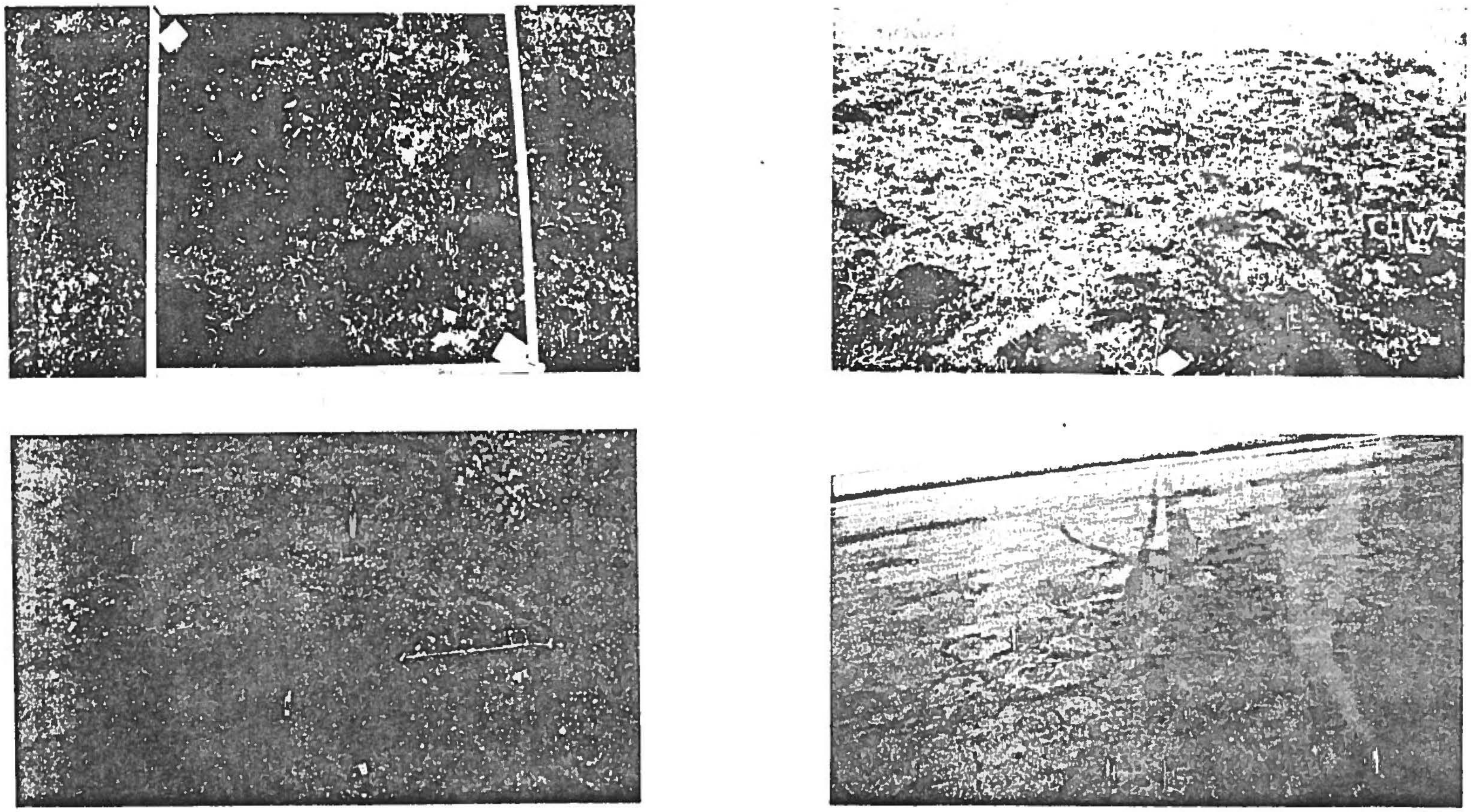


Plate 2. Quadrat photo (1 m^2) , ground photo, verticle aerial photo, and oblique aerial photo of a moist shrub tundra plot.

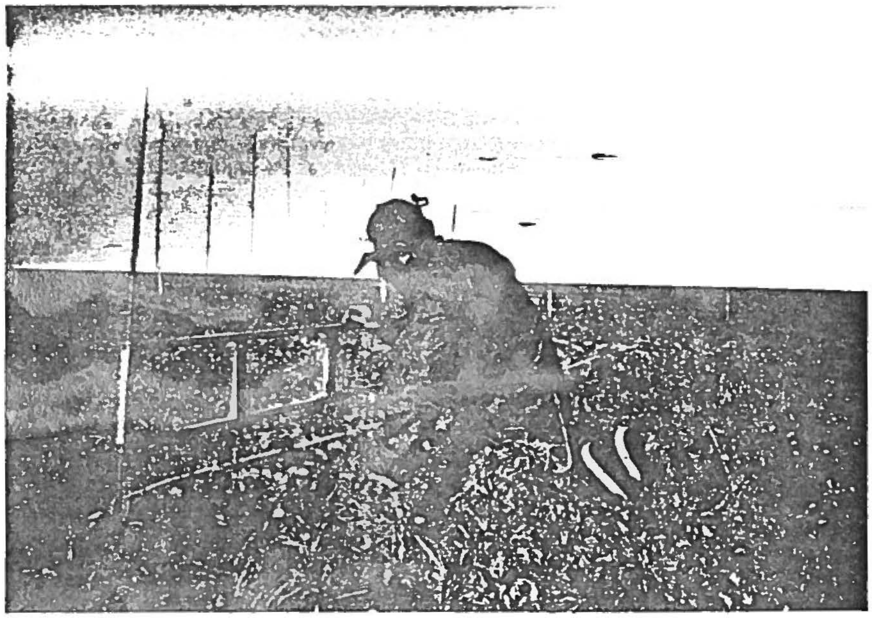


Plate 3. Point frame used to sample plant cover.

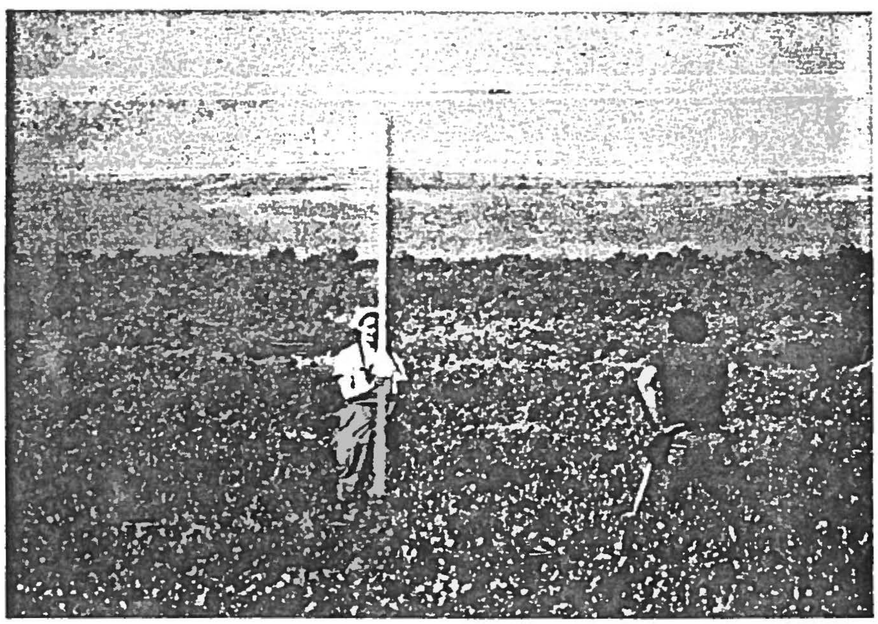


Plate 4. Surveying track height on a riparian willow study plot.

Nomenclature for vascular plants follows Hulten (1968), with the exception of willows which follow Argus (1973). Nonvascular plant nomenclature follows Crum and Anderson (1981) for mosses, and Thomson (1979) for lichens. Voucher collections of plants are stored in the ANWR Herbarium.

Cover estimates using the line-intercept method were also obtained on intensive study plots and some photo-trend plots. A 10-m transect was run diagonally across each end of both the disturbed and the control plots (2 transects per plot), and cover was estimated to the nearest centimeter along 20 consecutive 50-cm segments. Data were recorded for each of the following categories:

- ground cover (including vascular and nonvascular plants)
- canopy cover (plants layered above other plants)
- deciduous shrub cover
- dead plants or litter
- exposed peat, organic-mineral, or mineral soil
- water

The percent changes in ground cover, total plant cover (ground cover and canopy cover), and deciduous shrub cover on the disturbed plot (D) compared to the control plot (C) were calculated as (D-C)/C x 100. The change in litter, exposed soil, water, and bare ground (litter, soil, and water) were calculated as D-C.

Damage to tussocks was measured in 2 belt transects (2 m x 4 m, or 10 m x width of each vehicle track) on disturbed plots. The numbers of tussocks in the following categories were counted: undisturbed, scuffed (broken tillers evident), and mound top destroyed (peat core exposed and/or tussock cracked). The percentages of scuffed tussocks, destroyed tussocks, and total disturbed tussocks (scuffed and destroyed) were calculated.

Species frequency was sampled in both the disturbed and control plots to determine changes in vascular plant species which had low cover values. Thirty quadrats (10 x 30 cm) were placed along the diagonal of each plot, and the presence of each vascular plant species within each quadrat was recorded. The percentages of quadrats containing each species were calculated, tabulated, and reviewed to identify any large changes between disturbed and control plots.

Recolonization of bare ground (exposed soil or litter) in disturbed plots was estimated in 20 quadrats (0.5 x 0.5 m) placed along the diagonal of the plot. The percentage of ground covered by bare patches (over 100 cm^2) was estimated to the nearest 10%, using calibration marks along the quadrat edge. Only disturbance related bare patches were included in the estimates; natural frost scars or senescent tussocks were not included, patches of detached mosses were counted as litter and included in the estimate of total bare ground. All first or second year vascular plants within the bare area were recorded. Cover of new tillering of Eriophorum vaginatum and new growth on Dryas integrifolia were estimated to the nearest cm^2. Moss colonization was noted as trace, uncommon, or common.

Plant samples for nutrient analyses were collected from 6 intensive study plots in late July at the time of maximum growth. Shoots of current year's growth were collected for the major vascular species in each disturbed and control plot. The willow *Salix planifolia* ssp. *pulchra*, and the sedges *Eriophorum angustifolium* and *Carex aquatilis* were collected from moist sedge-shrub tundra plots M1 and T32. These 2 sedges were also collected from the wet graminoid tundra plot O11. Species harvested from tussock tundra plots M2 and S8 were *S. planifolia*, *Betula nana* s.l., *Vaccinium vitis-idaea*, *Ledum palustre* ssp. *decumbens*, and *E. vaginatum*. These same 5 species plus *Carex Bigelowii* were collected from the shrub tundra plot S4.

Shoots were systematically sampled along a meter tape placed across the plot. Four replicates of each species were collected from plots T32, O11, M2, and S4, and 3 replicates from plots M1 and S4 (due to time constraints). Each replicate included 20 individual shoots of *S. planifolia* ssp. *pulchra*, *E. angustifolium*, and *C. aquatilis*, and 40 shoots of all other species. Only mature sedge tillers characterized by the presence of overwintering dead leaves were collected, and dead leaves and leaf tips were discarded. All samples were placed in a drying oven the evening after collection, and dried at 40°C until completely dry (at least 48 hours). The samples were weighed, and analyzed for nitrogen and phosphorus concentrations by the ecophysiology laboratory of F.S. Chapin at the University of Alaska, following the methods of Kedrowski (1983). Total nitrogen and phosphorus in each plant sample were calculated by multiplying the concentration of each sample by its weight. The numbers of live and dead leaves per shoot for *E. angustifolium* and *C. aquatilis* (N=40) were counted, and shoot lengths of *B. nana* (N=40) and *S. planifolia* (N=20) were measured on disturbed and control plots.

Two-way analyses of variance of weight, nitrogen and phosphorus concentrations, and total nitrogen and phosphorus by treatment (disturbed and control) and plant part (stems and leaves) were conducted for each species in each plot (Dixon et al. 1985). When the interaction term was significant, a Bonferroni test for multiple comparisons of all pairs of means was conducted. One-way analyses of variance were conducted for leaves of *L. palustre* and *V. vitis-idaea*, since stems were too small for nutrient analyses. Levene's test for homogeneity of variances was conducted, and few significant differences occurred, indicating that the data meet this assumption of the analysis of variance test. T-tests were conducted between disturbed and control data for twig lengths and number of dead leaves and live leaves.

Thaw depths (depths of the active layer) were measured at both photo-trend and intensive study plots, using a 1-m long steel rod calibrated in cm. Thirty points were probed within the disturbed plot and 30 in an adjacent control area. Measurements were taken during August, at the time of maximum annual thaw. Probes which encountered rocks instead of frozen ground were easily distinguished by sound, and were remeasured. Plots with gravelly soils were excluded. Two-way analyses of variance of thaw depths by treatment (disturbed and control) and year were performed for the 11 plots with 2 years' data (SPSS Inc. 1986). Bartlett's test for homogeneity of variances was conducted, and few significant differences occurred, indicating that the data meet this assumption of the analysis of variance test. On plots with only 1 year's data, t-tests were calculated between disturbed and control data (SPSS Inc. 1986).

Track depression was measured at all intensive plots to obtain an estimate of the amount of subsidence, compression, or removal of material caused by disturbance. The surface height of the trail and surrounding areas was measured using a Ushikata portable surveying compass and a metric rod (Plate 4). Three transects were laid out perpendicular to the trail, each having 10 m of undisturbed control area on either side of the trail when possible. Transects were usually 25-35 m long, but varied depending on the width of the trail at each plot. Both ends of the transect were marked with 76 cm rebar which was sunk into permafrost. Elevations of the reference markers and every 0.5 m along the transect were measured. Each point was described as main trail (area of most disturbance), diffuse trail (less disturbed area adjacent to main trail), side trail (single tracks), or control.

A cross-sectional profile of each transect was plotted and examined for track depression. The original height each trail was estimated by calculating the regression line that best fit the control points on each side of the trail. For those plots where height of the track differed from the regression line, the average depth and cross-sectional area of the depression were calculated. On 1 plot (T32) where track depression occurred and 2 years' data was available, a t-test was conducted to compare the average depths and cross-sectional areas in 1984 and 1985.

Results and Discussion

Plot Descriptions

Vegetation types and disturbance levels of the intensive study plots and photo-trend plots are described in this section. Soil profiles and ice content of the permafrost are described for intensive study plots.

Vegetation Types

Aquatic graminoid marsh communities, dominated by emergent grasses or sedges, are found on permanently flooded sites, such as ponds, lake margins, and areas of low-centered polygons with deep basins. Characteristic species include *Arctophila fulva* and *Carex aquatilis*. No plots were established in this vegetation type because little to no damage was observed.

One intensive study plot (O11) and 10 photo-trend plots were located in wet graminoid tundra. These sedge-dominated communities were found on poorly drained, seasonally flooded sites. Typical locations included well-developed and disjunct low-centered polygons, and strangmoor. Characteristic plants included *Carex aquatilis*, *Eriophorum angustifolium*, *Carex chordorrhiza*, *Sphagnum* spp. and *Drepanocladus* spp. Plant communities at the intensive study plots are described in Table 2.

Ten intensive study plots and 12 photo-trend plots were located in moist sedge-shrub tundra. These plots were mostly on poorly developed polygonized ground, flat-centered polygons, and depressions in upland areas. Wetter sites such as C3 had high shrub cover. Drier sites such as O12 and N2 had some cover of tussocks (up to 15% of the area), hummocks, or frost scars (up to 30%

Table 2. Vegetation types and plant communities of intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Study plot	Plant community description
Wet graminoid tundra	O11	Wet Carex aquatilis, Eriophorum angustifolium, Eriophorum russeolum, Carex rariflora, Salix planifolia ssp. pulchra, Oncophorus wahlenbergii, Tomenthypnum nitens, Drepanocladus spp. sedge tundra.
Moist sedge-shrub tundra	M1	Moist Eriophorum angustifolium, Salix planifolia ssp. pulchra, Hylocomium splendens, Drepanocladus spp. sedge, dwarf shrub tundra.
	O18	Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra, Sphagnum spp., Drepanocladus spp. sedge, dwarf shrub tundra.
	O19	Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra, Salix reticulata, Campyllium stellatum sedge, dwarf shrub tundra.
	O20	Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra, Campyllium stellatum, Drepanocladus revolvens sedge, dwarf shrub tundra.
	C3	Wet Eriophorum angustifolium, Carex aquatilis, Salix lanata ssp. richardsonii, Salix planifolia ssp. pulchra, Tomenthypnum nitens, Meesia triquetra sedge, dwarf shrub tundra.
	O13	Moist Salix planifolia ssp. pulchra, Carex Bigelowii, Carex aquatilis, Aulacomnium palustre, Sphagnum spp., Aulacomnium turgidum dwarf shrub, sedge, moss tundra.
	O14	Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra, Sphagnum spp., Aulacomnium palustre sedge, dwarf shrub, moss tundra.
	O12	Moist Carex aquatilis, Cassiope tetragona, Salix planifolia ssp. pulchra, Tomenthypnum nitens, Hylocomium splendens, Aulacomnium turgidum sedge, dwarf shrub tundra.
	C1	Moist Eriophorum angustifolium, Salix planifolia ssp. pulchra, Hylocomium splendens, Drepanocladus spp., Tomenthypnum nitens, Aulacomnium spp., Ptilidium ciliare sedge, dwarf shrub, moss tundra.
	T32	Moist Eriophorum angustifolium, Salix planifolia ssp. pulchra, Hylocomium splendens, Aulacomnium turgidum, Tomenthypnum nitens sedge, dwarf shrub, moss tundra.
Moist graminoid/ barren tundra complex	N11	Moist Carex Bigelowii, Dryas integrifolia, Salix phlebophylla, Tomenthypnum nitens sedge, dwarf shrub/barren complex tundra.
	N12	Moist Carex Bigelowii, Eriophorum vaginatum, Dryas integrifolia, Salix arctica, Tomenthypnum nitens, Campyllium stellatum sedge, dwarf shrub/barren complex tundra.
	O3	Moist Carex Bigelowii, Eriophorum vaginatum, Vaccinium vitis-idaea, Salix phlebophylla, Dicranum spp., Aulacomnium turgidum, Peltigera apthosa sedge, dwarf shrub/barren complex tundra.
	O7	Moist Dryas integrifolia, Salix reticulata, Salix phlebophylla, Carex spp., Equisetum variegatum, Tomenthypnum nitens, Dicranum spp., Drepanocladus spp. dwarf shrub, sedge/barren complex tundra.
	C2	Moist Eriophorum angustifolium, Salix planifolia ssp. pulchra, Carex Bigelowii, Dryas integrifolia, Hylocomium splendens, Tomenthypnum nitens, Dicranum spp. sedge, dwarf shrub/barren complex tundra.

Table 2. Continued.

Vegetation type	Study plot	Plant community description
Moist sedge tussock tundra	M7S,V	Moist Eriophorum vaginatum, Salix planifolia ssp. pulchra, Betula nana s.l., Hylocomium splendens, Dicranum spp. sedge tussock, dwarf shrub tundra.
	S1	Moist Eriophorum vaginatum, Cassiope tetragona, Salix planifolia ssp. pulchra, Hylocomium splendens, Tomenthypnum nitens sedge tussock, dwarf shrub tundra.
	M11	Moist Eriophorum vaginatum, Cassiope tetragona, Salix planifolia ssp. pulchra, Hylocomium splendens, Tomenthypnum nitens sedge tussock, dwarf shrub tundra.
	S8	Moist Eriophorum vaginatum, Salix planifolia ssp. pulchra, Vaccinium vitis-idaea, Ledum palustre ssp. decumbens, Hylocomium splendens, Dicranum spp. sedge tussock, dwarf shrub tundra.
	M2	Moist Eriophorum vaginatum, Vaccinium vitis-idaea, Ledum palustre ssp. decumbens, Dicranum spp., Hylocomium splendens, Aulacomnium turgidum, Peltigera apthosa sedge tussock, dwarf shrub tundra.
	M3	Moist Eriophorum vaginatum, Betula nana s.l., Vaccinium vitis-idaea, Ledum palustre ssp. decumbens, Salix planifolia ssp. pulchra, Sphagnum spp., Dicranum spp. sedge tussock, dwarf shrub tundra.
	M10	Moist Eriophorum vaginatum, Betula nana s.l., Vaccinium vitis-idaea, Cassiope tetragona, Hylocomium splendens, Aulacomnium turgidum, Dicranum spp. sedge tussock, dwarf shrub tundra.
Moist shrub	S4	Moist Betula nana s.l., Vaccinium vitis-idaea, Ledum palustre ssp. decumbens, Carex Bigelowii, Dicranum spp., Hylocomium splendens, Aulacomnium turgidum, Peltigera apthosa dwarf shrub, sedge tundra.
	S6	Moist Betula nana s.l., Vaccinium vitis-idaea, Ledum palustre ssp. decumbens, Dicranum spp., Hylocomium splendens, Aulacomnium turgidum, Peltigera apthosa dwarf shrub, moss tundra.
Riparian shrubland	M4	Moist Salix hastata, Salix brachycarpa ssp. niphoclada, Dryas integrifolia, Arctostaphylos rubra, Salix reticulata, Hylocomium splendens, Tomenthypnum nitens, Peltigera spp. open riparian shrub, forb, moss terrace.
	S5	Moist Salix lanata ssp. richardsonii, Salix glauca, Salix planifolia ssp. pulchra, Poa arctica, Tomenthypnum nitens, Hylocomium splendens riparian shrub, graminoid terrace.
	O15	Moist Salix lanata, Salix reticulata, Dryas integrifolia, Tomenthypnum nitens, Equisetum variegatum low riparian shrub, moss terrace.
	H1	Moist Salix brachycarpa ssp. niphoclada, Arctostaphylos rubra, Salix reticulata, Dryas integrifolia, Oxytropis campestris, Tomenthypnum nitens, Hylocomium splendens, Equisetum variegatum, open riparian shrub, forb, moss terrace.
	H3	Moist Salix lanata ssp. richardsonii, Salix brachycarpa ssp. niphoclada, Salix reticulata, Tomenthypnum nitens, Equisetum variegatum low riparian shrub, moss terrace.
Dryas terrace	H4	Dryas integrifolia, Salix reticulata, Astragalus umbellatus, Tomenthypnum nitens, Equisetum variegatum dwarf shrub, forb, moss terrace.
	H5	Dry Dryas integrifolia, Salix reticulata, Tomenthypnum nitens, Equisetum variegatum dwarf shrub, moss terrace.
	O6	Dry Dryas integrifolia, Salix reticulata, Oxytropis spp., Tomenthypnum nitens, Hylocomium splendens dwarf shrub, forb, moss terrace.

of the area). Moss cover varied from low (on sites like M1 with dense standing litter) to nearly 100% (e.g. O14). Most sites in this vegetation type were dominated by Eriophorum angustifolium, Carex aquatilis, and Salix planifolia ssp. pulchra.

Moist graminoid/barren complex tundra (barren complex) was included in 5 intensive study plots and 13 photo-trend plots. These moist, well-drained graminoid communities had over 30% cover of hummocks or frost scars. Tussock cover range from none (C2) to 10% (O3). These barren complex communities often occurred on gentle slopes. Characteristic plants included Carex Bigelowii, Dryas integrifolia, and Arctagrostis latifolia.

Eight intensive study plots and 12 photo-trend plots were located on moist sedge tussock tundra (tussock tundra). Typical landforms were hillcrests, slopes, and flat and high-centered polygons. Common species included Eriophorum vaginatum, Salix planifolia ssp. pulchra, Betula nana s.l., Ledum palustre ssp. decumbens, and Vaccinium vitis-idaea.

The 2 intensive study plots and 7 photo-trend plots in moist shrub tundra were shrub-rich sites on high-centered polygons. Eriophorum vaginatum tussocks had close to 15% cover on some sites (S3, N3). Characteristic plants included Betula nana s.l., Ledum palustre ssp. decumbens, and Hylocomium splendens.

Riparian shrubland included 5 intensive study plots and 7 photo-trend plots with open or closed willow communities found on gravel bars and floodplains of streams and rivers. Characteristic plants included Salix brachycarpa ssp. niphocloda, S. lanata ssp. richardsonii, S. reticulata, and Oxytropis spp.

Three intensive study plots and 7 photo-trend plots were located on Dryas terraces. These dry, alkaline sites, dominated by Dryas integrifolia, were found on ridges, bluffs, and river terraces. Additional characteristic species included Salix reticulata, Oxytropis nigrescens, Tomenthypnum nitens, and crustose lichens.

Disturbance Levels

Four levels of disturbance (0, 1, 2, and 3) were described for most vegetation types. A list of the disturbance levels for intensive study plots and photo-trend plots can be found in Tables 3 and 4, respectively.

Level 1 disturbance in wet graminoid tundra knocked down the standing dead vegetation and the trail appeared as a green swath (N1, O5, O10). Few other traces of disturbance were visible on the ground, except for some occasional slight scuffing of microsites. At O11 (level 2), mosses were compressed and higher microsites were commonly scuffed, but track depression was not obvious. Level 3 sites had either obvious track depression (T21, T37), or significant reduction in plant cover due to fuel spills (O17, T5, T6, T17).

