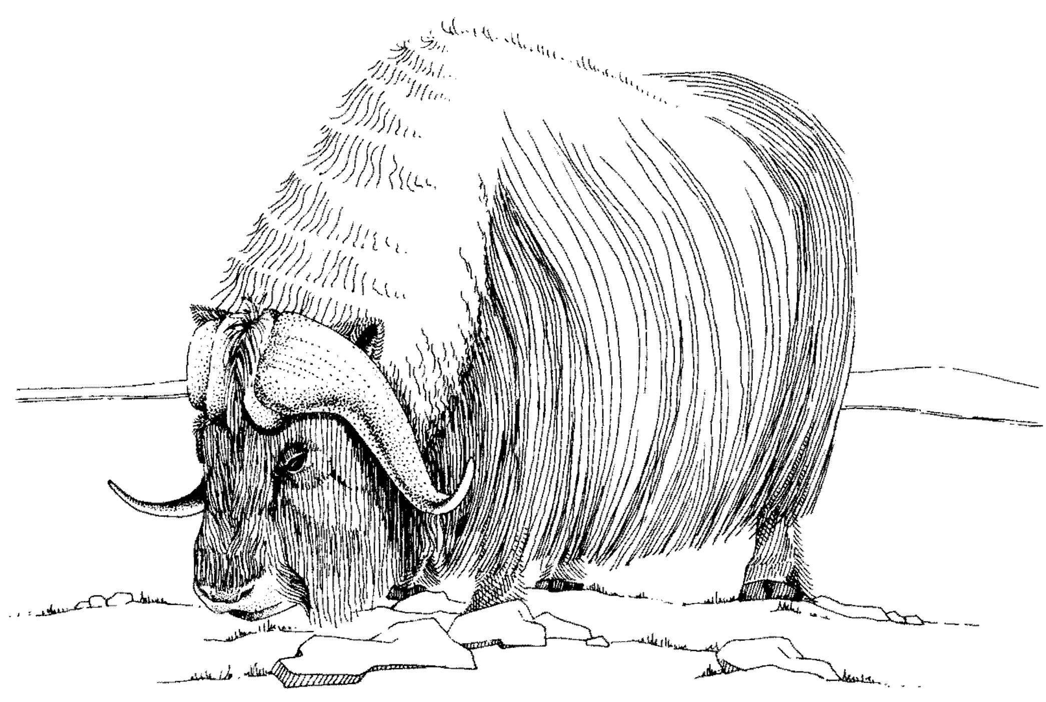
ARCTIC NATIONAL WILDLIFE REFUGE COASTAL PLAIN
RESOURCE ASSESSMENT

1985 UPDATE REPORT BASELINE STUDY OF THE FISH, WILDLIFE, AND THEIR HABITATS

Volume III
Section 1002C
Alaska National Interest Lands Conservation Act



U.S. Department of the Interior
U.S. Fish and Wildlife Service
Region 7
Anchorage, Alaska
December 1987

ARCTIC NATIONAL WILDLIFE REFUGE COASTAL PLAIN
RESOURCE ASSESSMENT

1985 UPDATE REPORT BASELINE STUDY OF THE FISH, WILDLIFE, AND THEIR HABITATS

Volume III of III

Section 1002C
Alaska National Interest Lands Conservation Act

Edited by
Gerald W. Garner and Patricia E. Reynolds

U.S. Department of the Interior
U.S. Fish and Wildlife Service
Region 7
Anchorage, Alaska
December 1987

TABLE OF CONTENTS

Chapter		Page
	VOLUME I	
1.	INTRODUCTION	1
	Literature Cited	1
2.	DESCRIPTION OF THE STUDY AREA	9
3.	SOILS AND VEGETATION	10
	Land Cover Mapping	10
	Other Studies	11
	Literature Cited	13
4.	BIRDS	14
	Bird Use of Tundra Habitats	14
	Terrestrial Bird Populations	14
	Species Accounts of Migratory Birds	16
	Tundra Swan Surveys	16
	Snow Goose Surveys	17
	Ecology of Staging Snow Geese	18
	Effects of Aircraft Disturbance Snow Geese	19
	Golden Eagle Distribution	20
	Raptor Surveys	20
	Bird Use of Lagoons and Offshore Habitats	21
	Lagoon Surveys	21
	Oldsquaw Habitat Use and Behavior	22
	Lagoon Invertebrates	24
	Literature Cited	24
5.	MAMMALS	26
	Ungulates	26
	Caribou	26
	Fall and Winter Distribution, Movements and Mortality	26
	Calving Distribution, Productivity and Mortality	27
	Distribution, Movements and Mortality in Canada	28
	Population Status	29
	Caribou Use of the 1002 Area	29
	Sampling Caribou Use	30
	Insects	30
	Muskoxen	32
	Ecology	32
	Satellite Telemetry	33
	Habitat Use	33
	Disturbance	33
	Moose	34

Chapter Page

5. MAMMALS (Cont.)

Predators.................................... 35
Brown Bears.............................. 35
Ecology.............................. 35
Behavior and Habitat Use............. 36
Wolves................................... 36
Ecology.............................. 36
Food Habits.......................... 38
Den Site Behavior and Summer Diets.... 38
Arctic Foxes............................. 39
Small Mammals................................ 41
Microtine Rodents........................ 41
1985 Population Status............... 41
Habitat Use.......................... 41
Literature Cited............................. 43

6. FISH... 44

Fairbanks Fishery Resource Station Studies...... 44
Fishery Investigations in Beaufort Lagoon.. 44
Fall Movements and Overwintering of Arctic Grayling.............................. 44
Age, Growth, Distribution and Summer Feeding Habits of Arctic Flounder in Arctic Beaufort Lagoon................................. 44
Baseline Histopathological and Contaminant Studies of Four Arctic Fish Species in Arctic Beaufort Lagoon......................... 45
Fisheries Investigations on the Kongakut River.................................. 45
The Freshwater Food Habits of Juvenile Arctic Char............................. 45
Other Studies................................ 46
Literature Cited............................. 46

7. HUMAN HISTORY AND ARCHAEOLOGY......................... 47

Subsistence.................................. 47
Kaktovik................................. 47
Literature Cited............................. 48

8. IMPACTS OF GEOPHYSICAL EXPLORATION.................... 49

Impacts on Vegetation and Surface Stability 49
Impacts on Visual Resources, Vegetation, and Surface Stability......................... 49
Wet Graminoid & Moist Sedge-Shrub Tundra 50
Moist Graminoid/Barren Tundra Complex. 51
Moist Sedge Tussock Tundra............ 51
Moist Shrub Tundra................... 52
Riparian Shrubland................... 52
Dryas Terrace........................ 52
Airphoto Analysis of Winter Seismic Trails. 53
Snow Distribution and Its Relation to Disturbance............................. 54
Effects on Muskoxen.......................... 55

Chapter	Page

9. IMPACTS OF FURTHER EXPLORATION, DEVELOPOMENT AND PRODUCTION OF OIL AND GAS RESOURCES.................. 56

APPENDICES.. 57

APPENDIX I VEGETATION... 58

Preliminary classification for a Landsat-derrived land cover map of two coastal plain study area, Arctic National Wildlife Refuge................................. 60

APPENDIX II BIRDS 64

ANWR Progress Report No. FY86-14
Terrestrial bird populations and habitat use in coastal plain tundra of the Arctic National Wildlife Refuge........ 66

ANWR Progress Report No. FY86-18
Species accounts of birds observed at eight study areas on the coastal plain of the Arctic National Wildlife Refuge, Alaska 1985.. 255

ANWR Progress Report No. FY86-13
Distribution, abundance and productivity of tundra swans in the coastal wetlands of the Arctic National Wildlife Refuge, Alaska 1985.. 325

ANWR Progress Report No. FY86-10
Distribution, abundance, and productivity of fall staging lesser snow geese on coastal habitats of northeast Alaska and northwest Canada, 1985.................................. 349

ANWR Progress Report No. FY86-11
Ecology of lesser snow geese staging on the coastal plain of the Arctic National Wildlife Refuge, Alaska, Fall 1985.. 370

ANWR Progress Report No. FY86-4
Distribution and relative abundance of golden eagles in relation to the Porcupine caribou herd during calving and post-calving periods, 1985.................................. 393

ANWR Progress Report No. FY86-15
Migratory bird use of the coastal lagoon system of the Beaufort Sea coastline within the Arctic National Wildlife Refuge, Alaska, 1985.................................... 421

ANWR Progress Report No. FY86-17
Habitat use and behavior of molting oldsquaw on the coast of the Arctic National Wildlife Refuge, 1985............... 451

ANWR Progress Report No. FY86.24
A preliminary study of epibenthic invertebrates and water quality in coastal lagoons of the Arctic National Wildlife Refuge.. 467

VOLUME II

Appendices Page

APPENDIX III MAMMALS.. 482

ANWR Progress Report No. FY86-21
Fall and winter movements, distribution, and annual mortality patterns of the Porcupine caribou herd, 1984-1985.. 484

ANWR Progress Report No. FY86-6
Calving distribution, initial productivity, and neonatal mortality of the Porcupine caribou herd, 1985.............. 496

ANWR Progress Report No. FY86-2
Ecology of muskoxen in the Arctic National Wildlife Refuge, Alaska 1982-1985.. 574

ANWR Progress Report No. FY86-5
Movements and activity patterns of a satellite-collared muskox in the Arctic National Wildlife Refuge, 1984-1985... 632

Progress Report No. FY86-9
Population size, composition, and distribution of moose along the Canning and Kongakut Rivers within the Arctic National Wildlife Refuge, Alaska, spring and fall 1985..... 649

ANWR Progress Report No. FY86-12
Ecology of brown bears inhabitating the coastal plain and adjacent foothills and mountains of the northeastern portion of the Arctic National Wildlife Refuge............. 665

ANWR Progress Report No. FY86-7
Wolves of the Arctic National Wildlife Refuge: their seasonal movements and prey relationships.................. 691

ANWR Progress Report No. FY86-19
Food habitats of denning wolves on the Arctic National Wildlife Refuge... 743

ANWR Progress Report No. FY86-1
A microtine rodent population increase in 1985 on the coastal plain of the Arctic National Wildlife Refuge, with notes on predator diversity................................ 764

APPENDIX IV FISH.. 776

FFR Progress Report No. FY86-1
Fisheries investigations in Beaufort Lagoon, Arctic National Wildlife Refuge, Alaska, 1985..................... 778

Appendices Page

FFR Progress Report No. FY86-2
Fall movements and overwintering of Arctic grayling in the Arctic National Wildlife Refuge, Alaska, 1985.............. 801

FFR Progress Report No. FY86-3
Age, growth, distribution and summer feeding habits of Arctic flounder in Beaufort Lagoon, Arctic National Wildlife Refuge, Alaska, 1985................................ 814

FFR Progress Report No. FY86-4
Baseline histopathological and contaminant studies in four arctic fish species in Beaufort Lagoon, Arctic National Wildlife Refuge, Alaska.................................... 827

FFR Progress Report No. FY86-5
Fisheries investigations on the Kongakut River, Arctic National Wildlife Refuge, Alaska, 1985...................... 875

FFR Progress Report No. FY86-6
The freshwater food habits of juvenile Arctic char in streams in the Arctic National Wildlife Refuge, Alaska..... 897

Volume III

APPENDIX V IMPACTS.. 909

ANWR Progress Report No. FY-2-Impacts
Effects of winter seismic exploration on visual resources, vegetation, and surface stability of the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985.......... 911

ANWR Progress Report No. FY86-1-Impacts
Airphoto analysis of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985. 994

ANWR Progress Report No. FY86-3-Impacts
Snow distribution on the arctic coastal plain and its relationship to disturbance caused by winter seismic exploration, Arctic National Wildlife Refuge, Alaska, 1985. 1045

ANWR Progress Report No. FY86-4-Impacts
Effects of winter seismic exploration activities on muskoxen in the Arctic National Wildlife Refuge January-May, 1984-1985.. 1081

ANWR Progress Report No. FY86-5-Impacts
Responses of muskox groups to aircraft overflights in the Arctic National Wildlife Refuge, 1982-1985................. 1095

ANWR Progress Report No. FY86-6-Impacts
Effects of aircraft disturbance on the energetics of staging lesser snow geese: a model........................... 1109

Appendix Page

Appendix VI OTHER STUDIES.................................. 1137

ADFG Interim Report
Population status and trend of the Porcupine caribou herd,
1982-1985.. 1139

CWS Report
Distribution, movements and juvenile mortality of the
Porcupine caribou herd in northern Yukon................... 1147

APPENDIX I:

Distribution, activity and range use of male caribou in
early summer in northern Yukon, Canada..................... 1184

AFWRC Progress Report: Subwork Unit 4
Caribou use of potential oil and gas development areas in
the 1002 region of the Arctic National Wildlife Refuge..... 1205

AFWRC Progress Report: Subwork Unit 3
A sampling method to determine caribou use of coastal
tundra on the Arctic National Wildlife Refuge : caribou
use of the area surrounding the Kaktovik Inupiat
Corporation (KIC) exploratory well No. 1 site.............. 1217

AFWRC Progress Report: Subwork Unit 5
Spatial and temporal distribution of biting and parasitic
insects on the coastal plain and adjoining foothills of
the Arctic National Wildlife Refuge........................ 1236

CONVERSION TABLE

For those readers who may prefer the commonly used American units, rather than the metric (Sl), the conversion factors for the units in this report are given below.

Multiply Metric S(l) Units	By	To obtain American Units
Centimeters (cm)	0.3937	Inches (in)
Meter (m)	1.0936	Yards (yd)
Kilometers (km)	0.6215	Miles (mi)
Grams (g)	0.0352	Ounces (oz)
Kilograms (kg)	2.2046	Pounds (lb)
Liters (L)	0.2642	Gallons (gal)
Square kilometers (km^2)	0.3861	Square miles (mi^2)
Square kilometers (km^2)	247.1050	Acres
Hectares (ha)	2.4711	Acres
Kilograms per hectare (kg/ha)	0.8262	Pounds per acre (lb/acre)
Cubic meters per second	35.7143	Cubic feet per second
Degrees Celsius (°C)	(°Cx1.8)=32	Degrees Fahrenheit (°F)

Appendix V

IMPACTS

Appendix V IMPACTS

Contents | Page

ANWR Progress Report No. FY-2-Impacts
Effects of winter seismic exploration on visual resources, vegetation, and surface stability of the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985......... 911

ANWR Progress Report No. FY86-1-Impacts
Airphoto analysis of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985 994

ANWR Progress Report No. FY86-3-Impacts
Snow distribution on the arctic coastal plain and its relationship to disturbance caused by winter seismic exploration, Arctic National Wildlife Refuge, Alaska, 1985 1045

ANWR Progress Report No. FY86-4-Impacts
Effects of winter seismic exploration activities on muskoxen in the Arctic National Wildlife Refuge January-May, 1984-1985.. 1081

ANWR Progress Report No. FY86-5-Impacts
Responses of muskox groups to aircraft overflights in the Arctic National Wildlife Refuge, 1982-1985................ 1095

ANWR Progress Report No. FY86-6-Impacts
Effects of aircraft disturbance on the energetics of staging lesser snow geese: a model........................ 1109

ANWR Progress Report Number FY86-2-Impacts

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

Key Words: Surface disturbance, winter seismic exploration, tundra, vegetation change, visual resources, permafrost, recovery, thaw depths, track depression, thaw settlement, traffic patterns, Alaska, Arctic National Wildlife Refuge, Arctic-Beaufort

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

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.

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

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

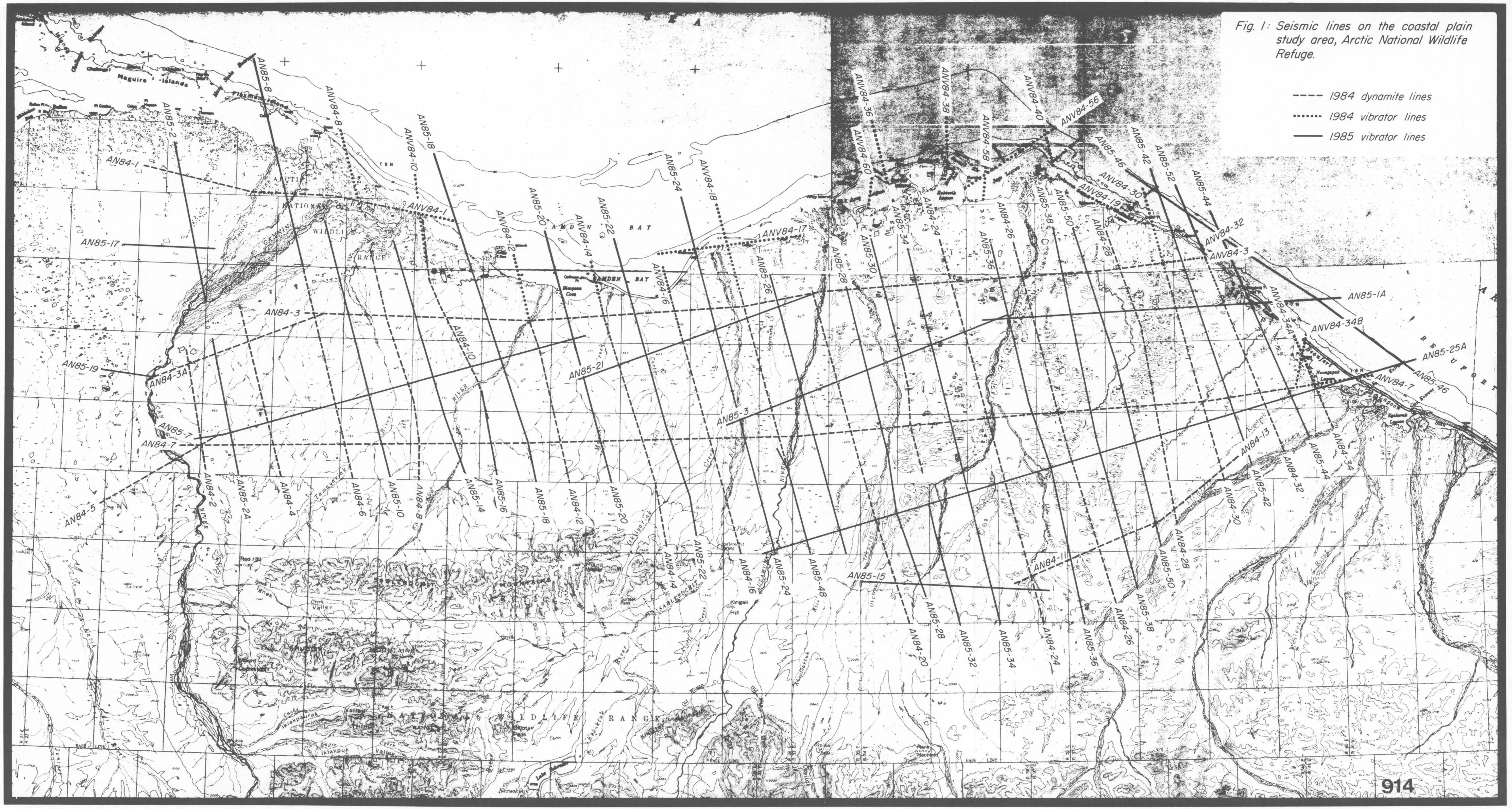


Fig. 1: Seismic lines on the coastal plain study area, Arctic National Wildlife Refuge.

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.

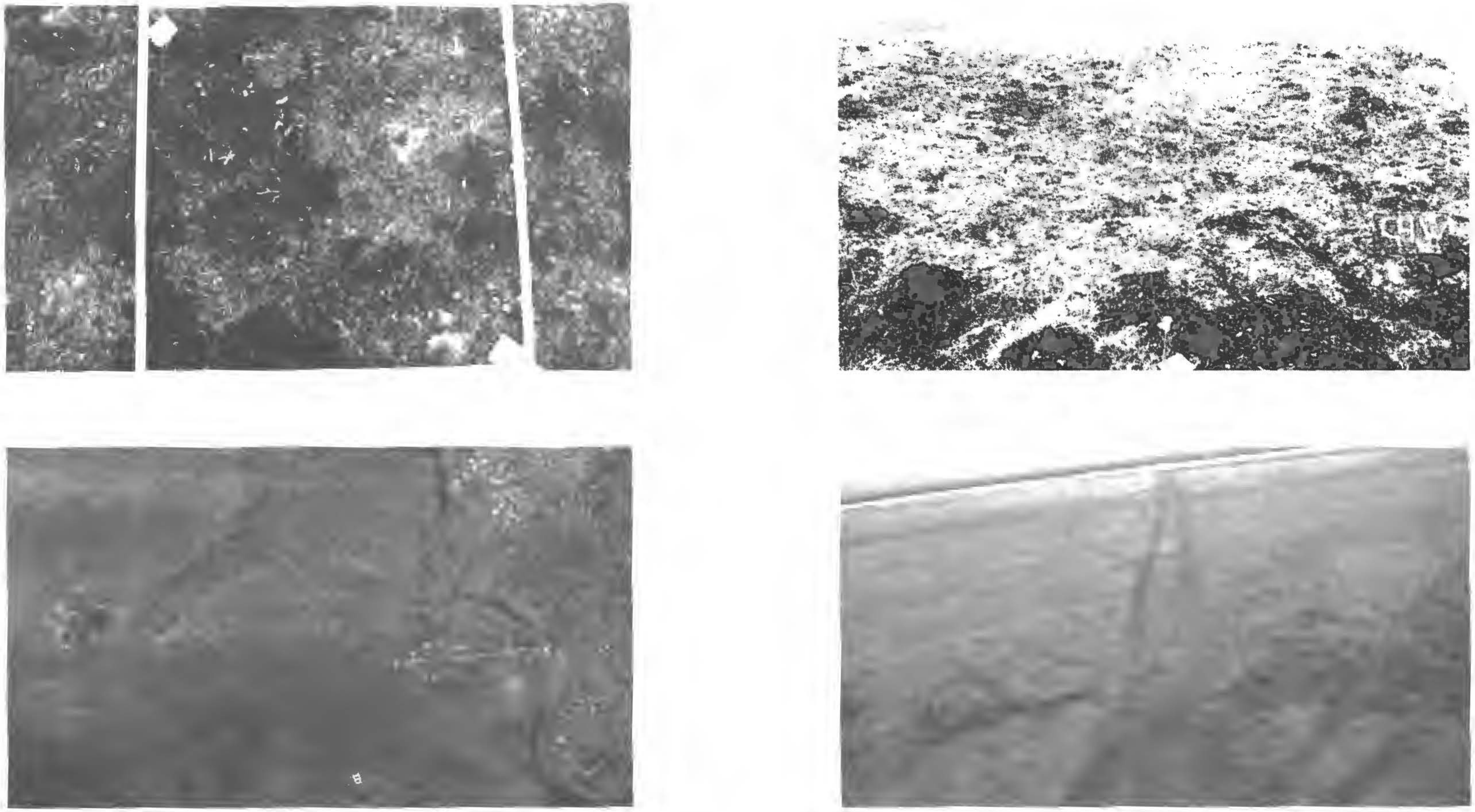


Plate 2. Quadrat photo (1 m^2), ground photo, verticle aerial photo, and oblique aerial photo of a moist shrub tundra plot.

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 sedge tussock tundra	T15	84 seismic-diffuse	84,85	0	1-25	tr	N
	T42	85 rolligon, single	85	0	0	0	N
	S7	84 camp-diffuse	84,85	1	1-25	0	N
	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 shrub tundra	N3	84 camp-diffuse	84,85	1	1-25	1-5	S1
	S2	84 seismic-diffuse	84,85	1	1-25	1-5	S1
	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 shrubland	O2	84 camp-narrow	84,85	1	1-25	1-5	S1
	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 terrace	T33	85 camp-diffuse	85	1	1-25	1-5	N
	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.

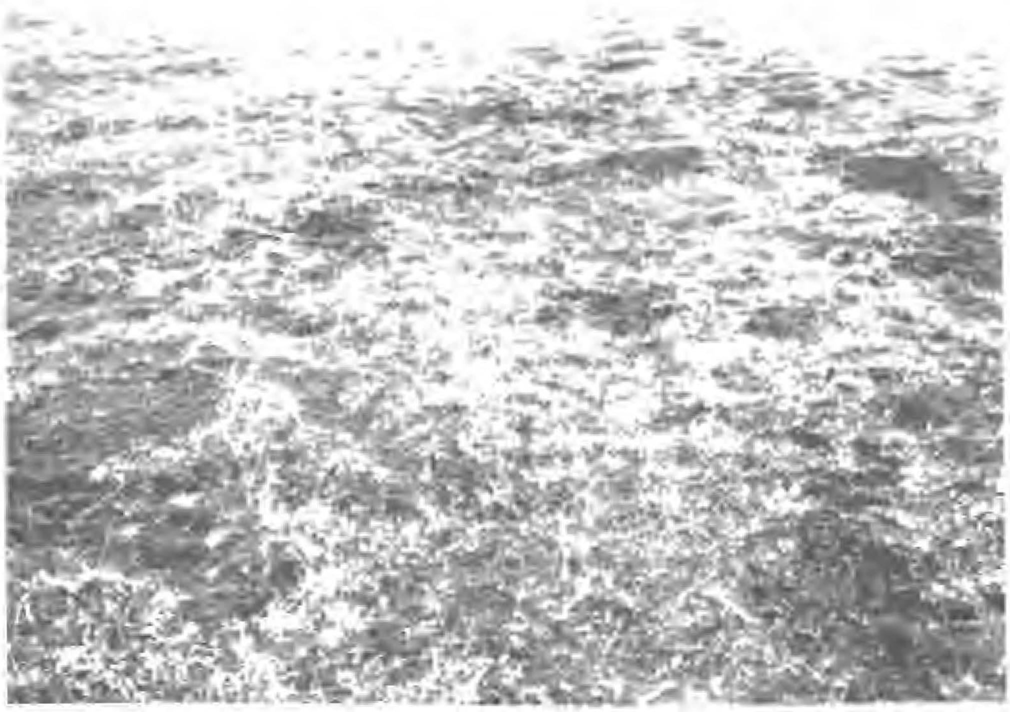


Plate 6. Level 3 disturbance on moist graminoid/barren tundra complex. Note exposed soil on mound tops.