Level 1 disturbance in moist sedge-shrub tundra, defined as compression of standing dead, less than 25% plant cover decrease, and less than 25% shrub canopy decrease, occurred at 4 photo-trend plots and 4 intensive study plots (Plate 5). Obvious compression of mosses, which sometimes included extensive areas with cleat marks, was the primary trait of the 8 level 2 plots. Soil exposure on these sites was mostly quite low (2-5%), but was higher for sites

Table 3. Disturbance type and levels for intensive study plots on seismic trails, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Disturbance year and type	Year sampled	Dist. level[a]	Disturbance in 1985 Veg.[b] (%)	Soil[c] (%)	Structure[d]
Wet graminoid	O11	84 camp-narrow	84,85	2	1-25	1-5	C2
Moist sedge-shrub tundra	M1	84 all-narrow	84,85	1	1-25	1-5	C1
	O18	85 seismic-diffuse	85	1	1-25	0	C1
	O19	85 camp-diffuse	85	1	1-25	0	C1
	O20	85 seismic-diffuse	85	1	1-10	0	C1
	C3	84 camp-narrow	85	2	1-25	1-5	C2
	O13	85 camp-narrow	85	2	1-25	1-5	C2
	O14	85 camp-narrow	85	2	1-25	0	C2
	O12	84 camp-narrow	84,85	3	50+	15+	S3
	C1	84 camp-narrow	85	3	25-50	1-5	C3
	T32	84 camp-narrow	85	3	25-50	1-5	C3
Moist graminoid/ barren tundra complex	N11	84 seismic-diffuse	84,85	2	25-50	5-15	S2
	N12	84 camp-diffuse	84,85	2	25-50	5-15	S2
	O3	84 camp-narrow	84,85	2	25-50	5-15	S2
	O7	84 seismic-diffuse	84,85	2	25-50	5-15	S2
	C2	84 camp-narrow	85	3	25-50	15+	S2
Moist sedge tussock tundra	M7S	85 seismic-diffuse	85	1	1-25	1-5	S1
	M7V	85 seismic-diffuse	85	1	1-25	1-5	S2
	S1	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	M11	85 camp-diffuse	85	2	25-50	5-15	S2
	S8	84 camp-diffuse	84,85	2	25-50	5-15	S2
	M2	84 all-narrow	84,85	3	25-50	5-15	S3
	M3	84 all-narrow	84,85	3	25-50	5-15	S3
	M10	85 camp-narrow	85	3	25-50	5-15	S3
Moist shrub tundra	S4	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	S6	84 camp-narrow	84,85	2	25-50	5-15	S2
Riparian shrubland	M4	84 all-narrow	84,85	1	1-10	0	
	S5	84 seismic-narrow	84,85	1	1-25	0	
	O15	85 camp-narrow	85	2	25-50	1-5	
	H1	85 seismic-narrow	85	3	50+	5-15	
	H3	85 all-narrow	85	3	25-50	5-15	
Dryas terrace	H4	84 seismic-diffuse	85	2	25-50	1-5	
	H5	85 camp-narrow	85	2	25-50	1-5	
	O6	84 seismic-narrow	84,85	3	50+	15+	

[a] Disturbance levels: 0 - none; 1 - low; 2 - moderate: 3 - high.
[b] Decrease in total plant cover.
[c] Increase in soil exposed.
[d] Structure: S1 - scuffing; S2 - mound top destruction; S3 - mound top destruction nearly continuous or ruts starting to form; C1 - compression of standing dead; C2 - evident track depression.

Table 4. Disturbance type and levels for photo-trend plots on seismic trails, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Disturbance year and type	Years sampled	Dist. level[a]	Disturbance in 1985 Veg.[b] (%)	Soil[c] (%)	Structure[b]
Wet graminoid tundra	T16	84 seismic-diffuse	84,85	1	1-5	0	C1
	N1	84 camp-diffuse	84,85	1	1-5	0	C1
	O5	84 seismic-diffuse	84,85	1	1-5	tr	C1
	O10	84 seismic-diffuse	84,85	1	1-5	0	C1
	O17	85 fuel spill	85	3	50+	0	
	T5	84 fuel spill	84,85	3	50+	0	
	T6	84 fuel spill	84,85	3	50+	0	
	T17	84 fuel spill	84,85	3	50+	1-5	
	T21	84 camp-narrow	84,85	3	1-25	1-5	C3
	T37	84 camp-narrow	85	3	1-25	1-5	C3
Moist sedge-shrub tundra	M6	85 seismic-diffuse	85	1	1-5	0	C1
	N2	84 camp-diffuse	84,85	1	1-5	0	C1
	N8	84 seismic-diffuse	84,85	1	1-25	0	C1
	T41	85 rolligon, single	85	1	1-5	0	C1
	T18	84 seismic-diffuse	84,85	2	25-50	5-15	S1
	T25	84 camp-diffuse	84,85	2	25-50	0	C2
	T26	84 camp-narrow	84,85	2	1-25[e]	1-5	C2
	T38	84 all-narrow	85	2	1-25	1-5	C2
	T39	85 seismic-narrow	85	2	25-50	1-5	C2
	T10	84 fuel spill	84,85	3	50+	0	
	T27	84 camp-narrow	84,85	3	1-25[e]	0	C3
	T31	84 Nodwell turn	84,85	3	25-50	1-5	C3
Moist graminoid/ barren tundra complex	N4	84 camp-diffuse	84,85	1	1-25	1-5	S1
	N5	84 camp-diffuse	84,85	1	1-25	1-5	S1
	N7	84 camp-diffuse	84,85	1	1-25	1-5	S1
	N9	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	T3	84 camp-diffuse	84,85	1	1-25	1-5	S1
	N6	84 camp-diffuse	84,85	2	25-50	5-15	S2
	T8	84 seismic-narrow	84,85	2	25-50	5-15	S1
	T12	84 seismic-diffuse	84,85	2	25-50	5-15	S2
	T20	84 camp-narrow	84,85	2	25-50	5-15	S1
	H2	85 seismic-narrow	85	3	50+	5-15	S2
	T7	84 seismic-narrow	84,85	3	50+	15+	S2
	T19	84 camp-narrow	84,85	3	50+	15+	S3
	T24	84 campsite	84,85	3	50+	15+	S3

Table 4. Continued.

Vegetation type	Plot no.	Disturbance year and type	Years sampled	Dist. level[a]	Disturbance in 1985 Veg.[b] (%)	Soil[c] (%)	Structure[d]
Moist	T15	84 seismic-diffuse	84,85	0	1-25	tr	N
sedge	T42	85 rolligon, single	85	0	0	0	N
tussock	S7	84 camp-diffuse	84,85	1	1-25	0	N
tundra	T13	84 seismic-diffuse	84,85	1	1-25	tr	S1
	T23	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	O8	84 seismic-narrow	84,85	2	25-50	5-15	S2
	T28	84 seismic-narrow	84,85	2	25-50	5-15	S2
	M5	84 all-narrow	84,85	3	25-50	5-15	S3
	T11	84 crater	84,85	3	50+	15+	
	T22	84 camp-narrow	84,85	3	25-50	15+	S3
	T30	84 crater	84,85	3	50+	15+	
	T40	85 fuel spill	85	3	50+	0	
Moist	N3	84 camp-diffuse	84,85	1	1-25	1-5	S1
shrub	S2	84 seismic-diffuse	84,85	1	1-25	1-5	S1
tundra	S3	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	O16	85 camp-narrow	85	2	25-50	5-15	S2
	T4	84 camp-narow	84,85	2	25-50	5-15	S2
	C4	84 seismic-diffuse	85	3	50+	5-15	S2
	T29	84 camp-narrow	84,85	3	50+	5-15	S3
Riparian	O2	84 camp-narrow	84,85	1	1-25	1-5	S1
shrubland	O9	84 seismic-narrow	84,85	1	1-25	1-5	S1
	T36	85 seismic-diffuse	85	1	1-25	0	N
	O1	84 camp-diffuse	84,85	2	25-50	5-15	S2
	S9	84 camp-narrow	84,85	2	1-25	1-5	S1
	T1	84 seismic-narrow	84,85	2	50+	1-5	S2
	T2	84 seismic-narrow	84,85	3	50+	1-5	S2
Dryas	T33	85 camp-diffuse	85	1	1-25	1-5	N
terrace	M8	85 seismic-narrow	85	1	1-25	1-5	S1
	T14	84 camp-narrow	84,85	2	25-50	5-15	S2
	T35	85 camp-diffuse	85	2	25-50	1-5	S1
	M9	85 seismic-narrow	85	2	25-50	5-15	S3
	T34	85 camp-diffuse	85	2	25-50	5-15	S1
	T9	84 seismic-narrow	84,85	3	50+	15+	S3

[a] Disturbance levels: 0 - none; 1 - low; 2 - moderate; 3 - high.
[b] Decrease in total plant cover.
[c] Increase in soil exposed. tr - trace.
[d] Structure: N - no observable damage; S1 - scuffing; S2 - mound top destruction; S3 - mound top destruction nearly continuous or ruts starting to form; C1 - compression of standing dead; C2 - compression of mosses and standing dead; C3 - evident track depression.
[e] Data from 1984.

Plate 5. Level 1 disturbance on moist sedge-shrub tundra. Light colored standing dead leaves were knocked down.

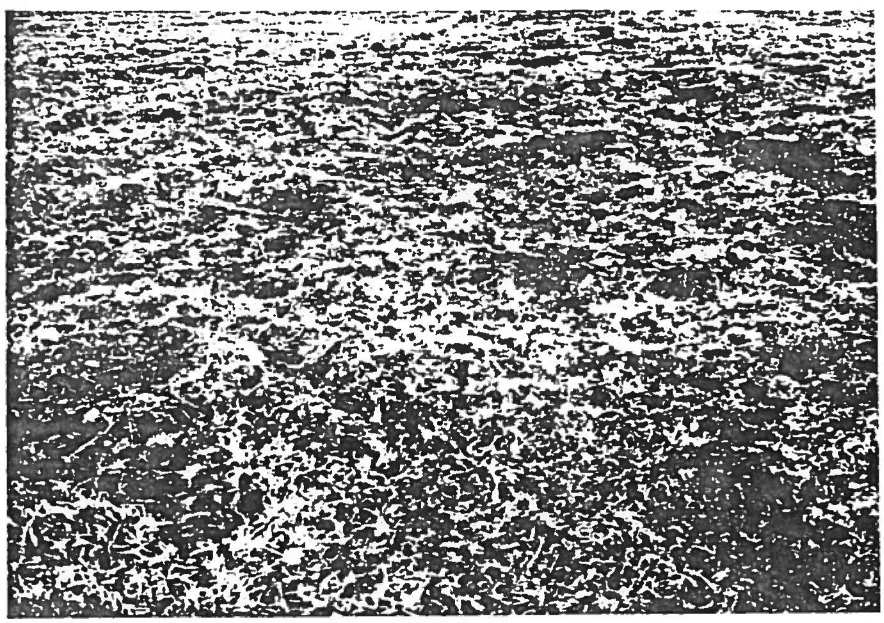


Plate 6. Level 3 disturbance on moist graminoid/barren tundra complex. Note exposed soil on mound tops.

containing frost boils. Level 3 determinations were based mainly on obvious track depression (C1, T32, T27), but also included areas with over 50% vegetation damage (012, T10, T31). Soil exposed was over 15% in some sites with higher microsites, such as polygon rims (012).

Levels 1 through 3 in barren complex were defined on the basis of plant cover decreases and soil exposure (0-25%, 25-50%, over 50%; and 0-5%, 5-15%, over 15%, respectively). Five plots had level 1 disturbance, 8 plots had level 2 disturbance, and 5 plots had level 3 disturbance. Scuffing of fragile mound tops or frost boils in this vegetation type caused soil exposure to increase linearly with disturbance level, and resulted in nearly complete removal of plant cover from mound tops at high levels of disturbance (Plate 6).

Disturbance to tussocks was the most reliable indicator of disturbance levels in tussock tundra (Plate 7). Level 1 disturbance at 5 plots resulted in mostly scuffed tussocks; the 4 plots with level 2 disturbance had many destroyed mound tops (over 30%); and level 3 sites had ruts starting to form (5 plots) or large losses in plant cover due to fuel spills (T40) or craters (blow outs at shotholes) (T11, T30). Plant cover decreases ranged from 5-25%, 25-50%, and over 50% for levels 1 through 3, respectively.

Disturbance in moist shrub tundra resulted in breakage of the low shrub canopy (Plate 8). Levels 1 through 3 were defined as less than 25%, 25-50%, and over 50% decreases in both shrub canopy and total plant cover. There were 4 level 1, 3 level 2, and 2 level 3 plots.

In riparian shrubland, shrub canopy breakage was the main result of disturbance at the 4 level 1 and 4 level 2 plots (less than 50% and 50-80% canopy loss, respectively) (Plate 9). Most of the shrub canopy was removed and further disturbance to the ground cover occurred at H1, H3, and T2, resulting in level 3 disturbance.

Disturbance to *Dryas* terraces caused damage to the thin, fragile vegetative mat. Level 1 disturbance, defined as less than 30% loss of plant cover, occurred on 1 plot (M8). Five plots had level 2 disturbance (30-60% loss of plant cover) (Plate 10), and 3 plots with over 60% loss in plant cover were described as having level 3 disturbance.

Soils

The 1 wet graminoid tundra plot (011) was situated on an abandoned floodplain deposit. The poorly drained soil was saturated throughout the summer and had water above the surface early in the summer. The soil had a thick, uniform fibrous organic horizon with some sand which extended down below the active layer (Table 5, Fig. 2). The organic layer had accumulated substantial amounts of silts and sand during floods.

The moist sedge-shrub tundra plots occurred on fine-grained retransported deposits, glaciofluvial deposits, and abandoned floodplain deposits. The soils were saturated for much of the thaw period and some had a water table close to the surface. The soils generally had a fairly uniform, moderately thick organic layer, that intergraded into well-decomposed organic-mineral material. Texture of the mineral material varied from silty clay loam to loam.

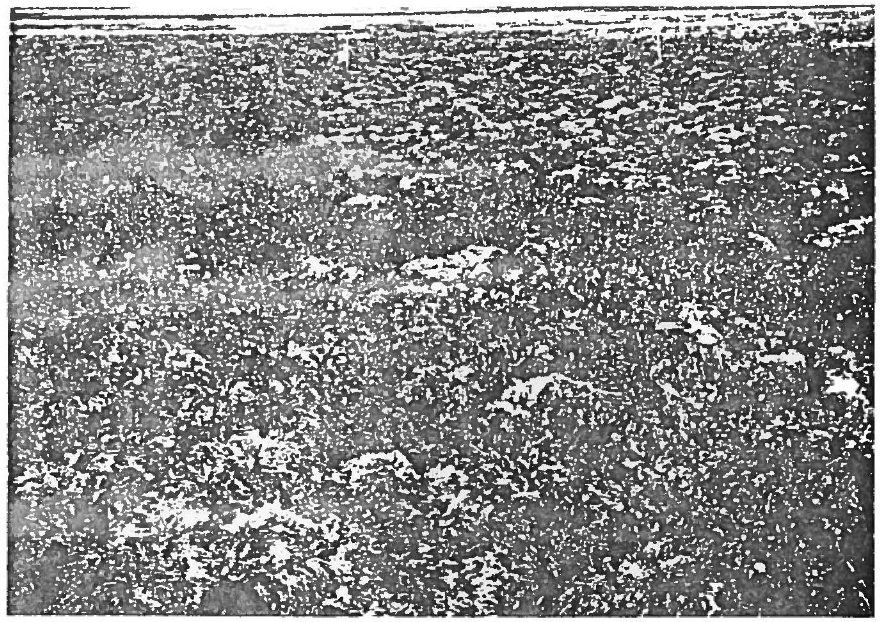


Plate 7. Trail through moist sedge tussock tundra. Disturbed tussocks are light colored because of dead tillers and exposed peat cores.

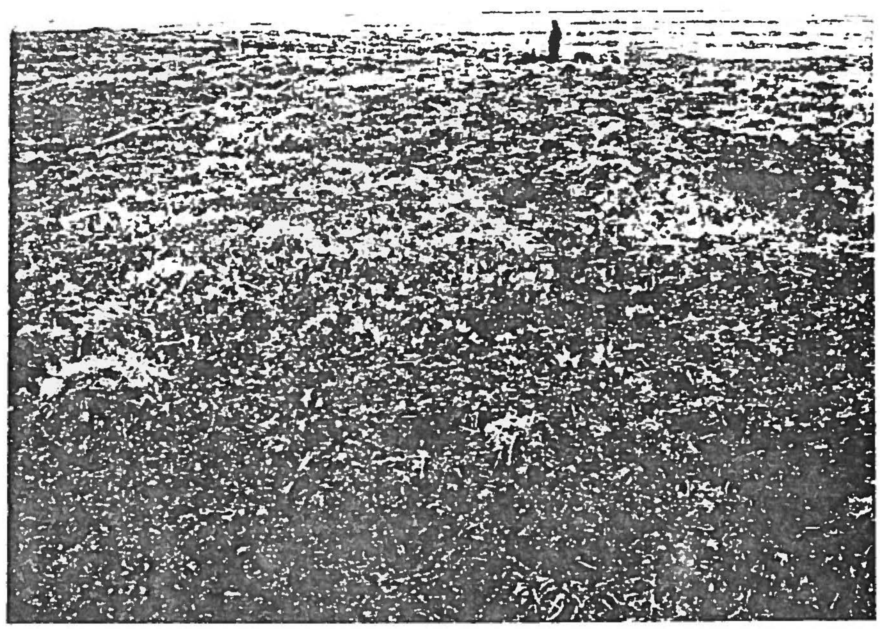


Plate 8. Disturbed plot (right) and control plot (left) in moist shrub tundra. Note loss of birch canopy on trail, and exposed soil from scraping of micro-relief.

Plate 9. Level 2 disturbance in low riparian shrubland. Note loss of willow canopy on trail.

Plate 10. Level 2 disturbance on *Dryas* river terrace. Note loss of plant cover on trail, and flowering on undisturbed areas.

Table 5. Mineral soil textures and depths (cm) of organic and organic-mineral horizons on the intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Texture[a] C horizon	Horizon depths (N=5) Organic $\bar{x}$	Organic SD	Org. + Org. min. $\bar{x}$	Org. + Org. min. SD
Wet graminoid	O11		33	3	33	3
Moist sedge - shrub tundra	M1	SiClL	14	7	17	3
	O18	L	13	2	13	2
	O19	L w/tr Gr	9	1	15	2
	O20	L w/tr Gr	17	3	17	3
	C3	SiClL	8	3	15	2
	O14	SaClL+L	5	4	15	2
	O12		11	12	30	9
	C1	SiClL	4	2	10	2
	T32	SiClL	12	2	13	2
Moist graminoid/ barren tundra complex	N11	SaL+L+LSa w/tr Gr	3	4	13	3
	N12	SaL+L+LSa w/tr Gr	2	1	15	13
	O3	L	7	2	13	4
	O7	L+Sa/Gr	2	1	12	6
	C2	SiClL	3	2	10	6
Moist sedge tussock tundra	M7S,V	SiClL	12	6	14	7
	S1	SiClL/Gr	11	3	11	3
	M11	SiClL/Gr	7	4	11	3
	S8		15	6	23	5
	M2	SiClL	10	3	12	3
	M3	Si w/tr Gr	9	7	18	5
	M10	SiClL/Gr	8	3	12	8
Moist shrub	S4	Si+SiClL	13	6	16	6
	S6	SiClL	9	5	10	7
Riparian shrubland	M4	Sa+SaL/Gr	0		3	2
	S5	SiClL+L/Gr	9	4	24	3
	O15	SaL/Gr	0		2	1
	H1	SaL+L/Gr	0		3	1
	H3	SaL+L/Gr	0		1	1
<u>Dryas</u> terrace	H4	LSa/Gr	0		5	1
	H5	L+Sa/Gr	0		3	1
	O6	LSa/Gr	0		2	1

[a]Texture: Cl - clay; Si - silt; Sa - sand; L - loam; Gr - gravel; w/tr - with trace; / - over.

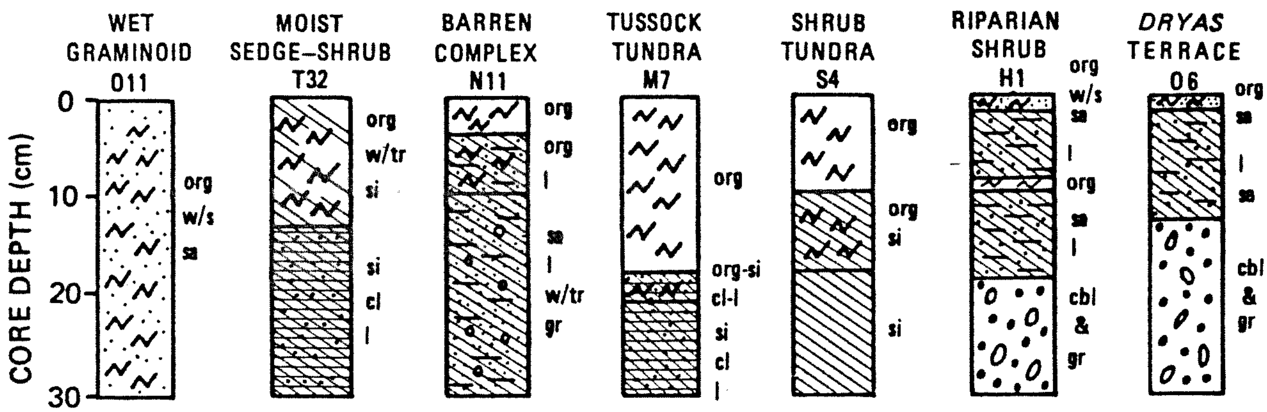


Fig. 2. Soil profiles of the active layer selected from plots in each vegetation type, coastal plain, Arctic NWR, Alaska, 1985. Soil textures: org - organic; cl - clay; si - silt; sa - sand; l - loam; gr - gravel; cbl - cobbles; w/tr - with trace; w/s - with some.

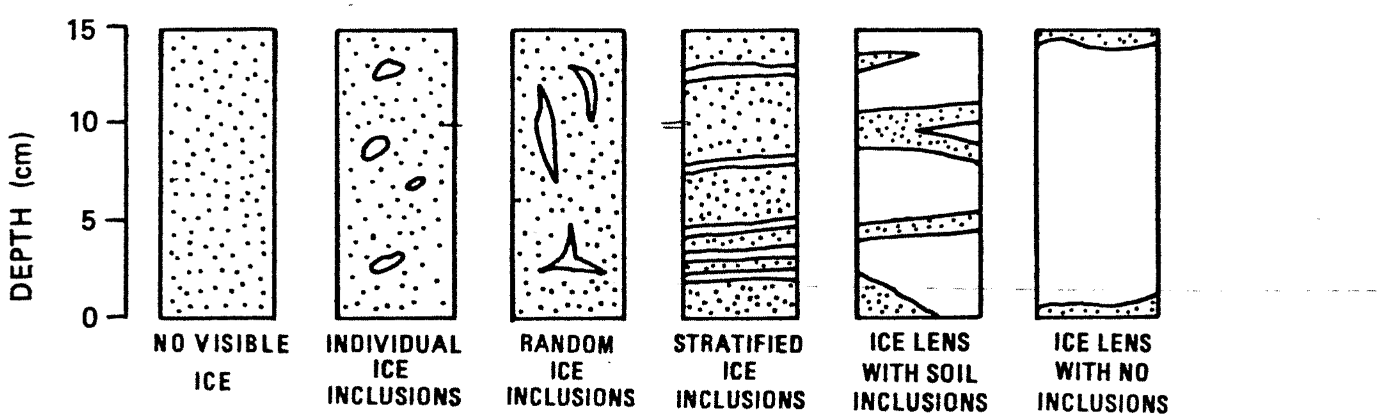


Fig. 3. Types of visible ice found in soils of the coastal plain (classification according to Pihlainen and Johnston 1963), Arctic National Wildlife Refuge, Alaska, 1985.

The moist graminoid/barren complex tundra was a diverse group of vegetation types occurring on a wide range of deposits unified by their hummocky, frost scar surface form. Our plots occurred on poorly sorted glaciofluvial, coastal marine deposits, and one loess deposit. The well to moderately drained soils were notable for their extremely variable organic horizons resulting from the prominent active and stabilized frost features. The organic layer was generally thin or absent on the frost scars. The texture of the parent materials was typically a sandy loam or loam, although this vegetation type did occur on silt at 1 site.

The moist sedge tussock tundra plots typically occurred on thin deposits of loess or colluvial material on top of coarser, residual materials, or glacial drift. The soils were moderately drained, with a variable organic horizon because of the tussocks and frost boils. Textures of the parent materials were silty clay loams or silts.

The moist shrub tundra plots occurred on fine-grained loess deposits with high-centered polygon surface morphology. The moderately well-drained soils had a moderately well-decomposed organic layer that often had a distinct organic and mineral horizon boundary. Textures of the mineral horizons were silty clay loams or silts.

The riparian shrubland plots occurred on both young braided floodplain deposits with mixed gravel and fine-grained material, and older terraces with a fine-grained alluvium layer over gravel. The plots typically had a very thin organic-mineral surface horizon over a thick cover deposit of interbedded layers of silty loam, loam, or sandy loam on top of gravel. One site (S5) had an organic-rich silty clay loam cover deposit over gravel.

The Dryas terrace plots occurred on thin, medium-grained braided floodplain cover alluvium. These well-drained soils had a very thin organic mat. The C horizon generally consisted of interbedded layers of loams, loamy sands, and fine sands over gravel with a thin buried organic-rich horizon occasionally present.

Soil moisture (volumetric) in undisturbed tundra was highly variable near the surface depending on microsite conditions and the type of soil material (Appendix Table 1). Average soil moistures in the organic horizon ranged from 37% at an upland site (S4) to 88% in a water track (M1). Average soil moisture ranged from 39% to 80% in organic-mineral materials, from 42% to 58% in fine-grained materials, and from 32% to 52% in sandy materials.

Bulk density was also highly variable near the surface, even within a plot, but was more consistent within the textural classes of the various horizons (Appendix Table 2). The average densities of organic material ranged from 0.09 to 0.29 g/cm^3, organic-mineral material ranged from 0.20 to 0.73 g/cm^3, and mineral soils ranged from 0.79 to 1.62 g/cm^3.

Ice Contents in the Permafrost

The amount of excess ice near the surface of the permafrost is an important factor in determining the effects of seismic trails on surface stability. Ice contents of the study plots were extremely variable ranging from 12% to 58% according to visual estimates of the top 30 cm or 2% to 45% according to lab determinations (Table 6). The lab determinations of ice content were generally lower than the visual estimates. The true amount of excess ice in the soil is probably somewhere between these 2 measures. Visible ice estimates generally overestimate the amount of excess ice, because some of the visible ice may be reabsorbed by the soil structure when it melts (Johnston 1981). The melted soil core may also swell to absorb more water than it would under field conditions where it is compressed and free drainage occurs, and therefore the lab determination underestimates the amount of excess ice.

Table 6. Excess ice contents (% volume) near the surface of the permafrost on intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Visual estimates Top 30 cm N	$\bar{x}$	SD	Top 10 cm N	$\bar{x}$	SD	Lab determination N	$\bar{x}$	SD
Wet graminoid	011	5	37	21	5	27	22	4	10	10
Moist sedge - shrub tundra	M1	4	49	2	4	52	5	3	39	14
	018	5	32	15	5	33	16	4	5	4
	019	4	31	10	5	44	15	4	11	4
	020	4	20	4	4	33	10	4	6	5
	C3	5	27	6	5	37	15	5	20	7
	014	5	35	18	5	41	24	3	18	5
	C1	5	29	6	5	50	19	4	28	5
	T32	5	58	5	5	58	5	3	45	2
Moist graminoid/ barren tundra complex	N11	5	35	22	5	17	6	3	40	27
	N12	4	37	31	5	9	17	4	37	19
	03	5	15	8	5	19	6	5	13	11
	C2	5	22	13	5	41	17	5	21	9
Moist sedge tussock tundra	M7	4	46	10	5	50	10			
	S8	5	12	7	5	14	7	5	2	4
	M2	5	36	9	5	46	26	3	25	9
	M3	5	35	18	5	55	28	2	22	18
	M10				5	66	6			
Moist shrub tundra	S4	4	21	6	5	38	35	4	8	4
	S6	5	44	24	5	51	22	3	11	17

The distribution of ice was highly variable within study plots as well as between them. Many authors have reported similar variability in ice volumes in fine-grained and organic-rich materials in other locations in Alaska and Canada (Johnston 1981, Kreig and Reger 1982, Lawson 1983).

Visual estimates of ice content in the top 10 cm of soil ranged from 9% to 66%, and were generally higher than those in the top 30 cm. The vertical distribution of ice in the cores was extremely variable (Fig. 3). Near the surface, ice occasionally occurred as thick ice lenses with or without soil inclusions. More often the ice occurred as stratified ice, random ice, or as individual inclusions. Only rarely did portions of the profiles have no visible ice. Often organic and mineral material was intermixed in random patterns. This intermixed and deformed stratigraphy contributed to highly variable ice contents. Typically the more massive stratified ice formations were found in mineral material and the lowest ice contents, often not visible, were found in organic material.

Effects of Vehicle Trails on Visual Resources

Visibility of Disturbance

One and 2-year-old trails were generally visible in all vegetation types, but visibility of trails varied from barely perceptible to easily visible (Plate 11). Trail visibility ratings from the air and the ground were often the same, but trails in wetter habitats were sometimes more visible from the air (Table 7). Small differences in vegetation on seismic lines, which were difficult to see on the ground, were often visible from the air due to the continuous, linear nature of these trails. Most of the easily visible disturbances were the result of narrow trails, fuel spills, shothole craters, or small-radius vehicle turns. Diffuse trails (seismic or camp move) rarely caused easily visible disturbances. Seismic vibrator trails (1985) were slightly more visible than seismic dynamite trails (1984). This was probably due to the heavier weight of vibrators compared to drills and to the additional year the dynamite trails had to recover.

Overall, plots which were photographed in both 1984 and 1985 showed either no change or slight improvement (less visibility) in 1985. Three plots (T28, T29, 06) looked worse on the ground photos in 1985 than in 1984 due to loss of the moss mat and exposure of soil. Fuel spills showed no change in visibility between 1984 and 1985. Factors which were responsible for the reduced visibility of some trails in 1985 include:

1. The additional year's growth which increased the amount of standing dead in the trail, thus reducing the contrast with the surrounding area.
2. A general lightening, or graying of the litter and soil (caused by weathering) which reduced the contrast with the surrounding vegetation.
3. The unusually low rainfall in 1985. Many trails that were easily visible in 1984 as water-filled tracks, were dry in 1985 and thus much less visible. The dry conditions also contributed to the lighter color of soil and litter.

Visibility ratings were usually correlated with disturbance levels so that trails rated not visible were usually disturbance level 0, trails rated barely perceptible were usually disturbance level 1, trails rated visible were usually disturbance level 2, and trails rated easily visible were usually disturbance level 3.

Wet Graminoid and Moist Sedge-Shrub Tundra. Trails were visible as continuous green tracks resulting from the compression of standing dead grass and sedge leaves. Air and ground visibility generally agreed, although several plots

Plate 11. Barely perceptible trail through moist graminoid/barren tundra complex, visible trail through moist sedge shrub and moist sedge tussock tundra, and easily visible trail through wet sedge tundra.

Table 7. Air and ground visibility ratings of intensive study and photo-trend plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Plot	Disturbance level[a]	Visibility[b]	
		Air	Ground
Wet graminoid tundra			
T16	1	1	0
N1	1	2	2
O5	1	2	1
O10	1	2	2
O11	2	2	2
O17	3	3	3
T5	3	3	3
T6	3	3	3
T17	3	3	3
T21	3	3	3
T37	3	3	3
Moist sedge-shrub tundra			
M1	1	1	1
O18	1	2	2
O19	1	2	2
O20	1	2	2
M6	1	1	1
N2	1	2	1
N8	1	2	1
T41	1	2	1
C3	2	2	3
O13	2	2	2
O14	2	3	2
T18	2	2	2
T25	2	2	2
T26	2	2	2
T38	2	2	2
T39	2	2	2
O12	3	3	2
C1	3	3	3
T32	3	3	2
T10	3	3	3
T27	3	3	3
T31	3	3	3
Riparian shrubland			
O2	1	0	1
M4	1	2	2
S5	1	1	1
O9	1	1	1
T36	1	1	1
O15	2	3	3
O1	2	2	2
S9	2	2	2
T1	2	2	2
H1	3	3	3
H3	3	3	3
T2	3	3	3
Dryas terrace			
T33	1	2	2
M8	1	2	1
H4	2	3	3
H5	2	3	3
T14	2	2	2
T35	2	2	2
M9	2	2	2
T34	2	2	2
O6	3	3	3
T9	3	2	3
Moist graminoid/barren complex tundra			
N4	1	1	1
N5	1	1	1
N7	1	1	1
N9	1	1	1
T3	1	1	1
N11	2	1	1
N12	2	2	2
O3	2	2	2
O7	2	2	1
N6	2	2	2
T8	2	2	2
T12	2	2	2
T20	2	2	2
C2	3	3	3
H2	3	2	3
T7	3	2	2
T19	3	3	3
T24	3	3	3
Moist sedge tussock tundra			
T15	0	1	1
T42	0	1	0
M7S	1	2	2
M7V	1	2	2
S1	1	1	1
S7	1	1	1
T13	1	1	2
T23	1	2	2
M11	2	3	3
S8	2	2	2
O8	2	3	3
T28	2	2	2
M2	3	2	2
M3	3	2	2
M10	3	3	3
M5	3	2	3
T11	3	3	3
T22	3	3	3
T30	3	3	3
T40	3	3	3
Moist shrub tundra			
S4	1	1	1
N3	1	1	1
S2	1	1	1
S3	1	1	1
S6	2	2	2
O16	2	2	2
T4	2	2	2
C4	3	2	3
T29	3	3	3

[a] Disturbance levels: 0 - none; 1 - low; 2 - moderate; 3 - high.
[b] Visibility ratings: 0 - not visible; 1 - barely perceptible; 2 - visible; 3 - easily visible.

were more visible from the air. An aerial view made small vegetation changes (e.g. compression of standing dead) visible as long, continuous green trails. Visibility ratings generally matched the related disturbance levels. Exceptions were level 1 disturbances, which were often rated as visible, since even low level disturbance caused compression of standing dead. Visibility on the ground was increased by the presence of strips of undisturbed tundra between the tracks. These strips had sharply defined edges and their grayish color (from the abundant standing dead) contrasted sharply with the green of disturbed areas. Although 1984 trails generally remained visible in 1985, many were less visible as a result of increased amounts of standing dead, a lack of standing water in the trails (because of the dry year), and some new growth of graminoids.

Moist Graminoid/Barren Tundra Complex. Trails were usually visible as discontinuous dark tracks resulting from exposed soil and were equally visible from both the ground and the air. Visibility ratings usually matched related disturbance levels, although, in a few cases the visibility rating was lower because of the large amount of natural disturbance (frost scars) surrounding the trails. Disturbance on study plots was less visible in 1985 photographs than in 1984 photographs because the exposed soil was drier and lighter and blended in with the soil of the naturally occurring frost boils and with the litter of the undisturbed areas. Actual recovery of the vegetation was not evident from the photos.

Moist Sedge Tussock Tundra. Trails usually appeared as brown (first year) or gray (second year) tracks of scuffed or broken tussocks. The brown 1985 trails were often more visible than the 1984 trails whose gray litter provided less contrast with the surrounding vegetation. Trails were usually equally visible from both the ground and the air, and were often more visible than the disturbance level would suggest. This was especially true of level 1 and level 2 disturbances because the scuffed or destroyed tussocks were an obvious feature on the ground and formed fairly continuous trails from the air. Most 2-year-old trails showed little change in visibility on the ground photos from 1984 and 1985 and some improvement on the aerial photos. This improvement was largely the result of a graying of the litter and disturbed moss mat which reduced the contrast of the trail with the undisturbed tundra. Resprouting of *Eriophorum vaginatum* from scuffed or damaged tussocks also lessened trail visibility. On more disturbed trails, the exposed soil was lighter in color in 1985 (as a result of weathering and the dry year), blending in with the litter and frost scars in the undisturbed tundra. One plot, T28, was unusual in that although it was much less visible from the air in 1985 (a result of the graying of what had been brown, crushed tussocks) it was more noticeable on the ground because the moss mat died, exposing more soil.

Moist Shrub Tundra and Riparian Shrubland. Trails in both of these shrub-rich vegetation types were equally visible from both the ground and the air. Visibility ratings also agreed with related disturbance levels, although removal of the shrub canopy, especially on riparian sites, sometimes made trails more visible than their disturbance rating would suggest. Of the 7 shrub tundra plots for which we had 1984 and 1985 photographs, several had trails which were less visible in 1985, but most showed no change. Most improvements resulted from lighter soil and litter color, and slight regeneration of shrubs, graminoids, and forbs. One plot with level 3 disturbance (T29) was more visible on the ground in 1985 because of additional loss of mosses. Most riparian plots also showed no change or slight improvement. One plot, S5, was markedly less visible from the air in 1985, but showed no change on the ground photos. Slight regeneration of willows was visible on quadrat photos in most riparian shrub plots, but only 1 plot (02) showed a substantial increase in willow cover.

Dryas Terrace. All trails on study plots in this easily disturbed vegetation type were rated either visible or easily visible. Ground ratings agreed with air ratings except on photo-trend plots M8 and T9. The patchy nature of the vegetation at M8 made it easier to see the continuous trail from the air. Plot T9 was on a short, steep river bank with many naturally disturbed areas alongside the trail, making the trail less visible from the air than on the ground. On plot 06, the trail was more visible in 1985 than in 1984 due to complete loss of the moss mat (which, though dead, had remained in place in 1984), exposing the soil underneath.

Photo Documentation of Disturbance

The entire series of aerial and ground photographs provided a valuable means for following changes in plots between 1984 and 1985. Ground oblique photos taken from both ends of the intensive study and photo-trend plots showed disturbance on the whole plot and helped reduce differences in lighting resulting from sun angle. Quadrat photos of typical disturbed areas helped reveal small scale changes such as increases or reductions in the growth of individual plants and changes in the soil or litter on individual bare patches. Aerial oblique photos showed the overall aspect of the trail in the landscape and were especially useful for those trails which were not easily seen on the ground but which formed long, continuous trails when seen from the air. Aerial vertical photos provided a low level, stereo view of the whole site and were useful in showing changes in the structure and color of the trail in comparison to the adjacent undisturbed tundra.

The use of photographs to document changes in trail visibility between 1984 and 1985 was complicated by the very different moisture and lighting conditions of the 2 years; 1984 was wet and overcast, while 1985 was dry and sunny. Trails which had standing water on them in 1984 were dry in 1985 and less visible. The wetter conditions in 1984 also made exposed soil more visible on the photos. Some photos were overexposed in 1985 making it difficult to see the trail, while other photos from 1985 had strong shadows which enhanced the visibility of trails. Differences in film and developing between the 2 years also caused variations in the colors and contrasts of the photos. Use of all ground and aerial photos of a plot helped reduce the influence of these variations on the viewer. In the future, as changes in the plots become more distinct, yearly variation in weather will have less influence on the photographic record.

Vegetation Impacts

Plant Cover and Frequency

Total plant cover showed statistically significant decreases on most disturbed plots compared to adjacent controls (Appendix Tables 3-14). Plots with higher disturbance levels generally showed larger decreases in plant cover. The largest drop in total plant cover occurred on a level 3 disturbance in *Dryas* terrace (plot 06) which had an 85% difference in plant cover between disturbed and control plots in both 1984 and 1985. Level 1 disturbances in moist sedge-shrub tundra had the smallest decreases in plant cover. All of the 14 disturbed plots which had statistically significant decreases in total plant cover in 1984 also had statistically significant decreases in 1985. At 7 of these plots the changes in total plant cover between disturbed and control plots ((D-C)/C x 100, where D = % cover on the disturbed plot and C = % cover on the control plot) were 8 to 31% less in 1985 than in 1984, indicating that slight recovery may have occurred even though statistically significant changes had not. At the other 7 plots, the change in total plant cover in 1985 was within 4% of the change in 1984.

Disturbance caused only small increases in exposed soil at most plots; 14 plots had statistically significant increases ranging from 2-26%. Statistically significant increases in exposed soil occurred most often on trails in barren complex and tussock tundra, and on 1 trail with well-developed high-centered polygons (011, 012). The high micro-relief (polygon rims, hummocks, and tussocks) in these plots was easily scuffed, disrupting the vegetative mat and exposing soil. The largest amount of soil was exposed on Dryas terrace plot 06 where much of the thin vegetative mat was removed by disturbance. Little recovery of exposed soil occurred between 1984 and 1985; only 1 plot (011) had a significant increase in exposed soil on the disturbed plot in 1984 and not in 1985.

More significant differences occurred for nonvascular plants than for vascular plants in moist sedge-shrub tundra indicating that mosses were particularly sensitive to disturbance in this vegetation type. Vascular plants were more sensitive to disturbance in tussock tundra and riparian shrubland. Shrubs and tussock sedges in these vegetation types were more susceptible to disturbance than mosses and lichens which were generally protected beneath the vascular plants.

The specific responses of life forms and species are discussed by vegetation type in the following sections. The sampling approach was often not sensitive enough to identify statistically significant differences in many individual species, especially those with low cover values. Trends were often evident in the data when the responses at a number of plots were compared. Since the differences in individual species cover were cumulative, statistically significant differences were often identified when species were grouped into life forms, or vascular, nonvascular, and total plants.

Disturbed and control plots with 2 years' data generally had higher plant cover values and lower percentages of unvegetated area (mostly litter alone) in 1985 than 1984. This difference may have been caused by increased plant productivity due to seasonal differences; there were approximately 25% more degree-days above 0°C during the summer of 1985 than in 1984 (U.S. Dept. of Commerce, N.O.A.A. 1984, 1985), and there were more sunny days and less cloud cover on the coastal plain in 1985. Differences in observers and sampling equipment may also have caused changes in the data between the 2 years. The largest differences between years occurred at the Marsh Creek plots (M1, M2, M3, M4) where the 1984 data was collected using different equipment (a string and pointer rather than the point frame), and individual mosses were not recognized. Since comparisons are being made between disturbed and control plots within both 1984 and 1985, treatment differences can still be identified despite the changes in cover values between years.

Changes in the frequency of occurrence of species in disturbed plots were generally similar to changes shown by cover values. Frequency data were particularly valuable on riparian shrubland plots where changes in forb species with small cover values were evident.

Wet Graminoid and Moist Sedge-Shrub Tundra. Overall, plant cover (life forms and species considered jointly) was significantly less on most plots with moderate and high levels of disturbance and on 2 out of 4 plots with low level disturbance, (Appendix Tables 3-5). Mosses and liverworts were the most sensitive vegetation component in these vegetation types. Statistically significant decreases in moss cover (ranging from 23 to 37%) occurred on 8 out of 11 disturbed plots compared to their adjacent controls (Fig. 4). The percent decrease in moss cover on plot O11 was less in 1985 than in 1984; although this difference was not significant, it may indicate that recovery is beginning to occur. Other studies have also shown that mosses are vulnerable to compression and abrasion in the winter while sedges are protected because their roots are in frozen soil (Hernandez 1973, Sterrett 1976, Lawson et al. 1978).

No significant decreases in sedge cover occurred on disturbed plots. However, 1 significant increase in Eriophorum angustifolium occurred on plot T32 in the second year after disturbance (Fig. 4, Appendix Tables 3-5). Three other plots (M1, C1, C3) showed similar increases in sedge cover but these were not statistically significant. Many researchers have reported increases in sedge cover on old trails in similar vegetation types (Challinor and Gersper 1975, Lawson et al. 1978, Chapin and Chapin 1980, Chapin and Shaver 1981, Reynolds 1982).

Cover of deciduous shrubs (including the willows Salix planifolia ssp. pulchra, S. reticulata, and S. lanata ssp. richardsonii) generally decreased on disturbed plots, with statistically significant changes on 4 plots with moderate or high levels of disturbance (Fig. 4, Appendix Tables 3-5). Decreases in willow cover on vehicle trails have been reported in previous studies (Hernandez 1973, Chapin and Shaver 1981). Forb species generally had lower cover and occurred less frequently ~~in~~ disturbed ~~plots~~ compared to adjacent controls as was observed by Chapin and Shaver (1981).

The amount of bare ground (litter and exposed soil) was significantly higher on most plots with moderate and high levels of disturbance compared to adjacent controls (Appendix Tables 3-5). Significant amounts of exposed soil (organic and organic-mineral) occurred at plot O12, where vehicles left ruts in the high polygon rims. At wet sedge plot O11, exposed soil was significantly higher in the disturbed plot compared to the adjacent control in 1984 but not in 1985, indicating that significant recolonization of bare patches had occurred.

Moist Graminoid/Barren Tundra Complex. The cover of life forms and species, when considered jointly, decreased significantly at all 5 disturbed plots in barren complex tundra (Appendix Tables 6,7). The evergreen shrub Dryas integrifolia was an important component of the vegetation in 4 of the 5 plots, and showed statistically significant decreases in cover, ranging from 4 to 11% (Fig. 5). No statistically significant changes in cover of D. integrifolia occurred between 1984 and 1985. The available literature suggests ~~that~~

recovery of *D. integrifolia* cover will occur on mesic sites such as barren complex tundra. *Dryas integrifolia* was a successful recolonizer after 20 years on a heavily used trail in sandy soil at Fish Creek (Everett et al. 1985). Reynolds (1982) also reported measurable recovery of total plant cover on a moderately disturbed dry upland meadow of *Dryas integrifolia*, *Lupinus arcticus*, mosses, and lichens after 2 growing seasons. Other studies have reported little recovery of *Dryas* spp. on more exposed sites. Barrett and Schulten (1975) observed that *D. integrifolia* was especially sensitive to disturbance and slow to recover in a study of dry arctic beach crests. Everett et al. (1985) reported that *Dryas octopetala* was not effective in recolonizing 20-year-old trails on exposed *Dryas* fell-fields at Cape Thompson.

Deciduous shrubs (mainly the willows *Salix phlebophylla*, *S. rotundifolia*, *S. arctica*, and *S. reticulata*) showed significant decreases in cover on 4 of the 5 disturbed plots (Fig. 5, Appendix Tables 6,7). Plot 03 had a significant decrease in cover on the disturbed plot in 1984 but not in 1985, indicating that some recovery had occurred.

Nonvascular plants were particularly sensitive to disturbance (Fig. 5, Appendix Tables 6,7). Lichens decreased in cover at all disturbed plots with statistically significant decreases at 3 of the 5 plots. Moss cover (including *Dicranum* spp., *Tomenthypnum nitens*, and *Drepanocladus* spp.) decreased in all disturbed plots; 4 of 5 plots had statistically significant decreases. Mosses and lichens showed little evidence of recovery.

The cover of litter or dead plants increased on all disturbed plots (Appendix Tables 6,7). Small patches of bare soil were common due to disruption of hummocks. Significant increases in soil exposure, ranging from 2 to 12%, occurred in all 5 plots. The exposed soil was approximately half mineral soil and half organic soil.

Moist Sedge Tussock Tundra. Overall, plant cover (life forms or species considered jointly) significantly decreased on most disturbed plots compared to adjacent controls (Appendix Tables 8-10). Statistically significant decreases in evergreen shrubs (ranging from 8 to 28%) occurred in 7 of the 8 disturbed plots (Fig. 6). The ericaceous shrubs *Ledum palustre* ssp. *decumbens* and *Vaccinium vitis-idaea* showed the largest cover decreases with significant changes at 6 of the 8 plots. Cover of deciduous shrubs (especially *Betula nana* s.l.) decreased in all disturbed plots, but only 3 plots had statistically significant differences (Fig. 6). Recovery of shrubs was not evident on any plot. Previous studies have reported that shrubby species, including *L. palustre*, *V. vitis-idaea*, and *B. nana*, were rare on disturbed areas many years after disturbance (Lambert 1972, Hernandez 1973, Lawson et al. 1978, Chapin and Chapin 1980, Chapin and Shaver 1981, Ebersole 1985).

Decreases in cover of cotton grass (*Eriophorum vaginatum*) occurred on most disturbed plots in tussock tundra, but statistically significant decreases ranging from 7 to 19% occurred on only 3 plots (Fig. 6). The increase in cotton grass flowering noted on disturbed trails by Hernandez (1973) was not seen on our plots. In 1984, less flowering was seen on the trail than in the surrounding tundra. 1985 was a dry year and flowering of sedges was not abundant anywhere on ANWR's coastal plain.