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 (O12, T10, T31). Soil exposed was over 15% in some sites with higher microsites, such as polygon rims (O12).

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 (O11) 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
Dryas 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.

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

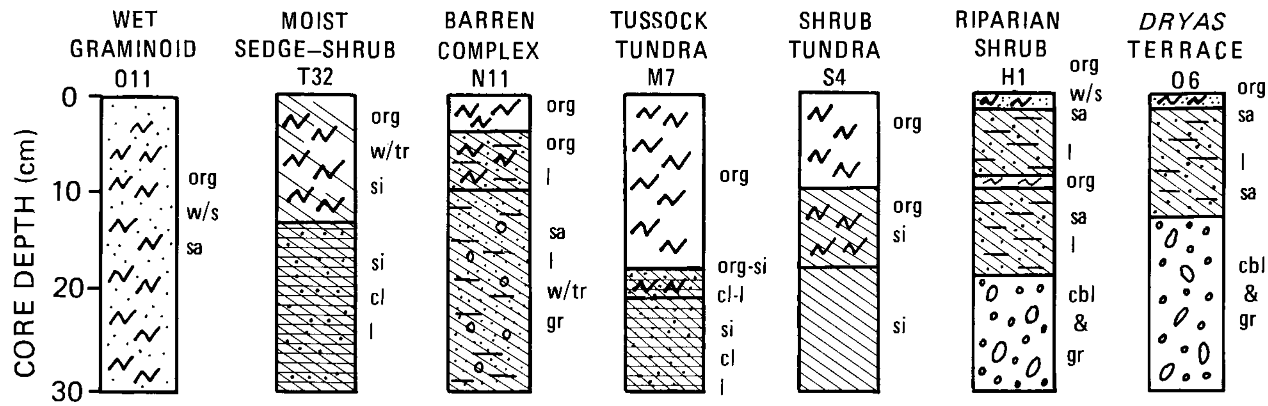


Fig. 2. Soil profiles of the active layer selected from plots in each vegetation type, coastal plain, Arctic NWR, Alaska, 1985. Soil textures: org - organic; cl - clay; si - silt; sa - sand; l - loam; gr - gravel; cbl - cobbles; w/tr - with trace; w/s - with some.

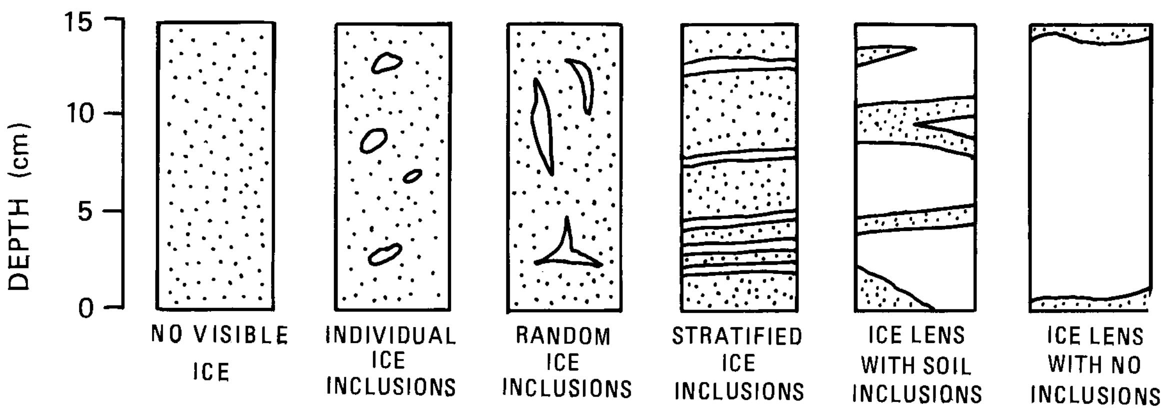


Fig. 3. Types of visible ice found in soils of the coastal plain (classification according to Pihlainen and Johnston 1963), Arctic National Wildlife Refuge, Alaska, 1985.

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.

		Visual estimates						Lab determination		
		Top 30 cm			Top 10 cm					
Vegetation type	Plot no.	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD
Wet graminoid	O11	5	37	21	5	27	22	4	10	10
Moist sedge - shrub tundra	M1	4	49	2	4	52	5	3	39	14
	O18	5	32	15	5	33	16	4	5	4
	O19	4	31	10	5	44	15	4	11	4
	O20	4	20	4	4	33	10	4	6	5
	C3	5	27	6	5	37	15	5	20	7
	O14	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
	O3	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	Visibility[b] Ground
Wet graminoid tundra			
T16	1	1	0
N1	1	2	2
05	1	2	1
010	1	2	2
011	2	2	2
017	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
018	1	2	2
019	1	2	2
020	1	2	2
M6	1	1	1
N2	1	2	1
N8	1	2	1
T41	1	2	1
C3	2	2	3
013	2	2	2
014	2	3	2
T18	2	2	2
T25	2	2	2
T26	2	2	2
T38	2	2	2
T39	2	2	2
012	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			
02	1	0	1
M4	1	2	2
S5	1	1	1
09	1	1	1
T36	1	1	1
015	2	3	3
01	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
06	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
03	2	2	2
07	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
08	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
016	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 (O11, O12). 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 (O11) 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

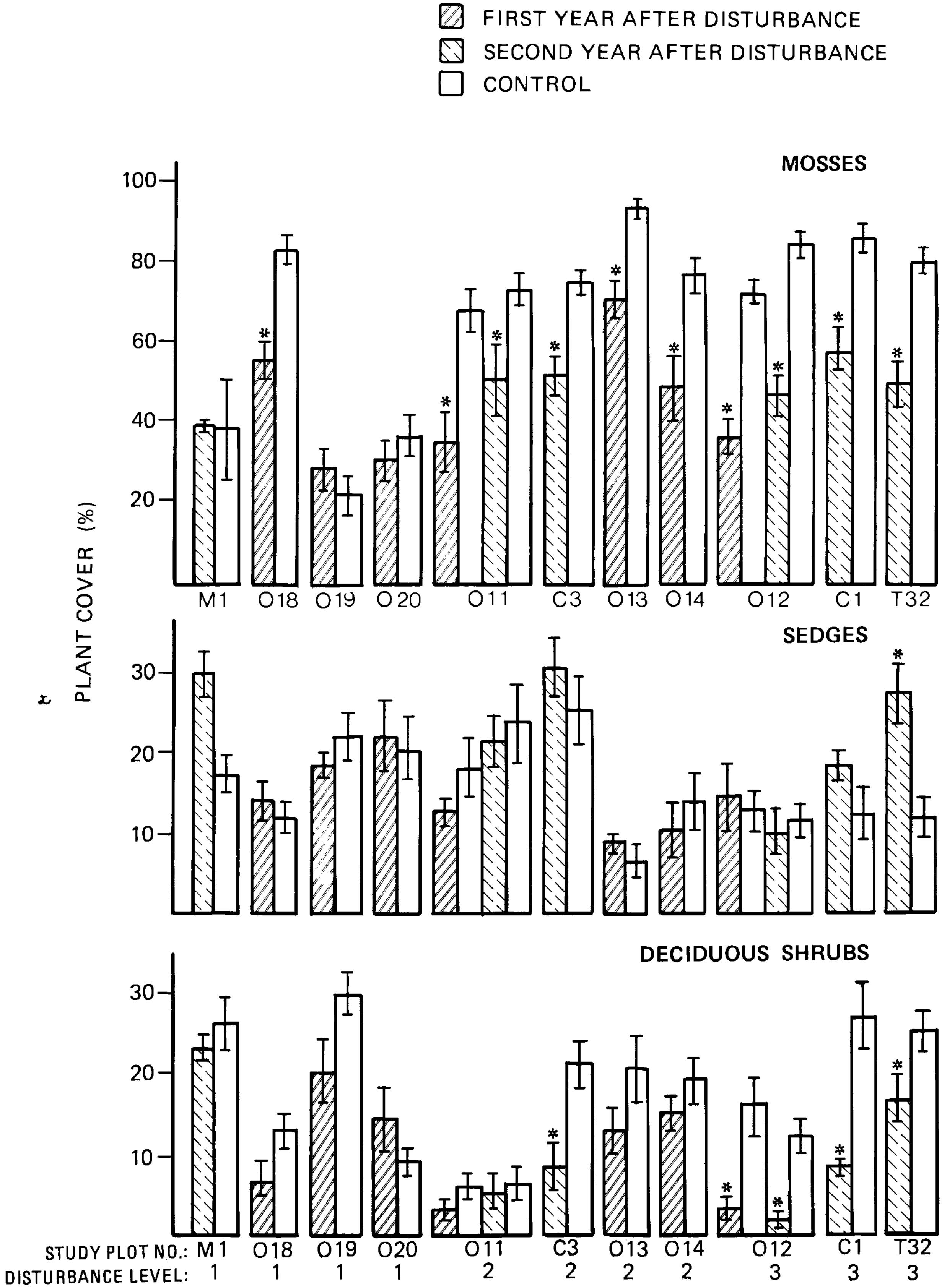


Fig. 4. Cover (%) of mosses, sedges, and deciduous shrubs in wet graminoid (O11) and moist sedge - shrub tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control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

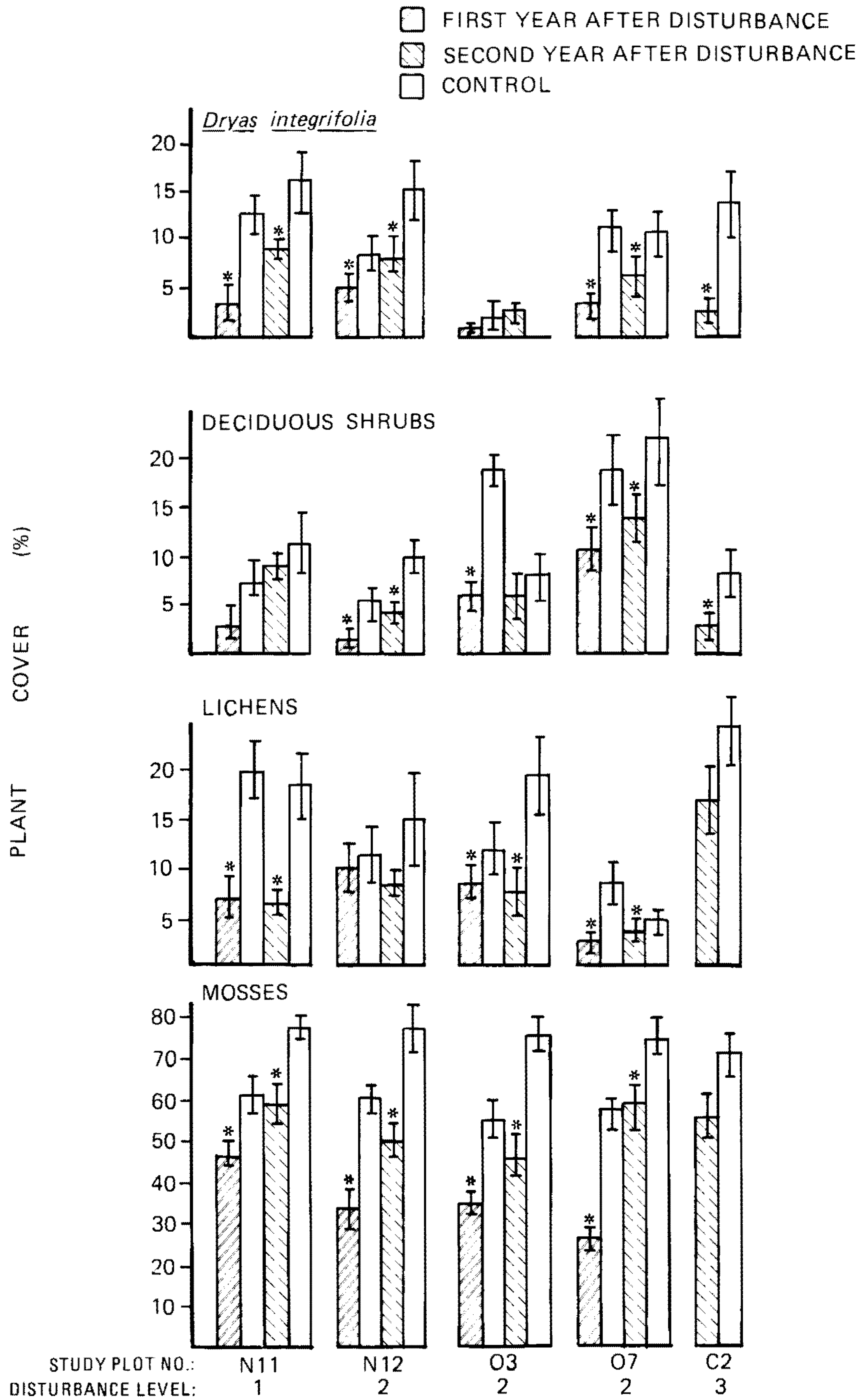


Fig. 5. Cover (%) of *Dryas integrifolia*, deciduous shrubs, lichens, and mosses in moist graminoid/barren tundra complex after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

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.

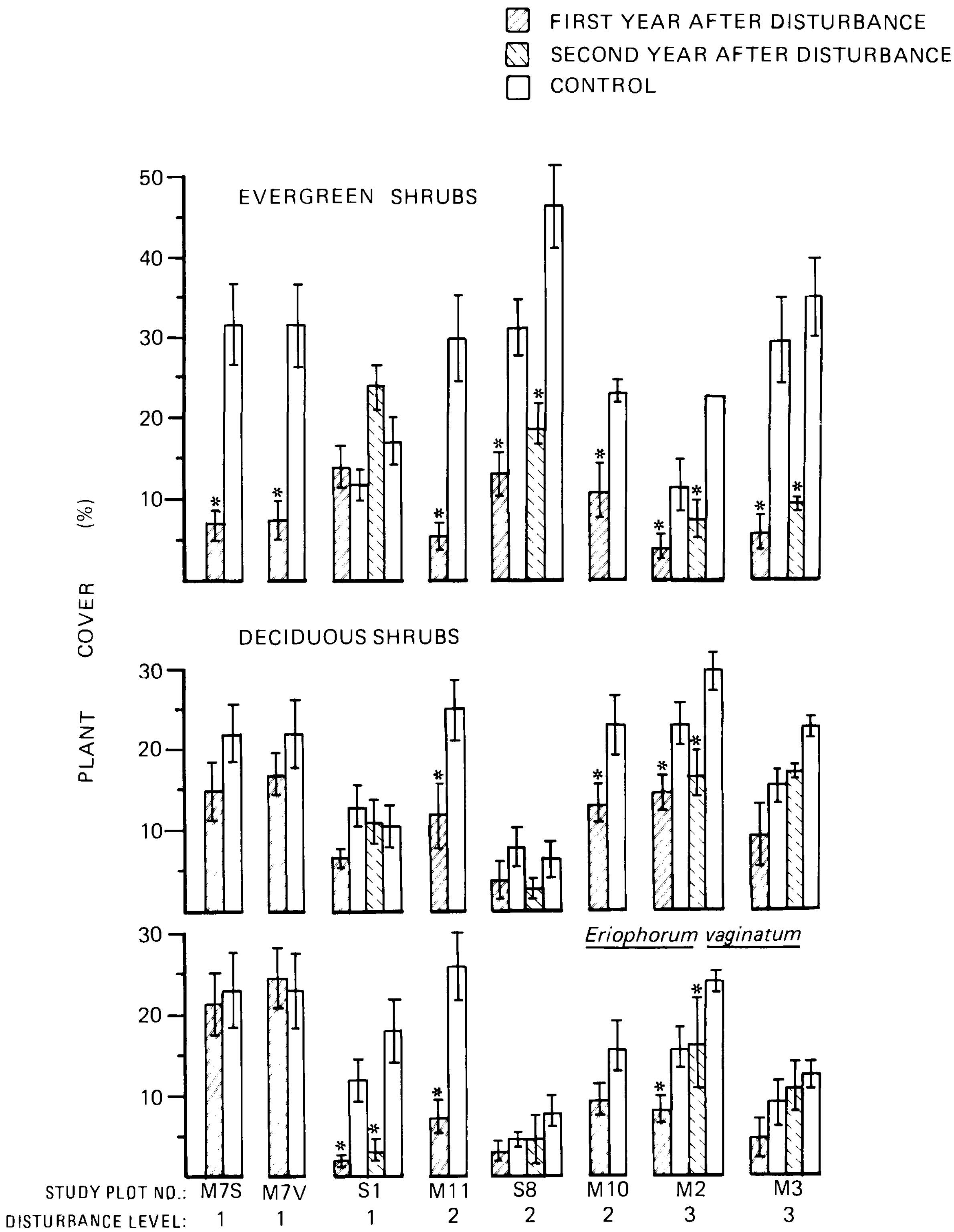


Fig. 6. Cover (%) of evergreen shrubs, deciduous shrubs, and Eriophorum vaginatum (cotton grass) in tussock tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control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

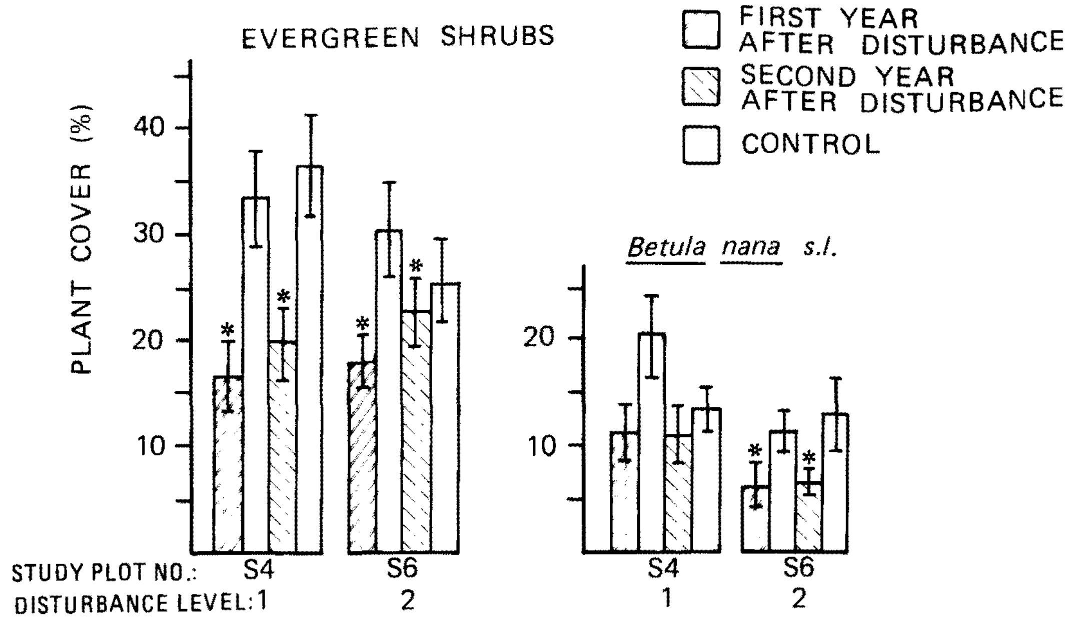


Fig. 7. Cover (%) of evergreen shrubs and Betula nana s.l. (dwarf birch) in shrub tundra after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985.

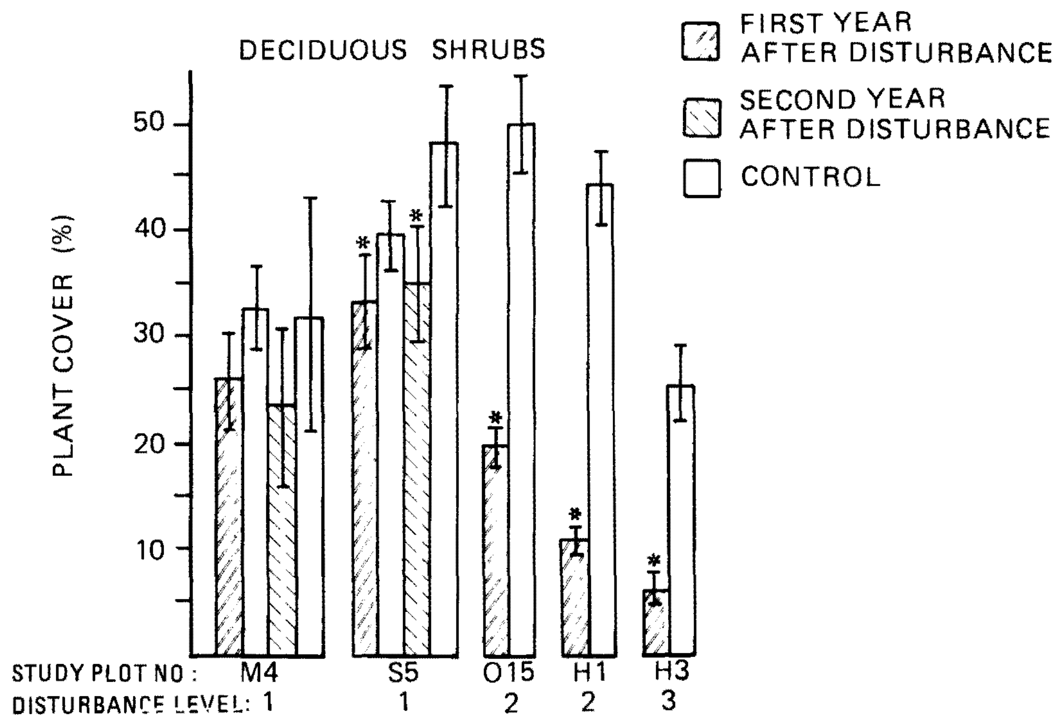


Fig. 8. Cover (%) of deciduous shrubs in riparian shrubland after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

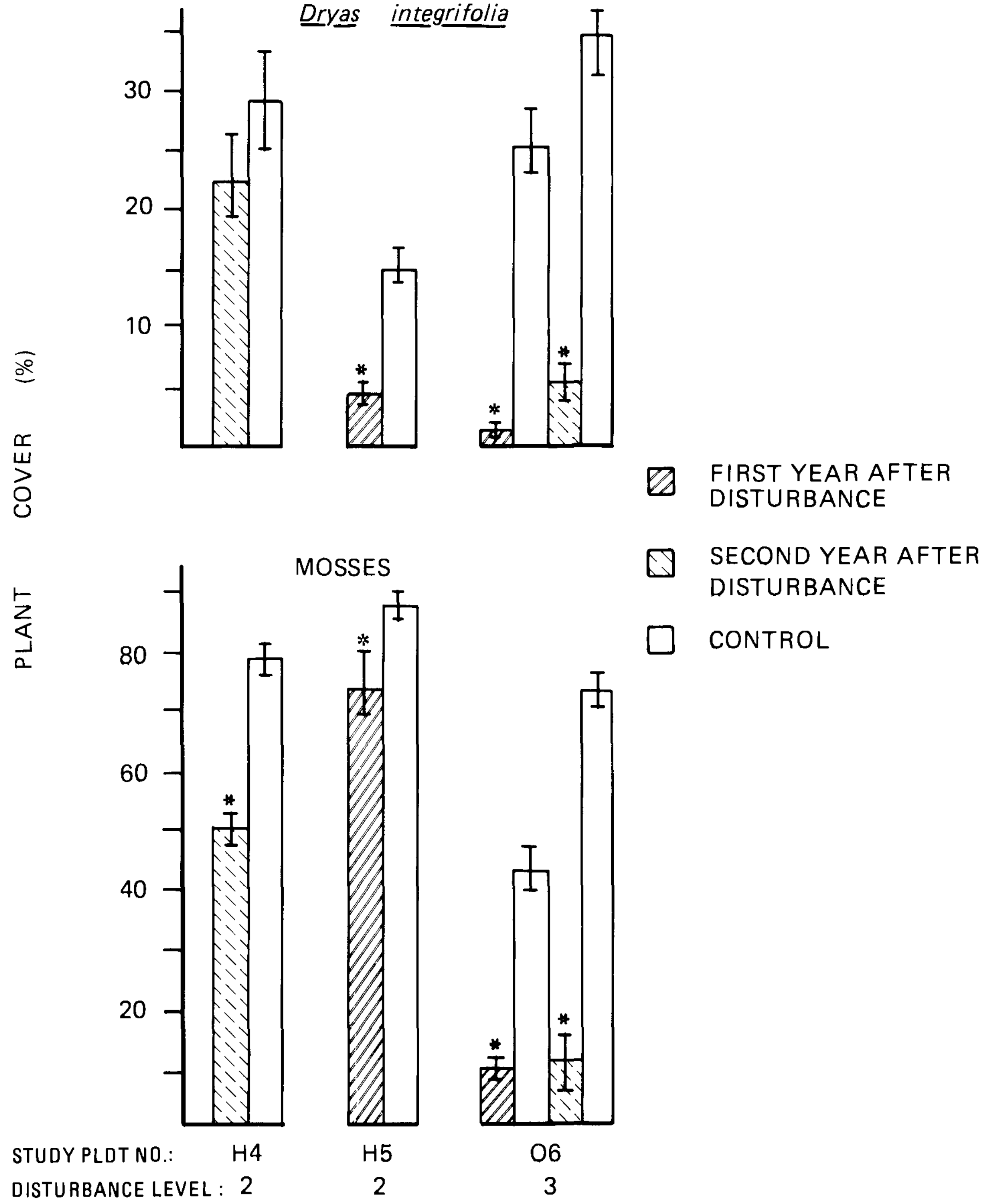


Fig. 9. Cover (%) of Dryas integrifolia and mosses in Dryas terrace after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1984-1985. Data are means ± SE, N=10. * indicates a significant difference between disturbed and control plots ($P < 0.05$).