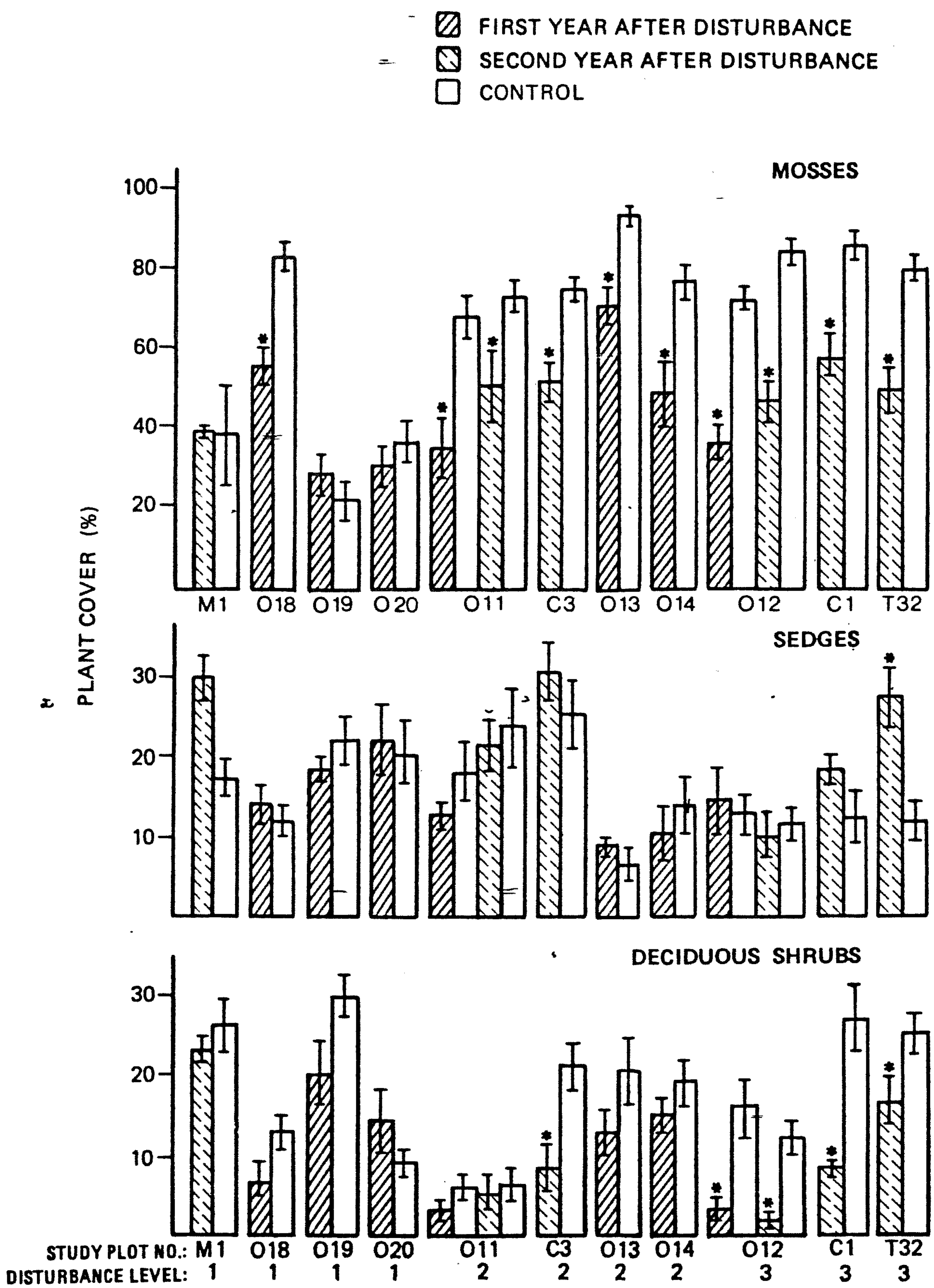


Fig. 4. Cover (%) of mosses, sedges, and deciduous shrubs in wet graminoid (O11) and moist sedge - shrub tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

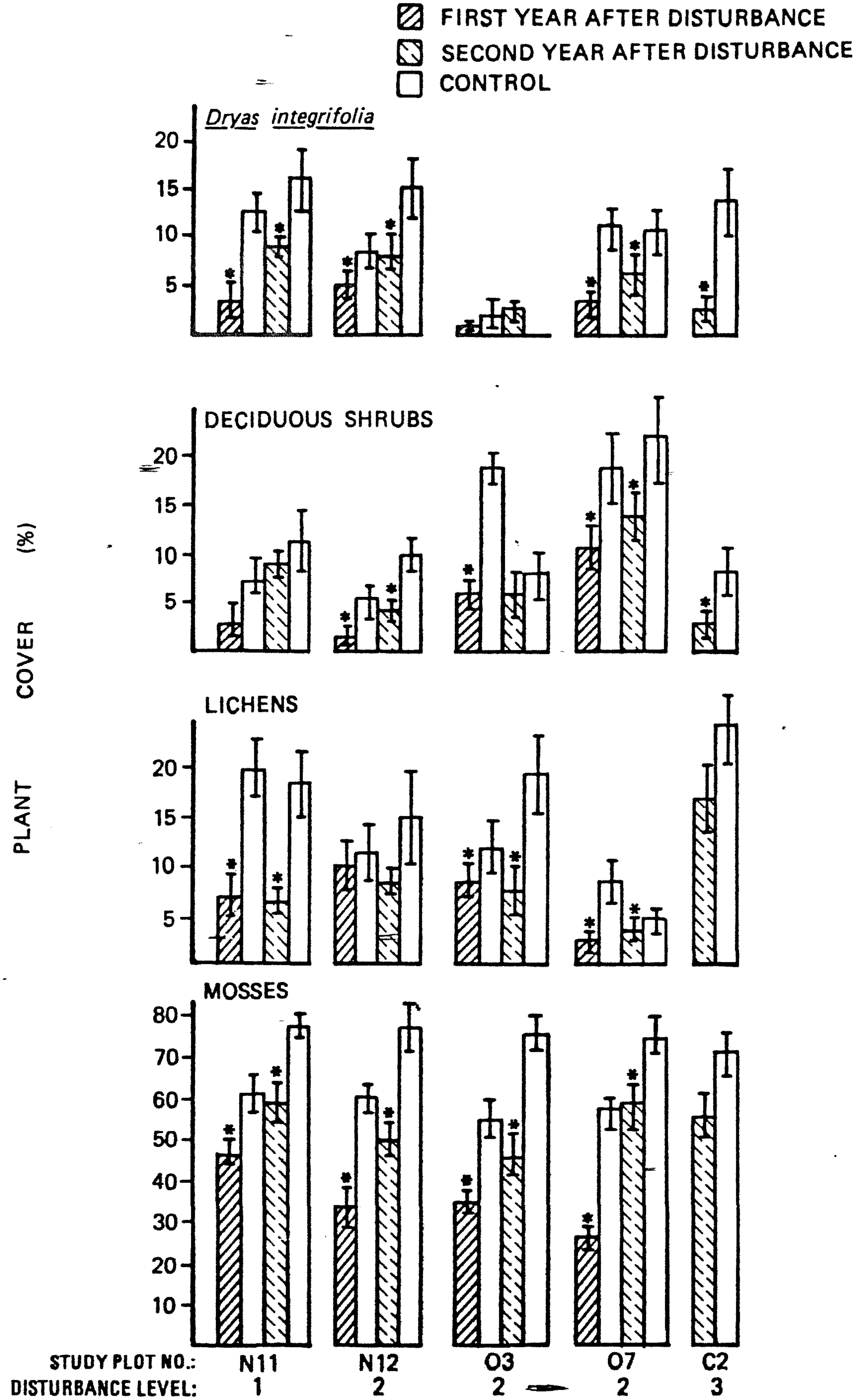


Fig. 5. Cover (%) of Dryas integrifolia, deciduous shrubs, lichens, and mosses in moist graminoid/barren tundra complex after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and

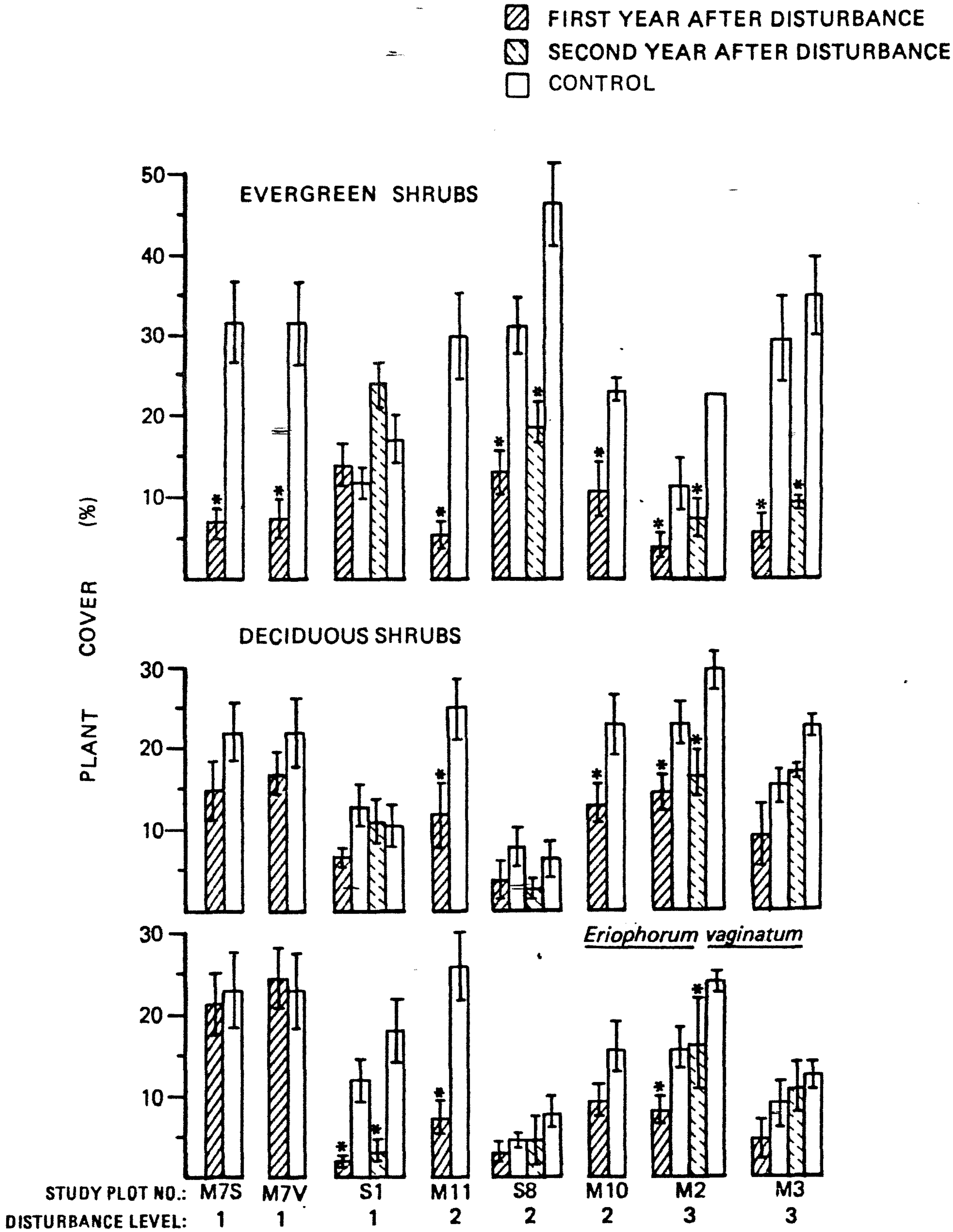


Fig. 6. Cover (%) of evergreen shrubs, deciduous shrubs, and Eriophorum vaginatum (cotton grass) in tussock tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

Moss cover, including Hylocomium splendens and Tomenthypnum nitens, decreased on all disturbed plots with significant changes on 5 of the 8 plots (Appendix Tables 8-10). Lichens (especially the foliose lichens Peltigera spp. and Nephroma arctica) had significant decreases in cover on 3 plots. Mosses and lichens generally showed smaller changes than vascular plants on disturbed plots in tussock tundra, because they were located between the tussocks where they were less susceptible to vehicle disturbance.

Small increases in exposed soil occurred on all plots due to disruption of tussocks which exposed their peat cores (Appendix Tables 8-10). Statistically significant increases ranging from 3 to 12% occurred on 5 of the 8 disturbed plots.

Moist Shrub Tundra. The low shrub canopy found on shrub tundra areas is vulnerable to breakage, and plant cover decreased significantly on both disturbed plots compared to adjacent controls. As in tussock tundra, evergreen shrubs (in particular the ericaceous shrubs Ledum palustre ssp. decumbens and Vaccinium vitis-idaea) were sensitive to disturbance (Fig. 7, Appendix Table 11). The deciduous shrub Betula nana s.l. also decreased in both disturbed plots with a statistically significant decrease at the more disturbed plot S6. Mosses, including Dicranum spp. and Polytrichum spp., had reduced cover.

Soil exposure increased with increasing disturbance levels (Appendix Table 11). The more disturbed plot S6 had significant increases in exposed soil averaging 7% in both years. On photo-trend plot T29, disruption of the moss ground cover led to 19% soil exposure and a 77% decrease in total plant cover.

Riparian Shrublands. Overall, plant cover (species or life forms considered together) decreased significantly at 4 out of 5 disturbed plots compared to adjacent controls (Appendix Tables 12,13). Deciduous shrubs, including willows (Salix spp.) and bearberry (Arctostaphylos rubra), decreased on all disturbed plots with statistically significant decreases in cover in 4 of the 5 plots (Fig. 8). Neither of the plots with 2 years' data showed changes in cover decreases between 1984 and 1985 which would indicate recovery. Willows were removed nearly to ground level at H3, while mean willow height decreased 20-50% at the 4 other plots.

Forb cover was significantly decreased on 4 of the 5 disturbed plots, and forb species were found less frequently on the disturbed plots than on control plots (Appendix Tables 12,13). Horsetail cover (mostly Equisetum variegatum) significantly decreased on 3 plots. Moss cover (especially Hylocomium splendens and Tomenthypnum nitens) decreased significantly on disturbed plots S5 and H3, which had the highest moss cover in the natural habitat. Soil exposed remained low (1-3%), while bare ground (litter and exposed soil) increased significantly at 4 plots.

Dryas Terrace. Overall, plant cover decreased significantly at all 3 disturbed Dryas terrace plots compared to their adjacent controls (Appendix Table 14). Statistically significant decreases in cover of Dryas integrifolia (ranging from 10 to 28%) occurred on 2 of the 3 plots sampled (Fig. 9). Deciduous shrubs (mainly the prostrate willow Salix reticulata) had significant decreases in cover on all disturbed plots. Recovery of Dryas integrifolia is expected to be extremely slow on these sites based on previous

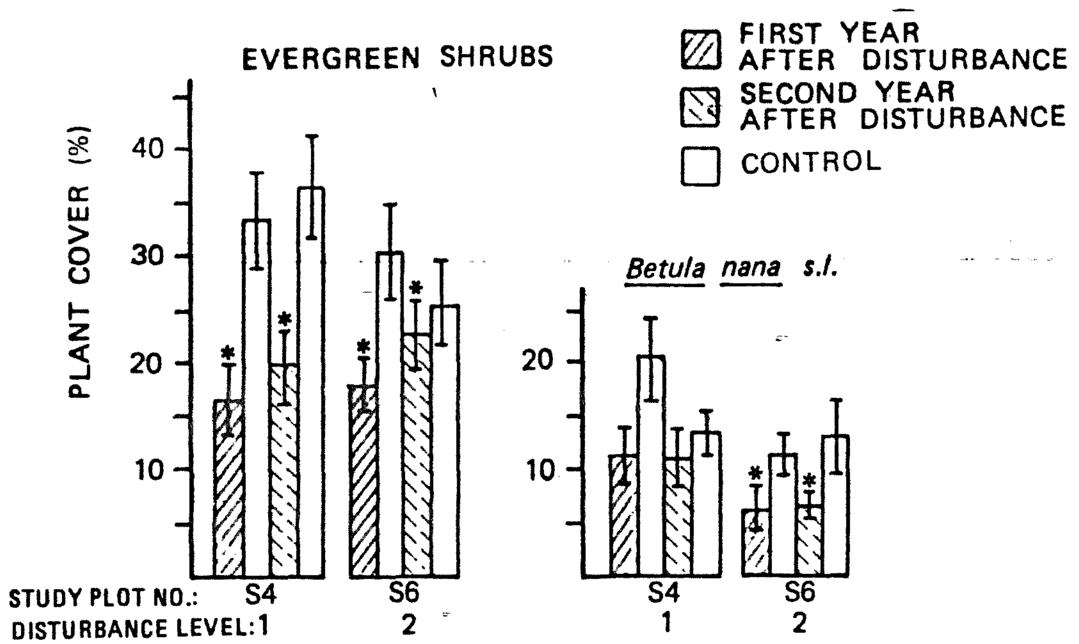


Fig. 7. Cover (%) of evergreen shrubs and Betula nana s.l. (dwarf birch) in shrub tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985.

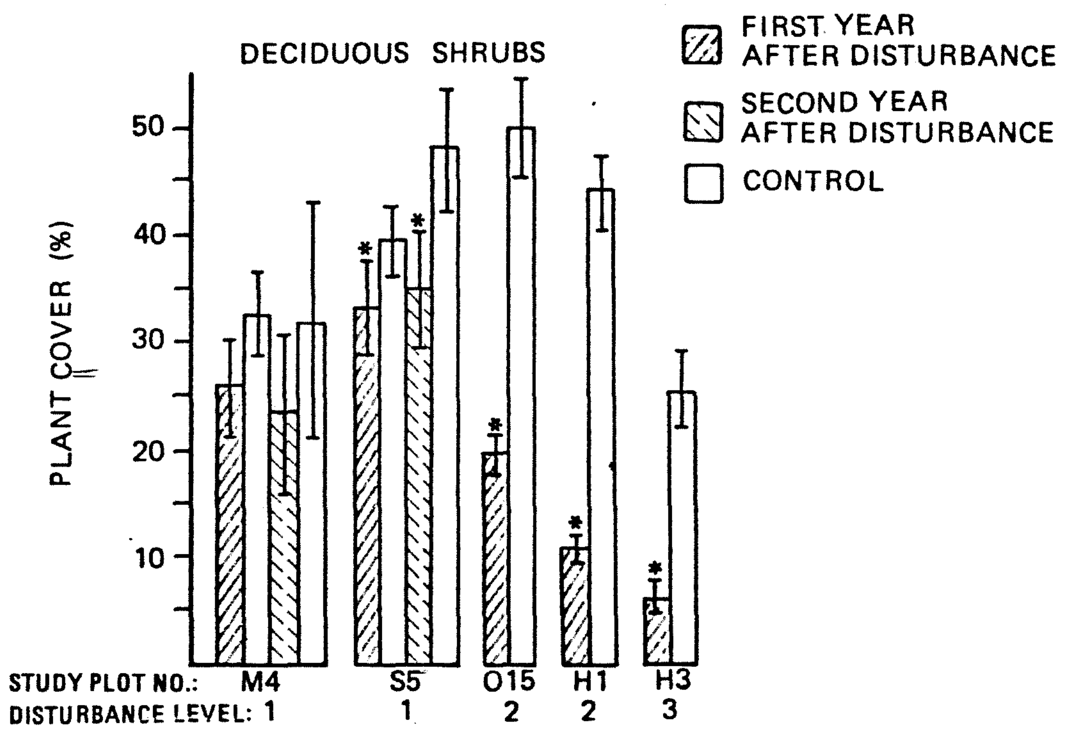


Fig. 8. Cover (%) of deciduous shrubs in riparian shrubland after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

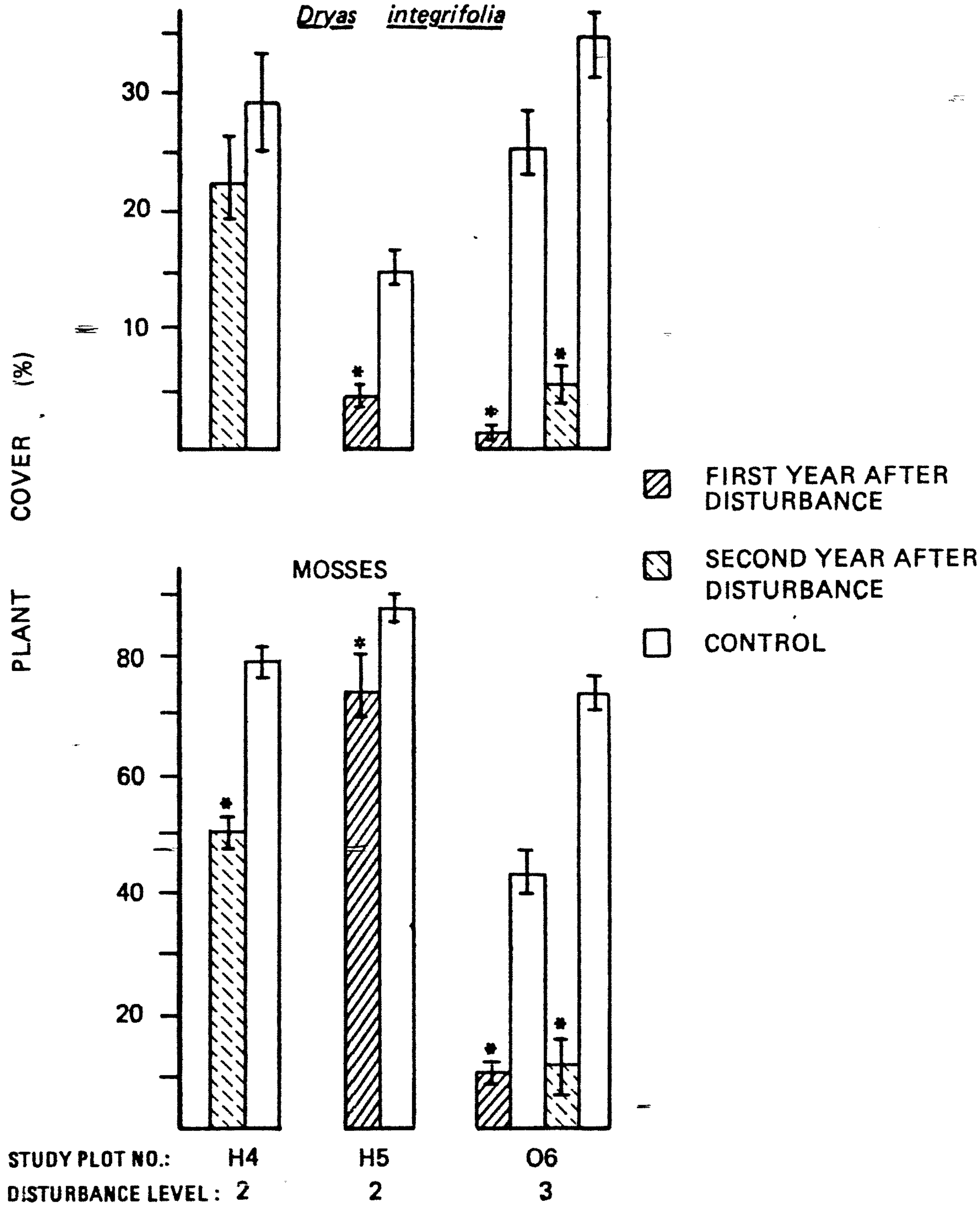


Fig. 9. Cover (%) of *Dryas integrifolia* and mosses in *Dryas* terrace after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

studies of recovery in xeric exposed sites (Barrett and Schulten 1975, Everett et al. 1985). On 1 river terrace in ANWR, cleat marks were still visible in the *Dryas* mat 20 years after disturbance.

Horsetails (mostly *Equisetum variegatum*) and mosses (especially *Tomenthypnum nitens*) decreased significantly on all plots (Fig. 9, Appendix Table 14). Disturbance to mosses at plot 06 appeared worse in 1985, because much of the moss cover which had been detached in 1984 had dried up and blown away. Forb cover was reduced in all disturbed plots with a statistically significant difference at H5 and 06, but no change in frequency of forb species occurred.

Recolonization

The percent of ground covered by bare patches increased within each vegetation type as the disturbance level increased (Table 8). Trails on *Dryas* terraces had the highest cover of bare ground and trails in moist sedge-shrub tundra had the lowest cover of bare ground.

Recolonization proceeded at a slow rate: 2-year-old bare patches had changed little in appearance since the year before. The number of shoots recolonizing bare ground ranged from 25 - $360/m^2$, but represented low cover values because of the small size of individual shoots (Table 8, Plate 12). Recolonization was largely the result of vegetative shoots growing in from the edges of bare patches. This was especially true in tussock tundra where *Eriophorum vaginatum* was vigorously resprouting on the edges of scuffed tussocks and covered up to 98 cm^2/m^2 (1%) of bare ground (Table 8, Plate 13). Seedlings were important recolonizers on the 1 wet graminoid plot (011) and on riparian shrub plots H3 and H1, where they comprised 19%, 20%, and 35% of all recolonizing shoots, respectively. Seedlings were generally absent or comprised less than 5% of recolonizing shoots on all other plots. Other studies (Chapin and Chapin 1980, Gartner et al. 1983) have found seedlings to be important in recolonizing more heavily disturbed areas located further south than our study area. Ebersole (1985), in a study of disturbed tundra at Oumalik, found that while seedlings were the principal recolonizers of large bare areas, they were less important on smaller plots (comparable in size to those in the present study).

All recolonizing species were found in adjacent undisturbed tundra, although some were more abundant on the disturbed sites. Graminoid species were the most important recolonizers in all vegetation types except riparian shrubland and *Dryas* terrace, where shrubs were the principal recolonizers. Mosses were rare or absent as colonizers of bare ground in most vegetation types. They were, however, common on the 1 wet graminoid plot (011) and on several tussock tundra plots. All plots with recolonizing mosses were on 2-year-old trails. Recolonization within specific vegetation types is discussed below.

Wet Graminoid and Moist Sedge-Shrub Tundra. Bare patches covered a small percentage of ground area on all but the most disturbed plots in wet graminoid and moist sedge-shrub tundra. Sedges, especially *Eriophorum angustifolium*, *Carex aquatilis*, and *C. Bigelowii*, made up most of the colonizing shoots on plots in these vegetation types. The dominance of sedges as recolonizers reflects their abundance in the undisturbed tundra and also agrees with the increases in sedge cover that other studies have found on trails through moist and wet graminoid tundra (Lawson et al. 1978, Reynolds 1982, Everett et al.

Table 8. Cover of bare ground and numbers of recolonizing vegetative shoots and seedlings on intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Plot	Dist.[a] level	Bare[b] ground (%cover)	Recolonizing vegetative shoots: Total number	No./m^2 bare ground	ERVA[c]	Recolonizing seedlings: Total number	No./m^2 bare ground
Wet graminoid tundra							
O11	2	4	48	240	0	11	55
Moist sedge-shrub tundra							
M1	1	3	10	77	8	1	8
O18	1	tr	0	0	0	0	0
O19	1	0	0	0	0	0	0
O20	1	tr	0	0	0	0	0
C3	2	0	0	0	0	0	0
O13	2	7	118	346	0	0	0
O14	2	2	5	62	0	0	0
O12	3	27	245	183	0	12	11
C1	3	20	150	150	0	0	0
T32	3	0	0	0	0	0	0
Moist graminoid/barren complex tundra							
N11	2	13	101	153	49	0	0
N12	2	13	51	81	13	1	2
O3	2	20	214	216	2	1	1
O7	2	15	177	243	0	6	8
C2	3	26	70	54	0	0	0
Moist sedge tussock tundra							
M7S	1	6	10	36	50	0	0
M7V	1	6	8	28	97	0	0
S1	1	5	60	231	35	1	4
M11	2	14	15	21	36	0	2
S8	2	9	40	91	46	1	0
M2	3	11	31	55	98	0	0
M3	3	24	106	90	22	3	3
M10	3	15	18	24	29	0	0
Moist shrub tundra							
S4	1	3	29	223	5	0	0
S6	2	10	71	148	0	1	2
Riparian shrubland							
M4	1	0	0	0	0	0	0
S5	1	0	0	0	0	0	0
O15	2	7	97	276	0	4	11
H1	3	24	68	57	0	37	31
H3	3	15	104	137	0	26	34
Dryas terrace							
H4	2	19	78[d]	81[d]	0	9	9
H5	2	24	257	218	0	4	3
O6	3	97	886[e]	189[e]	0	34	8

[a] Disturbance level: 1 - low; 2 - moderate; 3 - high.
[b] Based on estimated cover of bare patches over 100 cm^2. tr-trace, 1%.
[c] Cover of *Eriophorum vaginatum* tillers, measured in cm^2/m^2 of bare ground.
[d] Not including *Dryas integrifolia*, which covered 72 cm^2/m^2 of bare ground.
[e] Not including *Dryas integrifolia*, which covered 36 cm^2/m^2 of bare ground.

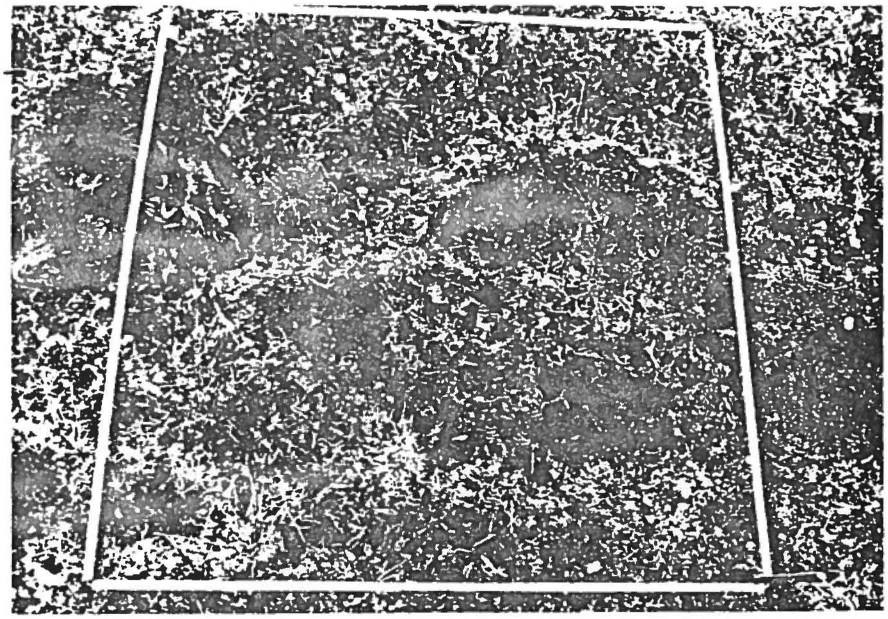


Plate 12. Quadrat photo (1 m^2) in *Dryas* terrace vegetation. Little recovery occurred on bare soil.

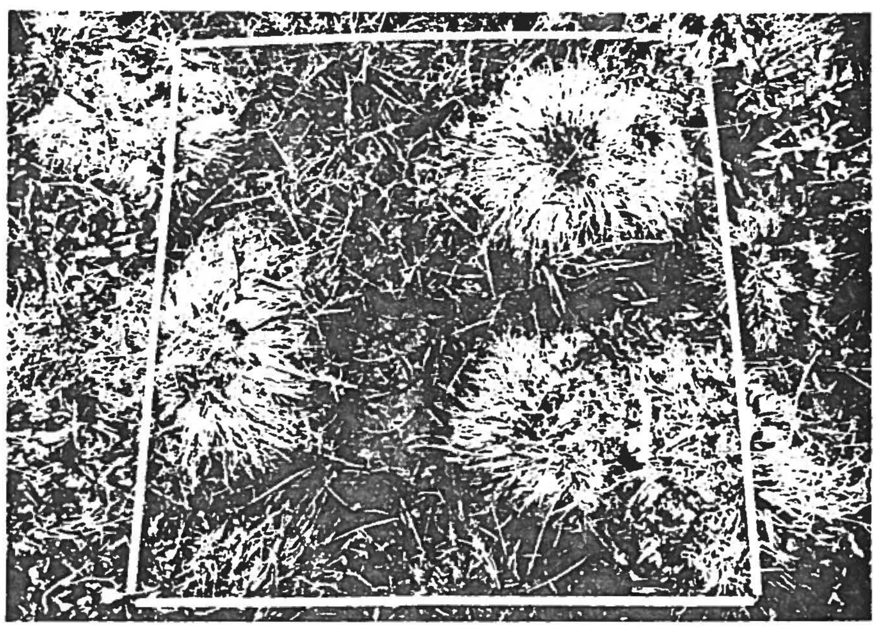


Plate 13. Quadrat photo (1 m^2) in moist sedge tussock tundra. Note tillering in center of scuffed tussock in upper right.

1985). The willow Salix planifolia ssp. pulchra was an important recolonizer on those plots where it was abundant in the undisturbed tundra. Forb species, including Polygonum viviparum, Polygonum bistorta ssp. plumosum, and Senecio atropurpureus, were common recolonizers at 2 plots. Mosses (in particular Aulacomnium turgidum) were common on the 1 wet graminoid plot (O11), but were rare to absent on the bare patches sampled in moist sedge-shrub plots.

Seedlings were rare on moist sedge-shrub plots, but accounted for 19% of all recolonizing shoots on the wet graminoid plot (O11). The high percentage of seedlings on plot O11 could be related to the unusually dry conditions of 1985. Bare patches in wet graminoid tundra plots had saturated soils but no standing water, making an ideal seedbed, whereas bare patches at other plots tended to be drier. Ebersole (1985) noted increased seedlings on sites with saturated soils, and found dry organic mats to be poor seedbeds.

Moist Graminoid/Barren Tundra Complex. This vegetation type included several floristically different communities, each of which had different recolonizing species, drawn from the common species in the undisturbed tundra. Graminoid species, especially the sedges Eriophorum angustifolium and Carex Bigelowii and the grass Arctagrostis latifolia, were the most important recolonizers of bare ground. Both Carex Bigelowii and Arctagrostis latifolia are important colonizers of the frost scars that are characteristic of barren complex. Other studies have also found A. latifolia to be important in the revegetation of disturbed sites in mesic tundra (Bliss and Wein 1972, Hernandez 1973, Lawson et al. 1978, Mitchell 1981, Ebersole 1985). Eriophorum vaginatum was an important recolonizer on plots N11 and N12.

The willows Salix phlebophylla and S. rotundifolia were common recolonizers on those plots where they were present in the undisturbed vegetation. Forbs varied in their importance as recolonizers but were the same species usually found as colonizers of natural disturbance such as frost scars, including Saussurea angustifolia, Polygonum bistorta ssp. plumosum, Polygonum viviparum, Cardamine hyperborea, and Astragalus umbellatus. Mosses and seedlings were both either rare or absent as recolonizers of barren complex tundra.

Moist Sedge Tussock Tundra. Recolonization of bare patches in tussock tundra was mainly by retillering of the tussock-forming sedge Eriophorum vaginatum. While there was no difference between 1984 and 1985 plots in the amount of E. vaginatum (cm^2/m^2 of bare ground), there were fewer shoots of other species on the 1-year-old plots. This was apparently due to the rapid resprouting of E. vaginatum tussocks in the first year after disturbance, followed by the slower regrowth of shrubs, forbs, and other graminoids in the second year. The complete absence of E. vaginatum seedlings is in marked contrast to other studies of disturbance in tussock tundra (Chapin and Chapin 1980, Gartner et al. 1983, Ebersole 1985), but agrees with the lack of germinable buried seed found in selected ANWR sites (Felix and Jorgenson 1985). Ebersole (1985) and Racine (1979) provide additional evidence for a decrease in tussock tundra seedbank size with increasing latitude. The grass Arctagrostis latifolia was also commonly found recolonizing bare ground in tussock tundra.

Shrubs made up a small percentage of the recolonizing shoots on bare patches in tussock tundra, and thus were infrequent recolonizers compared with graminoid species. Vaccinium vitis-idaea was the most common recolonizing shrub species; shoots of Salix planifolia ssp. pulchra and Ledum palustre ssp. decumbens occurred less frequently. Lawson et al. (1978) reported that shrubby species, including V. vitis-idaea, S. planifolia, and L. palustre, were rarely seen as pioneers on severely disturbed areas. Ebersole (1985) reported that these shrub species sprouted from buried roots in small bare patches, and that V. vitis-idaea was the most important recolonizing species.

Mosses were found recolonizing 2-year-old trails in tussock tundra. Common mosses included Aulacomnium turgidum, A. palustre, Pohlia sp. and Polytrichum juniperinum.

Moist Shrub Tundra. Conclusions about recolonization in this type are tentative because only 2 plots were sampled. Graminoids were again the most important recolonizers. Vegetative shoots of Eriophorum vaginatum and Hierochloe alpina were common on plot S4, and Arctagrostis latifolia and Luzula confusa were common on plot S6. The importance of Arctagrostis and other graminoids in shrub tundra agrees with studies on tundra recolonization by Hernandez (1973).

Shrubs were common recolonizers. The ericaceous shrub Vaccinium vitis-idaea was commonly found resprouting on both plots S4 and S6, and Salix phlebophylla accounted for 22% of all recolonizing shoots on site S6, where it was a minor component of the undisturbed vegetation. Betula nana s.l. and Ledum palustre ssp. decumbens were absent or rare as recolonizers. Forbs, as a group, were also important recolonizers of shrub tundra. Most recolonizing forbs were not important members of the undisturbed vegetation, but were species which have been previously found to be good colonizers, such as Cardamine hyperborea, Saxifraga punctata, Stellaria longipes, Rubus chamaemorus, Polygonum bistorta ssp. plumosum, and Pedicularis capitata (Bliss and Wein 1972, Lawson et al. 1978, Everett et al. 1985, Ebersole 1985). Little recolonization of mosses occurred on shrub tundra plots, as reported previously by Ebersole (1985).

Riparian Shrubland. Prostrate shrubs were the main recolonizers of riparian plots, usually resprouting from buried roots or stems. The prostrate willow Salix reticulata was the most important recolonizer on plots O15 and H3, while the ericaceous shrub Arctostaphylos rubra was the main recolonizer on H1. Increased cover of A. rubra has previously been reported on vehicle trails (Hernandez 1973). Recolonizing shoots of Salix hastata, S. lanata ssp. richardsonii, and S. brachycarpa ssp. niphoclada were found on bare patches when they occurred in the nearby undisturbed tundra.

Legumes (Astragalus umbellatus and various Oxytropis spp.) were the most common recolonizing forbs, constituting 15-20% of all recolonizing shoots on riparian sites. Here, as in other vegetation types, recolonization was principally by vegetative means. However, seedlings (in particular Oxytropis spp. or Astragalus umbellatus) were also important, constituting 4%, 20%, and 35% of all recolonizing shoots at the 3 plots with bare patches. Vegetative shoots of graminoids, including Festuca rubra and Carex spp., were also found on bare patches in riparian shrubland.

Dryas Terrace. Patches of bare ground were common on trails in this vegetation type. As in riparian shrubland, recolonization of bare ground was mainly by resprouting of prostrate shrubs, including Dryas integrifolia, Salix reticulata, and S. rotundifolia. The high numbers of recolonizing shoots suggest that while the surface stems and leaves were removed from the bare patches, some buried stems and roots were not seriously affected. The numbers of recolonizing shoots on *Dryas* terrace plots were probably overestimated somewhat, because small depressions that were not seriously disturbed were often difficult to distinguish from surrounding bare ground.

Equisetum variegatum also was commonly resprouting from buried rhizomes on sites H5 and O6. Other studies have found *E. arvense* to be an aggressive recolonizer of moist tundra (Lawson et al. 1978, Ebersole 1985), and it is possible that *E. variegatum* fills a similar role on those *Dryas* terrace sites where it is common.

Recolonizing forbs (mainly the legumes *Astragalus umbellatus* and *Oxytropis nigrescens*) were common although they comprised a small percentage of total recolonizing shoots. Legumes, especially *Oxytropis nigrescens*, were also the main seedlings found on *Dryas* terrace plots (seedlings, though common, were still less than 5% of all recolonizing shoots). *O. nigrescens* was also an important recolonizer of *Dryas* sites at Cape Thompson (Everett et al. 1985).

Plant Productivity and Nutrient Concentrations

Plant productivity was higher on disturbed plots than on adjacent controls in a number of cases. Mass of current year's growth of most major species increased significantly on at least 1 disturbed plot, and significant increases occurred in at least 1 species on each plot. Twigs (current year's growth) of dwarf birch (*Betula nana* s.l.) and diamond-leaf willow (*Salix planifolia* ssp. *pulchra*) were significantly longer on all disturbed plots than on corresponding control plots. The sedges *Carex aquatilis* and *Eriophorum angustifolium* had a significantly greater number of leaves per plant on disturbed plots in 4 out of 5 cases.

Nitrogen concentrations (% dry weight) in the major species generally increased on disturbed plots, while phosphorus concentrations were highly variable. Nitrogen and phosphorus concentrations in sedges generally decreased on disturbed plots in wet and moist sedge-shrub tundra. However, the total amount of nutrients in sedges on disturbed plots was similar to or greater than that on control plots, because the mass of sedges generally increased when nutrient concentrations decreased. A detailed discussion of productivity and nutrient changes of individual species follows.

Wet Graminoid and Moist Sedge-Shrub Tundra. Productivity of *Carex aquatilis* increased on the 2 most disturbed plots (O11, T32), where mass of leaves and number of live leaves per plant on disturbed plots were significantly higher than on control plots (Table 9, Fig. 10). Changes in nitrogen concentrations in shoots of *C. aquatilis* were variable. Nitrogen concentration showed a statistically significant decrease on the least disturbed plot (M1), an increase on the moderately disturbed plot (O11), and no change on the most disturbed plot (T32). Phosphorus concentrations (especially in the below ground stems) decreased significantly in all disturbed plots. The total amounts of nitrogen and phosphorus in *C. aquatilis* showed no significant decreases in disturbed plots compared to controls. Leaf mass had increased in all cases where nutrient concentrations decreased, and the total amount of nutrients in *C. aquatilis* on disturbed plots were either similar to or greater than those on control plots.

Table 10. Leaf and stem mass (g/20 shoots), nitrogen and phosphorus concentrations (% dry weight), and total nitrogen and phosphorus (mg/20 shoots) of current year's growth of major plant species in disturbed (D) and control (C) plots in tussock tundra (S8, M2) and shrub tundra (S4), coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	S8 (L2)[a]					M2 (L3)					S4 (L1)				
	Leaf		Stem			Leaf		Stem			Leaf		Stem		
Species	D	C	D	C	AOV[b]	D	C	D	C	AOV[b]	D	C	D	C	AOV[b]
Mass															
Carex Bigelowii											1.44	1.73	0.51	0.63	
Eriophorum vaginatum	0.78	0.71	0.62	0.54	*	1.03	0.99	0.75	0.71		0.75	0.80	0.73	0.63	
Betula nana s.l.[c]	0.92	0.86	0.38	0.37		1.33	0.91	0.57	0.33	*	1.06	0.74	0.48	0.30	*
Ledum palustre ssp. decumbens[c]	0.61	0.55				0.65	0.61				0.90	0.71			*
Salix planifolia ssp. pulchra						1.94	1.79	0.45	0.28	*	2.32	2.11	0.56	0.43	
Vaccinium vitis-idaea[c]	0.46	0.43				0.45	0.45				0.76	0.72			
Nitrogen															
Carex Bigelowii											2.50	2.30	1.71	1.39	
Eriophorum vaginatum	1.88A	1.73B	1.23C	1.20C	*	1.91	1.69	1.07	1.02	*	1.50	1.61	1.16	1.05	
Betula nana s.l.	2.39	2.30	2.06	2.12		2.72A	2.33B	2.11BC	2.04C	*	2.39	2.17	2.04	1.89	*
Ledum palustre ssp. decumbens	1.96	1.87			*	2.16	1.86			*	1.81	1.50			
Salix planifolia ssp. pulchra						2.41A	2.14B	1.59C	1.67C	*	2.86A	2.49A	1.89B	2.06B	
Vaccinium vitis-idaea	1.41	1.23			*	1.56	1.21				1.41	1.14			*
Total nitrogen															
Carex Bigelowii											35.4	40.0	8.6	8.7	
Eriophorum vaginatum	14.6	12.3	7.6	6.4	*	19.5	16.7	8.0	7.3	*	11.3	13.0	8.4	6.6	
Betula nana s.l.	21.9	19.8	7.9	7.8		36.0	21.0	12.0	6.8	*	25.4	16.2	9.7	5.6	*
Ledum palustre ssp. decumbens	11.9	10.2				13.9	11.4				16.3	10.7			*
Salix planifolia ssp. pulchra						46.6A	38.2B	7.1C	4.6C	*	66.2	52.9	10.5	9.1	
Vaccinium vitis-idaea	6.5	5.2				7.1	5.3				10.7	8.2			
Phosphorus															
Carex Bigelowii											0.16	0.15	0.21	0.19	*
Eriophorum vaginatum	0.22	0.20	0.32	0.31		0.21	0.19	0.28	0.27		0.19	0.17	0.33	0.27	
Betula nana s.l.	0.24	0.23	0.24	0.25		0.29	0.25	0.27	0.25	*	0.22	0.22	0.22	0.20	
Ledum palustre ssp. decumbens	0.21	0.20				0.25	0.21			*	0.19	0.17			
Salix planifolia ssp. pulchra						0.21A	0.18B	0.21A	0.22A		0.22	0.24	0.24	0.29	*
Vaccinium vitis-idaea	0.16	0.15				0.21	0.14			*	0.15	0.12			*
Total phosphorus															
Carex Bigelowii											2.3	2.5	1.1	1.2	
Eriophorum vaginatum	1.7	1.4	2.0	1.7	*	2.2	1.9	2.1	1.9		1.4	1.3	2.3	1.7	
Betula nana s.l.	2.2	2.0	0.9	0.9		3.8A	2.3B	1.6BC	0.8C	*	2.3	1.7	1.0	0.6	*
Ledum palustre ssp. decumbens	1.3	1.1			*	1.6	1.3				1.7	1.2			*
Salix planifolia ssp. pulchra						4.0A	3.1B	1.0C	0.6C	*	5.1	5.0	1.3	1.3	
Vaccinium vitis-idaea	0.7	0.7				1.0	0.6			*	1.1	0.8			

[a] L1, L2, L3 - low, moderate, and high levels of disturbance.
[b] AOV - 2-way analysis of variance by treatment and plant part.
* - significant difference between disturbed and control plots ($P<0.05$).
A,B,C - means with the same letter do not differ significantly ($P<0.05$, Bonferroni's test, conducted when interaction was significant).
[c] Mass equals g/40 shoots for B. nana, L. palustre, and V. vitis-idaea. Stem measurements were not made for L. palustre and V. vitis-idaea, because sample sizes were too small.

Table 9. Leaf and stem mass (g/20 shoots), nitrogen and phosphorus concentrations (% dry weight), and total nitrogen and phosphorus (mg/20 shoots) of current year's growth of major plant species in disturbed (D) and control (C) plots in wet graminoid (O11) and moist sedge-shrub tundra (M1, T32), coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	O11 (L2)[a]					M1 (L1)					T32 (L3)				
	Leaf		Stem			Leaf		Stem			Leaf		Stem		
Species	D	C	D	C	AOV[b]	D	C	D	C	AOV[b]	D	C	D	C	AOV[b]
Mass															
Carex aquatilis	2.60A	1.91B	0.84C	0.70C	*	4.76	4.40	1.48	1.50		3.46A	2.01B	1.13C	0.74C	*
Eriophorum angustifolium						3.68	3.70	2.50	2.72		2.98	2.07	2.10	1.97	*
Salix planifolia ssp. *pulchra*						2.87	1.81	1.09	0.34	*	1.82	1.27	0.84	0.24	*
Nitrogen															
Carex aquatilis	2.39A	2.11B	1.57C	1.64C	*	2.28	2.33	1.72	2.03	*	2.49	2.41	1.90	2.31	
Eriophorum angustifolium						1.93A	1.98A	1.32B	1.69A	*	1.93A	2.01A	1.34B	2.17A	*
Salix planifolia ssp. *pulchra*						2.60A	2.21B	1.51C	1.52C	*	2.93A	2.09B	1.78B	1.79B	*
Total nitrogen															
Carex aquatilis	61.9A	40.3A	13.1B	11.4B	*	108.4	103.1	25.2	30.9		86.4A	48.4A	21.4B	17.0B	*
Eriophorum angustifolium						71.2	73.1	32.9	46.0		57.3	41.5	28.0	42.0	
Salix planifolia ssp. *pulchra*						74.7A	40.0B	16.4C	5.1C	*	52.9A	26.4B	14.8BC	4.2C	*
Phosphorus															
Carex aquatilis	0.20	0.22	0.25	0.29	*	0.19	0.22	0.26	0.33	*	0.16A	0.19AB	0.22B	0.30C	*
Eriophorum angustifolium						0.18	0.20	0.27	0.32	*	0.18A	0.21A	0.24A	0.36B	*
Salix planifolia ssp. *pulchra*						0.23	0.19	0.20	0.20		0.26A	0.17B	0.22AB	0.22AB	*
Total phosphorus															
Carex aquatilis	5.3	4.1	2.1	2.0	*	9.0	9.4	3.7	5.0		5.5A	3.7B	2.5C	2.2C	*
Eriophorlum angustifolium						6.8	7.2	6.9	8.7		5.5	4.2	5.0	7.1	
Salix planifolia ssp. *pulchra*						6.5A	3.4B	2.2B	0.7C	*	4.6	2.1	1.9	0.5	*

[a] L1, L2, L3 - low, moderate, and high levels of disturbance.
[b] AOV - 2-way analysis of variance by treatment and plant part.
* - significant difference between disturbed and control plots ($P<0.05$).
A,B,C - means with the same letter do not differ significantly ($P<0.05$, Bonferroni's test, conducted when interaction was significant).