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.

			Recolonizing vegetative shoots			Recolonizing seedlings	
Plot	Dist.[a] level	Bare[b] ground (%cover)	Total number	No./m² bare ground	ERVA[c]	Total number	No./m² 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 cm². tr-trace, 1%.
[c] Cover of *Eriophorum vaginatum* tillers, measured in cm²/m² of bare ground.
[d] Not including *Dryas integrifolia*, which covered 72 cm²/m² of bare ground.
[e] Not including *Dryas integrifolia*, which covered 36 cm²/m² of bare ground.

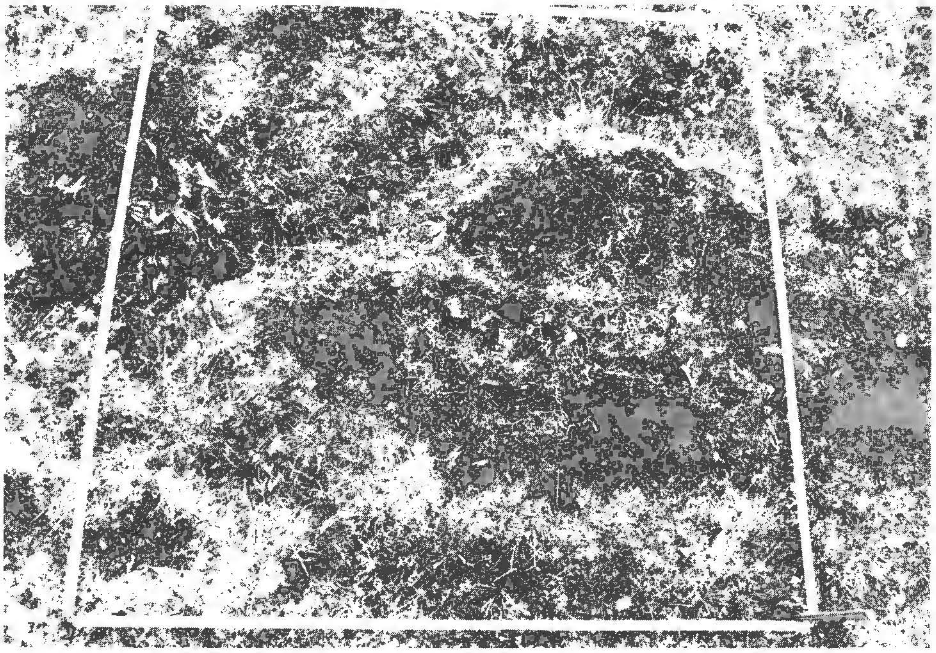


Plate 12. Quadrat photo (1 m^2) in *Dryas* terrace vegetation. Little recovery occurred on bare soil.

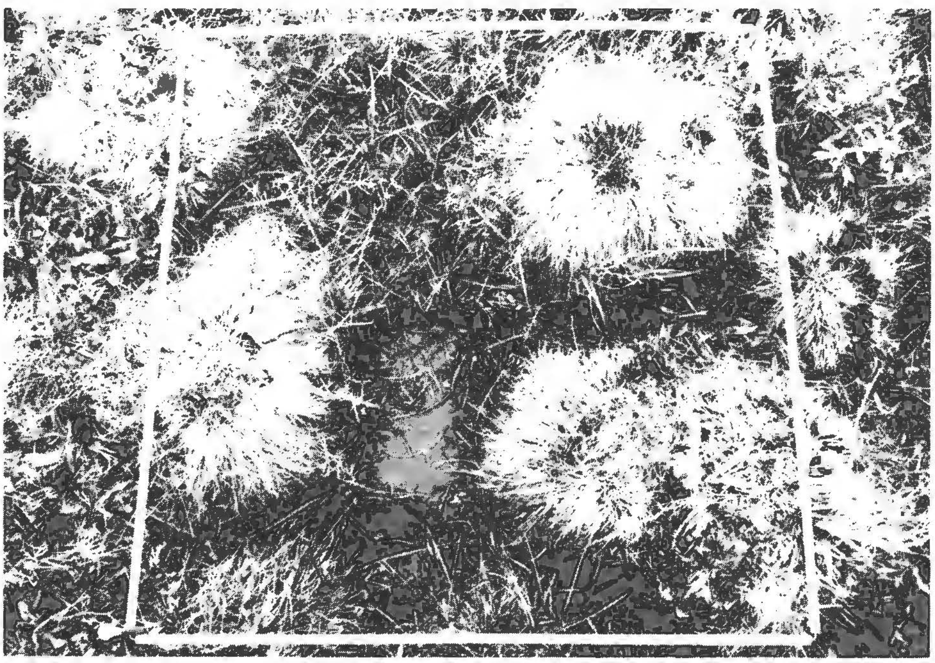


Plate 13. Quadrat photo (1 m^2) in moist sedge tussock tundra. Note tillering in center of scuffed tussock in upper right.

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 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 (011) and moist sedge-shrub tundra (M1, T32), coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	011 (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).

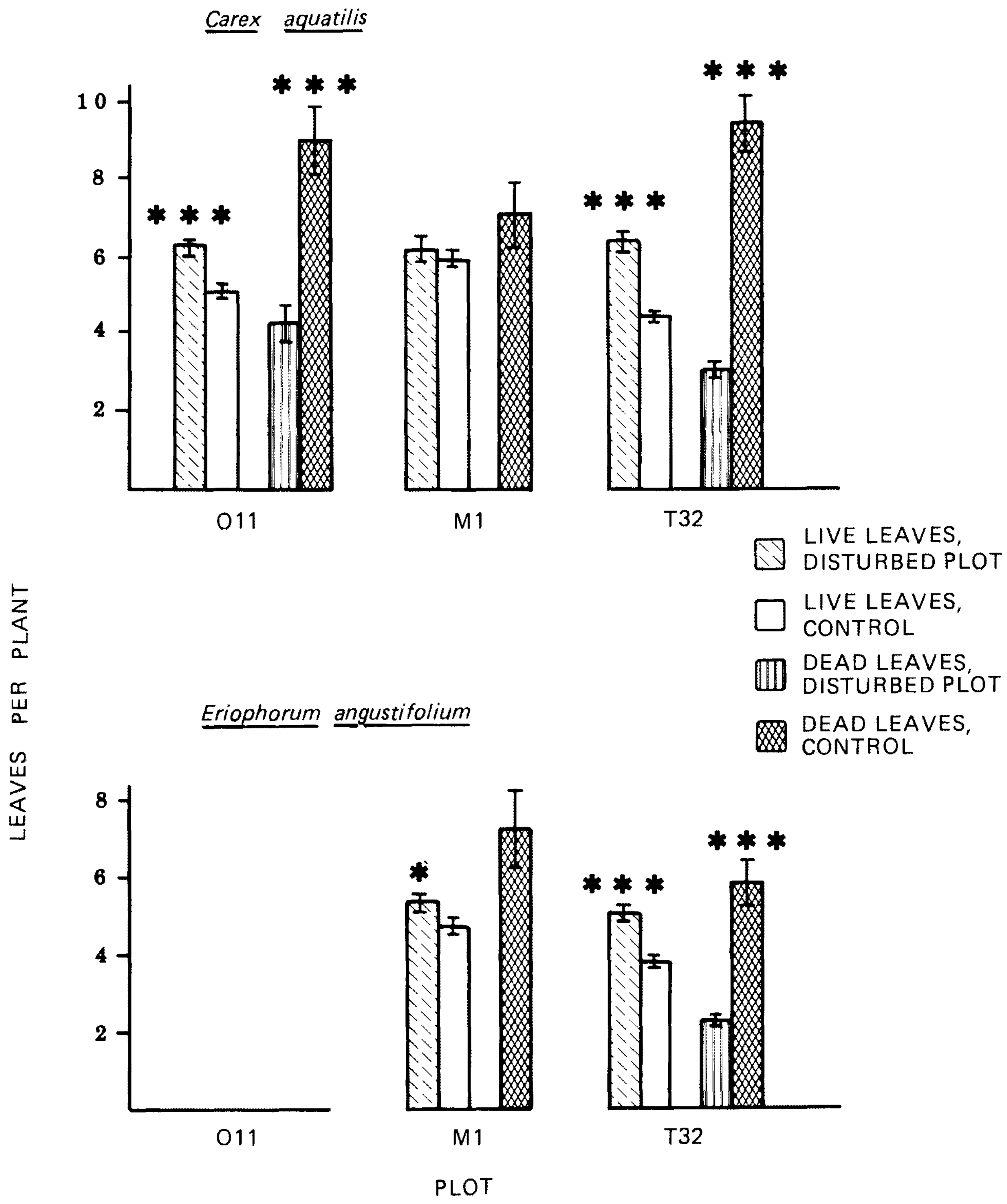


Fig. 10. Numbers of live and dead leaves per plant on Carex aquatilis and Eriophorum angustifolium 2 years after disturbance from winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1985. Data are means ± SE, N=20. *, *** indicates a significant difference between disturbed and control plots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

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.

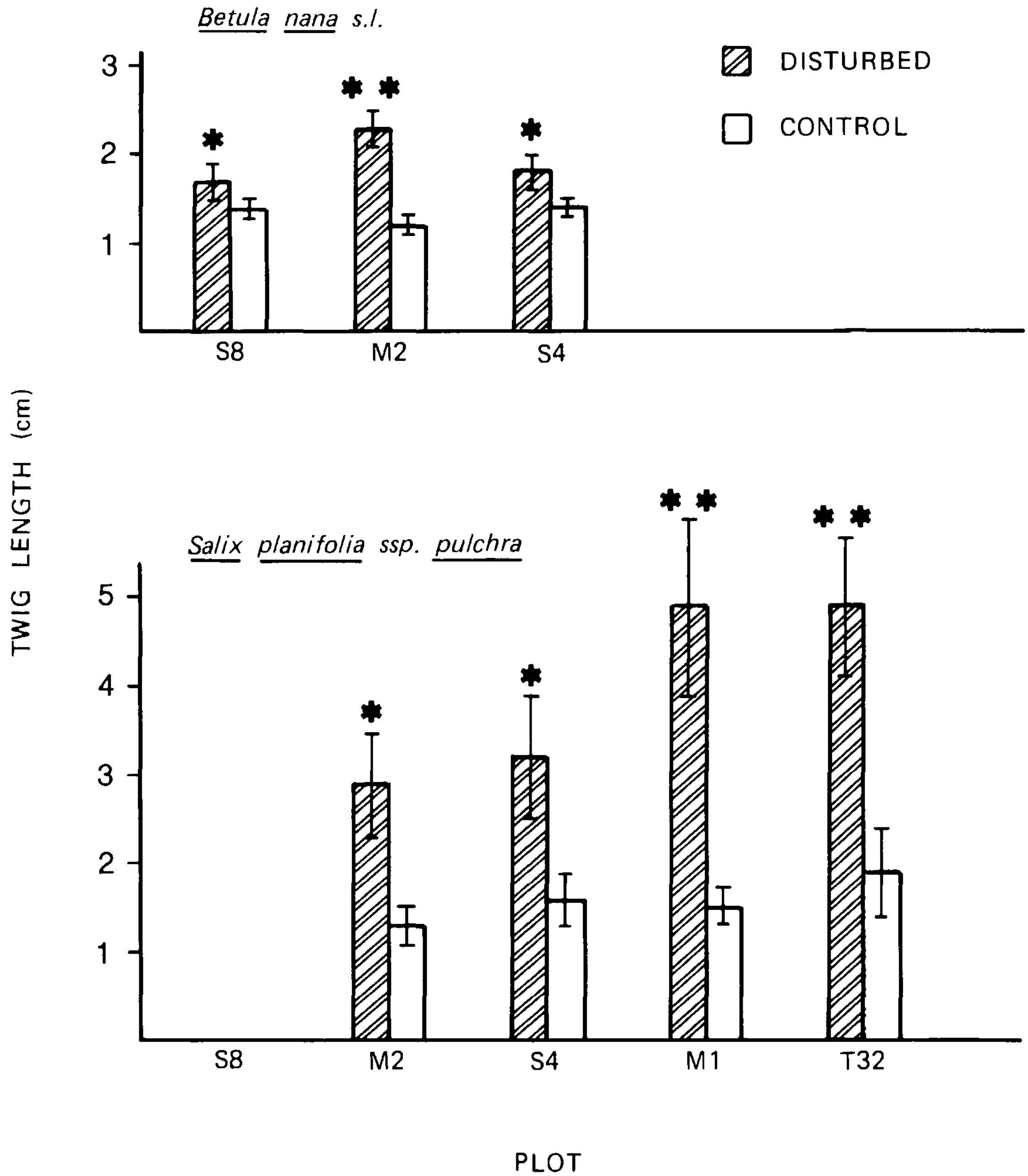


Fig. 11. Twig length of current year's growth of Betula nana s.l. (dwarf birch) and Salix planifolia ssp. pulchra (diamond-leaf willow) 2 years after winter seismic exploration, coastal plain, Arctic NWR, Alaska, 1985. Data are means ± SE, N=40 for B. nana, 20 for S. planifolia. *, ** indicates a significant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

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.

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 N	1984 D$\bar{x}$	1984 C$\bar{x}$	1985 N	1985 D$\bar{x}$	1985 C$\bar{x}$	1984 D-C	1985 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	05	1	10	38	40	30	34	29	2	5	*	*	
	010	1	16	30	29	30	34	31	1	3	*	*	
	011	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-	018	1				30	26	19		7	*		
shrub	019	1				30	28	28		0			
tundra	020	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			
	012	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	*		
	03	2	20	29	26	30	26	21	3	5	*	*	
	07	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 $D\bar{x}$	1984 $C\bar{x}$	1985 N	1985 $D\bar{x}$	1985 $C\bar{x}$	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	O1	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, O14, 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 O14 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).

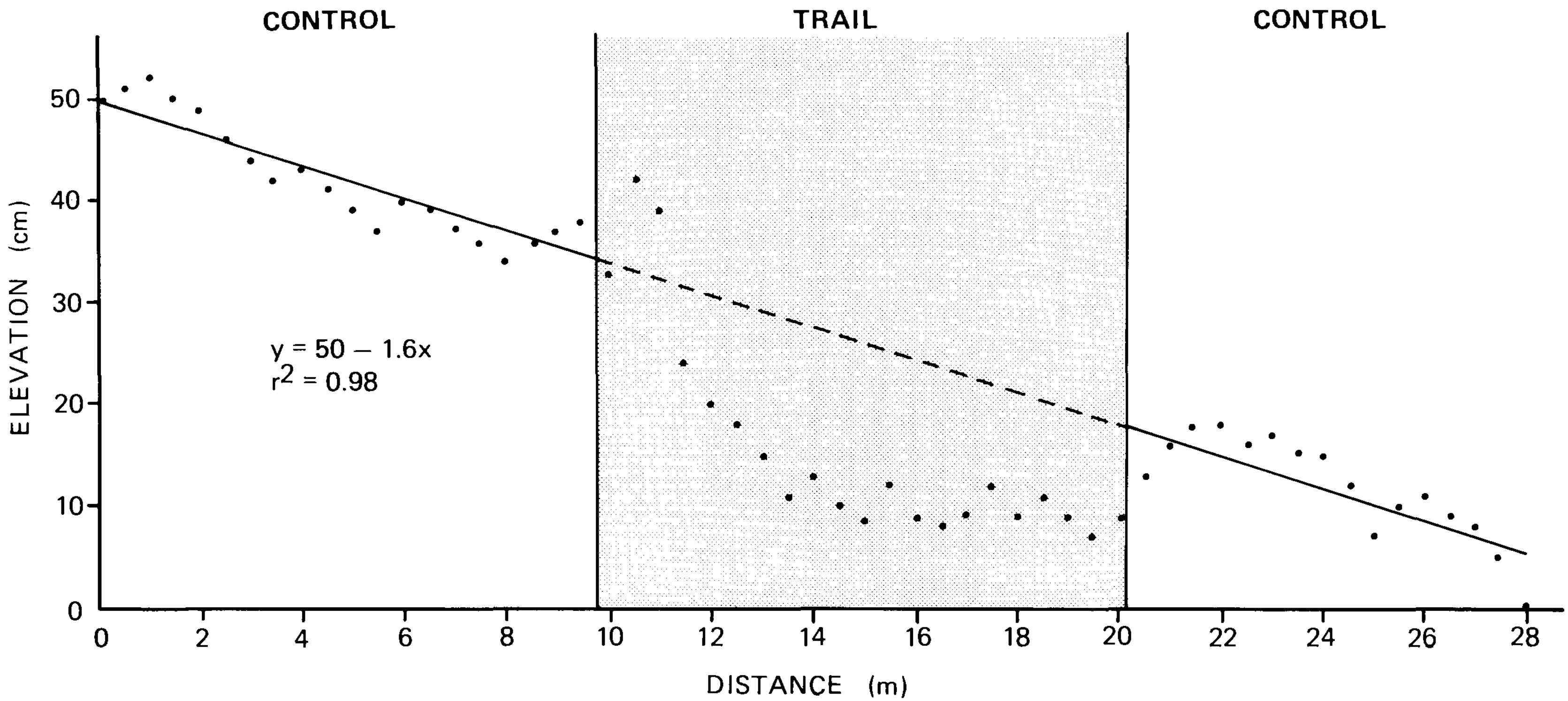


Fig. 12. Cross-section of narrow camp-move trail (plot C1) in moist sedge-shrub tundra, coastal plain, Arctic NWR, Alaska, 1985. Regression line through control points shows track depression in trail.

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)			Area (m^2)		
			N	$\overline{x}$	SD	N	$\overline{x}$	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.

Acknowledgments

We wish to thank ERA helicopter pilot Bob Dunbar for his safe and skillful logistical support as well as his entertaining insights into tundra ecology, and volunteer Sam Dashevsky for his help with data collection and his excellent photos of tundra plants. The U.S. Army Cold Regions Research and Engineering Laboratory in Fairbanks loaned equipment and lab facilities for the soils work. The plant nutrient analyses were conducted by the ecophysiology laboratory of F.S. Chapin at the University of Alaska-Fairbanks.

Literature Cited

Abele, G. 1976. Effects of Hovercraft, wheeled and tracked vehicle traffic on tundra. Pages 186-201 in Proc. of the Sixteenth Muskeg Res. Conf., Natl. Res. Counc. of Canada, Assoc. Comm. on Geotechnical Res., Tech. Memo 116.

Argus, G.W. 1973. The Genus *Salix* in Alaska and the Yukon. Natl. Museums of Canada, Ottawa. 279pp.

Barrett, P., and R. Schulten. 1975. Disturbance and the successional response of the arctic plants on polar desert habitats. Arctic 28(1):70-73.

Bates, D.N., J.M. Belisle, B.H. Cameron, L.J. Evans, R.K. Jones, G. Pierpoint, and B. van der Broek. 1982. Field manual for describing soils. Ontario Inst. of Pedology, Univ. of Guelph. O.I.P. Publication No. 82-1. 38pp.

Bliss, L.C., and R.W. Wein. 1972. Plant community responses to disturbance in the western Canadian Arctic. Can. J. Bot. 50:1097-1109.

Challinor, J.L., and P.L. Gersper. 1975. Vehicle perturbation effects upon a tundra soil-plant system: II. Effects on the chemical regime. Soil Sci. Soc. Amer. Proc. 39:689-695.

Chapin, F.S., and M.C. Chapin. 1980. Revegetation of an arctic disturbed site by native tundra species. J. Appl. Ecol. 17:449-456.

Chapin, F.S., and G.R. Shaver. 1981. Changes in soil properties and vegetation following disturbance of Alaskan arctic tundra. J. Appl. Ecol. 18:605-617.

Crum, H.A., and L.E. Anderson. 1981. Mosses of eastern North America. Columbia Univ. Press, New York. 1328pp.

Dixon, W.J., M.B. Brown, L. Engelman, J.W. Frane, M.A. Hill, R.I. Jennrich, and J.D. Toporek. 1985. BMDP statistical software manual. Univ. of Calif. Press, Berkeley. 725pp.

Ebersole, J.J. 1985. Vegetation disturbance and recovery at the Oumalik oil well, Arctic Coastal Plain, Alaska. Ph.D. Thesis, Univ. of Colo., Boulder, CO. 408pp.

Envirosphere Company. 1985. Effects of dynamite and vibrator seismic exploration on visual quality, soils, and vegetation of the Alaskan North Slope. Final report prepared for Geophysical Services, Inc., Anchorage, Alaska. 82pp + appendices.

Everett, K.R., B.M. Murray, D.F. Murray, A.W. Johnson, A.E. Linkins, and P.J. Webber. 1985. Reconnaissance observations of long-term natural vegetation recovery in the Cape Thompson region, Alaska, and additions to the checklist of flora. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 85-11. 76pp.

Felix, N.A., and M.T. Jorgenson. 1985. Effects of winter seismic exploration on the coastal plain of the Arctic National Wildlife Refuge, Alaska. Pages 622-699 in G.W. Garner and P.E. Reynolds, eds. 1984 update report: baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska. 777pp.

Felix, N.A., M.T. Jorgenson, M.K. Raynolds, R. Lipkin, D.L. Blank, and B.K. Lance. 1987. Airphoto analysis of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge, Alaska. U.S. Fish and Wildlife Service. In G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Gartner, B.L., F.S.Chapin, and G.R. Shaver. 1983. Demographic patterns of seedling establishment and growth of native graminoids in an Alaskan tundra disturbance. J. Appl. Ecol. 20:965-980.

Geophysical Service Inc. 1983a. Exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Geophysical Service Inc. 1983b. Plan of operation supplementing the GSI exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1983. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Geophysical Service Inc. 1984. Plan of operation for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1984. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Hays, R.L., C. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. Western Energy and Land Use Team, U.S. Fish and Wildl. Serv., Washington D.C. FWS/OBS-81/47. 111pp.

Hernandez, H. 1973. Natural plant recolonization of surficial disturbances, Tuktoyaktuk Peninsula Region, Northwest Territories. Can. J. Bot. 51:2177-2196.

How, G.T., and H. Hernandez. 1975. Terrain and vegetation response to disturbance in the Yukon Coastal Plain and Mackenzie Delta region and relevance to the proposed gas pipeline. Environ. Protection Board, Canada. 62pp.

Hulten, E. 1968. Flora of Alaska and neighboring territories, Stanford Univ. Press, Stanford, California. 1008pp.

Johnston, G.H. 1981. Permafrost, engineering design and construction. Natl. Res. Counc. of Canada. Wiley and Sons, New York. 540pp.

Jorgenson, M.T. 1986. Biophysical factors influencing the geographic variability of soil heat flux near Toolik Lake, Alaska: implications for terrain sensitivity. M.S. Thesis. Univ. of Alaska, Fairbanks, Alaska. 109pp.

Kedrowski, R.A. 1983. Extraction and analysis of nitrogen, phosphorus, and carbon fractions in plant material. J. of Plant Nutr. 6(11):989-1011.

Kreig, R.A., and R.D. Reger. 1982. Airphoto analysis and summary of landform soil properties along the Trans-Alaska Pipeline System. Alaska Div. of Geologic and Geophysical Survey. Geol. Rep. 66. 149pp.

Lambert, J.D.H. 1972. Botanical changes resulting from seismic and drilling operation, Mackenzie Delta area. Arctic Land Use Research Program, Dept. of Indian Affairs and Northern Development, Canada. 55pp and appendix.

Lawson, D.E., J. Brown, K.R. Everett, A.W. Johnson, V. Komarkova, B.M. Murray, D.F. Murray, and P.J. Webber. 1978. Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, northern Alaska. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 78-28. 81pp.

Lawson, D.E. 1983. Ground ice in perennially frozen sediments, northern Alaska. Pages 695-699 in Proceedings of the fourth international permafrost conference, July 17-22, 1983, Fairbanks, Alaska. Natl. Academy Press, Wash., D.C.

Mitchell, W.W. 1981. Alaskan-developed grass varieties coming into use. Agroborealis 13:56-58.

Muskeg Research Institute. 1970. Tests to define levels of terrain damage by tracked vehicles operating on tundra. Rep. prepared for Canadian Dept. of Indian Affairs and Northern Development. 32pp.

Pihlainen, J.A., and G.H. Johnston. 1963. Guide to a field description of permafrost. Canada, Natl. Res. Counc., Assoc. Comm. on Soil and Snow Mech. Tech. Memo 79. 23pp.

Racine, C.H. 1979. The 1977 tundra fires in the Seward Peninsula, Alaska: effects and initial revegetation. U.S. Bur. of Land Manage., Anchorage, Alaska. BLM-Alaskan Tech. Rep. 4. 51pp.

Reynolds, P.C. 1982. Some effects of oil and gas exploration activities on tundra vegetation in northern Alaska. Pages 403-417 in P.J. Rand, eds. Land and water issues related to energy development. Ann Arbor Science, Ann Arbor, Michigan.

SPSS Inc. 1986. SPSSX user's guide. McGraw-Hill Book Company, New York. 988pp.

Sterrett, K.F. 1976. The arctic environment and the arctic surface effect vehicle. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 76-1. 28pp.

Thompson, J.W. 1979. Lichens of the Alaskan Arctic Slope. Univ. of Toronto Press, Toronto. 314pp.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 1984, 1985. Local climatological data; monthly summary, Barter Island, Alaska. National Climate Data Center, Asheville, N.C.

U.S. Fish and Wildlife Service. 1982. Arctic National Wildlife Refuge coastal plain resource assessment - initail report. Baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska. 507pp.

Walker, D.A., K.R. Everett, W. Acevedo, L. Gaydos, J. Brown, and P.J. Webber. 1982. Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 82-27. 59pp.

Walker, D.A, P.J. Webber, and K.R. Everett. 1983. 1:63,360 scale geobotanical mapping studies in the Arctic National Wildlife Refuge, Alaska. Final report by Institute of Arctic and Alpine Research, Univ. of Colorado, Boulder. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska. 125pp.

APPENDIX

ANWR Progress Report Number FY 86-2-Impacts

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)			Organic			Organic-mineral			Mineral		
		N	$\overline{x}$	SD	N	$\overline{x}$	SD	N	$\overline{x}$	SD	N	$\overline{x}$	SD
Wet graminoid	O11	5	80	7	5	80	7						
Moist sedge-shrub tundra	M1	5	85	4	5	85	4	4	72	7	4	51	8
	O18	5	55	8	5	55	8				5	44	2
	O19	5	72	8	5	72	8	3	78	5	4	43	8
	O20	5	77	5	5	77	5				5	40	7
	C3	5	60	6	5	60	6	3	80	3	3	57	2
	O14	4	64	5	2	61	1	5	60	9	3	45	2
	O12	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
	O3	5	55	10	5	48	12	3	60	7	5	42	7
	O7	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
	O15	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
	O6	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 011 (L2) 1984 C	D	1985 C	D		Moist sedge-shrub tundra M1(L1) 1984 C	D	1985 C	D		018 (L1) 1985 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
Salix phlebophylla	5	1	7	5	T					
Salix arctica						2	1	6	1	T
Dryas integrifolia	13	4	16	9	TY	9	5	15	8	TY
Carex Bigelowii	7	5	7	4		10	3	8	8	
Eriophorum angustifolium	6	4	5	7		7	5	4	2	
Eriophorum vaginatum						1AB	2A	6B	1A	I
Aulacomnium spp.	4	4	7	8	Y	9	4	6	6	
Dicranum spp.	5	2	4	2	T	7	4	5	3	
Drepanocladus spp.						3	1	6	1	T
Hylocomium splendens	5	3	7	1	T					
Ptilidium ciliare	9	8	9	5		9	4	6	6	
Tomenthypnum nitens	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.

	Moist graminoid/barren tundra complex												
	03 (L2)					07(L2)					C2 (L3)		
Ground cover type	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
Arctostaphylos rubra	14	11	12	12						
Salix brachycarpa ssp. *niphoclada*	9	5	7	4						
Salix glauca						18	20	12	18	
Salix hastata	5	1	6	2						
Salix lanata ssp. *richardsonii*						19	12	24	9	T
Salix planifolia ssp. *pulchra*						6	7	8	5	
Salix reticulata	2	5	5	5		9	3	3	3	
Dryas integrifolia	11	3	14	10						
Carex Bigelowii						6	8	3	7	
Poa spp.						5	6	11	7	
Hedysarum spp.	5	5	3	7						
Lupinus arcticus						6	1	2	1	T
Pyrola grandiflora						7	0	4	0	T
Equisetum variegatum	3	1	10	3		0	0	4	1	T
Aulacomnium palustre						3	2	10	4	TY
Climacium dendroides						10	7	2	10	
Drepanocladus spp.						9	10	13	11	
Hylocomium splendens			29	33	*	6AB	6AB	14B	3A	TI
Tomenthypnum nitens			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)			H1(L2)			H3(L3)		
	1985			1985			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).

ANWR Progress Report Number FY86-1-Impacts

AIRPHOTO ANALYSIS OF WINTER SEISMIC TRAILS ON 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

Key Words: Surface disturbance, winter seismic exploration, tundra, disturbance levels, vegetation types, airphoto analysis, recovery, traffic patterns, Alaska, Arctic National Wildlife Refuge.

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

Airphoto analysis of winter seismic trails on 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: Color infrared airphotos (1:6000) were used to assess the impacts of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge. An accuracy assessment of photo interpretations made on trails in 1984 was conducted, and the results were used to improve the 1985 photo interpretation key. Nine vegetation types and 4 levels of disturbance within most types were described and interpreted on airphotos in 1985. A detailed discussion of the development of the photo interpretation key, and efforts to improve consistency between interpreters was prepared. Fifteen percent of the points on seismic trail were photo-interpreted as level 0 (none to slight disturbance), 57% were level 1 (low), 26% were level 2 (moderate), and 2% were level 3 (high). Moist graminoid/barren tundra complex, moist sedge tussock, and moist shrub tundra had higher levels of disturbance than other vegetation types, because tussocks and hummocks characteristic of these types were easily disturbed. Dryas terraces had a high number of points with level 2 and 3 disturbance indicating the high sensitivity of this vegetation type due to low snow cover and an easily disrupted vegetative mat. In contrast, trails in riparian shrubland had low disturbance, indicating good snow cover at the time of vehicle travel or recovery of damaged willows. The area west of the Sadlerochit River had higher disturbance levels than the area east of the Sadlerochit River due to differences in snow cover and vegetation types. Overlapping camp moves and seismic trails had higher levels of disturbance than either camp moves or seismic lines alone. Camp moves had more level 2 and 3 disturbance than seismic lines, and all level 3 camp moves were narrow trails. Camp moves also had more level 0 than seismic lines due to routing through less sensitive areas. 1985 camp moves had lower disturbance levels than 1984 camp moves due to improved routing and better snow cover in 1985. 1985 seismic trails had higher disturbance levels than 1984 seismic trails due to the use of the heavier vibrator trucks in 1985 and slight recovery of the 1984 trails. Final agreement checks between and within photo interpreters indicated that the interpreters were reasonably consistent, but some confusion still occurred between closely related vegetation types and disturbance levels. A ground check on the accuracy of the photo interpretations will be conducted during the 1986 field season.

Airphoto analysis of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985.

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 habitat and the environment. Geophysical Service Incorporated (GSI) was authorized to conduct a winter seismic exploration program on the coastal plain in January through May 1984 and 1985. A total of 2,000 km of seismic line, arranged in an approximately 5 x 10 km grid, were completed during the 2 years. The drilled shothole technique, using buried dynamite to create seismic waves, was used the first year. In the second year, large vibrator trucks were used as an energy source. Data collection on seismic lines required multiple passes of tracked vehicles along linear trails. A second set of tracks was created by ski-mounted camps pulled by D-7 Caterpillar tractors, which followed the seismic crews across the coastal plain. A more detailed description of the seismic program can be found in Felix et al. (1987a) or GSI's plans of operation (Geophysical Service Inc. 1983a, b, 1984).

Aerial photographs of a portion of the 1984 and 1985 seismic lines and camp moves were taken to document disturbance in the first and second years after winter seismic activities. Airphoto interpretation of vegetation types and disturbance levels was used to assess the impacts of vehicle trails over a wide variety of sites, and determine the relative sensitivity of vegetation types on the coastal plain of ANWR.

Methods

Airphoto Acquisition. Color infrared (CIR) and true color airphotos (1:6000 scale) were acquired for approximately 20% of the 1984 and 1985 seismic trails. The photography was taken by a private contractor between July 15 and July 28, 1985, at the peak of vegetative growth. Photography from August 27 and 30, 1984 was available for a portion of the 1984 seismic trails on the west side of the coastal plain (Felix and Jorgenson 1985).

The portions of vehicle trails to be photographed were selected by stratified random sampling. Three areas of the coastal plain, based on terrain types, were used to stratify the sample (Fig. 1). The West Sadlerochit area is composed mainly of low foothills extending from the Sadlerochit Mountains to the coast between the Sadlerochit and Canning Rivers. Between the Sadlerochit and Aichilik Rivers, the East Sadlerochit area includes the coastal area with hilly coastal plain and floodplains, and the Foothills area includes foothills in the southern portion. Line segments (16 km (10 mi) were randomly selected (by drawing) within each stratum. Camp-move routes and campsites associated with each line segment were also photographed. Photo coverage in 1985 included (Fig. 2):

- 1984 seismic lines and camp-move routes - 435 km (272 mi), 48 flight lines
- 1985 seismic lines and camp-move routes - 429 km (268 mi), 57 flight lines

The location of the areas to be photographed were marked in the winter with survey stakes. Airphoto markers, consisting of white crosses made of 4.5 x 0.5 m strips of nylon tafetta held down with rocks, were placed at the ends of each seismic line segment in the summer.

Accuracy Assessment of 1984 Airphoto Interpretation. Field studies were conducted to assess the accuracy of the photo interpretations made during the 1984 study (Felix and Jorgenson 1985). Fifty-six photo-interpreted points, a 20% sample, were randomly selected for ground verification. Additional points to cover all vegetation types and disturbance levels were added making a total of 84 points.

The accuracy assessment was conducted by 2 botanists. One botanist located the points on the ground using the aerial photos, while the other botanist made the field determinations of vegetation type and disturbance level. At each site, plant community descriptions, including moisture level, dominant species (3-7), and major life forms, were recorded. The site was then classified into 1 of the 9 vegetation types recognized on airphotos in 1984 (Felix and Jorgenson 1985). Disturbance level was determined by estimating decrease in total plant cover, decrease in shrub canopy cover, percent soil exposed, structural damage to hummocks and tussocks, and compression of mosses and litter. Disturbance levels were classified as 0, 1, 2, or 3 based on definitions developed by Felix and Jorgenson (1985).

The numbers of correct and incorrect calls were tallied, and omission and commission errors for each vegetation type and disturbance level were calculated. Commission errors occurred when a site was interpreted as 1 type on the photos but found to be another type on the ground, while omission errors occurred when types on the ground were not recognized on the photos. This information was used to identify classes which needed further definition or description in the 1985 photo interpretation key.

Development of 1985 Photo Interpretation Key. Field data were collected at control points to aid in the development of the photo interpretation key and to train photo interpreters. Data were collected at 214 points including: 20 snow vs. disturbance plots (Felix et al. 1987b), 37 photo-trend plots (Felix et al. 1987a), 34 intensive study plots, 56 accuracy assessment points, 60 airphoto markers, and 7 additional points. Descriptive data on vegetation types and disturbance levels were recorded at each site, as described previously. Ground level photos were taken, and aerial oblique photos (from a helicopter at 60 m altitude) were taken of some points to aid in locating the plots on the airphotos.

Quantitative data were collected at the snow vs. disturbance plots, 11 of the photo-trend plots, the intensive study plots, and the 7 additional points. Plant cover estimates were obtained using the line-intercept method. Measurements were recorded from 2 10-m transects in the disturbed area, and 2 in a nearby control area with similar vegetation. Disturbed

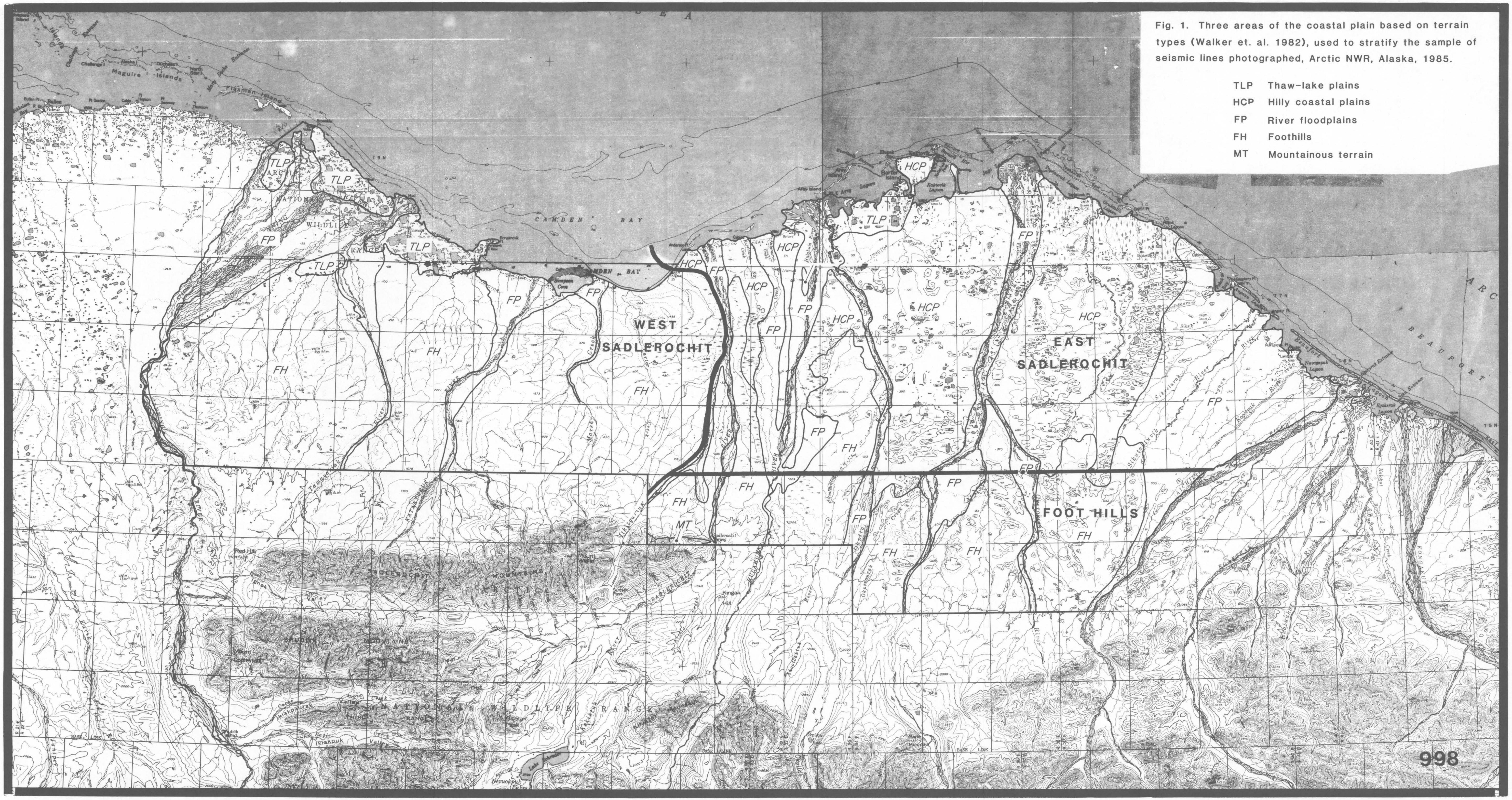


Fig. 1. Three areas of the coastal plain based on terrain types (Walker et. al. 1982), used to stratify the sample of seismic lines photographed, Arctic NWR, Alaska, 1985.

TLP Thaw-lake plains
HCP Hilly coastal plains
FP River floodplains
FH Foothills
MT Mountainous terrain

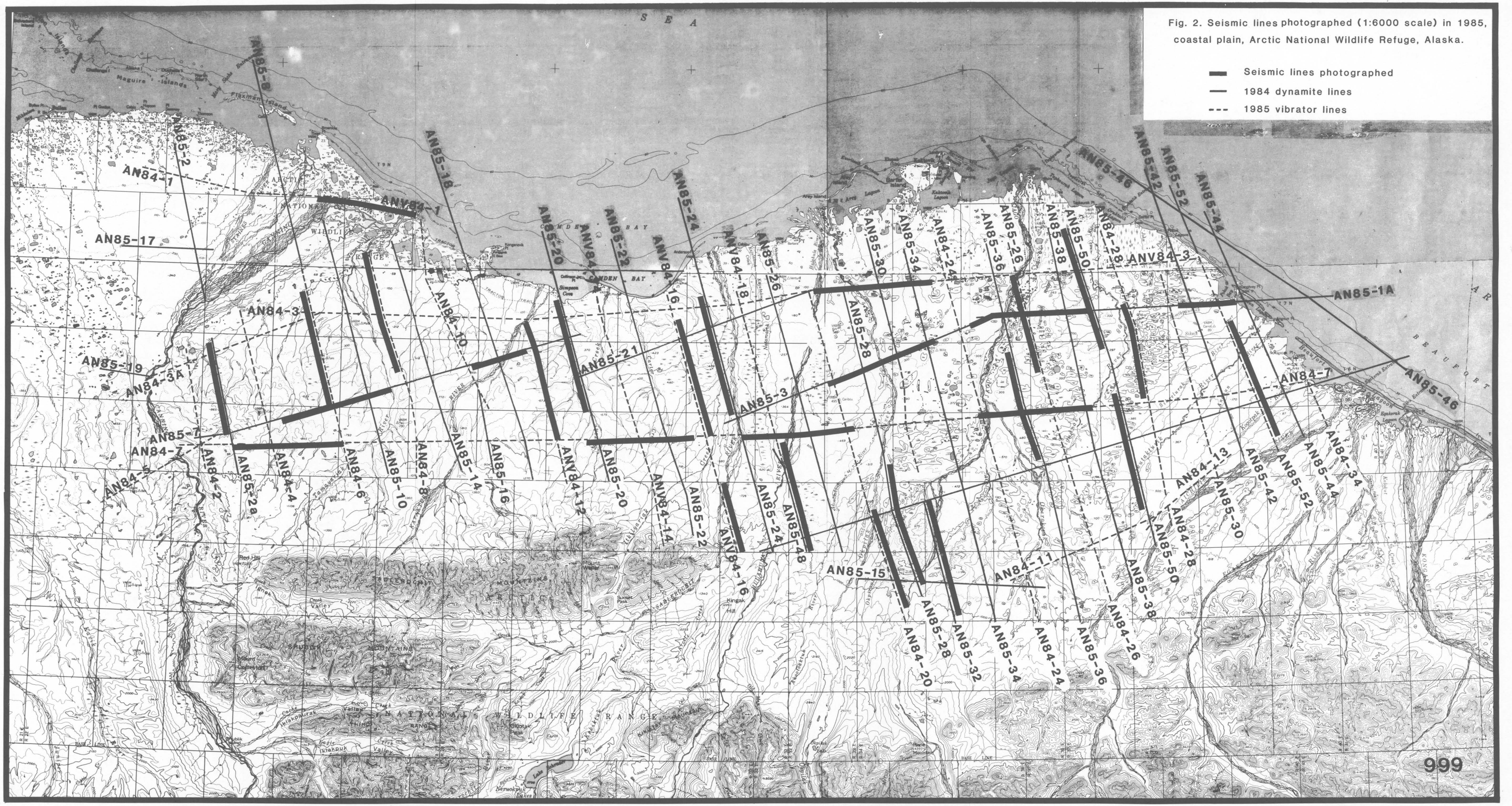


Fig. 2. Seismic lines photographed (1:6000 scale) in 1985, coastal plain, Arctic National Wildlife Refuge, Alaska.

transects were run down the tracks when individual tracks were distinct, or diagonally across more diffuse trails. Cover was estimated to the nearest cm along 20 consecutive 50-cm segments 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 ((D-C)/C x 100). The changes in litter, exposed soil, water, and bare ground (litter, soil, and water) were also calculated (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 each disturbed plot. 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.

Data from control points were used to modify and develop more complete descriptions of the vegetation types and disturbance levels described in 1984 (Felix and Jorgenson 1985). Plant community descriptions from all control points were listed and grouped into vegetation types based on the similarity of their responses to disturbance. An effort was made to minimize the number of vegetation types and to keep these consistent with the land cover types of Walker et al. (1982). Large scale aerial photos (1:300) of some control points and other selected areas were used to quantify the percent cover of tussocks and frost features used in the classification.

Four disturbance levels were defined within most vegetation types. The disturbance measures (cover changes and tussock damage) and disturbance level determinations were summarized for all control points. Scattergrams showing the relationships of decrease in total plant cover with increase in exposed soil, decrease in deciduous shrub cover, and increase in bare ground were plotted to help define cutpoints between disturbance levels. Box plots showing the magnitude of disturbance measures within each disturbance level were generated (Minitab, Inc. 1985) to show the amount of separation between disturbance levels, and to identify the most reliable measures for disturbance level definitions.

A key which was developed described photo characteristics of each vegetation type and disturbance level. The key used in 1984 had to be modified since photo signatures on the 1985 photos were markedly different from those on the 1984 photos. Control points were grouped into vegetation types and disturbance levels, and located on airphotos. The photo signature of each control point was described. These descriptions were summarized into a general description for each class (Appendix Table 1). Vegetation types and disturbance levels were modified when necessary to allow consistent interpretation on the airphotos.

Three agreement tests were conducted as the key was being developed. These tests included photo interpretation of 156 cm of trail by 2 interpreters, 141 cm of trail by 3 interpreters, and 100 3-mm circles by 3 interpreters. Differences in interpretations were discussed, and the key was refined to improve agreement among the interpreters. The sixty control points at airphoto markers, for which ground data were available, were then interpreted. Further discussion and modification of the key was done based on these known points. The development of the photo interpretation key is described in more detail in Appendix Item A.

Photo Analysis of Winter Seismic Trails. Two interpreters analyzed the airphotos using the photo interpretation key (Appendix Table 1). They made frequent use of the control points, and consulted with each other on difficult determinations. Interpretations of vegetation types and disturbance levels were made in 3-mm circles (18 m ground distance) located every 2.5 cm (150 m ground distance) along the 1984 and 1985 seismic lines and camp moves. Circles were centered on the area of highest disturbance on wide trails. The first circle was placed 1 cm from the airphoto marker on the end of each seismic line, and 2 cm from the edge of the first photo on each camp move. The circles were permanently marked and numbered on photo sleeves.

The photo number, circle number, vegetation type, disturbance level and trail type were recorded for each circle. A note was made if the circle was on or near a control point. Determinations were made on the dominant vegetation type within each circle and the disturbance level which covered over half of the most disturbed trail within the circle. In rare instances, the vegetation type of the most highly disturbed portion of the trail differed from the dominant vegetation type. In those cases, the vegetation type on the most disturbed portion of the trail was recorded. Trail types were classified as follows:

- overlapping, diffuse - camp move and seismic line on a wide trail which can not be easily separated

- overlapping, narrow - camp move and seismic line on a narrow trail (less than 2 vehicle widths)

- camp, diffuse - single cat-train trail, may have one track overlapping another cat-train trail

- camp, narrow - 2 or more totally overlapping cat-train trails

- seismic, vibrators - main trail on a 1985 seismic line

- seismic, diffuse vibrators - single vibrator tracks

- seismic, shothole - main trail on a shothole seismic line

- seismic, narrow - seismic vehicles on narrow trail (less than 2 vehicle widths)

Data were tallied separately for the seismic lines, camp moves, and overlapping trails on each line segment. Statistical comparisons were conducted using chi-square analysis. All data were added together to determine the percentage of trail in each disturbance level within each vegetation type. The total distance of trail within each level of disturbance was estimated. For this estimate, the total length of camp-move trails was calculated by multiplying the total length of seismic lines (1910 km) by the ratio of camp moves to seismic lines (based on numbers of photo-interpreted points). Trail widths of seismic lines were measured in the center of each photo.

Three sets of points were interpreted by both observers to check agreement during the photo interpretation. These sets included the first 223 points on shothole seismic lines and camp moves, the first 100 points on vibrator seismic lines, and a set of 100 points in the middle of the interpretation. These agreement checks allowed the observers to identify and discuss consistency problems before continuing the interpretation. After completion of the photo analysis, each observer interpreted a set of 200 points which they had previously interpreted and 200 points which the other observer had interpreted. The agreement between and within photo interpreters was summarized by vegetation type and disturbance level.

Results and Discussion

Accuracy Assessment of 1984 Airphoto Interpretation

Vegetation Types. Airphoto interpretations of vegetation types were accurate for 57% of the 56 randomly selected sites (and 51% of all 84 sites) with the errors generally occurring between vegetation types which were closely related on water, shrub, or tussock gradients (Table 1). The interpretations of the upland and shrub-rich vegetation types (moist graminoid/barren tundra complex (barren complex), moist sedge tussock tundra, moist shrub tundra, and riparian shrubland) had a relatively low omission error of 20%, i.e. at 20% of the sites these types were not recognized on the photos when they were present on the ground. The vegetation structure or characteristic surface morphology of these types produced distinct signatures on the photos and allowed for fairly reliable identification. In contrast, the wetter vegetation types (aquatic graminoid marsh, wet graminoid tundra, moist/wet tundra complex, moist sedge-shrub tundra had a high omission error of 77%. This was primarily due to the similarity of these vegetation types along a moisture gradient and to the differences in moisture regimes between the times that the photos were taken and the accuracy assessment was carried out (1984 was wetter than average and 1985 was drier than average). Strict, less moisture dependent definitions of vegetation types (including their characteristic surface forms) were needed to be consistent between years.

Only 1 out of 6 sites interpreted as moist/wet tundra was called that on the ground. Wet sedge and moist sedge-shrub were often intermixed in lowland areas. One problem was the much larger, aerial perspective that the photo interpreter had of the site, as compared to the more limited perspective of the ground observer (Plate 1, 2). As a result, 2 sites that appeared to be a complex of moist/wet sites on the photos were called wet sedge on the

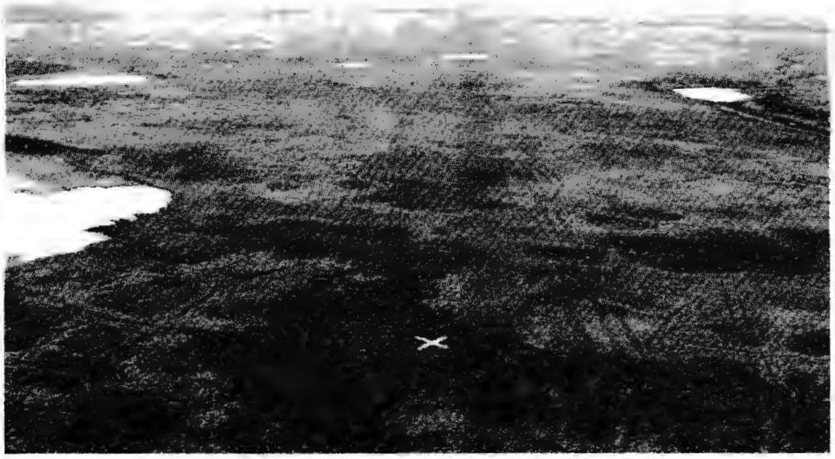


Plate 1. Intermixed patches of wet tundra (dark areas) and moist sedge-shrub tundra (light areas). The upper half of the lake on the left is covered by aquatic graminoid vegetation.

Plate 2. Patches of moist sedge-shrub tundra (in foreground) and wet graminoid tundra (darker patches in middle).

ground, and 2 sites that appeared to have a higher proportion of moist sedge-shrub tundra were called wet graminoid tundra and moist/wet tundra on the ground.