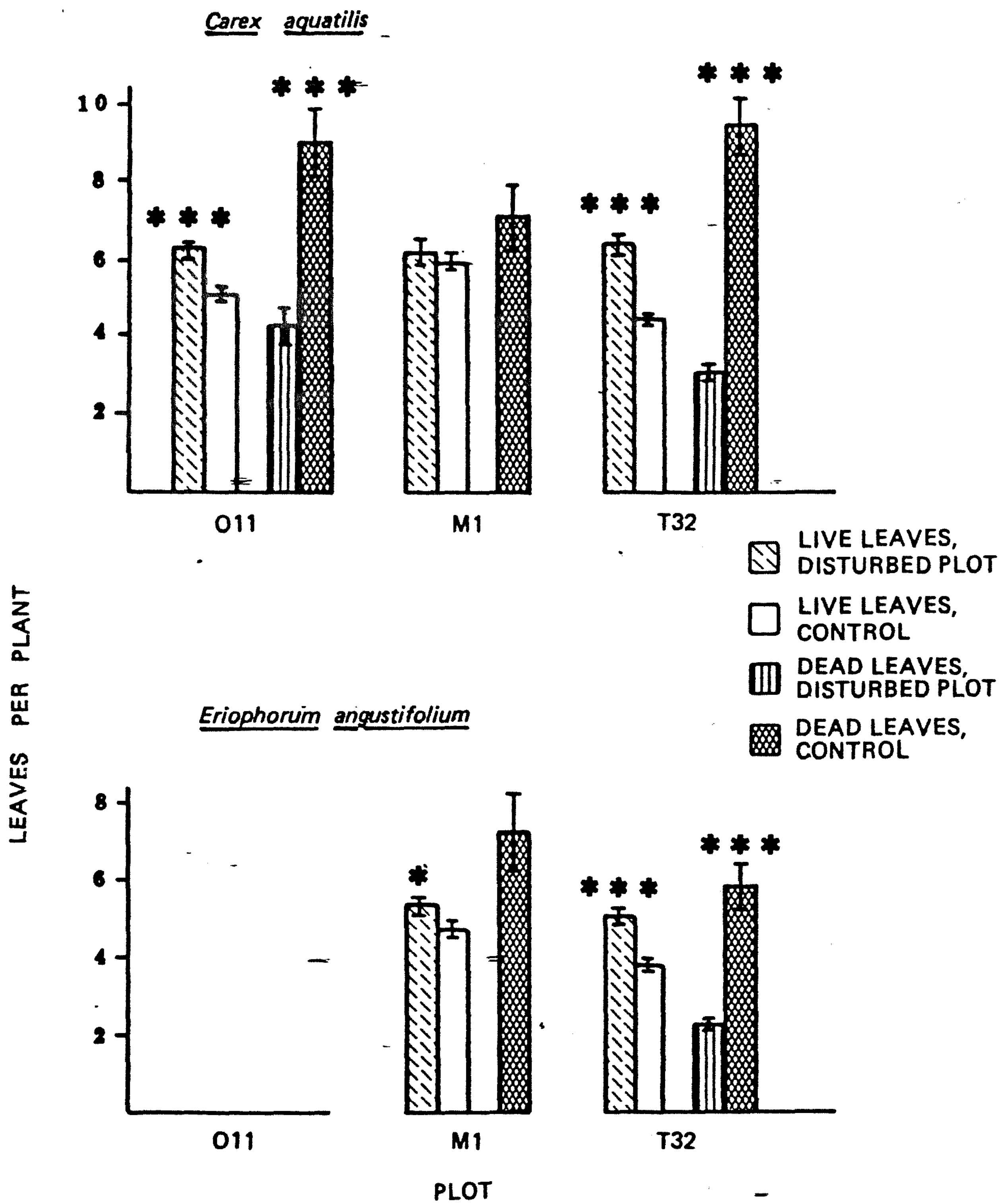


Fig. 10. Numbers of live and dead leaves per plant on Carex aquatilis and Eriophorum angustifolium 2 years after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1985. Data are means ± SE, N=20. *, *** indicates a significant difference between disturbed and control plots (t-test, $P < 0.05$, 0.001).

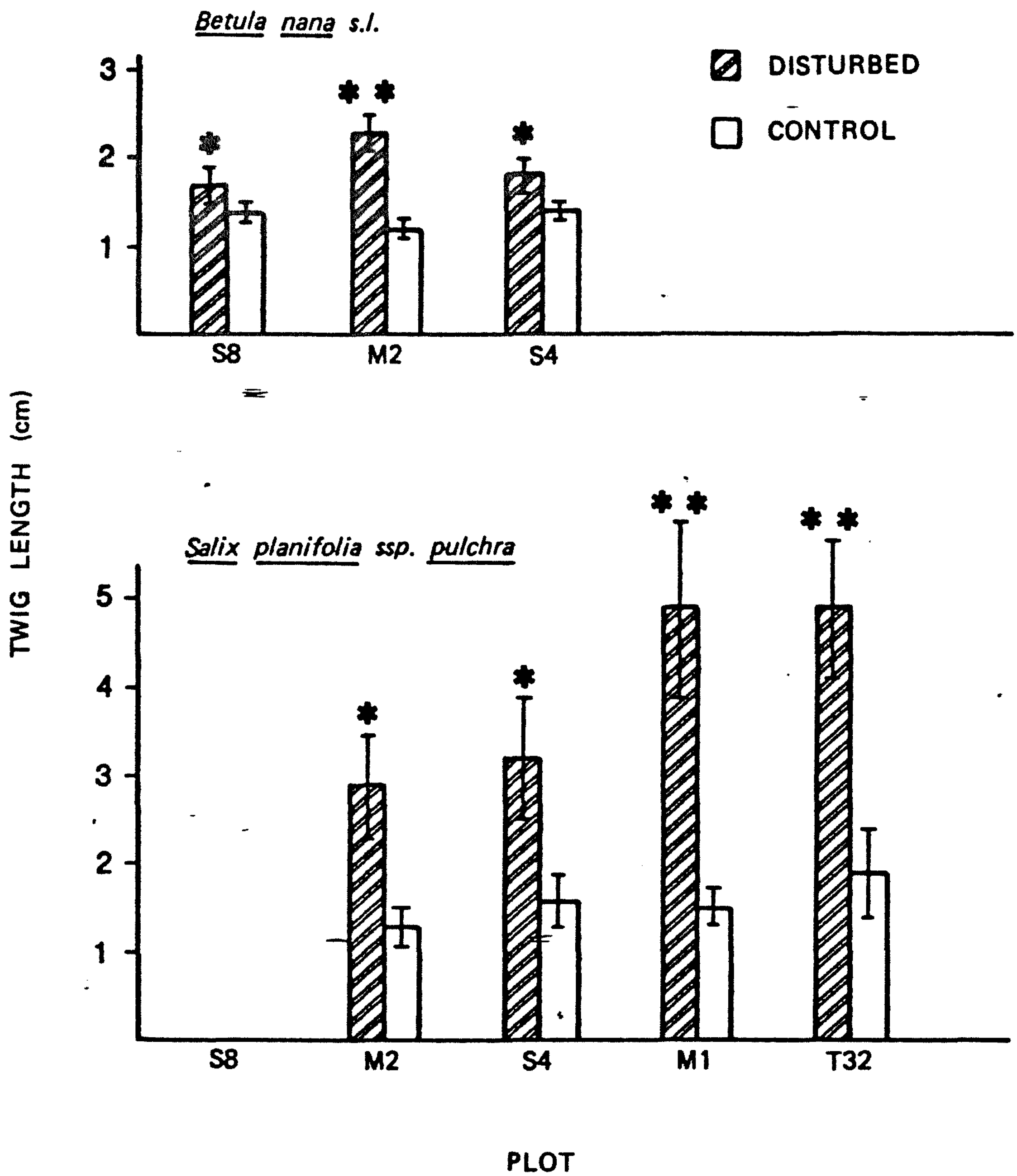


Fig. 11. Twig length of current year's growth of Betula nana s.l. (dwarf birch) and Salix planifolia ssp. pulchra (diamond-leaf willow) 2 years after winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1985. Data are means $\pm$ SE, N=40 for B. nana, 20 for S. planifolia. *, ** indicates a significant difference from control (t-test, $P < 0.05, 0.01$).

Similar productivity increases in *Eriophorum angustifolium* occurred on disturbed plots M1 and T32, with significant increases in leaves per plant on both plots and a significant increase in mass on the most disturbed plot T32. Nitrogen and phosphorus concentrations in the below ground stems decreased significantly on both disturbed plots. The total amounts of nitrogen and phosphorus in *E. angustifolium* ~~in~~ disturbed and control plots did not differ significantly.

The numbers of standing dead leaves on individual plants of *E. angustifolium* and *C. aquatilis* were significantly lower on the vehicle trails than on adjacent controls (Fig. 10), making the trails appear greener than the surrounding area. Control plots had approximately 3 times more dead leaves per plant than the 1-year-old disturbed plots. Therefore, if leaves are added at the same rate each year, dead leaves on plants in disturbed and control plots should be equal in 2 more years, and trails should no longer appear as visible green trails due to a decrease in standing dead vegetation.

Productivity of *Salix planifolia* ssp. *pulchra* increased on both disturbed plots in moist sedge-shrub tundra. Leaf and stem mass and twig length of current year's growth had statistically significant increases on the disturbed plots (Table 9, Fig. 11). Nitrogen concentrations and total nitrogen in the leaves increased significantly on both disturbed plots. Phosphorus concentration in the leaves increased significantly on the most disturbed plot (T32), and total phosphorus increased in stems and leaves on both plots.

Increases in productivity of plants on vehicle trails in wet and moist sedge tundra have been reported in previous studies (Challinor and Gersper 1975, Chapin and Shaver 1981). These studies measured biomass per area, whereas we have measured biomass per shoot of current year's growth. The productivity increases that we measured in current year's growth were rarely reflected in cover of plants on disturbed plots compared with adjacent controls. *E. angustifolium* was the only species with significantly higher cover on disturbed plots. These higher cover values were related to the increased number of leaves per plant on plots M1 and T32 and increased mass on T32. Chapin and Shaver (1981) also found that tillers of *E. angustifolium* produced more leaves in vehicle tracks than in adjacent controls. Cover of *S. planifolia* was significantly less on the most disturbed plot T32 than on its adjacent control, indicating that although productivity per shoot was greater, shoot density was much lower on the disturbed plot. The significantly longer twigs and greater mass of current year's growth on T32 indicate that recovery is beginning to occur, but more time will be required for the cover and biomass of *S. planifolia* to reach predisturbance conditions.

Previous studies reported increased nitrogen and phosphorus concentrations on plants in vehicle trails, similar to our findings for *S. planifolia* (Challinor and Gersper 1975, Chapin and Shaver 1981). However, we found decreased nutrient concentrations in sedges, especially in the below ground stems, on vehicle trails. Most of the trails in the previous studies had more disruption of the organic mat and were older than the seismic trails on ANWR, which could account for the difference in results.

Increased plant productivity and nutrients in disturbed areas are due in part to higher soil temperatures and greater thaw depths which permit deeper root penetration of some plant species (Chapin and Shaver 1981). Other factors which may influence plant growth on vehicle trails include: earlier thawing of soil which lengthens the growing season, changes in soil bulk density or pH which increase nutrient availablility, and more rapid decomposition of litter making nutrients available.

Moist Sedge Tussock and Shrub Tundra. Sedges had some increases in productivity and nutrients on disturbed plots in tussock and shrub tundra. *Carex Bigelowii* had increased concentrations of nitrogen and phosphorus but no change in mass on the 1 disturbed plot where it was sampled (Table 10). *Eriophorum vaginatum* had higher mass on 1 disturbed plot (S8) and higher concentrations of nitrogen and total amounts of nitrogen on the 2 most disturbed plots (S8, M2). No changes occurred in phosphorus concentrations in *E. vaginatum*.

The deciduous shrubs *Betula nana* s.l. and *Salix planifolia* ssp. *pulchra* had longer twigs of current year's growth on the 3 disturbed plots than on nearby controls (Fig. 11). Mass, nitrogen concentration, and total nitrogen of both species on the most disturbed plot M2 and of *B. nana* on S4 were significantly greater. Phosphorus concentrations were variable, higher in *B. nana* on the most disturbed plot M2, but lower in *S. planifolia* on plot S4. Total amounts of phosphorus in the deciduous shrubs were greater on disturbed plots in all cases except for *S. planifolia* on plot S4 which showed no significant differences between the disturbed and control samples.

The evergreen shrubs *Ledum palustre* ssp. *decumbens* and *Vaccinium vitis-idaea* showed no changes in mass in most cases. Higher nitrogen concentrations in leaves occurred in each species on 2 disturbed plots. Phosphorus concentration was significantly greater for leaves of both species in the most disturbed plot (M2) and for *V. vitis-idaea* on plot S4. Total nitrogen and phosphorus in evergreen shrubs did not differ between control and disturbed plots in most cases.

Although increased species productivity occurred in a number of cases on disturbed plots in tussock and shrub tundra, plant cover values for all species remained the same or were significantly lower on disturbed plots compared to adjacent controls. These cover values indicate that the number of shoots and biomass per area were generally lower when twig length or mass per shoot were greater. Increased productivity on disturbed plots in ANWR indicates that recovery is beginning to occur. Increases in shoot weight and nitrogen concentrations have been reported previously for *E. vaginatum* on vehicle trails in tussock tundra (Chapin and Shaver 1981). This study also found increased phosphorus concentrations in *E. vaginatum*, which were not found in our study. Regrowth of *S. planifolia* has been reported in disturbed areas in a number of studies (Lawson et al. 1978, Ebersole 1985). Evergreen shrubs including *L. palustre* and *V. vitis-idaea* are rare on old vehicle trails (Lambert 1972, Hernandez 1973, Lawson et al. 1978, Chapin and Chapin 1980, Chapin and Shaver 1981, Ebersole 1985) which is consistent with our findings of little increase in productivity after disturbance. However, these studies also reported that *B. nana* was rare ~~in~~ disturbed sites, and no previous studies have reported increased productivity of *B. nana* similar to our results.

Impacts to the Active Layer

Thaw Depths

Thaw depths (depth to permafrost) were significantly greater ($P<0.01$) in disturbed plots than in corresponding control plots at 31 of the 69 plots (Table 11). Thaw depth increases ranged from 2 to 16 cm, and occurred at all levels of disturbance. Most plots did not have significant interaction effects indicating that the change in thaw depths between disturbed and control plots was consistent over the 2 years. Four plots did have a significant interaction with a larger difference between disturbed and control plots in 1985 than in 1984. The response of the active layer in the wetter, sedge-dominated vegetation types and the drier upland vegetation types differed due to the nature of the disturbances.

Five of the 8 wet graminoid plots had statistically significant increases in thaw depth in disturbed plots, ranging from 3 to 10 cm in 1985 (Table 11). Significant increases in thaw depth occurred at 2 plots with level 1 disturbance, and was probably caused by increases in heat absorption on the trails due to knocking down of the light-colored standing dead leaves. There was a general increase in the difference between disturbed and control from 1984 to 1985 at 5 of the 6 plots with 2 years' data. Only 1 increase (T21) was significant as shown by the interaction effect. This plot was on a narrow cat-train trail, which had obvious track depression and standing water the first year after disturbance.

Within moist sedge-shrub tundra, there was a general trend of more significant thaw depth increases at higher levels of disturbance. Significant increases occurred at 2 of 8 level 1 plots, at 3 of 6 level 2 plots, and at 3 of 4 level 3 plots (Table 11). Some of the greatest increases in thaw depths occurred on narrow cat-train trails with obvious track depression as in wet graminoid tundra. Large increases in thaw depths occurred on disturbed plots C1 and T32, where the surface had been compacted to below water level along portions of these trails in 1984. Three plots (M1, T25, and T32) had significant treatment by year interaction effects and deeper thaw depths on disturbed plots as compared with the control plots in 1985 than in 1984. Thaw depths in this vegetation type appeared particularly sensitive to disturbance, because compaction of trails can cause visible changes in surface moisture which increases energy absorption on trails.

Statistically significant increases in thaw depth occurred at moderate and high levels of disturbance in barren complex tundra. Thaw depths were highly variable, corresponding with the amount of frost scar activity in each area. In tussock tundra and shrub tundra, thaw depth increases occurred at all levels of disturbance and no general pattern was evident. This lack of pattern may be related to the changes in short wave energy absorption and reflection (albedo) on trails which are evident on aerial photography. Trails in upland vegetation types appear lighter on photos when considerable amounts of litter are present and darker when soil is exposed. The contrasting albedos of litter (high reflectance) and exposed soil (low reflectance) may influence thawing of the active layers.

Table 11. Changes in thaw depths (cm) resulting from winter seismic exploration, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Veg. type	Plot	Dist. level	1984			1985			1984	1985			
			N	$\overline{Dx}$	$\overline{Cx}$	N	$\overline{Dx}$	$\overline{Cx}$	D-C	D-C	D>C	84>85	Int.
Wet	T16	1	10	35	32	30	26	26	3	0		*	
graminoid	N1	1	10	45	47	30	38	32	-2	6		*	
tundra	O5	1	10	38	40	30	34	29	2	5	*	*	
	O10	1	16	30	29	30	34	31	1	3	*	*	
	O11	2	40	35	31	30	34	28	4	6	*	*	
	T5	3	10	40	38				2				
	T21	3	30	35	31	30	35	25	5	10	*	*	*
	T37	3				30	33	27		6	*		
Moist	M1	1	40	35	33	30	34	26	2	9	*	*	*
sedge-	O18	1				30	26	19		7	*		
shrub	O19	1				30	28	28		0			
tundra	O20	1				30	34	32		2			
	M6	1				30	30	30		1			
	N2	1	30	42	40	30	33	44	2	-11	+		*
	N8	1	30	41	37	30	38	35	4	4	*	*	
	T41	1				30	29	25		5	*		
	C3	2				30	23	17		7	*		
	T18	2	30	35	38	30	35	35	-3	0			
	T25	2	30	26	25	30	24	16	1	8	*	*	*
	T26	2	10	32	29				4				
	T38	2				30	27	17		9	*		
	T39	2				30	50	48		2			
	O12	3	40	39	33	30	36	30	6	6	*	*	
	C1	3				30	32	16		16	*		
	T32	3	39	32	28	30	32	17	5	14	*	*	*
	T31	3				30	18	17		1			
Moist	N4	1	30	45	46	30	41	40	1	0		*	
graminoid/	N5	1	30	59	55	30	46	50	4	-5		*	
barren	N7	1	30	34	33	30	29	25	1	4		*	
tundra	N9	1	30	62	57	30	50	44	4	6		*	
complex	T3	1				30	39	39		0			
	N11	2	40	57	49	30	48	43	8	6	*	*	
	N12	2	10	52	41	30	52	42	11	10	*		
	O3	2	20	29	26	30	26	21	3	5	*	*	
	O7	2				30	22	25		-2			
	N6	2	30	42	44	30	33	30	-2	3		*	
	T8	2	10	47	44	30	42	35	3	7	*	*	
	T12	2	10	41	37	30	36	32	5	4			
	C2	3				30	31	27		3			
	T19	3	30	48	41	30	41	30	7	11	*	*	
	T24	3				30	39	31		8	*		

Table 11. Continued.

Veg. type	Plot	Dist. level	1984 N	1984 $\overline{Dx}$	1984 $\overline{Cx}$	1985 N	1985 $\overline{Dx}$	1985 $\overline{Cx}$	1984 D-C	1985 D-C	D>C	84>85	Int.
Moist sedge tussock tundra	T15	0	10	43	42	30	37	29	2	8	*	*	
	T42	0				30	39	40		1			
	M7S	1				30	34	32		2			
	M7V	1				30	30	32		2			
	S1	1	40	36	31	30	29	21	5	8	*	*	
	S7	1	10	26	29	30	22	19	-3	3		*	
	T13	1	10	38	42	30	30	28	-4	1		*	
	T23	1	31	41	38	30	38	29	3	8	*	*	
	M11	2				30	30	29		1			
	S8	2	40	27	26	30	20	18	1	2		*	
	08	2	10	32	26	30	29	24	6	5	*		
	T28	2	30	27	24	30	25	23	2	2			
	M2	3	40	37	33	30	32	30	4	2		*	
	M3	3	40	29	24	30	26	23	5	3	*		
	M10	3				30	29	29		0			
	M5	3	20	40	32	30	34	30	8	4	*	*	
	T22	3	35	42	38	30	40	31	4	9	*	*	
Moist shrub tundra	S4	1	40	27	27	30	23	23	0	1		*	
	N3	1	30	29	27	30	23	21	2	2	*	*	
	S2	1	10	32	28	30	23	22	4	1		*	
	S3	1	10	33	28	30	24	26	5	-2		*	
	S6	2	40	25	22	30	20	19	3	1	*	*	
	T4	2	10	28	30	30	22	21	2	1		*	
	C4	3				30	23	21		2			
	T29	3	10	23	22	30	20	18	1	2		*	
Riparian shrubland	01	2	10	51	49				3				
	S9	2				30	28	26		3	*		
	H3	3				30	43	48		-5	+		

D - disturbed plots.
C - control plots.
Int. - treatment x year interaction effect.
* - indicates a significant difference (P' 0.01) between treatments or years (t-test on plots with 1 year's data, 2-way analysis of variance on plots with 2 years' data).
+ - C D, P 0.01.

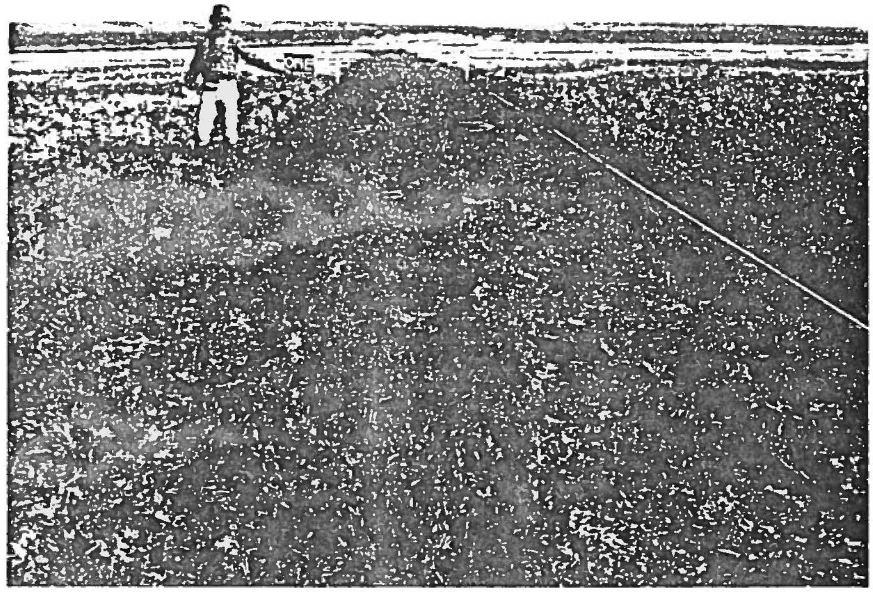
Thaw depths were generally less deep in 1985 than in 1984. The mean thaw depth of the 1984 control plots was 35 cm as compared to 28 cm for the same plots in 1985. The thaw penetration in the trails in 1985 generally did not exceed the amount measured in the same trails in 1984, indicating that the increased thaw depths measured in 1985 did not penetrate the permafrost. The substantial difference in thaw depths between the 2 years can be attributed in large part to the wetter tundra surface in 1984 since surface moisture is one of the principal factors controlling heat absorption (Jorgenson 1986). The total precipitation for the 3 summer months was 95 mm in 1984 as compared to 28 mm in 1985 at Barter Island (U.S. Dept. of Commerce, NOAA 1984, 1985). Summer temperatures appeared to have little influence, as 1984 averaged 1° C cooler than 1985.

The thaw depth increases measured on seismic trails in ANWR are likely to persist for quite a while. Thaw depth increases of 4 to 6 cm in moist sedge tundra, 9 to 10 cm in barren complex, and 4 to 8 cm in tussock tundra were still evident on winter seismic trails just west of the Canning River and in the NPR-A, 4 years after disturbance (Envirosphere 1985). Hernandez (1973), studying winter seismic trails on dwarf-shrub heath, found a 4 cm increase on a 1-year-old trail and an 8 cm increase on a 4-year-old trail on the Tuktoyaktuk Peninsula, N.W.T. Thaw depths in low level disturbances around a drill site in NPR-A were not found to be different from undisturbed terrain 28 years later (Lawson et al. 1978). Abele et al. (1984) found a thaw depth difference of 6 cm on a 5-year-old trail resulting from 10 passes of a large rolligon. They also found, however, that recovery towards initial levels could be rapid. Thaw depth differences in a track resulting from 50 passes of a weasel decreased from 11 cm in the second year to 1 cm the fourth year.

Track Depression

Increased thaw depth in a trail can cause track depression if thaw settlement occurs. Thaw settlement is defined as the subsidence of the ground surface that results from melting of excess ice in the soil and consolidation of the soil mass. Track depression measurements represent the trail depth or cross-sectional area lost in the trail due to both thaw settlement and compression of the surface (Plate 14). Depths and cross-sectional areas were estimated for the 4 intensive study plots (C1, C3, 014, T32) where track depressions were evident on cross-sectional profiles plotted from the elevation data (Table 12, Fig. 12). Track depressions at the other 23 plots were too slight to discern from the profiles or were not evident because of the variable micro-relief of the plots. The 4 plots with measurable track depression were all moist sedge-shrub tundra sites where multiple passes of cat-trains occurred on narrow paths. Track depressions on C1 and T32 were obvious in the field, but the smaller depressions of 5 and 6 cm on plots C3 and 014 were not obvious. Track depression was also evident at photo-trend plot T21 in wet graminoid tundra, but no measurements were made.

Changes in track depression (depth or cross-sectional area) between 1984 and 1985 were not significant on T32, the only plot with measurable track depressions and 2 years' data. An increase in track depression in 1985 would have indicated that thaw settlement had occurred. Since the thaw penetration in the trails in 1985 generally did not exceed the amount of thaw in the trails in 1984, no thaw settlement resulting from melting out of excess ice is expected to have occurred in 1985.