Moist sedge-shrub tundra had the highest omission error rate, 78%, because it was a frequent inclusion and graded into many other vegetation types (Plates 3, 4). Its commission error rate was much lower (36%) because in its most characteristic form as pure sedge-willow, it was easily identified on the photos. Evidently, the definition of moist sedge-shrub tundra used for the photo interpretation allowed fewer tussocks, frost boils, or hummocks, and less dwarf birch than the definition that the observers used on the ground. The cutpoints between moist sedge-shrub tundra and barren tundra complex, tussock tundra, and shrub tundra needed to be better defined for both the photo interpreter and the ground observer.

Table 1. Photo interpretations and ground determinations of 8 different vegetation types at 84 sites, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination	Photo interpretation Vegetation type								Omission
Vegetation type	AG	WG	MW	MS	GB	TT	ST	RS	Error
Aquatic graminoid (AG)									
Wet graminoid (WG)	2	2 [a]	2	1					5/7
Moist/wet tundra (MW)	2		1	1					3/4
Moist sedge-shrub (MS)		3	3	7	10	4	5		25/32
Barren complex (GB)					9	4			4/13
Tussock tundra (TT)				2		18	2		4/22
Shrub tundra (ST)							4		0/4
Riparian shrubland (RS)								2	0/2
Commission Error	4/4	3/5	5/6	4/11	10/19	8/26	7/11	0/2	41/84

[a] Circled values are the number of agreements between ground determinations and photo interpretations.

Both tussock tundra and barren tundra complex had similar gray, grainy photo characteristics, and 4 out of 13 points determined to be barren tundra complex on the ground were interpreted as tussock tundra (Plates 3, 4). The barren tundra complex differed from tussock tundra, however, in that frost boils or hummocks appeared as larger dots and often had a linear orientation on slopes. Moist sedge-shrub tundra was frequently misinterpreted as barren tundra complex, indicating that the amount of frost boils allowable in moist sedge-shrub tundra needed to be further defined. Generally if a site had even a few frost boils it was interpreted as barren tundra complex.

The omission error for tussock tundra (4 out of 22 observations) was a result of its being misinterpreted as moist sedge-shrub tundra or moist shrub tundra. The difference in the cover of tussocks used to delineate these types needed better definition.

Plate 3. Mosaic of tussock tundra and moist sedge-shrub tundra.

Plate 4. Moist graminoid/barren tundra complex intermixed with moist sedge-shrub tundra. The frost boils in barren complex tundra are slightly larger than tussocks and have a linear orientation.

Commission errors for shrub tundra were common (7/11), with sites determined to be tussock tundra and moist sedge-shrub tundra on the ground (Plate 5, 6). Again, a definition (with photographic examples) of the amount of tussock cover allowed in shrub tundra was needed. Moist sedge-shrub tundra and shrub tundra commonly occurred intermixed in the upland basins of hilly terrain, where the polygons varied in their micro-relief. A better definition of the amount of willow and dwarf birch allowed in each class was needed. Since moist sedge-shrub tundra typically occurred on flat-centered polygons, and shrub tundra was often associated with high-centered polygons, surface form descriptions would also help the interpretation.

Disturbance Levels. The accuracy of disturbance level interpretations for the 56 randomly selected points was 57%, and all but 2 of the errors were 1 disturbance level off. Disturbance levels were accurately interpreted on 44% of the 43 sites with wet vegetation types (aquatic graminoid tundra, wet graminoid tundra, moist/wet tundra, and moist sedge-shrub tundra). Accuracy was low within these vegetation types for 3 reasons. First, distinguishing between level 1 (compaction of standing dead) and level 2 (definite compression of mosses) on the photos was difficult because of the lack of recognizable structural changes. Second, the photo signatures for disturbance levels were sensitive to changes in moisture and to the relative amounts of moss and standing dead - all of which can be extremely variable in these vegetation types. Last, there was a lack of ground control points having higher level disturbances. In wet graminoid tundra, disturbance levels were accurately determined in 3 out of 7 observations. While all sites were called level 1 on the ground, 3 sites were interpreted as level 2 on the photos, and 1 site was interpreted as level 3. This overestimation of the disturbance was partly due to some sites being photo interpreted as moist/wet tundra or moist sedge-shrub tundra with their different disturbance signatures. Reliable photo interpretation of level 2 may not be possible for wet graminoid tundra since compression was difficult to measure even in the field. The differences between levels 1 and 2 may, however, be significant in terms of recovery because the more compressed, wetter sites may be more susceptible to thermal and active layer changes that make the trails long-lasting features.

Disturbance levels in moist sedge-shrub tundra were accurately interpreted on 44% of the sites, with most of the errors occurring between level 1 and level 2 (Table 2). Distinguishing among disturbance levels depended largely on color changes from pink to red to reddish brown, making consistent interpretations a problem where these colors were variable in adjacent undisturbed tundra. Four sites with obvious track depression (level 3 disturbance) had characteristic photo signatures of dark reddish brown, which were not recognized to be level 3 signatures during the interpretation. Four sites rated as level 0 in the field had trails evident on the photos from the previous summer, indicating that recovery may have occurred.

Plate 5. Gradation between moist shrub tundra and tussock tundra.

Plate 6. Patches of moist shrub tundra and moist sedge-shrub tundra. Moist shrub tundra appears darker due to the presence of dwarf birch.

Table 2. Photo interpretation and ground determination of disturbance levels at 32 sites in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination Disturbance level	Photo interpretation Disturbance level 0	1	2	3	Omission Error
0		4			4/4
1	1	(7)[a]	5		6/13
2		4	(7)		4/11
3			4		4/4
Commission Error	1/1	8/15	9/16		18/32

[a] Circled values are the number of agreements between ground determinations and photo interpretations.

Disturbance levels in moist/wet tundra were accurately interpreted for 2 out of 4 sites. Errors were made between level 1 and level 2 determinations due to the problems detailed above.

The most accurate photo interpretation of disturbance levels was in barren complex (11/13), because the pronounced scuffing of the frost boils and hummocks was easily recognized on the photos (Table 3). The black speckling used to distinguish between level 1 and 2 disturbances was a good diagnostic character.

Table 3. Photo interpretation and ground determination of disturbance levels at 13 sites in moist graminoid/barren tundra complex, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination Disturbance level	Photo interpretation Disturbance level 0	1	2	3	Ommission Error
0	(3)[a]	1			1/4
1		(6)	1		1/7
2			(1)		0/1
3				(1)	0/1
Commission Error	0/3	1/7	1/2	0/1	2/13

[a] Circled values are the number of agreements between ground determinations and photo interpretations.

In tussock tundra, the disturbance levels were accurately interpreted for 12 out of 22 sites (Table 4). Three sites that were called level 1 or 2 on the ground were not visible on the photography, possibly because of the late date of the photography by which time much of the vegetation had senesced.

Six sites had lower disturbance levels than were interpreted which may have been due to graying of litter that made the damage less visible or to resprouting of tussocks. Commission errors for levels 1 and 2 were 3 out of 11 and 1 out of 3 respectively, indicating that trails identified as levels 1 and 2 on the photos usually were called these disturbance levels on the ground. Level 3 had a commission error of 3 out of 3, indicating that the photo signature for this level was poorly defined, or that the definition was not adhered to. The high amount of soil exposed (over 15%), and its blue-black photo signature, was an important characteristic of level 3 disturbance (ruts starting to form).

Table 4. Photo interpretation and ground determination of disturbance levels at 22 sites in moist sedge tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination	Photo interpretation Disturbance level				Ommission
Disturbance level	0	1	2	3	Error
0	(2)[a]	2			2/4
1	2	(8)	1	2	5/13
2	1	1	(2)	1	3/5
3					
Commission Error	3/5	3/11	1/3	3/3	10/22

[a] Circled values are the number of agreements between ground determinations and photo interpretations.

In shrub tundra, disturbance levels were accurately interpreted in 2 out of 5 sites (a level 1 and a level 2 disturbance). The remaining 3 sites were called level 1 on the ground but were interpreted as level 2 on the photos. Recovery at these sites was slow and did not seem to be the reason that ground calls were lower than photo interpretations.

For riparian shrubland, with only 1 observation, a site called level 1 on the ground was interpreted as a level 0 on the photos. Since the disturbance was not evident on the photos, the ground definition of the amount of disturbance allowed in level 0 needed to be broadened.

In summary, most of the errors in the 1984 photo interpretation were among closely related vegetation types and disturbance levels. The accuracy assessment allowed us to identify the sources of error and needs for additional information. The main revisions which were incorporated in the 1985 photo interpretation key are described in Appendix Item A. These changes should improve the accuracy of the 1985 photo analysis.

Photo Interpretation

Vegetation Types

Nine vegetation types were described and interpreted on the aerial photos in 1985.

Aquatic Graminoid Marsh. These communities, dominated by emergent grass or sedges, are found on permanently flooded sites which have more than 10 cm of standing water throughout the summer. Typical locations include ponds, lake margins, and some areas of low-centered polygons with deep basins. Mosses are generally absent. Temporarily dried shallow ponds with exposed bacterial benthic mats are also included in this unit. Typical plant communities are listed in Table 5. Other common vascular plants include *Hippuris vulgaris*, *Sparganium hyperboreum*, *Caltha palustris*, and *Menyanthes trifoliata*. Other common nonvascular plants include *Scorpidium scorpioides*, *Drepanocladus* spp. and *Calliergon* spp.

Wet Graminoid Tundra. Included here are sedge or grass dominated communities on poorly drained, seasonally flooded sites; some sites may have up to 10 cm of standing water throughout the summer. Typical locations include drained lake basins, lake and stream margins, intermittent drainages, abandoned floodplains, and tidal mud-flats. Micro-relief features common of these sites include well-developed or disjunct low-centered polygons, and strangmoor. Moss cover is usually low and limited to higher microsites. Typical plant communities are listed in Table 5. Other common vascular plants in noncoastal areas include *Carex chordorrhiza*, *C. rotundata*, *C. rariflora*, *C. saxatilis* ssp. *laxa*, *C. membranacea*, *Eriophorum russeolum*, *E. scheuchzeri*, *Hierochloe pauciflora*, *Poa arctica*, *Caltha palustris*, *Potentilla palustris*, *Polygonum viviparum*, *Salix lanata*, and *S. planifolia* ssp. *pulchra*. Other common vascular plants in coastal and saline areas include *Carex ursina*, *C. ramenskii*, *Arctophila fulva*, *Hierochloe pauciflora*, *Poa arctica*, *Alopecurus alpinus*, *Petasites frigidus*, *Saxifraga cernua*, *Cerastium beeringianum*, *Salix ovalifolia*, and *S. arctica*. Other common nonvascular plants include *Campylium stellatum*, *Tomenthypnum nitens*, *Bryum* spp., *Calliergon* spp., and *Oncophorus wahlenbergii*.

Moist Sedge-Shrub Tundra. Moist sedge-shrub tundra is found on poorly developed polygonized ground, flat-centered polygons, and depressions in upland areas. The soils are fine-grained and more or less well-drained. Willow cover varies from scattered prostrate willows to denser, more erect stands on lusher sites near streams. Moss cover varies from low percentages on sites with dense standing litter to nearly 100%. This vegetation type is commonly found intermixed with areas of wet graminoid tundra, barren complex, tussock tundra, or shrub tundra. Hummock and frost scars may cover up to 30% and tussocks may cover up to 15% of the area. Shrub-rich, wet graminoid communities dominated by *Carex aquatilis* or *Eriophorum angustifolium*, in association with *Salix lanata* or *S. planifolia* ssp. *pulchra*, are included here because they were indistinguishable from moist sedge-shrub tundra on the aerial photographs. Typical plant communities are listed in Table 5. Other common vascular plants include *Arctagrostis latifolia*, *Salix arctica*, *S. ovalifolia*, *S. lanata*, *S. phlebophylla*, Polygonum bistorta, Stellaria longipes, Saxifraga punctata, S. hirculus, Pyrola grandiflora, Pedicularis kanei, P. Langsdorffii, Valeriana capitata, and Petasites frigidus.

Moist Graminoid/Barren Tundra Complex (Barren Complex). These moist, well-drained graminoid communities have over 30% cover of hummocks or frost scars. Barren complex sites are typically dominated by sedges and Dryas integrifolia although ericaceous shrubs may be dominant on some locations. Tussocks may cover up to 15% of the area and often form distinct rings around the frost features. Barren complex communities are often found on gentle slopes of the hilly coastal plains, and on steeper slopes and ridges of the foothills. The hummocks and frost scars are often oriented in lines trending downslope. Hummocky, old river terrace floodplains are also included here. Typical plant communities are listed in Table 5. Other common vascular plants include Salix arctica, Ledum palustre ssp. decumbens, Rumex arcticus, Silene acaulis, Pyrola grandiflora, and Senecio atropurpureus. Other common nonvascular plants include Cetraria cucullata, Cladonia spp., Dactylina spp., Thamnolia spp., and crustose lichens.

Moist Sedge Tussock Tundra (Tussock Tundra). Included here are all sites on which Eriophorum vaginatum tussocks provide more than 15% of the cover. Tussock tundra is found on well-drained, relatively stable sites with fine-grained alkaline to acidic soils. This vegetation type is typically found on hillcrests, slopes, and flat- and high-centered polygons. Hummocks and frost scars are frequent inclusions in tussock tundra and may cover up to 30%. In some areas, the continuous gradation in tussock cover makes it difficult to distinguish between tussock tundra and other vegetation types. Typical plant communities are listed in Table 5. Other common vascular plants include Salix rotundifolia, Cassiope tetragona, Rubus chamaemorus, Polygonum bistorta, Pedicularis labradorica, P. lapponica, Petasites frigidus, Senecio atropurpureus, and Saussurea angustifolia. Other common nonvascular plants include Aulacomnium spp., Dicranum spp., Polytrichum juniperinum, Cetraria spp., Cladonia spp., Dactylina spp., Nephroma arctica, and Peltigera spp.

Moist Shrub Tundra (Shrub Tundra). Non-riparian, shrub-rich tundra is found on palsas and high-centered polygons. Soils are acidic, and shrub cover varies from erect birch communities with closed canopies to dwarf, ericaceous mats. Eriophorum vaginatum tussocks are common and may have up to 15% cover. In upland thaw basins with mixed polygon development, shrub tundra frequently intergrades with moist sedge-shrub tundra. Typical plant communities are listed in Table 5. Other common vascular plants include Arctagrostis latifolia, Hierochloe alpina, Carex Bigelowii, Polygonum bistorta, and Senecio atropurpureus. Other common nonvascular plants include Dicranum spp., Polytrichum juniperinum, Rhytidium rugosum, Cetraria spp., Peltigera spp., and Thamnolia spp.

Riparian Shrubland. This type includes open or closed willow communities found on gravel bars and floodplains of streams and rivers and extending up stream banks and river bluffs. Soils are moist and well-drained, and plant cover is over 30%. Typical plant communities are listed in Table 5. Other common vascular plants include Salix hastata, Dryas integrifolia, Alopecurus alpinus, Festuca altaica, F. rubra, Polygonum bistorta, P. viviparum, Parnassia spp., Anemone parviflora, Astragalus umbellatus, A. eucosmus ssp.

Table 5. Photo-interpreted vegetation types of the coastal plain, Arctic NWR, Alaska, 1985.

Vegetation type	Typical plant communities
Aquatic graminoid marsh - emergent communities on permanently flooded, deep water sites (more than 10 cm standing water). Ponds, lake margins, and low-centered polygons with deep basins.	Emergent Arctophila fulva grass marsh (deeper water, up to 2 m). Emergent Carex aquatilis, Eriophorum angustifolium, E. scheuchzeri sedge marsh (shallower water). Aquatic bacterial benthic mat with mixed algal flora (temporarily dried ponds and polygon basins).
Wet graminoid tundra - sedge or grass dominated communities on poorly drained, seasonally flooded sites. Low-centered polygons, strangmoor, tidal flats, lake, and stream margins.	Wet Carex aquatilis, Pedicularis sudetica ssp. albolabiata, Saxifraga foliolosa, Sphagnum spp. sedge meadow (usually acidic). Wet Carex aquatilis, Eriophorum angustifolium, Pedicularis sudetica ssp. albolabiata, Scorpidium scorpioides, Drepanocladus spp. sedge meadow (alkaline). Wet Dupontia fisheri, Eriophorum angustifolium, Carex aquatilis graminoid meadow (acidic coastal tundra and along stream banks inland). Wet Puccinellia phryganodes, Stellaria humifusa, Cochlearia officinalis grass meadow (saline; tidal mud-flats). Wet Carex subspathacea, Puccinellia phryganodes, Carex ursina graminoid meadow (saline: coastal marshes and borders of brackish ponds).
Moist sedge-shrub tundra - sedge-willow meadows of upland slopes and flat or poorly developed high-centered polygons.	Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra sedge, dwarf shrub tundra. Moist Eriophorum angustifolium, Carex aquatilis, Salix planifolia ssp. pulchra, Betula nana s.l., Hylocomium splendens, Sphagnum spp., Aulacomnium turgidum sedge, dwarf shrub, moss tundra (acidic and water-track tundra). Moist Eriophorum angustifolium, Carex aquatilis, Salix reticulata, Dryas integrifolia, Tomenthypnum nitens, sedge, dwarf shrub, moss tundra (alkaline tundra).
Moist graminoid/barren tundra complex - moist tundra communities with over 30% cover of hummocks or frost scars, and less than 15% tussocks.	Moist Arctagrostis latifolia, Salix rotundifolia, Dryas integrifolia, Salix reticulata, Petasites frigidus, Rumex arcticus, Hylocomium splendens graminoid, dwarf shrub (frost boils): Moist Eriophorum angustifolium, Salix planifolia ssp. pulchra, Tomenthypnum nitens sedge, dwarf shrub tundra (lower microsites) (alkaline sites common on the western portion of the coastal plain). Moist Carex Bigelowii, Eriophorum angustifolium, E. vaginatum, Arctagrostis latifolia, Dryas integrifolia, Salix rotundifolia, Salix reticulata, Tomenthypnum nitens, sedge, dwarf shrub tundra (alkaline sites with hummocks or diffuse frost scars). Moist Carex Bigelowii, Cassiope tetragona, Salix phlebophylla, Vaccinium spp., Hylocomium splendens, Dicranum spp. sedge, dwarf shrub (slightly acidic hummocky ridges) Moist Carex Bigelowii, Dryas integrifolia, Salix reticulata, Arctostaphylos rubra, Salix lanata, Equisetum variegatum, Tomenthypnum nitens sedge, dwarf dwarf shrub tundra (hummocky, moist river terrace)
Moist sedge tussock tundra - areas with more than 15% cover of cottongrass tussocks.	Moist Eriophorum vaginatum, Carex Bigelowii, Dryas integrifolia, Salix reticulata, Tomenthypnum nitens sedge tussock, dwarf shrub tundra (alkaline tussock tundra: frost scars common) Moist Eriophorum vaginatum, Carex Bigelowii, Salix planifolia ssp. pulchra, Salix reticulata, Hylocomium splendens, Tomenthypnum nitens, Ptilidium ciliare sedge tussock, dwarf shrub tundra (neutral to slightly alkaline tussock tundra). Moist Eriophorum vaginatum, Betula nana s.l., Salix planifolia ssp. pulchra, Ledum palustre ssp. decumbens, Vaccinium vitis-idaea, Hylocomium splendens, Sphagnum spp. sedge tussock, dwarf shrub tundra (acidic tussock tundra).

Table 5. Continued.

Vegetation type	Typical plant communities
Moist shrub tundra - shrub-rich high-centered polygons and palsas.	Moist Betula nana s.l., Salix planifolia ssp. pulchra, Eriophorum vaginatum, Ledum palustre ssp. decumbens, Vaccinium vitis-idaea, Hylocomium splendens, Sphagnum ssp. dwarf shrub, tussock tundra.
	Moist Betula nana s.l., Salix planifolia ssp. pulchra, Vaccinium uliginosum, Hylocomium splendens, Aulacomnium turgidum, Polytrichum juniperinum dwarf shrub, moss tundra (dwarf birch dominated).
	Moist Ledum palustre ssp. decumbens, Vaccinium vitis-idaea, Betula nana s.l., Rubus chamaemorus, Dicranum spp., Hylocomium splendens, Aulacomnium turgidum dwarf shrub, moss tundra (ericaceous shrub dominated)
	Moist Cassiope tetragona, Vaccinium uliginosum, Salix phlebophylla, Dryas integrifolia, Lupinus arcticus, Hylocomium splendens, Dicranum spp., Aulacomnium turgidum, dwarf shrub, forb, moss tundra (river banks and snow accumulation areas).
Riparian shrubland - willow shrubland on gravel bars, floodplains, and river banks.	Moist Salix brachycarpa ssp. niphoclada, S. lanata, S. reticulata, Equisetum variegatum, Astragalus spp., Oxytropis spp., Tomenthypnum nitens open low shrub, forb, moss tundra (forb-rich riparian shrubland).
	Moist Salix brachycarpa ssp. niphoclada, S. lanata, S. reticulata, Arctostaphylos rubra, Lupinus arcticus, Tomenthypnum nitens, Hylocomium splendens open low shrub, dwarf shrub, moss tundra (dwarf shrub-rich riparian shrubland).
	Moist Salix alaxensis, S. arctica, Astragalus alpinus, Hedysarum spp., Equisetum spp., Oxytropis spp. open low shrub, forb tundra (partially vegetated river bars).
	Moist Salix glauca, S. lanata, S. planifolia ssp. pulchra, Poa spp., Carex Bigelowii, Aulacomnium turgidum, Hylocomium splendens, Drepanocladus spp. closed low shrub, graminoid, moss tundra. (graminoid-rich, riparian shrubland).
Dryas terrace - dry, alkaline, ridges, river terraces, and bluffs.	Dry Dryas integrifolia, Salix reticulata, Oxytropis nigrescens, Equisetum variegatum, Tomenthypnum nitens, Dicranum spp., Lecanora epibryon, Pertussaria spp. dwarf shrub, forb, crustose lichen tundra (Dryas river terrace: drier, more exposed sites).
	Dry Dryas integrifolia, Cassiope tetragona, Vaccinium uliginosum, Salix lanata, S. reticulata, Lupinus arcticus, Astragalus umbellatus, Tomenthypnum nitens, Hylocomium splendens dwarf shrub, forb, moss tundra (Dryas river terrace: mesic sites).
	Dry Dryas integrifolia, Cassiope tetragona, Carex spp., Silene acaulis, Lecanora epibryon, Ochrolechia frigida, Pertussaria spp. dwarf shrub, crustose lichen tundra (ridges and river bluffs).
Sparsely vegetated or barren area - plant cover less than 30%.	Moist or dry Epilobium latifolium, Salix alaxensis, S. lanata, Bromus pumpellianus, Castilleja caudata, Hedysarum spp., Astragalus alpinus, Artemisia arctica herb, shrub gravel bar.
	Moist Honckenya peploides, Puccinellia spp., Mertensia maritima strand.
	Dry Elymus arenarius ssp. mollis, Bromus pumpellianus, Salix spp. sand dunes.
	Dry Dryas spp., Salix phlebophylla, Carex rupestris, Poa glauca, Oxytropis nigrescens, Umbilicaria spp. fell-field.
	Dry Deschampsia caespitosa, Poa glauca, Kobresia spp. river bluffs.
	Wet Puccinellia phryganodes, Stellaria humifusa tidal mud-flats.

sealei, Oxytropis borealis, O. campestris, O. deflexa, O. maydelliana, and Castilleja caudata. Other common nonvascular plants include Aulacomnium palustre, Dicranum spp., Cladonia spp., Cetraria cucullata, Peltigera spp., and Thamnolia spp.

Dryas Terrace. Dry, alkaline sites dominated by Dryas integrifolia are found on ridges, bluffs, and river terraces. Typical plant communities are listed in Table 5. Other common vascular plants include Carex capillaris, C. rupestris, C. scirpoidea, Kobresia spp., Salix rotundifolia, Polygonum viviparum, Oxytropis borealis, O. campestris ssp. jordalii, O. maydelliana, Castilleja caudata, and Pedicularis kanei. Other common nonvascular plants include Distichium capillaceum, Ditrichum flexicaule, Polytrichum juniperinum, Racomitrium lanuginosum, Cetraria cucullata, C. islandica, C. nivalis, and Dactylina spp.

Sparsely Vegetated or Barren Areas. Areas with less than 30% cover of vegetation are included in this category. Typical sites are active floodplains, sand dunes, mud-flats, gravel outcrops on ridges and river bluffs, and gravel strand. Typical plant communities are listed in Table 5.

Disturbance Levels

Four levels of disturbance were described and interpreted on the aerial photos for most vegetation types (Table 6).

Aquatic Graminoid Marsh. Winter disturbance of aquatic graminoid habitat knocked down any standing dead vegetation which was above the ice, creating a visible darker swath in the summer. Level 1 was the maximum level of disturbance for sites in this vegetation type, since the roots of grasses and sedges were protected by being frozen in the ice. The disturbance rating was based on field observations, but not on quantitative data, as we had no aquatic graminoid study plots.

Wet Graminoid Tundra. In level 1 disturbance in wet graminoid tundra the standing dead vegetation was knocked down and the trail appeared as a green swath (Plate 7). Few other traces of disturbance were visible on the ground, except for some occasional slight scuffing of microsites. Disturbance evaluations did not rely heavily on measures of plant cover decreases. Cover values were not reliable, because of difficulties in finding equivalent plant communities nearby for control plots. Variation in the moss understory obscured differences between disturbed and control areas. Level 2 was used to describe sites where mosses were compressed and higher microsites were commonly scuffed, but track depression was not obvious. In 1984 (a wet year), level 2 trails appeared wetter than the surrounding area. Level 2 disturbance was difficult to define and recognize in the field and on photos, and was subsequently dropped from the 1985 photo key. Level 3 sites had obvious track depression and standing water was present on these trails in 1984 (Plate 8).

Moist Sedge-Shrub Tundra. Level 0 disturbance included widely scattered scuffing of microsites, which could not be identified on the airphotos. This was seen most often on older trails where compression of standing dead was no longer visible. Level 1 disturbance was defined as compression of

Table 6. Disturbance levels of winter seismic vehicle trails as recognized on color infrared aerial photographs (1:6000 scale), coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Disturbance levels 0	1	2	3
Aquatic graminoid marsh	No impact.	Compression of standing dead emergent vegetation.		
Wet graminoid tundra	No impact.	Compression of standing dead to ground surface. May include slight scuffing of higher microsites.	Obvious compression of mosses and standing dead. Trail appears wetter than surrounding area. Common scuffing of micro-relief.	Obvious track depression. Standing water apparent on trail that is not present in surrounding area during wet years.
Moist sedge - shrub tundra	No impact. May have a few widely scattered scuffed microsites.	Compression of standing dead. Some scuffing of higher microsites or frostboils if present. Less than 25% vegetation damage and broken shrubs.	Obvious compression of mosses and standing dead. Trail appears wetter than surrounding area. Scuffing of micro-relief common, small patches of soil may be exposed. Vegetation damage and broken shrubs 25-50%.	Obvious track depression, over 50% vegetation damage. Compression of mosses below water surface. Standing water apparent on trail that is not present in adjacent area during wet years.
Moist graminoid/ barren tundra complex	No impact to slight scuffing of micro-relief.	Compression of standing dead. May have up to 25% vegetation damage. Some scuffing of mound tops. 0-5% soil exposed.	Vegetation damage-25-50%. Exposed organics or mineral soil 5-15%. Scraping of mound tops common.	Nearly all mound tops scraped. Over 50% vegetatiion damage. Over 15% soil exposed.
Moist sedge tussock tundra	No impact to slight scuffing of tussocks and breakage of shrubs.	Scuffing of tussocks or mound tops. Vegetation damage 5-25%. Exposed organics or mineral soil - less than 3%.	Mound top destruction of tussocks over 30%. Common mound top scuffing. Vegetation damage 25-50%. Exposed organics or mineral soil 3-15%.	Destruction of tussocks or mound tops nearly continuous. Ruts starting to form. Vegetation damage over 50%. Exposed soil over 15%.
Moist shrub tundra	No impact to occasional breakage of shrubs.	Vegetation damage 5-25%. Less than 25% shrub canopy decrease. Scuffing of tussocks and hummocks if present.	25-50% vegetation damage and shrub canopy decrease. Mound top destruction of some tussocks and hummocks.	Over 50% vegetation damage and over 50% broken shrubs.
Riparian shrubland	No impact to slight breakage of shrubs.	Less than 50% shrubs broken, little impact to ground cover. Less than 25% decrease in total plant cover.	50-80% shrubs broken, sometimes to ground level. Some disturbance to ground cover. Total plant cover decrease 25-50%.	Over 80% removal of shrub canopy. Substantial disturbance to ground cover, over 50% decrease in total plant cover.
Dryas terrace	No impact to few widely scattered scuffed microsites.	Less than 30% vegetation killed. Less than 5% soil exposed.	30-60% vegetation killed. Little disruption of vegetative mat. 5-15% soil exposed.	Over 60% vegetation killed and vegetative mat mostly disrupted. Over 15% soil exposed or over 50% increase in bare ground.

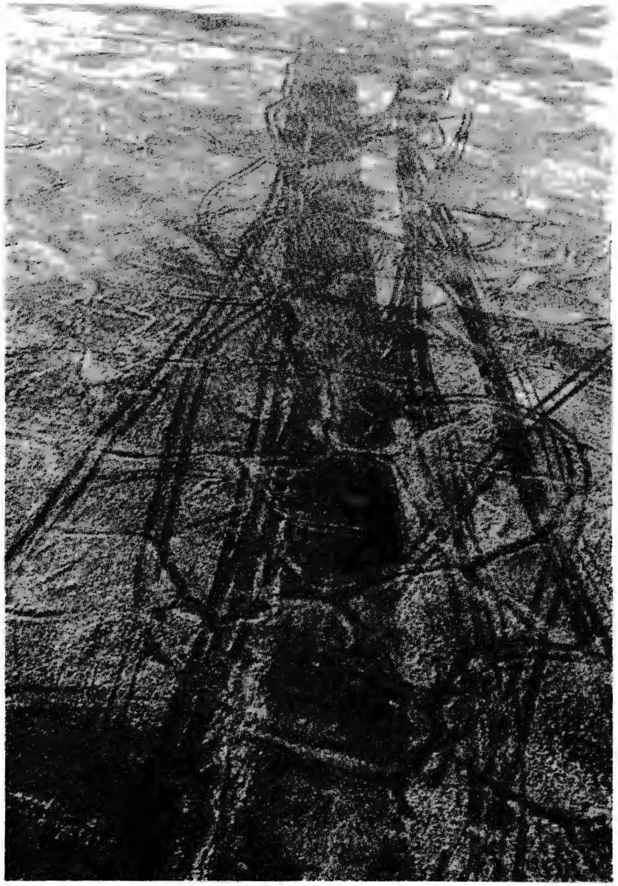


Plate 7. Level 1 disturbance in wet graminoid tundra. Trail is visible due to knocking down of standing dead leaves, but higher microsites remain undisturbed.

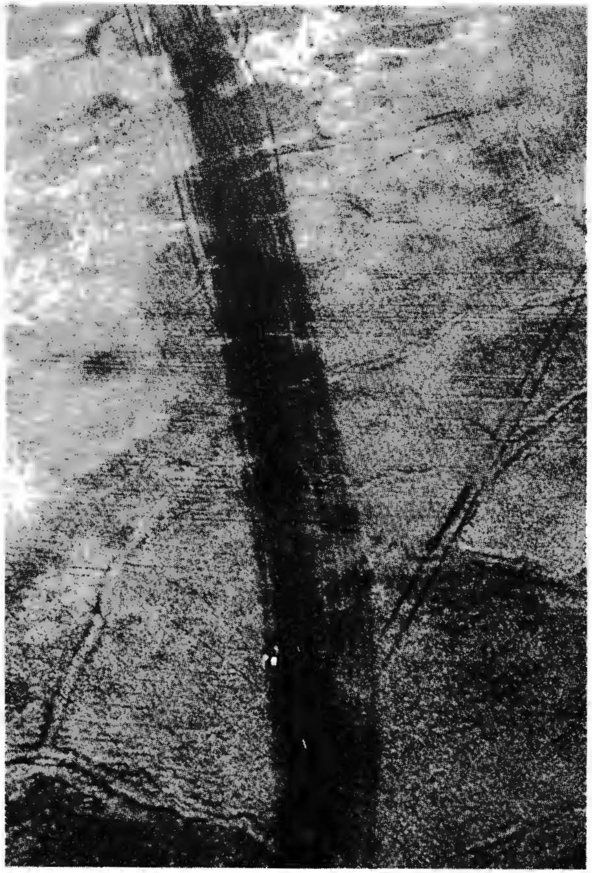


Plate 8. Level 3 disturbance in wet graminoid tundra. All higher microsites have been compressed and standing water is evident in the trail.

standing dead, less than 25% decrease in total plant cover, and less than 25% decrease in shrub canopy (Plate 9). Cover data were more reliable than for wet graminoid tundra, but discontinuous moss understories and variations in control plots still caused problems, making it difficult to define moist sedge-shrub disturbance levels quantitatively. The total plant cover and shrub canopy decrease ranges included in the disturbance definitions are similar to those in other vegetation types. The mean cover changes of the moist sedge-shrub ground points in each disturbance level were within these ranges, but there was overlap between categories. For any specific site, structural damage provided a better evaluation of disturbance level than estimates of cover decreases.

During the 1984 field season, levels 2 and 3 were defined largely on the basis of moisture changes in the trail. These differences were not noticeable during the dry summer of 1985, so the definitions were revised. Obvious compression of mosses, which might include extensive areas with cleat marks, was the primary trait of level 2 plots. Soil exposure on these sites was usually quite low (2-5%), but was higher for sites containing frost boils. The amount of soil exposed was as much related to the amount of micro-relief in a site as to the disturbance level. The photo characteristics for level 2 differed on 1984 and 1985 trails (Appendix Table 1). Level 3 determinations were based mainly on obvious track depression (Plate 10). Level 3 trails may also have over 50% vegetation damage or over 50% broken shrubs. We were unable to define photo characteristics for level 3 on 1985 trails, because no level 3 trails were found on the ground in moist sedge-shrub tundra.

Moist Graminoid/Barren Tundra Complex. Levels 1 through 3 in this vegetation type were defined on the basis of plant cover decreases and soil exposure. Scuffing of fragile mound tops or frost boils in this vegetation type caused nearly complete removal of plant cover from mound tops at high levels of disturbance. Soil exposure increased linearly with disturbance levels, providing a reliable quantitative characteristic by which to determine disturbance levels. The upper range of soil exposure in each disturbance level may have been slightly higher than for other vegetation types, but we did not have enough data to define a separate set of cutpoints based on this vegetation type alone.

Moist Sedge Tussock Tundra. Level 0 included areas where widely scattered scuffed tussocks were present on the ground. This scattered disturbance was not visible on the airphotos. Tussock disturbance categories were the most reliable measure for ground determinations of disturbance levels. Level 1 disturbance had mostly scuffed tussocks (Plate 11); level 2 had many destroyed mound tops (over 30%) (Plate 12); and level 3 had ruts starting to form. Plant cover decreased linearly with increasing levels of disturbance. Many plots, however, fell on a continuum between 20% and 40% vegetation decrease, which made the distinction between level 1 and 2 difficult to estimate visually.

Moist Shrub Tundra. Shrub tundra had well-defined disturbance categories, based on 2 quantifiable characteristics: plant cover decrease and shrub canopy decrease. Disturbance levels at the 17 ground points in shrub tundra

Plate 9. Level 1 disturbance in moist sedge-shrub tundra. Light-colored standing dead leaves have been compressed on the trail, and higher microsites are slightly scuffed.

Plate 10. Level 3 disturbance in moist sedge-shrub tundra. Higher microsites have been compressed and track depression has occurred.

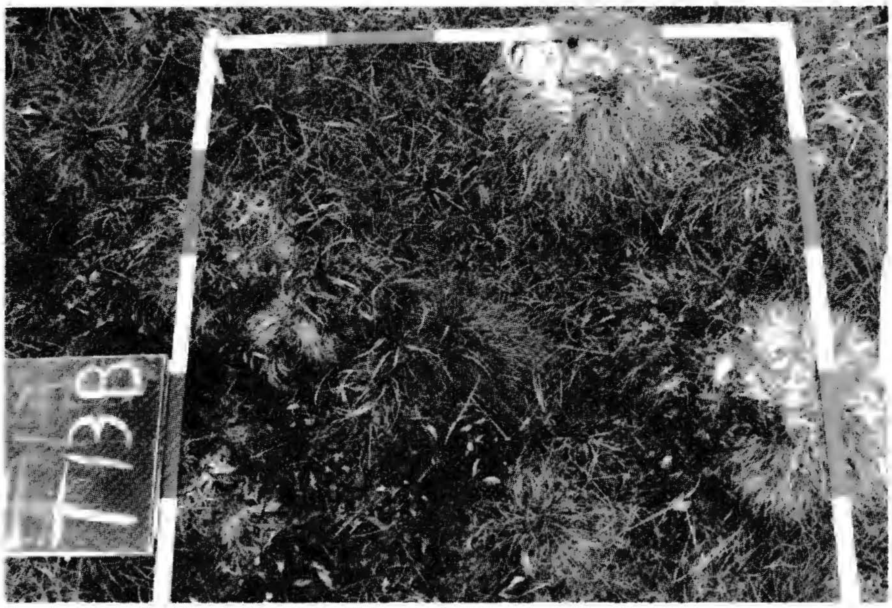


Plate 11. Scuffed tussocks with broken tillers characteristic of level 1 disturbance in tussock tundra.

Plate 12. Mound top destruction of tussocks characteristic of level 2 and 3 disturbance in tussock tundra. Peat cores are exposed in the center of destroyed tussocks.

fit well within ranges defined for other vegetation types. Visual estimates were difficult on some plots because shrub cover was patchy and some of the moss understory was detached but not totally dead yet.

Riparian Shrubland. Shrub canopy decrease was the most reliable measure of disturbance level in riparian shrublands. Shrub canopy breakage up to 50% was the main result of level 1 disturbance. Over 50% breakage of shrubs and some disturbance to ground cover characterized level 2. Level 3 disturbance included nearly complete removal of the shrub canopy and damage to the ground cover (Plate 13). As in shrub tundra, soil exposure was too variable to be a useful disturbance level characteristic.

Dryas Terrace. Plant cover decreases were the main result of disturbance on *Dryas* terraces. Level 1 disturbance had up to 30% decrease in vegetation, level 2 had 30 to 60% decrease, and level 3 had over 60% decrease with the vegetative mat mostly disrupted (Plate 14). Plant cover was hard to estimate or measure on first year disturbances, because damaged mosses still looked somewhat green. But the second summer after disturbance, the differences between dead and live mosses became much more obvious, and the plant cover decrease ranges worked well for defining disturbance levels. The amount of soil exposed was sometimes low, depending on whether the site had a persistent dead *Dryas* mat covering the soil. Increase in cover of bare ground (defined as areas with no live vegetation) in the disturbed plots, was a more accurate measure of disturbance than exposed soil.

Sparsely Vegetated or Barren Areas. Disturbance in this vegetation type was very difficult to see on airphotos because of the patchiness of the vegetation, therefore no disturbance levels were defined.

Photo Analysis of Winter Seismic Trails

Interpretation of the airphotos provided an estimate of the amount of disturbance which occurred on winter seismic trails. Overall, 15% of the points were interpreted as having no disturbance (level 0), 57% as level 1, 26% as level 2, and 2% as level 3 (Appendix Table 2). Extrapolating this to an estimate of the total distance of seismic lines and camp-move trails, approximately 540 km had no visible disturbance in 1985, 2050 km had level 1 disturbance, 960 km had level 2 disturbance, and 60 km of trail had level 3 disturbances. This estimate is conservative, because it includes only the camp moves adjacent to seismic lines and does not include moves from 1 line to the next, which frequently had high levels of disturbance. It also does not include other trails associated with exploration activities such as supply routes, survey trails to benchmarks, and routes between camps and seismic lines.

The distribution of disturbance levels varied within vegetation types (Table 7). Nine percent of the points were located in water or partially vegetated areas, and therefore had no disturbance (level 0). Only 1 out of 11 points in aquatic graminoid tundra had visible disturbance (level 1). Most of the points in wet graminoid tundra were identified as level 1 disturbance (94%). Some of these points might be classified as level 2 on the ground, but could not be differentiated on the photos. The percentage of level 0 disturbance was low in wet graminoid tundra because even light traffic created visible disturbance by knocking down the standing dead.

Plate 13. Distinct trail through riparian shrubland. Shrub canopy has been removed and moss layer has been damaged.

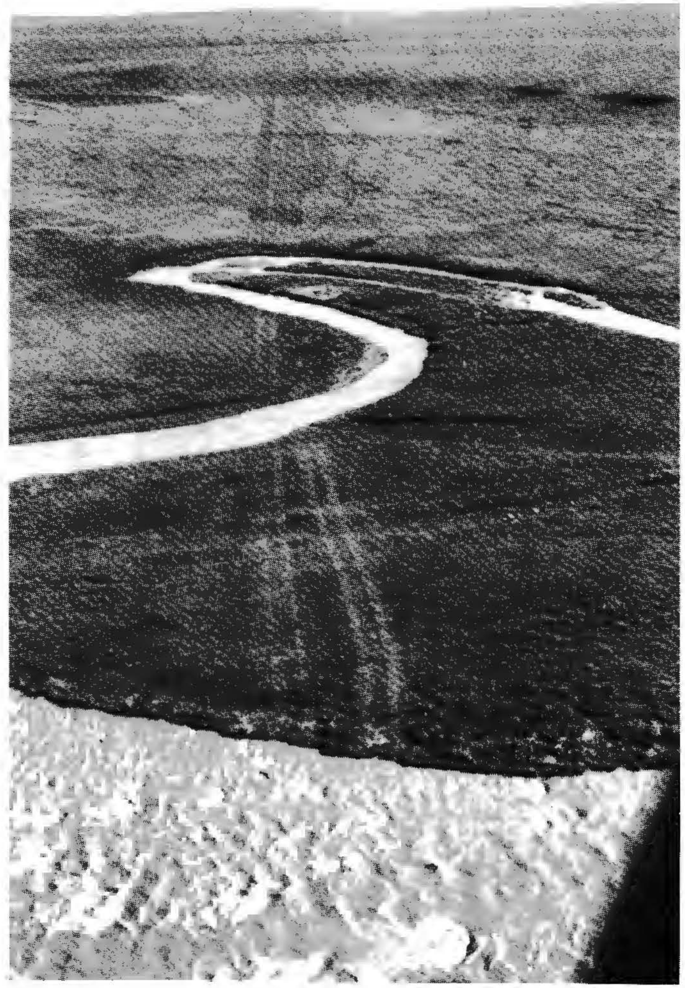


Plate 14. Level 3 disturbance on a ***Dryas*** river terrace. Well over 60% of the vegetation has been killed and soil is exposed over much of the main trail.

Table 7. Percentage of disturbance levels within vegetation types from photo interpretation of vehicle trails resulting from winter seismic exploration on the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Disturbance level 0	1	2	3	Number of points interpreted
Water[a]	100.0				161
Aquatic graminoid marsh[a]	90.9	9.0			11
Wet graminoid tundra[a]	6.1	93.0		0.9	769
Moist sedge-shrub tundra[a]	10.4	62.1	25.8	1.7	1751
Moist graminoid/barren tundra complex	5.4	52.1	40.0	2.5	405
Moist sedge tussock tundra	1.0	51.9	44.1	2.9	1165
Moist shrub tundra	4.3	43.9	50.5	1.3	305
Riparian shrubland	40.5	36.5	21.6	1.4	74
Dryas terrace	9.1	27.3	36.4	27.3	11
Partially vegetated areas[a]	100.0				262
Percentage of all points	14.9	56.8	26.5[b]	1.8	4914

[a] There is no level 1, 2, or 3 in water and partially vegetated areas; no level 2 or 3 in aquatic graminoid marsh; level 2 was combined with level 1 in wet graminoid tundra; and level 3 was not defined for 1985 trails in moist sedge-shrub tundra.

[b] The overall percentage of level 2 disturbance may be underestimated, because level 1 and 2 were combined for wet graminoid tundra.

Moist sedge-shrub tundra had a distribution of disturbance levels that was close to the overall percentages. Barren complex, tussock tundra, and shrub tundra all had lower percentages of level 0 disturbance and higher percentages of level 2 disturbance than average, indicating that these vegetation types were easily disturbed. The shift to higher disturbance levels is due in part to the fragility of the higher microsites (mounds, tussocks, hummocks, and high-centered polygons) which characterize these vegetation types.

Riparian shrubland had a high percentage of points with level 0 disturbance. Level 0 disturbance was found more frequently on 2-year-old trails (55%) than on 1-year-old trails (24%) (Appendix Table 2), indicating that recovery was partially responsible for the high percentage of level 0 disturbance in this vegetation type. Disturbance levels were also lower in this vegetation type, because vehicles were often routed around riparian vegetation unless there was good snow cover. Also patchy disturbance in open riparian sites was difficult to identify on photos so that some slightly damaged areas may have been interpreted as level 0.

Dryas terrace had a high percentage of level 2 and 3 disturbances. This sensitivity to disturbance was characteristic of _Dryas_ terraces: the thin vegetative mat, consisting mostly of dwarf shrubs and mosses was easily disrupted, and usually had little protective snow cover (Felix et al. 1987b).

The western half of the coastal plain (west of the Sadlerochit River) had a larger percentage of moderate and high disturbance levels than the eastern side (Fig. 3). In 1985, the western side had a lower average snow depth (25 cm) than the eastern side (32 cm) (Felix et al. 1987b). The trails on the western side crossed 8% more tussock tundra and 16% less wet graminoid tundra. These differences in vegetation types and snow cover would account for much of the differences in disturbance levels.

Trails which had overlapping seismic and camp-move traffic were more severely disturbed, with higher amounts of level 2 and level 3 disturbance than either seismic lines or camp moves alone (Fig. 3). Camp moves alone had higher percentages of level 2 and 3 disturbance than seismic trails alone, with all level 3 disturbance found on narrow trails. Camp moves also had more level 0 than seismic lines, due to routing of camp moves through less sensitive vegetation types and areas with deeper snow cover. Seismic lines were evenly distributed over the coastal plain and therefore provide a good estimate of the overall distribution of vegetation types, while camp moves were routed to avoid disturbance to specific vegitation types. Camp moves went over 4% more water and 8% more partially vegetated terrain, where little disturbance could occur (Table 8). Camp-move routes also avoided easily disturbed upland areas, crossing 17% less tussock tundra than seismic lines did.

Table 8. Percentage of vegetation types on photo-interpreted points on winter seismic trails on the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Trail type		
Vegetation type	Seismic line	Camp move	Overlapping
Water	1.7	5.4	0.7
Aquatic graminoid marsh	0.1	0.3	0.7
Wet graminoid tundra	13.2	16.6	21.0
Moist sedge-shrub tundra	34.5	36.1	39.6
Moist graminoid/barren tundra complex	9.2	6.8	10.8
Moist sedge tussock tundra	32.7	15.8	19.4
Moist shrub tundra	4.9	7.7	5.3
Riparian shrubland	1.5	1.6	1.4
Dryas terrace	0.4	0.1	0.0
Partially vegetated	1.9	9.6	1.1

Disturbance levels on 1984 shothole seismic lines were generally lower than those on 1985 vibrator seismic lines, with more areas of level 0 and fewer areas of level 2 disturbance on the 1984 lines (Fig. 3). Level 3 disturbance rarely occurred on either 1984 or 1985 seismic lines. The higher disturbance levels on 1985 seismic lines were due in part to the fact that vibrator units were heavier (4.5 psi) and their tracks dug more deeply into the vegetative mat than the drills (2.8 psi) used in 1984. The 1984 trails also showed slight recovery of visible impacts due to weathering of exposed soil, peat, and litter to a lighter color, and some recovery of plant cover (Felix et al. 1987a).

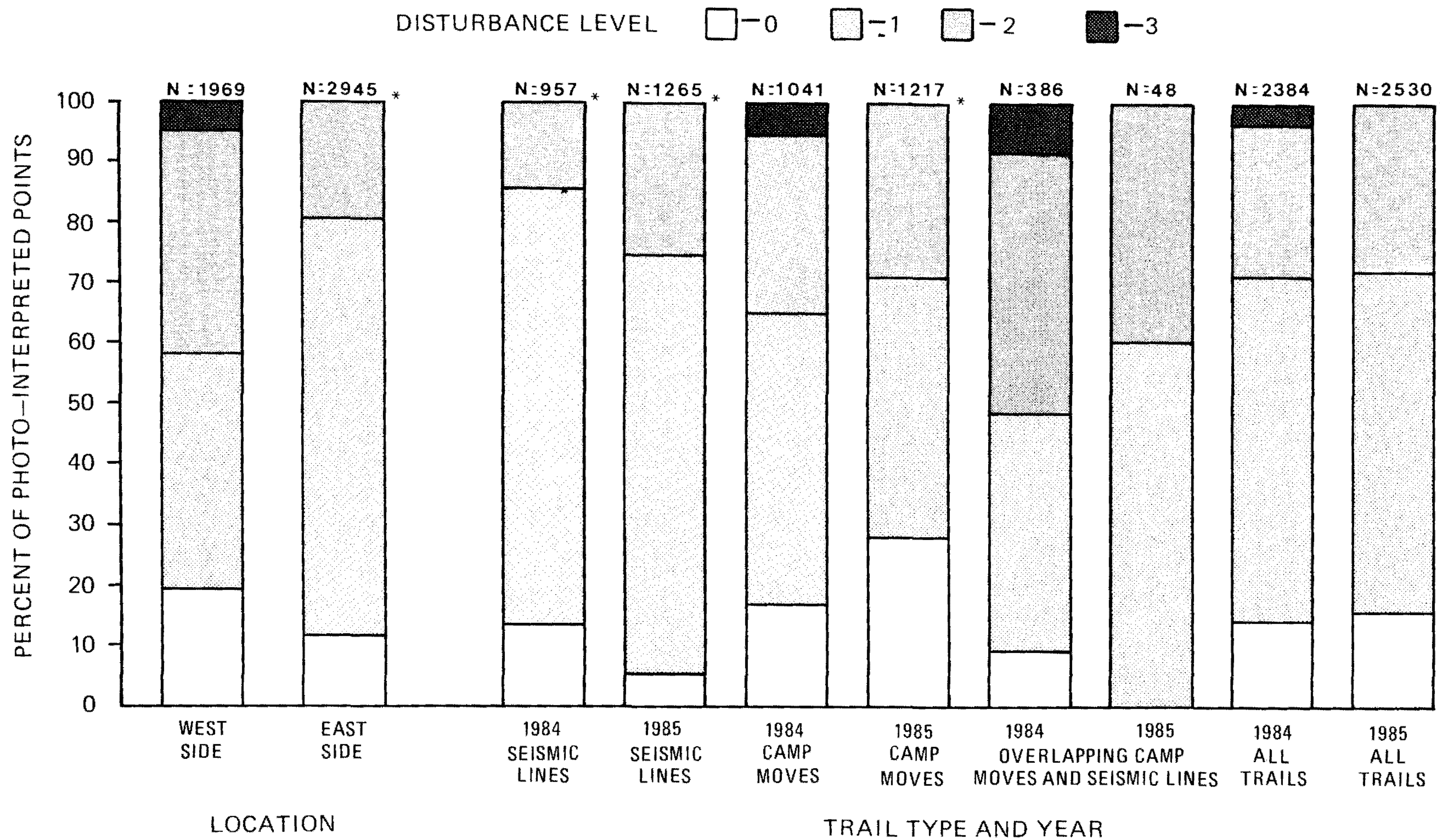


Fig. **3.** Distribution of disturbance levels within location, trail type, and year from photo interpretation of winter seismic trails, coastal plain, Arctic NWR, Alaska, 1985. The comparison between locations and the comparisons between years for each trail type were all significant (chi-square analysis, $p<0.01$). * indicates less than 1% of points were level 3.