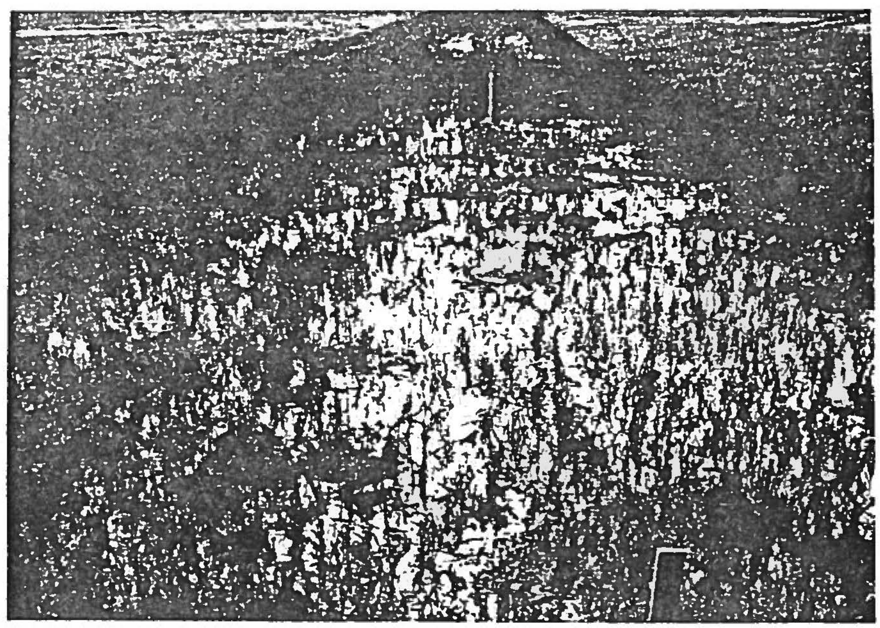


Plate 14. Trails with track depression were dry in 1985, but were mostly filled with standing water in 1984 (lower photo).

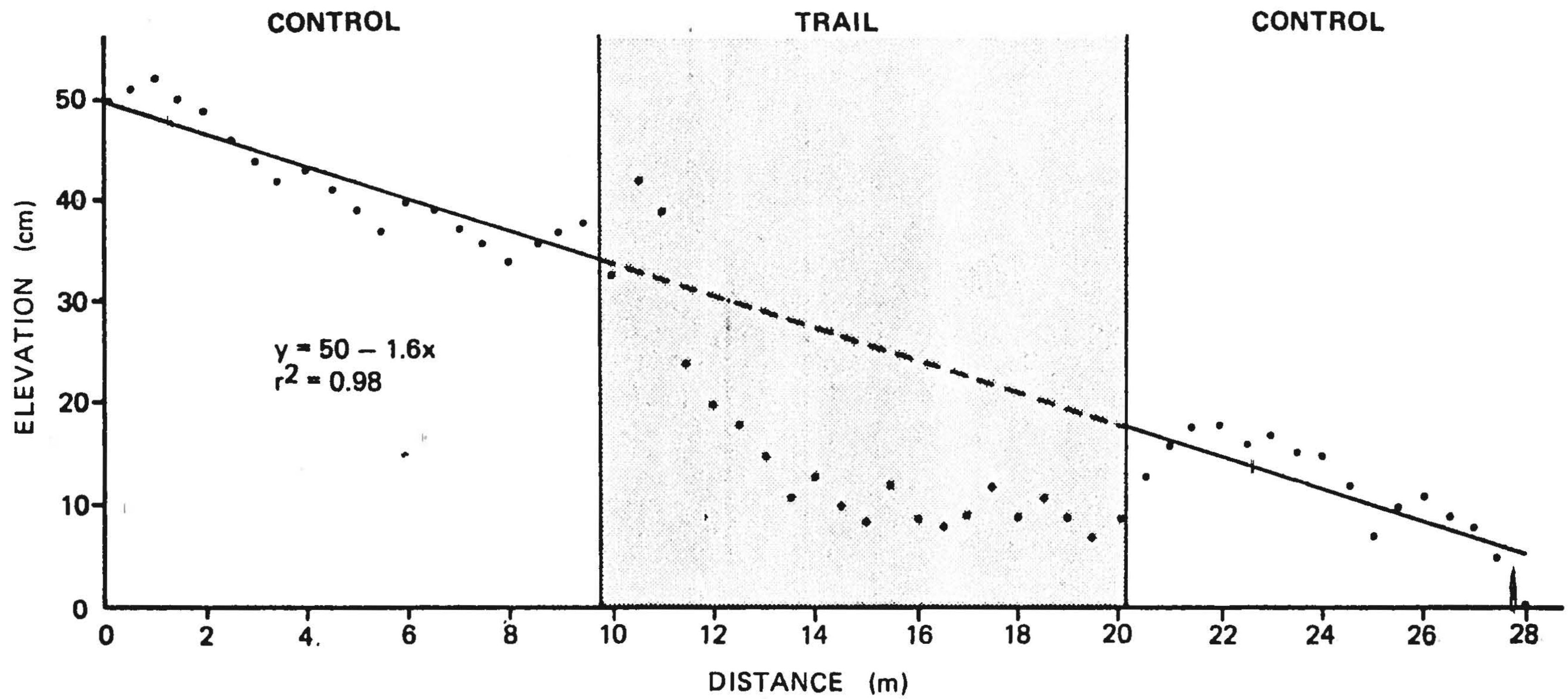


Fig. 12. Cross-section of narrow camp-move trail (plot C1) in moist sedge-shrub tundra, coastal plain, Arctic NWR, Alaska, 1985. Regression line through control points shows track depression in trail.

Table 12. Depths (cm) and cross-sectional areas (m^2) of track depressions on vehicle trails in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Plot no.	Trail age (yrs.)	Trail width (m)	Depth (cm) N	Depth (cm) $\bar{x}$	Depth (cm) SD	Area (m^2) N	Area (m^2) $\bar{x}$	Area (m^2) SD
C3	2	5.0	3	6	3	3	0.26	0.16
014	1	4.5	3	5	2	3	0.22	0.08
C1	2	10.5	3	12	3	3	1.24	0.32
T32	1*	4.5	5	8	3	5	0.37	0.15
T32	2	4.5	5	11	5	5	0.49	0.20

N - number of transects.
* - 1984 data.

The amount of excess ice in the permafrost is important in determining how much thaw settlement results from an increase in thaw depths. The amount of settlement that results from thawing a given amount of material is roughly proportional to the amount of excess ice. For example, at site T32 thaw penetration was 5 cm deeper in the trail in 1984, representing the amount of material left after the surface of the permafrost was thawed. Since we found that the permafrost at the site was approximately 40% soil material and 60% visible ice, the total thaw increase in the trail was approximately 12.5 cm (5 cm of soil and 7.5 cm of ice) in the original ice-rich material. The thickness of excess ice originally present and lost during melting was approximately 7.5 cm, which is close to the estimated track depression of 8.4 cm. It is important to note here that track depression is also the result of compression or removal of material, and does not always represent thaw settlement. No general rule can be applied as to how much settlement accompanies thaw penetration as ice contents are extremely variable and site specific information is needed.

From a general reconnaissance of trails in 1984 and 1985, the major areas of obvious track depression were the result of narrow camp-move trails through extensive stretches of moist sedge-shrub tundra. These included trails adjacent to seismic lines 84-6 and 84-8 near the Tamayariak River, between lines 84-8 and 84-10 near the Katakturuk River, and near Simpson Cove. Less obvious track depression occurred on a narrow camp move along the 1984 seismic line 7 between the Katakturuk River and the Sadlerochit River, where the trail through tussock tundra appeared as ruts starting to form. Because of the uneven surface of the tussocks, track depression in these narrow trails could not be documented. Few 1985 trails with obvious track depression were found in the field, since narrow traffic patterns were usually avoided in 1985.

Evidence as to the future of those tracks with obvious track depression is conflicting. How and Hernandez (1975) measured track depressions ranging from 10 to 15 cm on 4-year-old seismic lines on the Yukon coastal plain where plant cover was reduced but the peat layer remained intact. Summer vehicle trails in a moist sedge-shrub community at Oumalik left 10-cm deep tracks 35 years after disturbance even through the organic mat had not been broken (Ebersole 1985). Abele et al. (1984) found a remarkable ability of a depressed surface to rebound to its normal level. An original surface depression of 15 cm resulting from 50 weasel passes on a narrow trail rebounded to 1 cm within 5 years, and a depression of 8 cm, rebounded to the original level in 4 years. The wider tracks of rolligons and tracks with standing water had slower rebound rates. All trails studied by Abele et al. (1984) showed some decrease in surface depression in the first year after disturbance. In contrast, we found no rebound at the 1 plot with obvious track depression that we monitored for 2 years.

Summary

Seismic trails were generally visible in all vegetation types. Narrow trails, fuel spills, craters (blow outs at shotholes), and small radius vehicle turns were the most visible. Seismic vibrator trails were slightly more visible than dynamite trails. Trails showed either no change or slight improvement in visibility between 1984 and 1985. Reduced visibility of 2-year-old trails was due to the increase in standing dead leaves, the lighter color of weathered litter and drier soil, and the lack of standing water in 1985.

Plant cover decreased on most disturbed plots. Smaller decreases in plant cover in 1985 compared to 1984 occurred for some species at a few plots, but overall little recovery of plant cover was evident. Vegetative shoots and some seedlings were present recolonizing bare patches on trails, but these covered very little ground area. Plant productivity of current year's growth, as measured by plant mass, twig length of shrubs, and numbers of leaves per sedge plant, were generally higher on 2-year-old disturbed plots than on adjacent controls. These factors indicate that recovery of vegetation is beginning to occur on trails in ANWR, but will take many years to reach predisturbance conditions.

Significantly greater thaw depths occurred on 31 of 69 disturbed plot compared to adjacent controls. Only 4 plots had significantly greater changes between disturbed and control plots in 1985 than in 1984. Measurable track depressions occurred at 4 plots on narrow trials in moist sedge-shrub tundra. Track depression increased slightly but not significantly in the second year at plot T32. The overall impacts of disturbance due to winter seismic exploration on each of the 7 major vegetation types are summarized below.

Wet Graminoid and Moist Sedge-Shrub Tundra. Low level disturbances produced visible green trails due to knocking down of the lighter colored standing dead leaves. Trails were more visible at higher disturbance levels due to the obvious track depression or visible wetness of trails (especially when summer precipitation was high). Total plant cover decreased on plots with moderate and high disturbance levels. Soil was exposed only in plots with the highest level of disturbance.

Mosses were easily scuffed and compressed by vehicles, and thus were the most sensitive life form in this vegetation type. Mosses were important recolonizers in the 1 wet sedge plot (O11), but rarely recolonized bare patches in the moist sedge-shrub plots.

Cover of willows (mostly *Salix planifolia* ssp. *pulchra* and *S. lanata* ssp. *richardsonii*) decreased on most disturbed plots. Vegetative shoots of *S. planifolia* were present recolonizing bare patches on a few plots.

Productivity (mass and twig length) of current year's growth of S. planifolia was higher on 2-year-old disturbed plots than on adjacent controls. Nitrogen and phosphorus concentrations of new shoots were also higher on disturbed plots.

Sedges (Carex aquatilis and Eriophorum angustifolium) had no significant changes in cover in the first year after disturbance. In the second year, sedge cover increased at 4 disturbed plots compared to their adjacent controls, with a statistically significant increase at 1 plot. Mass of leaves and number of leaves per plant for these 2 sedges were significantly higher on 2-year-old disturbed plots than on control plots. Nitrogen and phosphorus concentrations in the sedges (especially the below ground stems) was generally lower on disturbed plots. The total amount of nutrients in sedges on disturbed plots was similar to or greater than that on control plots, because the mass of sedges generally increased when the nutrient concentrations decreased. Vegetative shoots of E. angustifolium and C. aquatilis were the main recolonizers of bare patches; graminoid seedlings were also important at wet sedge plot 011. Sedge plants on trails had 1/3 the number of dead leaves as plants on control areas in the second year after disturbance. Two more growing seasons are expected to produce a full complement of standing dead leaves per plant resulting in reduced visibility of green trails. Forbs generally decreased in frequency and cover on disturbed plots.

Thaw depths increased significantly on trails at all levels of disturbance. The decrease of lighter colored standing dead and increased moisture on trails caused decreases in energy reflection (albedo) and increases in energy absorption which led to deeper thaw. Four plots had significantly greater differences in thaw depths between disturbed and control plots in 1985 than in 1984. Measurable track depression (5-12 cm) occurred on 4 plots which were all narrow trails made by multiple vehicle passes in moist sedge-shrub tundra. One photo-trend plot in wet graminoid tundra also had obvious track depression on the ground, but no measurements were made.

Moist Graminoid/Barren Tundra Complex. Trails were visible as discontinuous dark tracks due to exposed soil. Small patches of bare soil due to scuffing of mound tops and frost boils were common, but sometimes difficult to see due to the patchy nature of vegetation in the undisturbed habitat. Two-year-old trails were less visible, because standing dead increased in the trail and soil patches were drier and lighter, blending into surrounding vegetation.

Cover of the evergreen shrub Dryas integrifolia, the deciduous shrubs Salix phlebophylla and S. reticulata, mosses, and lichens was generally lower on trails. Little recovery of plant cover was evident on 2-year-old trails; only deciduous shrubs on 03 had a significant decrease in cover in 1984 but not in 1985. Bare patches changed little between 1984 and 1985, but vegetative shoots of Eriophorum angustifolium, Carex Bigelowii, Arctagrostis latifolia, Salix phlebophylla, and S. rotundifolia were recolonizing. Mosses and seedlings were rare or absent on bare patches.

Thaw depths were significantly greater on many level 2 and 3 disturbances in barren complex tundra. No track depression was evident in the field or in the surveyed elevational data. Small surface depression would be difficult to measure in this habitat due to the natural variation in micro-relief.

Moist Sedge Tussock Tundra. Trails appeared brown due to broken tillers and exposed peat cores of tussocks. Trails were less visible in the second year after disturbance, because the plant litter had weathered to a less noticeable gray and the exposed peat was drier and lighter in color. Disturbance ranged from scuffed tussocks (tillers broken) to tussock mound tops destroyed (peat cores exposed or tussocks cracked) to ruts starting to form (continuous mound top destruction). Total plant cover decreased significantly on most plots when compared to nearby controls. Small patches of exposed soil were common on disturbed plots due to disrupted tussocks.

Cover of the deciduous shrubs Betula nana s.l. and Salix planifolia ssp. pulchra and the evergreen shrubs Ledum palustre ssp. decumbens and Vaccinium vitis-idaea decreased on disturbed plots compared to adjacent controls. Little recovery in shrub cover was evident on 2-year-old plots. Vegetative shoots of V. vitis-idaea, S. planifolia, and L. palustre were found on bare patches, but shrubs accounted for only a small percentage of recolonizing shoots. In some cases, B. nana and S. planifolia had more current year's growth (longer twigs and greater mass) and higher nitrogen concentrations on 2-year-old disturbed plots than on adjacent controls, but few changes in phosphorus concentrations. Current year's growth of L. palustre and V. vitis-idaea showed little change in mass, but some increases in nitrogen and phosphorus concentrations.

Cover of cottongrass (Eriophorum vaginatum) generally decreased due to scuffing and destruction of tussocks. Tillers of E. vaginatum were commonly found recolonizing the edges of bare patches. Most retillering occurred in the first year after disturbance. E. vaginatum had some significant increases in mass and nitrogen concentration on 2-year-old disturbed plots, but no changes in phosphorus. The grass Arctagrostis latifolia was also an important recolonizer.

Mosses, including Hylocomium splendens and Tomenthypnum nitens, were sensitive to disturbance and decreased on all vehicle trails in tussock tundra. The mosses Aulacomnium turgidum, A. palustre, Pohlia sp., and Polytrichum juniperinum were important recolonizers on bare patches. Cover of lichens (mainly the foliose lichens Peltigera spp. and Nephroma arctica) decreased significantly on 3 disturbed plots.

Increased thaw depths were present in some plots of all disturbance levels. No track depression was identified from surveyed elevational data. Track depression would be difficult to identify in this habitat due to the uneven surface of the tussocks. The Marsh Creek plots with ruts starting to form appeared to have track depressions. However without knowledge of the original surface height, depression in these narrow tracks could not be documented.

Moist Shrub Tundra. Visible trails resulted from removal of shrubs. The ericaceous shrubs Ledum palustre ssp. decumbens and Vaccinium vitis-idaea and deciduous shrubs (especially Betula nana s.l.) decreased due to disturbance. Vegetative shoots of V. vitis-idaea and Salix phlebophylla were present recolonizing bare patches, while shoots of L. palustre, B. nana, and Salix planifolia ssp. pulchra were rare or absent. Cover of mosses, including Hylocomium splendens and Dicranum spp. decreased significantly on the more disturbed plot (S6).

Exposed soil increased with increasing levels of disturbance. At 1 highly disturbed photo-trend plot (T29), soil exposed was 19% and the percent decrease in total plant cover decrease was 77%. Bare patches changed little between 1984 and 1985 as recolonizing shoots covered very little ground area. Graminoid species, including Eriophorum vaginatum, *Arctagrostis latifolia*, *Hierochloe alpina*, and *Luzula confusa*, and various forb species were important colonizers. Some significant increases in thaw depth occurred on disturbed plots, but no track depression was found.

Riparian Shrubland. Trails were visible due to canopy removal. Disturbance to ground cover, especially mosses, increased the visibility of more highly disturbed trails. Two-year-old trails were often less visible due to the lighter color of litter and drier soil in 1985. Willows (*Salix* spp.) and bearberry (*Arctostaphylos rubra*) were the main plants affected by disturbance. Cover of forbs, horsetails, and mosses also decreased on some disturbed plots. Fewer forb species were found in frequency quadrats on disturbed plots than control plots. No recovery was evident from plant cover data. Recolonizing shoots on bare patches included the shrubs *Salix reticulata* and *Arctostaphylos rubra* and the forbs *Oxytropis* spp. and *Astragalus umbellatus*. Seedlings, especially forb seedlings, were important recolonizers in this habitat.

Dryas Terrace. Disturbance was visible as a brown trail due to removal of the vegetative mat and exposure of soil. Visibility on 1 plot (06) increased in the second year after disturbance due to loss of the moss mat. Total plant cover decreased on all 3 disturbed plots sampled. Plot 06 had the largest decreases in plant cover of any disturbed plot with an average of 85% less cover in the disturbed plot than control in 1984 and 1985. *Dryas* terrace plots had the largest amount of bare ground, because the vegetative mat was easily removed.

Cover of the evergreen shrub *Dryas integrifolia*, deciduous shrubs (especially *Salix reticulata*), horsetails (*Equisetum variegatum*), forbs, and mosses (especially *Tomenthyphum nitens*) decreased at disturbed plots. No recovery of plant cover was evident in 1985 on 06, the only plot with data from 2 years. However, *Dryas integrifolia* was frequently found sprouting from buried stems on the edges of bare patches. Horsetail (*Equisetum variegatum*) and forbs (mainly legumes) were also common recolonizers.

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APPENDIX

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Appendix Table 1. Volumetric moisture contents (%) near the surface and of underlying horizons of undisturbed soils on intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Surface[a] (3-6 cm) N	x̄	SD	Organic N	x̄	SD	Organic-mineral N	x̄	SD	Mineral N	x̄	SD
Wet graminoid	011	5	80	7	5	80	7						
Moist sedge-shrub tundra	M1	5	85	4	5	85	4	4	72	7	4	51	8
	018	5	55	8	5	55	8				5	44	2
	019	5	72	8	5	72	8	3	78	5	4	43	8
	020	5	77	5	5	77	5				5	40	7
	C3	5	60	6	5	60	6	3	80	3	3	57	2
	014	4	64	5	2	61	1	5	60	9	3	45	2
	012	5	62	10	3	62	14	3	68	10			
	C1	5	53	18	3	41	13	4	70	2	3	58	1
	T32	5	74	5	5	74	5				5	51	3
Moist graminoid/ barren tundra complex	N11	5	60	26	5	80	2	3	73	11	5	38	8
	N12	5	72	16	4	79	1	4	71	7	5	36	4
	03	5	55	10	5	48	12	3	60	7	5	42	7
	07	5	56	4				4	56	4	3	48	8
	C2	5	52	17				4	60	10	4	47	5
Moist sedge tussock tundra	M7	5	50	16	4	44	12	3	78	5	4	48	3
	S1	5	88	7	5	88	7						
	M11	5	55	15	3	44	5	3	71	8	3	45	2
	S8	5	63	17	5	63	17	2	72	3			
	M2	5	64	8	5	64	8				4	57	7
	M3	5	58	20	4	61	23	5	69	13	3	58	3
	M10	5	43	14	5	43	14				4	50	2
Moist shrub tundra	S4	5	37	17	5	37	17	3	55	12	3	60	3
	S6	5	43	13	5	38	15	3	63	17	3	48	3
Riparian shrubland	M4	5	38	4							4	38	5
	S5	5	50	12	5	50	12	3	52	8	3	50	5
	015	3	32	17							5	38	15
	H1	5	40	15							5	40	15
	H3	5	32	10							5	32	10
Dryas terrace	H4	4	40	4				3	39	5	4	32	8
	H5	5	52	4							5	52	4
	06	5	35	6							5	35	6

[a] Surface samples are also included in the means for soil horizons according to soil type (organic, orgainic-mineral, or mineral).

Appendix Table 2. Bulk densities (g/cm^3) near the surface and of underlying horizons of undisturbed soils on intensive study plots, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Plot no.	Surface[a] (3-6 cm)			Organic			Organic-mineral			Mineral		
		N	$\overline{x}$	SD	N	$\overline{x}$	SD	N	$\overline{x}$	SD	N	$\overline{x}$	SD
Wet graminoid	011	5	0.44	0.05	5	0.44[b]	0.05						
Moist sedge-shrub tundra	M1	5	0.14	0.02	5	0.14	0.02	4	0.50	0.30	4	1.24	0.26
	018	5	0.17	0.03	5	0.17	0.03				5	1.56	0.11
	019	5	0.20	0.04	5	0.20	0.04	3	0.31	0.03	4	1.53	0.23
	020	5	0.18	0.02	5	0.18	0.02				5	1.56	0.18
	C3	5	0.12	0.02	5	0.12	0.02	3	0.21	0.05	3	1.17	0.02
	014	4	0.37	0.22	2	0.18	0.02	5	0.56	0.10	3	1.47	0.03
	012	5	0.48	0.25	3	0.29	0.09	3	0.64	0.17			
	C1	5	0.13	0.05	3	0.09	0.03	4	0.20	0.03	3	0.93	0.07
	T32	5	0.15	0.01	5	0.15	0.01				5	1.38	0.08
Moist graminoid/barren tundra complex	N11	5	0.81	0.80	5	0.23	0.03	3	0.46	0.19	5	1.49	0.34
	N12	5	0.52	0.63	4	0.24	0.04	4	0.34	0.24	5	1.62	0.08
	03	5	0.24	0.08	5	0.24	0.08	3	0.45	0.12	5	1.32	0.20
	07	5	0.75	0.08				4	0.73	0.08	3	1.17	0.31
	C2	5	0.38	0.45				4	0.22	0.05	4	1.22	0.21
Moist sedge tussock tundra	M7	5	0.13	0.07	4	0.11	0.04	3	0.22	0.04	4	1.38	0.14
	S1	5	0.20	0.03	5	0.20	0.03						
	M11	5	0.15	0.09	3	0.10	0.01	3	0.23	0.06	3	1.38	0.07
	S8	5	0.15	0.07	5	0.15	0.07	2	0.44	0.19			
	M2	5	0.46	0.49	5	0.10	0.01				4	1.10	0.20
	M3	5	0.16	0.15	4	0.09	0.02	5	0.34	0.12	3	0.82	0.15
	M10	5	0.12	0.04	5	0.12	0.04				4	1.23	0.07
Moist shrub tundra	S4	5	0.17	0.07	5	0.17	0.07	3	0.41	0.15	3	0.86	0.14
	S6	5	0.31	0.47	5	0.10	0.05	3	0.42	0.19	3	1.19	0.05
Riparian shrubland	M4	5	0.80	0.06							4	0.79	0.07
	S5	5	0.21	0.02	5	0.21	0.02	3	0.59	0.21	3	1.31	0.03
	015	3	1.34	0.08							5	1.33	0.07
	H1	5	1.03	0.15							5	1.03	0.15
	H3	5	1.18	0.11							5	1.18	0.11
Dryas terrace	H4	4	0.64	0.35				3	0.46	0.06	4	1.11	0.04
	H5	5	1.22	0.14							5	1.22	0.14
	06	5	0.96	0.05							5	0.96	0.05

[a] Surface samples are also included in the means for soil horizons according to soil type (organic, organic-mineral, or mineral).

[b] There is some sand in this horizon which may help to explain the high bulk density.