Seismic trail widths in 1984 ranged from 10 to 80 m, and averaged 31 m. This was significantly narrower (t-test, p 0.05) than 1985 trails, which averaged 41 m in length, and ranged from 20 to 110 m.

Camp moves in 1985 had a lower average level of disturbance than 1984 camp moves (Fig. 3), despite having 1 less year of recovery. The 1985 camp-move trails had almost no level 3 disturbance, because there were fewer kilometers of narrow trails or overlapping camp moves and seismic lines. The lower disturbance levels were also due to deeper snow and to routing changes. The average snow depth in 1985 was 30 cm as compared with 23 cm in 1984 (Felix et al. 1987b). Routing changes by FWS monitors were also more successful at minimizing disturbance the second year. Camp moves were routed to avoid sensitive vegetation types, and 4 times as much partially vegetated area was crossed by 1985 camp moves than by the 1984 camp moves (Appendix Table 2).

Overall, disturbance levels were similar on all 1984 and 1985 trails (Fig. 3). The main exception was that more level 3 disturbance occurred in 1984 because there were more overlapping trails and narrow camp moves. In 1985 FWS monitors minimized these damaging traffic patterns. 1985 seismic lines had more level 2 disturbance and less level 0 disturbance than 1984 seismic lines. Hoever, 1984 trails included more overlapping trails with level 2 disturbance than 1985 trails, and 1985 camp moves had more level 0 disturbance than 1984 camp moves.

Consistency of Photo Interpretations

Intermediate agreement checks. Three checks of agreement between photo interpreters were performed during the interpretation: the first 223 points on 1984 trails, a middle 100 points, and the first 100 points on 1985 trails were interpreted by both observers. Agreements on vegetation types was 86%, 75%, 82%; and on disturbance levels was 88%, 50%, and 75% for the 3 checks, respectively (Tables 9, 10). Most of the disagreements on vegetation types were between the following groups: wet graminoid and moist sedge-shrub tundra, moist sedge-shrub and tussock tundra, barren complex and tussock tundra, moist sedge-shrub and barren complex, and moist sedge-shrub and shrub tundra. Most of the disagreements on disturbance levels were between levels 1 and 2 particularly on moist sedge-shrub and tussock tundra points. On points for which the interpreters did not agree on vegetation type, disturbance level was agreed on less often (61%) than for the overall sample (76%). These initial agreement checks allowed the interpreters to identify consistency problems, and attempt to improve agreement during the interpretation.

Final Agreement Check. Consistency checks of each photo interpreter with himself and with the other interpreter were conducted after all photo interpretations were completed. The second interpretations of vegetation types by interpreter 1 agreed with his initial interpretations on 96% of the points, while the agreement of interpreter 2 between his initial and second interpretations was 82% (Table 11). Most of the disagreements for both interpreters occurred between the following closely related vegetation

Table 9. Agreement and disagreement between 2 interpreters on vegetation type determination on winter seismic trails, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Number of points		
	Agreement check 1	Agreement check 2	Agreement check 3
Agreements			
Water	5	2	9
Aquatic graminoid (AG)	0	1	0
Wet graminoid (WG)	64	17	7
Moist sedge-shrub (MS)	78	39	45
Barren complex (GB)	12	3	1
Tussock tundra (TT)	21	10	13
Shrub tundra (ST)	4	1	3
Riparian shrubland (RS)	1	0	1
Dryas terrace (DT)	1	0	0
Partially vegetated (PV)	5	2	3
Total agreement(%)	191(86%)	75(75%)	82(82%)
Disagreements			
AG/WG	0	1	0
WG/MS	8	5	6
MS/GB	5	2	3
MS/TT	8	4	5
MS/ST	6	4	0
GB/TT	3	7	3
GB/ST	1	0	0
GB/PV	0	1	0
RS/PV	0	1	1
DT/PV	1	0	0
Total disagreement(%)	32(14%)	25(25%)	18(18%)
Total Points	223	100	100

Table 10. Disturbance level determinations within vegetation types by 2 photo interpreters, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type[a]	Disturbance level							Agreement	
	0	0-1[b]	1	1-2[b]	2	2-3[b]	3	no.	%
Agreement check 1									
Wet graminoid	0	2	61	1	0	0	0	61/64	95
Moist sedge-shrub	3	1	41	8	23	2	0	67/78	86
Barren complex	2	1	2	0	6	1	0	10/12	83
Tussock tundra	1	1	17	2	0	0	0	18/21	86
Shrub tundra	0	0	2	0	2	0	0	4/4	100
Riparian shrubland	0	0	0	0	1	0	0	1/1	100
Dryas terrace	0	0	0	0	0	0	1	1/1	100
Other[c]	1	3	15	3	8	1	0	24/31	77
Total	7	8	138	14	40	4	1	186/212	88
Agreement check 2									
Wet graminoid	2	1	14	0	0	0	0	16/17	94
Moist sedge-shrub	2	2	4	20	10	1	0	16/39	41
Barren complex	0	0	2	1	0	0	0	2/3	67
Tussock tundra	0	0	0	5	4	1	0	4/10	40
Shrub tundra	0	0	0	0	1	0	0	1/1	100
Other[c]	1	4	4	11	2	0	0	7/22	32
Total	5	7	24	37	17	2	0	46/92	50
Agreement check 3									
Wet graminoid	0	0	7	0	0	0	0	7/7	100
Moist sedge-shrub	0	0	25	11	9	0	0	34/45	76
Barren complex	0	0	1	0	0	0	0	1/1	100
Tussock tundra	0	0	4	6	3	0	0	7/13	54
Shrub tundra	0	0	0	0	3	0	0	3/3	100
Riparian shrubland	1	0	0	0	0	0	0	1/1	100
Other[c]	0	0	9	5	3	0	0	12/17	71
Total	1	0	46	22	18	0	0	65/87	75

[a] Points that were determined to be water or partially vegetated have been excluded from this table.
[b] Interpreters disagreed on disturbance levels for these points.
[c] Interpreters disagreed on the vegetation type for these points.

Table 11. Agreements and disagreements on vegetation type interpretations between initial and second interpretations of each interpreter and between the 2 interpreters, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Interpreter		
Vegetation type	1	2	1x2
Agreements			
Wet graminoid (WG)	35	25	49
Moist sedge-shrub (MS)	73	65	129
Barren complex (GB)	25	10	22
Tussock tundra (TT)	34	48	68
Shrub tundra (ST)	5	5	9
Riparian shrub (RS)	2	2	3
Dryas terrace (DT)	1	0	1
Partially vegetated (PV)	5	6	11
Water (WA)	11	3	12
Total agreement (%)	191 (96%)	164 (82%)	304 (77%)
Disagreements			
WG/MS	3	7	20
MS/GB	2	5	12
MS/TT	2	9	18
MS/ST	0	2	6
MS/RS	0	1	1
MS/PV	0	1	0
GB/TT	2	7	30
GB/DT	0	1	0
TT/ST	0	3	3
RS/WA	0	0	1
GB/ST	0	0	2
Total disagreements (%)	9 (5%)	36 (18%)	93 (23%)
Total points	200	200	397

types: wet graminoid and moist sedge-shrub tundra, moist sedge-shrub and barren complex, barren complex and tussock tundra, and tussock tundra and moist sedge-shrub tundra. Agreement on vegetation types between the 2 interpreters was 77% (Table 11). Disagreements on 4% of the points were due to the difficulty in deciding on the dominant vegetation type in the circle when nearly equal percentages of 2 or 3 types were present. Disagreements between interpreters occurred most grequently between the same vegetation types as listed above.

Agreement between the first and second interpretations of disturbance level by each interpreter was 94% and 81% respectively (Table 12). Most of the disagreements for interpreter 1 were between levels 1 and 2 of tussock tundra and barren complex. Most of the disagreements for interpreter 2 occurred between levels 0-1 and 1-2 in moist sedge-shrub tundra and between all levels in tussock tundra.

Agreement between the 2 interpreters on disturbance levels was 76% (Table 12). Agreement on disturbance levels in wet graminoid tundra was very high (96%), because level 1 and 2 were combined for the interpretation. Disturbance levels in moist sedge-shrub tundra were agreed on for 73% of the points. Much of the disagreement was between level 1 and 2, where compression of mosses, common scuffing of micro-relief, increased moisture in the trail, and more breakage of shrubs signified level 2 disturbance. The photo signatures in this vegetation type were quite variable due to the natural variation in moisture and cover of moss, shrubs, and litter in undisturbed tundra. Agreement between levels 1 and 2, and 2 and 3 in tussock tundra was particularly low. The amount of scuffed and destroyed tussocks define disturbance levels in tussock tundra, and some overlap between levels occurs even in field identification. The photo signatures for these levels were less distinct in the 1985 photos, since both dried peat and litter in tussock centers appeared white. On the 1984 photos, peat appeared as black speckling making destroyed tussocks more distinct. The overall agreement on disturbance levels was the same on points where observers disagreed on vegetation types as it was on those where they agreed.

Although many disagreements occurred on vegetation types and disturbance levels of individual points, the total percentage of points estimated by each interpreter were similar in most cases (Table 13, 14). The largest difference between interpreters occurred on points called barren complex and tussock tundra. Interpreter 2 called 6% fewer points barren complex and 9% more points tussock tundra than did interpreter 1. The photo-signature of small hummocks or frost scars are similar to tussocks making this interpretation difficult as discussed in the 1984 accuracy assessment in this paper and Appendix Item A. The total disturbance level determinations were also similar between observers.

The consistency checks indicated that some confusion still occurred between closely related vegetation types and disturbance levels, but that the overall results of the photo interpretation were fairly consistent within and between observers. Therefore, we feel that the photo analysis provided us with a reasonable determination of the amount of disturbance within vegetation types on seismic trails. The accuracy of these results will be tested on the ground during the 1986 field season.

Table 12. Disturbance level determinations within vegetation types from initial and second interpretations by interpreters 1 and 2 and interpretations by both interpreters, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type[a]	Disturbance level							Agreement	
	0	0-1[b]	1	1-2[b]	2	2-3[b]	3	no.	%
Interpreter 1									
Wet graminoid	2	0	33	0	0	0	0	35/35	100
Moist sedge-shrub	10	0	39	1	21	1	1	71/73	97
Barren complex	2	0	14	2	6	0	1	23/25	92
Tussock tundra	1	0	14	2	15	1	1	31/34	91
Shrub tundra	0	0	2	0	3	0	0	5/5	100
Riparian shrub	1	0	0	1	0	0	0	1/2	50
Dryas terrace	0	0	0	0	0	0	1	1/1	100
Other[c]	0	1	5	2	1	0	0	6/9	67
Total	16	1	107	8	46	2	4	173/184	94
Interpreter 2									
Wet graminoid	2	2	21	0	0	0	0	23/25	92
Moist sedge-shrub	5	2	34	8	15	0	1	55/65	85
Barren complex	0	0	3	0	5	1	1	9/10	90
Tussock tundra	0	2	13	4	20	6	3	36/48	75
Shrub tundra	0	1	2	0	2	0	0	4/5	80
Riparian shrub	0	1	0	0	1	0	0	1/2	50
Other[c]	1	2	20	7	6	0	0	27/36	75
Total	8	10	93	19	49	7	5	155/191	81
Interpreters 1 and 2									
Wet graminoid	2	2	45	0	0	0	0	47/49	96
Moist sedge-shrub	11	5	59	27	24	3	0	94/129	73
Barren complex	1	1	8	2	8	1	1	18/22	82
Tussock tundra	1	3	19	12	25	5	3	48/68	71
Shrub tundra	0	1	2	4	2	0	0	4/9	44
Riparian shrub	1	1	0	1	0	0	0	1/3	33
Dryas terrace	0	0	0	0	0	0	1	1/1	100
Other[c]	5	6	49	14	17	1	0	71/92	77
Total	21	19	182	60	76	10	5	284/373	76

[a] Points that were determined to be water or partially vegetated have been excluded from this table.
[b] Interpreters disagreed on disturbance levels for these points.
[c] Interpreters disagreed on vegetation types for these points.

Table 13. Percentage of 400 photo-interpreted points determined to be in each vegetation type by 2 interpreters, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Interpreter 1	Interpreter 2
Wet graminoid	14	16
Moist sedge-shrub	41	39
Barren complex	14	8
Tussock tundra	19	28
Shrub tundra	4	3
Riparian shrub	1	1
Dryas terrace	0.3	0.3
Partially vegetated	3	3
Water	3	3

Table 14. Percentage of 400 photo-interpreted points determined to be in each disturbance level by 2 interpreters, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Disturbance level	Interpreter 1	Interpreter 2
0	9	8
1	59	60
2	30	29
3	2	3

Acknowledgments

We wish to thank ERA helicopter pilot Bob Dunbar for his safe and skillful logistical support as well as his entertaining insights into tundra ecology. Howard Langston of Flightec, Inc., Clinton, Mississippi provided the airphotos in a timely manner. Survey crews for GSI helped to locate and stake the ends of flight lines for the airphotos.

Literature Cited

Felix, N.A., and M.T. Jorgenson. 1985. Effects of winter seismic exploration on the coastal plain of the Arctic National Wildlife Refuge, Alaska. Pages 622-694 in G.W. Garner and P.E. Reynolds, eds. 1984 update report: baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska. 777pp.

Felix, N.A., M.T. Jorgenson, M.K. Raynolds, R. Lipkin, D.L. Blank, and B.K. Lance. 1987a. Effects of winter seismic trails on visual resources, vegetation, and surface stability of the coastal plain of the Arctic National Wildlife Refuge, Alaska. In G.W. Garner and P.E. Reynolds, eds. 1985 update report: baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Felix, N.A., M.T. Jorgenson, M.K. Raynolds, R. Lipkin, D.L. Blank, and B.K. Lance. 1987b. Snow distribution on the arctic coastal plain and its relationship to disturbance caused by winter seismic exploration, Arctic National Wildlife Refuge, Alaska. In G.W. Garner and P.E. Reynolds, eds. 1985 update report: baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Geophysical Service Inc. 1983a. Exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Geophysical Service Inc. 1983b. Plan of operation supplementing the GSI exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1983. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Geophysical Service Inc. 1984. Plan of operation for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1984. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Alaska.

Minitab, Inc. 1985. Minitab reference manual. State College, Pennsylvania 232pp.

Walker, D.A., K.R. Everett, W. Acevedo, L. Gaydos, J. Brown, and P.J. Webber. 1982. Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 82-27. 59pp.

APPENDIX

ANWR Progress Report Number FY86-2-Impacts

Appendix Item A

Development of Photo Interpretation Key

The photo interpretation key developed in 1984 had to be revised due to changes in the signatures of the vegetation and differences in the amount of moisture between the 2 years. The 1985 photos had different and more variable colors than the 1984 photos. Descriptions of photo signatures for vegetation types, which had been based mainly on color, had to be changed to emphasize more consistent features, such as terrain and texture characteristics. The accuracy assessment of the 1984 photos had also pointed out the need for stricter, less moisture dependent definitions of vegetation types. Vegetation types that were characterized by differences in moisture regimes (wet graminoid, moist/wet tundra complex, and moist sedge-shrub tundra) were drier in 1985 than in 1984, and difficult to tell apart. Disturbance level definitions also needed some revisions because of the differences between the years. Trails that had been filled with standing water in 1984 were dry in 1985. Exposed soil was drier in 1985 and not as visible on the photos. Also the signature of the vibrator trails differed somewhat from that of the shothole trails. This section discusses development of the 1985 photo interpretation key, problems which were encountered in the process, and the main revisions that were made.

Procedures Used to Develop the 1985 Key

A preliminary key was constructed based on descriptions of the new photo signatures, and information gained from the accuracy assessment of the 1984 photo interpretations. This key was used by 2 observers to interpret 157 cm of trail (9.4 km on the ground). On this first check, the 2 observers had 76% agreement on vegetation types, and only 36% agreement on disturbance levels (Appendix Table 3). The observers had difficulty identifying shrub tundra and barren complex, and distinguishing between moist/wet tundra and moist sedge-shrub, and had different interpretations of level 1 and level 2 disturbance. After a discussion of the areas of disagreement and comparison with relevant control points, the observers developed a better understanding of the range of photo signatures in each vegetation type and disturbance level.

Three observers then interpreted 141 cm of trail (8.5 km on the ground). All 3 observers agreed on vegetation types on 59% of the trails, while agreement between any 2 observers ranged from 67% to 80%. For disturbance levels, agreement was 84% for all 3 observers and ranged from 84% to 93% between any 2 observers (Appendix Table 3). Disturbance level agreement improved greatly over the first agreement check. Interpretation of vegetation types had not improved. Wet graminoid, moist/wet, and moist sedge-shrub tundra were still difficult to tell apart, because the dry weather reduced the amount of standing water on the ground, and reduced the moisture gradients that normally occurred with small changes in micro-relief. Another problem area was distinguishing between barren complex and tussock tundra. Discussion of the areas of disagreement led to some modifications of the key.

One of the problems encountered was that each observer had to determine which part of the trail to interpret and where the dividing lines between vegetation types or disturbance levels occurred. Despite guidelines specifying that the most disturbed area of the trail be interpreted down to 3-mm resolution, disagreements on interpretations along the trail were often due to interpretations in different locations. Therefore, we decided to change from interpreting complete trails to interpreting the vegetation type and disturbance level within sample circles along the trails. Since 1 of our goals was to document recovery of trails through photographs taken in successive years, we wanted the photo interpretation to be as repeatable as possible.

We tried interpreting 2, 3, and 5-mm circles on the photos. We found that 2-mm circles had too few features inside them to allow accurate interpretation, and that 5-mm circles were larger than necessary, and often included more than 1 vegetation type. Thus 3-mm circles (18 m on the ground) were used. Circles were spaced every 2.5 cm (150 m on the ground), which resulted in approximately 7 sample circles per photo, and approximately 100 points along a 16-km segment of seismic line.

When 100 3-mm circles were interpreted, all 3 interpreters agreed on vegetation types for 58% of the points, and on disturbance levels for 65% of the points (Appendix Table 3). Agreement between any 2 observers ranged from 66% to 76% for vegetation types and from 71% to 80% for disturbance levels. These agreement figures were calculated differently than those in the previous 2 trials. The agreement figures given previously compared the total length of trail determined to be in each category (e.g. total of wet graminoid tundra interpreted by each observer), rather than agreement on each section of trail. Agreement on each section of trail would be lower, and would more accurately represent the repeatability of the interpretation. All subsequent agreement figures are based on point by point agreement.

After this agreement check, areas of disagreement were discussed, and the photo key was examined to see if it could be improved. Our goal was to bring our agreement into the 80% range, preferably the high 80's. Each vegetation type and disturbance level description was considered along with its most commonly confused counterparts. Definitions were refined and quantified where possible.

The key was then used to interpret 60 points which were unknown to the 3 interpreters, but for which ground data were available. The accuracy of interpreters was 60%, 76%, and 78% on vegetation types, and 72%, 77%, and 78% on disturbance levels (Appendix Tables 4, 5). The figures indicated that the process of refining the key had improved accuracy, up from 57% accuracy for both vegetation types and disturbance levels on the 1984 photo interpretation. Despite our efforts, several vegetation types were still error prone. Barren complex sites were rarely identified correctly on the photos, and tussock tundra sites were frequently interpreted as other types, especially moist-sedge shrub and barren complex tundra. One interpreter identified moist sedge-shrub tundra only 40% of the time, while the other 2 interpreters had high accuracy rates in this vegetation type. All interpreters had problems in identifying wet graminoid tundra, and often interpreted these sites as moist sedge-shrub tundra. The most common error among disturbance levels was interpreting a level 2 as a level 1. Only 36% of the level 2 points were correctly identified (Appendix Table 5). This demonstrates that even though overall accuracy for disturbance levels was approximately 76%, this was due mostly to the large number of level 1 points (correctly identified 86% of the time). The identification of level 2 and 3 disturbances was much less accurate.

The 60 ground points from the accuracy check were used, along with the rest of our control points, to make final modifications to the photo interpretation key (see Appendix Table 1 for copy of final key). Definitions of wet graminoid, moist sedge-shrub, barren complex, and tussock tundra were reviewed and refined where possible, as were level 2 and level 3 definitions for all types. The decision was made to carry out the interpretation using 2 observers, and to encourage consultation on any ambiguous points, so as to minimize observer differences. Interpretation of 3-mm circles was continued, in order to provide subsequent interpreters and accuracy assessors the same small finite circle within which to describe the vegetation type and disturbance level.

Revisions in the 1985 Key

The main revisions made in the 1985 key are described below. Level 0 ground definitions in many vegetation types were revised to include a low level of disturbance which was visible on the ground, but was not visible on the air photos. Aquatic graminoid marsh, which was interpreted on the 1984 photos in 2 locations where it was not found on the ground, was given a more restrictive photo definition. The new definition excluded very wet sedge and included small ponds (less than 60 m diameter). Since only minor disturbance was ever visible, level 1 disturbance was defined, but level 2 and 3 were not.

We eliminated the moist/wet tundra complex vegetation type, because errors often occurred when deciding whether to place a site in the complex, in moist sedge-shrub tundra, or in wet graminoid tundra. By eliminating the complex type, we reduced the decision to whether a site has a predominance of either moist or wet vegetation. Wet graminoid tundra level 2 could not be consistently identified on the photos, and was difficult to define on the ground, so it was combined with level 1. Moist sedge-shrub tundra had been defined too restrictively, so that many moist sedge-shrub sites in 1984 were interpreted as other types on the photos. The definition was broadened by quantifying the amount of frost boils (less than 30%), tussocks (less than 15%), and wet graminoid inclusions (less than 50%) allowed. 1984 and 1985 trails through moist sedge-shrub tundra had different signatures, therefore separate disturbance descriptions were developed for levels 1 and 2. 1985 trails were lighter than the 1984 trails, probably because the litter was not water-soaked. Level 3 disturbance was not described for 1985 trails in moist sedge-shrub tundra, because no such sites were found during our ground reconnaissance.

We considered eliminating the moist graminoid/barren tundra complex vegetation type because it so frequently intergraded with moist sedge-shrub and tussock tundra. Distinguishing between these 3 types was our most persistent vegetation problem. However, eliminating it would have meant designating all barren complex sites as either moist sedge-shrub or tussock tundra, requiring a much broader definition of those vegetation types. We decided that barren complex and its disturbance characteristics were distinctive enough to merit separate interpretation.

Known ground points with tussocks and frost hummocks were studied on the airphotos in order to better delineate the differences between barren complex and tussock tundra. Frost boils and hummocks often had a linear orientation on hill slopes and were larger than tussocks (over 0.08 mm diameter on the photos). These characteristics were incorporated in the key. The amount of tussock tundra inclusion allowable in any other vegetation type was defined as 15% cover of tussocks. Tussock tundra disturbance levels 1 and 2 were also more precisely defined. Many trails, especially the 1985 vibrator lines, were on the border between level 1 and level 2 disturbances. The frequent occurrence of crushed tussocks, which could be seen as white speckles on the photos was used to define level 2 disturbance. The definitions of the photo signatures of the rarer vegetation types such as moist shrub tundra, Dryas terrace, and riparian shrubland were elaborated to include more of the variation seen on the photos.

Appendix Table 1. Color-infrared aerial photo interpretation key (1:6000 scale) for vegetation types and trail disturbance levels, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Photo description	Disturbance level 0	1	2	3
Water	Lakes, streams, and rivers. Black to milky blue color. Includes snow and ice patches (white).	None.			
Aquatic graminoid marsh	Covering shallow ponds or on edges of deeper ponds. Brownish black with no gray from litter. Dried ponds may be greenish to white.	No change visible.	Darker line visible.		
Wet graminoid tundra	Low-centered polygons, green to gray. Grayer in less wet sites; dark green in very wet sites. Higher microsites gray to gray-pink, rarely pink. May be bright red in wet intermittent drainage channels. Also found on widely spaced strangmoor with distinct dark flarks or drained lake basins.	No change visible.	Levels 1 and 2 not separable on photos. Trail barely perceptible to visible continuous line with distinct color change. Colors range from same as background or olive-brown to pinkish-red with scattered black patches. On drier sites increased litter may be visible as gray line. Higher microsites respond as in moist sedge-shrub tundra.		Distinct dark red-brown trail.
Moist sedge - shrub tundra	Mostly mottled pink, smooth texture. Color ranges from very light pink to pink to gray with pink cast. May be bright pink to reddish on creek banks, or patchy olive brown on weak high-centered polygons. Little to no texture evident. May have closely spaced strang or scattered tussocks (less than 15%), or up to 30% hummocks or frost scars. Commonly found on flat-centered polygons or gentle slopes.	No change visible.	Barely preceptible, discontinuous lineation of changed vegetation, darker or lighter tone; or continuous light pink trail--easily visible, but little color change. Not reddish. 1985 trails usually have slightly lighter tone but little color change. Can have sporadic whitish spots.	Continuous trail, distinct color change to reddish pink. Easily visible on photo. Sometimes brown with some pink-gray in wetter sites, or rarely green-gray (mossy sites). 1985 trails continuously white to whitish pink, distinct color change, loss of pink.	Dark, red to brown-red trail. No pink or gray evident. Continuous strong contrast with un-disturbed areas. Track depression may be evident. Photo characteristics of 1985 trails are unknown.
Moist graminoid/ barren tundra complex	Hummocks and irregular frost scar features appear as bluish-gray to brown dots; or irregular patches with distinct boundaries covering 30% or more of ground. Hummocks and frost boils have linear orientation on slopes and greater than 0.08 mm diameter. Tussocks may appear as scattered specks around or between frost features but not continuous (less than 15%).	No change visible.	Barely perceptible color change, slightly lighter tone. No blue-gray dots.	Distinctly darker or lighter gray trail. Few to some blue-gray dots evident.	Almost all frost boils blue-black forming distinct blue-gray trail. Little pink evident.