Appendix Table 3. Plant cover (%) on disturbed (D) and control (C) plots in wet graminoid and moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Wet graminoid tundra					Moist sedge-shrub tundra							
	011 (L2)					M1(L1)					018 (L1)		
	1984		1985			1984		1985			1985		
	C	D	C	D		C	D	C	D		C	D	
LIFE FORMS					T					Y			T
Deciduous shrubs	6	3	7	6		15	19	27	24	Y	14	7	
Evergreen shrubs	7	2	5	4									
Sedges	18	13	24	22	Y	12	11	18	30	Y	12	14	
Forbs	1	0	4	3	Y								
Mosses and liverworts	68	35	73	50	T	7	3	39	39	Y	83	55	T
Bare ground	17	46	17	35	T						13	35	T
SPECIES					T								T
Salix planifolia ssp. _pulchra_	3	3	5	4		14	16	24	21	Y	9	4	
Carex aquatilis	12	8	10	13									
Eriophorum angustifolium								16	27*		6	7	
Aulacomnium palustre								4	6*		10	10	
Aulacomnium turgidum	10	2	7	7							10	6	
Campyllium stellatum											12	0	
Drepanocladus spp.	11	3	12	2	T			5	6*		13	9	
Hylocomium splendens								8	4*				
Oncophorus wahlenbergii	13	2	15	3	T								
Sphagnum spp.											17	14	
Tomenthypnum nitens	18	17	13	18							3	6	
Litter	16	35	17	32	T						13	35	T
Soil	1A	11B	0A	3A	TYI								
VASCULAR PLANTS	31	18	38	35	Y	28	30	44	54	Y	27	22	
NONVASCULAR PLANTS	68	36	74	50	T	7	3	40	41	Y	83	57	T
TOTAL PLANT COVER	99	53	112	85	TY	35	33	84	95	Y	110	78	T

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P < 0.05$, Scheffe's test, conducted when the interaction effect was significant).
* - 1985 data analyzed alone.

Appendix Table 4. Plant cover (%) on disturbed (D) and control (C) plots in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist sedge-shrub tundra											
	019 (L1)			020 (L1)			C3 (L2)			013 (L2)		
	C	D		C	D		C	D		C	D	
LIFE FORMS			T						T			T
Deciduous shrubs	30	21		9	15		22	9	T	21	13	
Evergreen shrubs												
Sedges	22	19		21	22		25	31		7	9	
Forbs				6	0	T				4	1	T
Mosses and liverworts	22	29		37	30		74	51	T	93	70	T
Bare ground	42	47		35	43		16	26		3	20	T
SPECIES						T			T			T
Salix lanata ssp. *richardsonii*							14	1	T			
Salix planifolia ssp. *pulchra*	22	17		7	13		5	7		14	11	
Salix reticulata	8	4								6	1	T
Carex aquatilis	11	5		7	11		9	9				
Carex Bigelowii										5	7	
Eriophorum angustifolium	12	13		9	9		17	22				
Aulacomnium palustre										30	27	
Aulacomnium turgidum										18	11	
Campyllium stellatum				6	4							
Drepanocladus spp.				8	15		6	11				
Hylocomium splendens										6	8	
Meesia triquetra							17	9	T			
Sphagnum spp.										27	11	T
Tomenthypnum nitens	5	7					18	7	T	5	9	
Liverworts							18	13				
Bare ground	42	47		35	43		16	26		3	20	T
VASCULAR PLANTS	52	39	T	36	37		47	39	T	33	22	
NONVASCULAR PLANTS	22	29		37	31		74	52	T	97	72	T
TOTAL PLANT COVER	74	68		73	68		121	91	T	129	94	T

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P<0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).

Appendix Table 5. Plant cover (%) on disturbed (D) and control (C) plots in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist sedge-shrub tundra														
	014 (L2)			012(L3)					C1 (L3)			T32 (L3)		
	1985			1984		1985			1985			1985		
	C	D		C	D	C	D		C	D		C	D	
LIFE FORMS			T					T			T			T
Deciduous shrubs	19	15		16	3	12	2	T	27	8	T	25	17	T
Evergreen shrubs				18	11	22	5	T						
Sedges	14	10		13	14	12	10		12	18		12	27	T
Forbs									5	3				
Mosses and liverworts	76	48	T	72	36	84	47	TY	86	58	T	79	49	T
Lichen				8	4	9	4	T	6	5		3	1	
Bare ground	14	40	T	8	49	4	43	T	5	28	T	11	27	T
SPECIES								TY			T			T
Salix planifolia ssp. *pulchra*	18	14		6	1	7	2	T	27	8	T	25	14	T
Salix reticulata				6	1	4	0	T						
Dryas integrifolia				7	3	2	1	Y						
Cassiope tetragona				8AB	7A	17B	4A	TI						
Carex aquatilis	6	4		3	7	3	3					2	8	
Eriophorum angustifolium	7	5							11	17		9	19	T
Aulacomnium palustre	15	9							9	18	T	5	10	
Aulacomnium turgidum	7	3		16	6	20	14	T	7	6		13	3	T
Campyllium stellatum												4	10	
Dicranum spp.				3	7	2	2							
Drepanocladus spp.									12	2	T	6	5	
Hylocomium splendens				15	10	22	13	T	15	4	T	30	5	T
Ptilidium ciliare									20	2	T	7	0	T
Sphagnum spp.	35	21												
Tomenthypnum nitens	3	5		14	7	23	7	T	11	21		9	1	T
Other liverworts												0	11	T
Bare ground									5	28	T			
Litter	14	40	T	8	28	3	26	T				11	27	T
Soil				1	21	1	18	T						
VASCULAR PLANTS	34	25		50	28	48	18	T	44	30	T	40	44	
NONVASCULAR PLANTS	78	49	T	80	40	93	50	T	91	62	T	82	50	T
TOTAL PLANT COVER	112	74	T	130	68	140	68	T	135	92	T	121	94	T

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P<0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P<0.05$, Scheffe's test, conducted when the interaction effect was significant).

Appendix Table 6. Plant cover (%) on disturbed (D) and control (C) plots in moist graminoid/barren complex tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist graminoid/barren tundra complex									
	N11 (L1)					N12 (L2)				
	1984		1985			1984		1985		
	C	D	C	D		C	D	C	D	
LIFE FORMS					TY					TY
Deciduous shrubs	8	3	12	9	Y	5	2	10	4	TY
Evergreen shrubs	13	4	16	9	TY	9	6	16	8	T
Sedges	16	10	16	14		18	9	19	13	T
Forbs	2	3	1	3		1	1	2	3	
Mosses and liverworts	62	47	77	59	TY	60	34	77	50	TY
Lichens	20	7	19	7	T	12	10	15	9	
Bare ground	11	36	5	21	TY	18	48	5	32	TY
SPECIES					TY					TY
<u>Salix phlebophylla</u>	5	1	7	5	T					
<u>Salix arctica</u>						2	1	6	1	T
<u>Dryas integrifolia</u>	13	4	16	9	TY	9	5	15	8	TY
<u>Carex Bigelowii</u>	7	5	7	4		10	3	8	8	
<u>Eriophorum angustifolium</u>	6	4	5	7		7	5	4	2	
<u>Eriophorum vaginatum</u>						1AB	2A	6B	1A	I
<u>Aulacomnium</u> spp.	4	4	7	8	Y	9	4	6	6	
<u>Dicranum</u> spp.	5	2	4	2	T	7	4	5	3	
<u>Drepanocladus</u> spp.						3	1	6	1	T
<u>Hylocomium splendens</u>	5	3	7	1	T					
<u>Ptilidium ciliare</u>	9	8	9	5		9	4	6	6	
<u>Tomenthypnum nitens</u>	24	21	25	32		18	12	24	15	T
Crustose lichen						3	3	7	2	
Litter	11	32	3	17	TY	15	41	4	29	TY
Soil	1	5	2	4	T	3	7	2	4	T
VASCULAR PLANTS	39	20	44	36	TY	35	18	48	29	TY
NONVASCULAR PLANTS	82	54	96	66	TY	72	44	92	59	TY
TOTAL PLANT COVER	121	74	140	101	TY	107	63	140	88	TY

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P < 0.05$, Scheffe's test, conducted when the interaction effect was significant).

Appendix Table 7. Plant cover (%) on disturbed (D) and control (C) plots in moist graminoid/barren complex tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist graminoid/barren tundra complex												
	03 (L2)					07(L2)					C2 (L3)		
	1984		1985			1984		1985			1985		
	C	D	C	D		C	D	C	D		C	D	
LIFE FORMS					TY					TY			T
Deciduous shrubs	19B	6A	8A	6A	TYI	19	11	23	14	T	9	3	T
Evergreen shrubs	14	5	20	5	T	11	4	12	8	T	14	3	T
Sedges	20	17	13	15		9	9	7	6		8	8	
Grasses											4	2	
Forbs	5	3	4	4		2	3	4	3		10	2	T
Horsetails						10	3	11	5	T			
Mosses and liverworts	55	35	75	46	TY	56	26	75	58	TY	71	56	
Lichens	12	9	20	8	T	9	3	5	4	T	25	17	
Bare ground	12	43	6	35	TY	14	47	5	27	TY	5	35	T
SPECIES					TY					TY			T
Salix phlebophylla	15B	0A	8AB	3A	TI								
Salix reticulata						13	7	14	10	T			
Salix rotundifolia						6	3	7	3		5	1	T
Dryas integrifolia						11	3	12	7	T	14	3	T
Vaccinium vitis-idaea	11	4	19	2	T								
Carex Bigelowii	13	9	8	8							3	6	
Eriophorum vaginatum	5	6	4	4									
Equisetum variegatum						10	3	11	5	T			
Aulacomnium turgidum	11	7	18	10	TY						6	9	
Dicranum spp.	16	9	20	6	T	9	5	18	6	TY	12	6	
Drepanocladus spp.						7	1	12	16	Y			
Hylocomium splendens	10	7	9	9							16	14	
Polytrichum juniperinum	5	3	8	2	T								
Ptilidium ciliare											11	11	
Tomenthypnum nitens	3	9	2	6	T	18	16	26	23	Y	15	8	
Crustose lichen											8	0	T
Peltigera spp.	7	6	12	7							7	7	
Thamnolia subuliformis						6	2	1	2				
Litter	9	28	6	27	T	14	36	5	17	TY	4	23	T
Soil	3	15	0	8	TY	0	11	0	10	T	2	12	T
VASCULAR PLANTS	58	31	45	30	T	51	29	56	34	T	43	18	T
NONVASCULAR PLANTS	67	43	95	54	TY	65BC	29A	80C	62B	TYI	95	73	T
TOTAL PLANT COVER	125	74	140	84	T	116	57	135	96	TY	138	91	T

L1, L2, L3 - low, moderate, and high levels of disturbance.

T,Y,I - indicate a significant difference ($P<0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).

A,B,C - means with the same letter do not differ significantly ($P<0.05$, Scheffe's test, conducted when the interaction effect was significant).

Appendix Table 8. Plant cover (%) on disturbed (D) and control (C) plots in moist sedge tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist sedge tussock tundra										
	M7S(L1)			M7V(L1)			S1 (L1)				
	1985			1985			1984		1985		
	C	D		C	D		C	D	C	D	
LIFE FORMS			T			T					TYI
Deciduous shrubs	22	15		22	17		13	7	11	11	
Evergreen shrubs	32	7	T	32	8	T	12	14	18	24	Y
Sedges	28	23		28	27		16	6	23	12	
Forbs	5	1	T	5	1		2	2	3	6	
Mosses and liverworts	63	52		63	56		61AB	45B	63A	67A	YI
Lichens	8	6		8	9		6	11	12	14	
Bare ground	6	28	T	6	23	T	17	32	13	18	TY
SPECIES											TY
Betula nana s.l.	6	3		6	5						
Salix planifolia ssp. *pulchra*	14	11		14	13		4	1	5	2	
Salix reticulata							8A	2A	4A	7A	I
Dryas integrifolia							3	3	2	7	T
Cassiope tetragona							6	10	12	15	Y
Ledum palustre ssp. *decumbens*	13	3	T	13	3	T					
Vaccinium vitis-idaea	13	3	T	13	4	T					
Carex Bigelowii							4	4	5	8	
Eriophorum vaginatum	23	22		23	25		12	2	18	3	T
Aulacomnium turgidum	8	9		8	5		9	5	9	8	
Dicranum spp.	9	9		9	9		1	4	6	6	Y
Hylocomnium splendens	15	8	T	15	10		19	15	26	22	Y
Sphagnum spp.				3	5						
Tomenthypnum nitens	10	5		10	6		15	11	14	24	
Ptilidium ciliare	4	8		4	9						
Other liverworts				6	4						
Foliose lichen (*Peltigera* spp. and *Nephroma arctica*)	5	3		7	3		5	10	8	9	
Bare ground				6	21	T	17	32	13	18	TY
Litter	6	22	T								
Soil	1	6	T	0	2						
VASCULAR PLANTS	87	46	T	87	53	T	43	30	54	54	T
NONVASCULAR PLANTS	71	58	T	71	65		66	56	74	81	Y
TOTAL PLANT COVER	158	104	T	158	118	T	109AC	86A	128BC	134B	YI

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P < 0.05$, Scheffe's test, conducted when the interaction effect was significant).

Appendix Table 9. Plant cover (%) on disturbed (D) and control (C) plots in moist sedge tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist sedge tussock tundra										
	S8 (L2)					M11(L2)			M10(L3)		
	1984		1985			1985			1985		
	C	D	C	D		C	D		C	D	
LIFE FORMS					T			T			T
Deciduous shrubs	8	4	7	3		25	12	T	25	14	T
Evergreen shrubs	32	14	47	19	TY	30	6	T	22	10	T
Sedges	6	4	9	5		28	9	T	17	10	
Forbs	3	4	2	3		4	1		7	4	
Mosses and liverworts	70	43	69	49	T	55	49		79	59	T
Lichens	14	11	23	13	T	17	8	T	15	12	
Bare ground	10	40	6	37	T	9	35	T	5	23	T
SPECIES					T			T			
Betula nana s.l.	6	3	6	1	T	10	5		16	7	T
Salix planifolia ssp. *pulchra*						16	8		5	4	
Cassiope tetragona									8	5	
Ledum palustre ssp. *decumbens*	13	7	19	11	T	14	2	T			
Vaccinium vitis-idaea	19	7	28	9	T	16	3	T	9	4	
Carex Bigelowii											
Eriophorum vaginatum	5	3	8	5		27	8	T	16	10	
Aulacomnium turgidum	11	9	13	13		10	8		15	13	
Dicranum spp.	28	13	22	13	T	11	9		13	9	
Hylocomnium splendens	14	9	17	8	T	13	13		22	17	
Sphagnum spp.	10	8	8	7		5	5				
Tomenthypnum nitens									8	6	
Ptilidium ciliare									9	6	
Foliose lichen (*Peltigera* spp. and *Nephroma arctica*)	8	7	13	5	T	11	5	T	9	6	
Litter	10	29	6	25	T	7	26	T	5	19	T
Soil	0	11	0	12	T	2	10	T	0	4	
VASCULAR PLANTS	49	26	65	30	T	87	29	T	73	38	T
NONVASCULAR PLANTS	84	53	91	62	T	72	57	T	94	71	T
TOTAL PLANT COVER	133	79	156	91	T	158	85	T	167	108	T

L1, L2, L3 - low, moderate, and high levels of disturbance.

T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).

Appendix Table 10. Plant cover (%) on disturbed (D) and control (C) plots in moist sedge tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist sedge tussock tundra									
	M2(L3)					M3(L3)				
	1984		1985			1984		1985		
	C	D	C	D		C	D	C	D	
LIFE FORMS					TY					TY
Deciduous shrubs	23	14	30	17	T	16	9	23	18	Y
Evergreen shrubs	12	4	23	8	TY	30	6	35	10	T
Sedges	19	10	26	18	T	9	6	15	16	
Forbs	4	2	8	2	T					
Mosses and liverworts	21	9	62	42	TY	24B	7A	76C	28B	TYI
Lichens	5	1	9	7	Y	5	2	11	5	T
SPECIES					T					
Betula nana s.l.	14	5	16	8	T	15	8	20	8	T
Salix planifolia ssp. *pulchra*	9	9	14	9		1	1	4	10	TY
Ledum palustre ssp. *decumbens*	6	1	10	3	T	12	3	15	7	T
Vaccinium vitis-idaea	5	1	10	4	T	16	2	20	3	T
Eriophorum vaginatum	16	8	24	17	TY	9	5	13	11	
Aulacomnium turgidum			9	7	*			11	4	T*
Dicranum spp.			4	9	*			16	6	T*
Hylocomium splendens			14	8	*			12	5	T*
Sphagnum spp.			8	2	T*			16	6	*
Ptilidium ciliare			11	6	*			12	4	T*
Foliose lichen (*Peltigera* spp. and *Nephroma arctica*)			6	5	*					
Litter			10	27	T*			9	39	T*
Soil	0	4	1	6	T	1	4	0	5	T
VASCULAR PLANTS	57	31	86	46	TY	56	23	74	47	TY
NONVASCULAR PLANTS	25	10	71	49	TY	29A	10A	87B	33A	TYI
TOTAL PLANT COVER	83AB	41A	157C	94B	TYI	85A	32A	160B	79A	TYI

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P < 0.05$, Scheffe's test, conducted when the interaction effect was significant).

Appendix Table 11. Plant cover (%) on disturbed (D) and control (C) plots in moist shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Moist shrub tundra									
	S4(L1)					S6(L2)				
	1984		1985			1984		1985		
	C	D	C	D		C	D	C	D	
LIFE FORMS					T					TY
Deciduous shrubs	25	16	16	15		15	7	15	8	T
Evergreen shrubs	34	17	37	20	T	31	18	26	23	T
Sedges	8	7	5	3						
Forbs	5	3	3	5		7	3	7	4	
Mosses and liverworts	59	53	71	63	Y	69	56	85	66	TY
Lichens	21	20	29	16		25	18	26	22	
Bare ground	11	19	4	22	T	4	25	1	2	T
SPECIES					T					T
Betula nana s.l.	21	12	14	11		12	7	13	7	T
Ledum palustre ssp. decumbens	12	6	11	5	T	11	10	9	11	
Vaccinium vitis-idaea	22	11	26	15	T	20	9	17	12	T
Carex Bigelowii	7	3	4	1	T					
Rubus chamaemorus						5	1	4	2	
Aulacomnium turgidum	13	11	15	14		12	12	20	15	
Dicranum spp.	20	19	20	19		27	18	24	20	T
Hylocomium splendens	13	13	18	18		14	10	21	16	Y
Polytrichum spp.	4	2	5	1	T					
Rhytidium rugosum						5	6	9	9	
Cetraria spp.	3	3	5	3						
Foliose lichen (Peltigera spp. and Nephroma arctica)	9	13	11	10		15	8	15	12	T
Crustose lichen	3	1	7	2	T					
Litter						4	16	1	15	T
Soil						0	9	0	6	T
Bare ground	11	19	4	22	T					
VASCULAR PLANTS	71	41	61	42	T	55	30	49	35	T
NONVASCULAR PLANTS	80	73	100	79	TY	94	74	111	88	TY
TOTAL PLANT COVER	150	114	160	120	T	149	103	160	123	TY

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).

Appendix Table 12. Plant cover (%) on disturbed (D) and control (C) plots in riparian shrubland, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Riparian shrubland									
	M4(L1)					S5(L1)				
	1984		1985			1984		1985		
	C	D	C	D		C	D	C	D	
LIFE FORMS										TY
Deciduous shrubs	33	26	32	24		53	44	48	35	T
Evergreen shrubs	11	3	14	10						
Sedges						6	8	5	8	
Grasses						11	10	17	16	Y
Forbs	19	10	16	15		19	4	14	5	T
Horsetails	3	1	10	3		3	0	5	1	T
Mosses and liverworts	40	20	67	66	Y	75	65	89	68	TY
Lichens	16	6	18	19	Y					
Bare ground						4	13	2	11	T
SPECIES										TY
<u>Arctostaphylos</u> <u>rubra</u>	14	11	12	12						
<u>Salix</u> <u>brachycarpa</u> ssp. <u>niphoclada</u>	9	5	7	4						
<u>Salix</u> <u>glauca</u>						18	20	12	18	
<u>Salix</u> <u>hastata</u>	5	1	6	2						
<u>Salix</u> <u>lanata</u> ssp. <u>richardsonii</u>						19	12	24	9	T
<u>Salix</u> <u>planifolia</u> ssp. <u>pulchra</u>						6	7	8	5	
<u>Salix</u> <u>reticulata</u>	2	5	5	5		9	3	3	3	
<u>Dryas</u> <u>integrifolia</u>	11	3	14	10						
<u>Carex</u> <u>Bigelowii</u>						6	8	3	7	
<u>Poa</u> spp.						5	6	11	7	
<u>Hedysarum</u> spp.	5	5	3	7						
<u>Lupinus</u> <u>arcticus</u>						6	1	2	1	T
<u>Pyrola</u> <u>grandiflora</u>						7	0	4	0	T
<u>Equisetum</u> <u>variegatum</u>	3	1	10	3		0	0	4	1	T
<u>Aulacomnium</u> <u>palustre</u>						3	2	10	4	TY
<u>Climacium</u> <u>dendroides</u>						10	7	2	10	
<u>Drepanocladus</u> spp.						9	10	13	11	
<u>Hylocomium</u> <u>splendens</u>			29	33	*	6AB	6AB	14B	3A	TI
<u>Tomenthypnum</u> <u>nitens</u>			20	17	*	19	10	18	5	T
Foliose lichens			17	14	*					
VASCULAR PLANTS	66	40	73	52	T	92	66	87	64	TY
NONVASCULAR PLANTS	56	26	85	84	Y	78	65	89	68	TY
TOTAL PLANT COVER	121	67	158	136	TY	170	131	176	132	TY

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P < 0.05$, Scheffe's test, conducted when the interaction effect was significant).
* - 1985 data analyzed alone.

Appendix Table 13. Plant cover (%) on disturbed (D) and control (C) plots in riparian shrubland, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground cover type	Riparian shrubland					
	015(L2) 1985		H1(L2) 1985		H3(L3) 1985	
	C	D	C	D	C	D
LIFE FORMS		T		T		T
Deciduous shrubs	41	18 T	44	11 T	26	6 T
Evergreen shrubs	9	2 T	7	0 T		
Grasses	4	2				
Forbs	23	8 T	14	1 T	9	2 T
Horsetails	9	5	13	1 T	15	1 T
Mosses and liverworts	52	54	67	65	89	72 T
Lichens			3	7	3	4
Bare ground	6	27 T	5	20 T	2	21 T
SPECIES		T		T		T
Arctostaphylos rubra			25	6 T		
Salix brachycarpa ssp. _niphoclada_	4	5	7	2		
Salix hastata	3	4				
Salix lanata ssp. _richardsonii_	20	4 T			9	1 T
Salix reticulata	14	6 T	10	1 T	9	4 T
Dryas integrifolia	9	2 T	7	0 T		
Astragalus spp.	9	5				
Oxytropis spp.	9	2 T	9	1 T		
Equisetum variegatum	8	3	13	1 T	14	1 T
Dicranum spp.	4	1				
Hylocomium splendens			13	7		
Tomenthypnum nitens	35	41	40	41	71	62
Bare ground					2	21 T
Litter	5	23 T	5	18 T		
Soil	1	4	0	2 T		
VASCULAR PLANTS	85	35 T	82	13 T	52	10 T
NONVASCULAR PLANTS	52	54	70	72	92	76 T
TOTAL PLANT COVER	137	89 T	152	85 T	143	85 T

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P < 0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way univariate analyses of variance for individual life forms and species).

Appendix Table 14. Plant cover (%) on disturbed (D) and control (C) plots on *Dryas* terraces, coastal plain, Arctic National Wildlife Refuge, Alaska 1985.

Ground cover type	Dryas terrace										
	H4(L2)			H5(L2)			06(L3)				
	1985			1985			1984		1985		
	C	D		C	D		C	D	C	D	
LIFE FORMS			T			T					TYI
Deciduous shrubs	19	7	T	21	13	T	9	2	13	5	TY
Evergreen shrubs	29	23		15	5	T	26	1	34	6	TY
Forbs	10	7		11	5	T	13	1	13	1	T
Horsetails	18	3	T	22	9	T	1	0	6	1	T
Mosses and liverworts	79	51	T	88	74	T	43B	9A	74C	12A	TYI
Lichens	9	28	T	4	3		6	1	9	3	T
Bare ground	6	20	T	3	14	T	19	89	5	78	TY
SPECIES			T			T					TYI
Salix reticulata	16	5	T	16	12		7	1	12	3	TY
Dryas integrifolia	29	23		15	5	T	26	1	34	6	TY
Astragalus spp.	5	2		4	2						
Oxytropis spp.	4	5		5	3						
Oxytropis nigrescens							7	0	5	0	T
Equisetum variegatum	18	3	T	22	8	T	1	0	6	1	T
Dicranum spp.	6	21	T								
Hylocomium splendens							1A	0A	11B	3A	TYI
Tomenthypnum nitens	46	6	T	71	56		26B	1A	42C	4A	TYI
Crustose lichen				2	15	T					
Bare ground	6	20	T	3	14	T					
Litter							18B	62C	5A	62C	TYI
oil							1	27	0	17	TY
VASCULAR PLANTS	76	40	T	70	33	T	49	3	67	12	TY
NONVASCULAR PLANTS	88	79		92	77	T	49B	10A	83C	14A	TYI
TOTAL PLANT COVER	164	118	T	61	110		98B	13A	149C	26A	TYI

L1, L2, L3 - low, moderate, and high levels of disturbance.
T,Y,I - indicate a significant difference ($P<0.05$) between treatments, between years, or an interaction effect, respectively (multivariate analyses of variance for all life forms or species considered together, and 1-way or 2-way univariate analyses of variance for individual life forms and species).
A,B,C - means with the same letter do not differ significantly ($P<0.05$, Scheffe's test, conducted when the interaction effect was significant).