Appendix Table 1. Continued.

Vegetation type	Photo description	Disturbance level 0	1	2	3
Moist sedge tussock tundra	Obvious grainy texture. Gray, brown-gray or green-gray specks on background of pink or reddish-pink. Specks with continuous moderate spacing, not scattered, less than 0.08 mm diameter. Frost features, if present, composed of aggregated specks. Found on high-centered polygons and slopes.	No change visible.	Barely perceptible lighter line to noticeable line formed by lighter speckles. Darker speckles still visible. May include a few distinct white speckles.	Continuous lighter to white line with few to no undisturbed tussocks, but little blue-gray color either. Usually with frequent to continuous white speckles.	Continuous blue-gray line, texture blurred, no undisturbed tussocks visible. Dark speckling evident. Ruts starting to form.
Moist shrub tundra	Reddish-brown patches on high-centered polygons. Color varies from orange-red to red to brown, fairly uniform, sometimes mottled. Smooth to slightly textured. Some tussocks (less than 15%) may be present as scattered tiny specks. Also found on less distinct higher microsites, particularly upland basins. Distinct edges on trails are characteristic of this vegetation type.	No change visible.	Barely perceptible to distinct trail, slightly lighter than undisturbed with less red visible. Sometimes appears as slightly darker with less red evident. No black speckling.	Distinct trail, discontinuous to continuous gray line, with little or no red. Some black speckling may be present.	Very distinct whitish trail mottled with light bluish-gray or black spots.
Riparian shrubland	River terraces and banks. Shrubs evident as red to purple-red dots, patches or continuous color. Background varies from white to pink to greenish gray. Texture varies from smooth to grainy.	No change visible.	Trail barely visible, lighter spots sometimes evident. Trail sometimes slightly darker from shadows of shrubs at edge of trail. In open riparian areas, reddish spots (shrubs) still common.	Distinct light gray or pink line. Never with black speckling. Trail sometimes darker from shadows. In open riparian areas, few reddish spots.	Distinct trail, continuous or nearly so, gray to greenish-gray lines. No red or pink. Black speckling sometimes evident.
<u>Dryas</u> terrace	River terraces and exposed river bluffs. Light pink-gray to reddish pink. Scattered gray or brown patches occasionally present. Little to no texture.	No change visible.	Barely perceptible, slightly grayer trail.	Distinct, usually continuous light gray trail, some pinkish hue may be evident. Black speckling rare.	Distinct, contrasting trail. Bluish gray, no pinkish hue. Usually some black patches evident.
Partially vegetated or barren area	Less than 30% vegetated. Generally white or light blue with scattered patches of pink or red.	None.			

Appendix Table 2. Vegetation types and disturbance levels of photo-interpreted points on 1984 and 1985 winter seismic trails, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Vegetation type	Disturbance level 0	1	2	3	Total	Percentage
		1984 seismic lines				
Water[a]	20				20	2.1
Aquatic graminoid marsh[a]	2	0			2	0.2
Wet graminoid tundra[a]	17	165		0	182	19.0
Moist sedge-shrub	22	220	58	0	300	31.3
Barren complex	13	44	14	0	71	7.4
Tussock tundra	12	220	47	1	280	29.3
Moist shrub tundra	9	33	11	0	53	5.5
Riparian shrubland	14	3	1	0	18	1.9
Dryas terrace	1	2	1	1	5	0.5
Partially vegetated[a]	26				26	2.7
Total	136	687	132	2	957	
Percentage	14.2	71.8	13.8[b]	0.2		
		1985 seismic lines				
Water[a]	17				17	1.3
Aquatic graminoid marsh[a]	0	0			0	0.0
Wet graminoid tundra[a]	2	118		0	120	9.5
Moist sedge-shrub[a]	16	402	46		464	36.7
Barren complex	1	84	48	0	133	10.5
Tussock tundra	0	239	202	2	443	35.0
Moist shrub tundra	1	34	20	0	55	4.3
Riparian shrubland	5	8	2	0	15	1.2
Dryas terrace	0	1	1	1	3	0.2
Partially vegetated[a]	15				15	1.2
Total	57	886	319	3	1265	
Percentage	4.5	70.0	25.2[b]	0.2		
		1984 camp-move trails				
Water[a]	55				55	5.3
Aquatic graminoid marsh[a]	3	0			3	0.3
Wet graminoid tundra[a]	25	228		7	260	25.0
Moist sedge-shrub	42	157	155	19	373	35.8
Barren complex	2	33	41	6	82	7.9
Tussock tundra	0	55	87	17	159	15.3
Moist shrub tundra	2	24	25	2	53	5.1
Riparian shrubland	8	6	2	0	16	1.5
Dryas terrace	0	0	1	1	2	0.2
Partially vegetated[a]	38				38	3.6
Total	175	503	311	52	1041	
Percentage	16.8	48.3	29.9[b]	5.0		

Appendix Table 2. Continued.

Vegetation type	Disturbance level 0	1	2	3	Total	Percentage
			1985 camp-move trails			
Water[a]	66				66	5.4
Aquatic graminoid marsh[a]	2	1			3	0.2
Wet graminoid tundra[a]	3	113		0	116	9.5
Moist sedge-shrub[a]	78	252	112		442	36.3
Barren complex	6	39	26	1	72	5.9
Tussock tundra	0	80	119	0	199	16.4
Moist shrub tundra	1	36	84	0	121	9.9
Riparian shrubland	3	7	9	0	19	1.6
Dryas terrace	0	0	1	0	1	0.1
Partially vegetated[a]	178				178	14.6
Total	337	528	351	1	1217	
Percentage	27.7	43.4	28.8[b]	0.1		
		1984 overlapping camp-move trails and seismic lines				
Water[a]	3				3	0.8
Aquatic graminoid marsh[a]	3	0			3	0.8
Wet graminoid tundra[a]	0	82		0	82	21.2
Moist sedge-shrub	24	37	73	10	144	37.3
Barren complex	0	11	31	3	45	11.7
Tussock tundra	0	11	51	14	76	19.7
Moist shrub tundra	0	7	13	2	22	5.7
Riparian shrubland	0	3	2	1	6	1.6
Dryas terrace	0	0	0	0	0	0.0
Partially vegetated	5				5	1.3
Total	35	151	170	30	386	
Percentage	9.1	39.1	44.0[b]	7.8		
		1985 overlapping camp-move trails and seismic lines				
Water[a]				0	0.0	
Aquatic graminoid marsh[a]	0	0			0	0.0
Wet graminoid tundra[a]	0	9		0	9	18.8
Moist sedge-shrub[a]	0	20	8		28	58.3
Barren complex	0	0	2	0	2	4.2
Tussock tundra	0	0	8	0	8	16.7
Moist shrub tundra	0	0	1	0	1	2.1
Riparian shrubland	0	0	0	0	0	0.0
Dryas terrace	0	0	0	0	0	0.0
Partially vegetated[a]	0				0	0.0
Total	0	29	19	0	48	
Percentage	0.0	60.4	39.6[b]	0.0		

[a] Blanks indicate that certain disturbance levels were not defined for these vegetation types.

[b] The overall percentage of level 2 disturbance may be underestimated, because level 1 and 2 were combined for wet graminoid tundra.

Appendix Table 3. Photo interpretation of vegetation types and disturbance levels on winter seismic trails showing agreement between pairs of interpreters, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Interpreter	Vegetation type[a] AG	WG	M/W	MS	GB	TT	ST	RS	DT	PV	Disturbance level 0	1	2	3
Trial 1 (mm)														
1	0	0	17	275	92	1011	146	6	0	0	0	459	1023	65
3	0	0	111	474	195	805	3	0	0	0	0	1476	112	0
Agreement between interpreters[b]					76%							36%		
Trial 2 (mm)														
1	4	117	144	309	389	157	210	83	0	3	70	975	340	31
2	4	74	83	593	384	84	127	60	0	0	60	1085	214	50
3	9	101	78	497	91	377	143	62	43	14	143	901	363	8
Agreement between interpreters[b]		1&2 - 80%			2&3 - 72%			1&3 - 67%			1&2-91%	2&3-84%	1&3-93%	
Trial 3 (no. of points)														
1	0	5	12	28	3	39	10	3	0	0	2	63	33	2
2	0	2	11	37	6	33	7	4	0	0	5	78	17	0
3	0	5	4	40	7	37	3	4	0	0	7	70	23	0
Agreement between interpreters[c]		1&2 - 76%			2&3 - 74%			1&3 - 66%			1&2-76%	2&3-80%	1&3-71%	

[a] AG - aquatic graminoid marsh; WG - wet graminoid tundra; MW - moist/wet sedge tundra; MS - moist sedge-shrub tundra; GB - barren complex; TT - tussock tundra; ST - shrub tundra; RS - riparian shrubland; DT - *Dryas* terrace; PV - partially vegetated areas.

[b] Agreement was calculated as the total length of trail in each vegetation type determined by both interpreters.

[c] Agreement was calculated on a point by point basis.

Appendix Table 4. Photo interpretation and ground determination of vegetation types at 55 sites on winter seismic trails, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination	Photo interpretation WG	MS	GB	TT	ST	RS	DT	Accuracy no.	%
Interpreter 1									
Wet graminoid (WG)	8	2						8/10	80
Moist sedge-shrub (MS)	7	8	1	3	1			8/20	40
Barren complex (GB)			1	2			1	1/4	25
Tussock tundra (TT)	1	1	2	13	1			13/18	72
Shrub tundra (ST)					1			1/1	100
Riparian shrubland (RS)						1		1/1	100
Dryas terrace (DT)							1	1/1	100
Total								33/55[a]	60
Interpreter 2									
Wet graminoid	6	4						6/10	60
Moist sedge-shrub		19			1			19/20	95
Barren complex			1	2			1	1/4	25
Tussock tundra		2	2	14				14/18	78
Shrub tundra					1			1/1	100
Riparian shrubland						1		1/1	100
Dryas terrace							1	1/1	100
Total								43/55[a]	78
Interpreter 3									
Wet graminoid	6	4						6/10	60
Moist sedge-shrub	1	18	1					18/20	90
Barren complex			2	1			1	2/4	50
Tussock tundra		2	2	13	1			13/18	72
Shrub tundra					1			1/1	100
Riparian shrubland						1		1/1	100
Dryas terrace							1	1/1	100
Total								42/55[a]	76

[a] Five sites were eliminated due to problems with ground determinations.

Appendix Table 5. Photo interpretation and ground determination of disturbance levels at 60 sites in winter seismic trails, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Ground determination	Photo interpretation Disturbance level				Accuracy	
Disturbance level	0	1	2	3	no.	%
Interpreter 1						
0	7	2			7/9	78
1	1	31	6		31/38	82
2		6	4	2	4/12	33
3				1	1/1	100
Total					43/60	72
Interpreter 2						
0	9				9/9	100
1	3	34	1		34/38	89
2		9	3		3/12	25
3			1		0/1	0
Total					46/60	77
Interpreter 3						
0	9				9/9	100
1	2	32	4		32/38	84
2		5	6	1	6/12	50
3			1		0/1	0
Total					47/60	78

ANWR Progress Report Number FY86-3-Impacts

SNOW DISTRIBUTION ON THE ARCTIC COASTAL PLAIN AND ITS RELATIONSHIP TO DISTURBANCE CAUSED BY WINTER SEISMIC EXPLORATION, ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA, 1985

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

Key Words: Surface disturbance, winter seismic exploration, tundra, vegetation change, traffic patterns, snow depth, Alaska, Arctic National Wildlife Refuge, Arctic-Beaufort

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

Snow distribution on the arctic coastal plain and its relationship to disturbance caused by winter seismic exploration, 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: Annual and seasonal variations in snow cover on Barter Island were studied. Snow accumulation data from Wyoming snow gauges near the ANWR coastal plain were summarized for the period 1976-1986. Total snow accumulation was low in 1984 and closer to average in 1985 and 1986. Monthly snow measurements were made on 2 transects on Barter Island in 1985 and 1986. Snow depths gradually increased during both winters, while depth hoar increased early in the season and remained the same from January through May. Hardness of snow or the strength of bonding between crystals was measured using a Rammsonde penetrometer. The Rammsonde hardness increased during the first part of both winters, then decreased after March or April. Hardness was highly variable at individual points along the transects. Snow density averaged 0.30 g/cm^3 over both years. Snow depths were measured as seismic crews traveled across the coastal plain in 1984 and 1985. These snow depths averaged 23 cm in 1984 and 30 cm in 1985. Snow distribution across the coastal plain was highly variable due to wind transport of snow which resulted in little cover on hill crests or ridges and deep accumulations in basins and drainages. The area west of the Sadlerochit River had less snow than the eastern portion of the coastal plain. On the western side, moist sedge tussock tundra and moist graminoid/barren tundra complex had less snow than wet graminoid tundra. Overall, wet graminoid tundra and closed riparian shrubland had the highest snow depths, while *Dryas* terrace and open riparian shrubland had the lowest snow depths. No significant differences in average snow depths were observed between terrain types, elevations, and aspects. Ninety study plots were established on seismic lines and camp moves in tussock tundra and moist sedge-shrub tundra to study the relationship between snow cover and disturbance. Snow depth data were collected in the winter, and plant cover changes, tussock disturbance, and trail visibility were measured in the summer. Plots with greater snow depths were generally less disturbed. In tussock tundra, plots with snow depths over 25 cm had significantly less disturbance than those with less than 25 cm. Snow depths over 25 cm or slab depths over 15 cm prevented moderate disturbance. The relationship between snow cover and disturbance was less clear in moist sedge-shrub tundra, and in a number of cases, slab depth appeared to be a better measure of protective snow cover than total snow depth which included the underlying depth hoar. Snow depths over 35 cm or slab depths over 20 cm prevented moderate disturbance in moist sedge-shrub tundra. Many other factors were important in determining the amount of disturbance, especially at lower snow depths.

Snow distribution on the arctic coastal plain and its relationship to disturbance caused by winter seismic exploration, Arctic National Wildlife Refuge, Alaska, 1985.

Oil and gas exploration activities on the coastal plain of the Arctic National Wildlife Refuge (ANWR) were authorized by the Alaska National Interest Lands Conservation Act (ANILCA), Section 1002. Federal regulations required that seismic exploration be conducted in the winter when there was adequate protective snow cover to prevent significant disturbance to fish and wildlife habitat and the environment (Federal Register 48:76-16863). In January through May 1984 and 1985, Geophysical Service Incorporated (GSI) conducted winter seismic exploration across the coastal plain. A total of 2000 km of seismic line, arranged in an approximately 5 x 10 km grid, was completed during the 2 years. The drilled shothole technique, using dynamite to create seismic waves, was used in 1984, and the vibrator technique, using large trucks as an energy source was used in 1985. Data collection on seismic lines required multiple passes of tracked vehicles along linear trails. Ski-mounted camps pulled by D-7 Caterpillar tractors (cat-trains) followed the crews across the tundra, leaving a second series of trails. More information on the 1984 and 1985 seismic exploration programs can be found in Felix et al. (1987a) or in GSI's plans of operations (Geophysical Service Inc. 1983a, 1983b, 1984).

Little information was available on snow precipitation or distribution on the coastal plain of ANWR. The only long-term record of snow precipitation in the area was the weather service data from Barter Island, 15 km north of the ANWR boundry. These data included daily records of the amount of snowfall and snow on the ground, and measurements of the water equivalent of snow precipitation in an unshielded gauge. Measurements of snow precipitation were also available from a Wyoming snow gauge on Barter Island maintained by the U.S. Soil Conservation Service (SCS) since 1976. Wyoming snow gauges have been reported to give more reliable estimates of snow precipitation than unshielded gauges under the typical windy conditions of Barter Island (Benson 1982). Wyoming snow gauges were also operated at Kavik and the Jago River in 1977 and 1979, and provided the only sources of snow precipitation data on the coastal plain. Reconnaissance surveys of snow distribution were done in the National Petroleum Reserve-Alaska (NPR-A), 450 km west of ANWR, and at a few sites on ANWR in April and May 1977, 1978, and 1979, when winter cross-country travel associated with oil and gas exploration was occurring (Sloan et al. 1979, Glude and Sloan 1980). These surveys found that snow distribution across the coastal plain was extremely variable ranging from bare patches on ridgetops to deep drifts in drainages.

There was also a scarcity of information on the relationship between snow cover and disturbance. Although the protective nature of snow cover has long been recognized, the amount of snow cover needed to protect the tundra from disturbance due to off-road vehicle traffic has not been well-defined. Most studies have focused on construction of snow or ice-capped roads to protect tundra vegetation (Joint Snow Compaction Program 1954, Abele 1963, Adam and Hernandez 1977, Keyes 1977, Johnson and Collins 1980). Two studies, Reynolds (1982) and Envirosphere Company (1985), considered the changes in plant cover due to winter vehicle traffic under differing snow conditions, although neither study had detailed snow data available. Reynolds (1982) noted that significant changes in plant cover occurred on vehicle trails even when at least 15 cm of snow was present, and that vehicle trails created under low snow cover conditions recovered more slowly than trails created during a high snow cover year. Envirosphere Company (1985) found no clear relationship between tussock damage on trails from 4 different years and the relative amounts of snow cover during these years. Site specific snow data were unavailable, and the lack of a relationship was attributed to snow distribution patterns, since snow on tussock covered slopes is generally subject to wind scouring, even in heavy snowfall years.

Data relevant to the ANWR coastal plain were needed to regulate and monitor seismic exploration activity on the refuge, and to minimize its impact. The objectives of this study were:

1. Determine typical winter precipitation patterns.

2. Determine the characteristics of the snow pack (depth, % depth hoar, hardness, density, water content) and how those characteristics change over the course of a winter and between years.

3. Determine the pattern of snow distribution across the coastal plain.

4. Investigate the relationship between snow cover and the degree of disturbance by winter vehicle use.

Methods

Precipitation data were collected monthly during 1985 and 1986 from 2 Wyoming snow gauges on Barter Island, and forwarded to the SCS in Anchorage, Alaska. The Barter Island lake gauge was established on the south shore of the fresh water lake in 1976 and the Barter Island DEW line station gauge was established in 1984 just west of the DEW line station. Wyoming snow gauge data from previous years were obtained from the monthly bulletins of Alaska snow surveys (U.S. Dept. of Agric., Soil Conservation Service 1976-1986).

Characteristics of the snow pack were measured along permanent 50-m transects at 2 sites on Barter Island at monthly intervals from January through May 1985 and November 1985 through April 1986. The field station transect was established in an area with moist graminoid/barren tundra complex vegetation, located approximately 300 m from the U.S. Fish and Wildlife Service (FWS) field station. The lakeside transect was established in wet graminoid tundra, located on the south shore of the fresh water lake near the Wyoming snow gauge. The ends of both transects were marked with short wooden stakes and rebar with yellow caps.

Measurements were taken in undisturbed areas adjacent to the permanently marked transects each month. Snow depth, slab depth, and depth hoar thickness were measured at 30 random points along the monthly 50-m transects. Slab depth included the top layer of densely compacted wind slab, and depth hoar thickness included the layer of loosely crystallized snow next to the ground surface. Snow depths were also measured at 1-m intervals along the permanently staked 50-m transects each month to establish a cross-sectional profile. These monthly profiles were plotted to identify changes due to deposition and erosion.

The Rammsonde hardness of the snow was measured with a Rammsonde penetrometer (Abele 1963). Two determinations were made at each of the 30 random points on the monthly transects. Usually the 0.5-kg hammer was used and released at the 50 cm height, and the number of blows and penetration depth were recorded. The 1-kg hammer was occasionally used for very hard snow. Rammsonde hardness was calculated with the following equation:

$$R = (Q + W) + (WFN/P)$$

where Q = weight of tube, 1.1 kg; W = weight of hammer, 0.5 or 1.0 kg, P = penetration depth (cm), F = height of fall (cm); and N = number of blows.

Snow samples for density and total water content (cm equivalent) were collected with a thin-walled, galvanized steel coring tube, 6.95 cm in diameter and graduated in cm. Thirty samples were collected on each transect.

Descriptive statistics were calculated for the above variables. The water content of snow on the transects was compared to the water content of snowfall collected in the Wyoming snow gauge at the Barter Island DEW line station.

Snow data were collected across the coastal plain by FWS monitors on the seismic crews. These data provided a record of snow depths and distribution within various landscape components at the time of the seismic activity. In 1984, snow data were collected at 10 random locations along 13 randomly located 5-km segments of seismic lines for a total of 130 locations. At each location snow depth was sampled at 20 points along a line transect parallel to the seismic line. In 1985, snow data and site descriptions were collected at 3.2-km intervals (every 100 shotpoints) along the seismic lines for a total of approximately 250 observations. Data collected at each location included:

- total snow depths at 20 undisturbed sample points along a line transect parallel to the seismic line
- slab depth and depth hoar thickness at 10 undisturbed sample points
- landform
- vegetation type
- terrain type
- elevation

Landforms, vegetation types, and terrain types were adapted from Walker et al. (1982, 1983). The vegetation types are described in detail in Felix et al. (1987b). Aspect and drainage density were determined from topographic maps (1:63,360 scale). Drainage density was defined as the number of drainages within 5 km to the east and west of the location. One-way and 2-way analyses of variance of snow depth by site characteristics and Scheffe's test for multiple comparisons were run using the SPSSx statistical package on the mainframe computer at University of Alaska (SPSS Inc. 1986).

Ninety study plots were established in the winter and revisited in the summer to collect data on the relationship between snow cover and surface disturbance. Plots were located on seismic lines and camp-move trails in tussock tundra and moist sedge-shrub tundra. Plots on seismic lines were usually located where 1 vibrator pass plus multiple passes of other seismic vehicles had occurred, while single passes of a cat-train occurred on camp-move trail plots. Plots were selected in the winter to include a range of snow depths.

Snow depth, slab depth, and depth hoar thickness were measured at 20 points along 10-m line transects adjacent to vehicle trails. The transects were marked with rebar and survey lathe, and locations were mapped on topographic maps and/or aerial photos (1:18,000 true color) to facilitate relocation in the summer.

In the summer, the vegetation type was described for each plot, and cover estimates were obtained using the line-intercept method (Mueller-Dombois and Ellenberg 1974). Two 10-m transects were run in the disturbed plot and 2 in a control area, and cover was estimated to the nearest cm 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 differences 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 ((D-C)/C x 100). The differences in percent cover of litter, exposed soil, water, and bare ground (litter, soil, and water) were calculated (D-C).

Damage to tussocks was measured in 2 belt transects (2 m x 4 m, or 10 m x the width of each vehicle track) on each disturbed plot. The numbers of tussocks in the following categories was 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.

The visibility of disturbance was rated from the air (at 60 m altitude) and on the ground, using the following classes adapted from Abele (1976):

- not visible - trail could not be discerned
- barely perceptible - trail could be discerned from discontinuous 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

Disturbance level was rated using the following classes: 0-none, 1-low, 2-moderate, and 3-high. These classes are described in detail for each vegetation type in Felix et al. (1987b).

Data were analyzed separately for tussock tundra and moist sedge-shrub tundra. Simple regression lines were calculated for the disturbance measures by snow depths and slab thicknesses. Regression lines for seismic lines and camp moves were calculated separately and compared, using the BMDP statistical package (Dixon et al. 1981). Residual plots were examined to determine where a nonlinear model might be more appropriate or where a transformation might be needed to stabilize error variances. In these cases, a logarithmic transformation ($Y' = \log(Y+1)$) or a square root transformation ($Y' = \sqrt{Y}$) was used, and the regression analysis was compared to that using the untransformed data. A 1-way analysis of variance of disturbance measures vs. snow depth classes was also conducted, and a Bonferroni's test was used for multiple comparisons between means.

Chi-square tests were run to analyze the distribution of visibility ratings and disturbance ratings within snow depth and slab thickness classes, using SPSSx (SPSS Inc. 1986). Total snow depths were divided into 4 classes: $\leq$15.0 cm, 15.1-25.0 cm, 25.1-35.0 cm, and $>$35.0 cm. Slab depths were divided into the following classes: $\leq$10.0 cm, 10.1-20.0 cm, 20.1-30.0 cm, and $>$30.0 cm. Using minitab, box plots and summary statistics were generated to compare the distribution of snow depths within disturbance levels (Minitab Inc. 1985).

Results and Discussion

Annual and Seasonal Variations in Snow Cover on Barter Island

<u>Winter Precipitation</u>. A record of winter precipitation over an 11-year period was available from 3 Wyoming snow gauges on or adjacent to the coastal plain of ANWR (Fig. 1). Comparison of the annual variation of snowfall was limited by the differing time spans for which the data were collected. Capping over of the gauge by snow and rime ice sometimes occurred and may have led to an underestimation of snowfall. Capping was noted 5 times in the past 2 years, and probably occurred in previous years when the gauges were less frequently attended.

Snowfall during the winter of 1984 (1983-1984) was about 1/3 less than that during 1985 and 1986, with very little snowfall before February 1984. Total accumulation in the gauge was only 74 mm (ending 1 June). Snowfalls during the winters of 1985 and 1986 were closer to the average snowfall.

<u>Snowpack</u>. Snow depth on the ground at Barter Island increased steadily during both 1985 and 1986 winters (Fig. 2). Monthly snow depths were similar in both years on the field station transect, but were much lower on the lakeside transect in 1986.

Depth hoar forms when the lower layer of the arctic snow pack sublimates and recrystallizes due to the heat flow from the ground, through the snow, to the cold winter air. The recrystallized snow forms a loose layer composed of columns of large hexagonal crystals called depth hoar (Plate 1). This

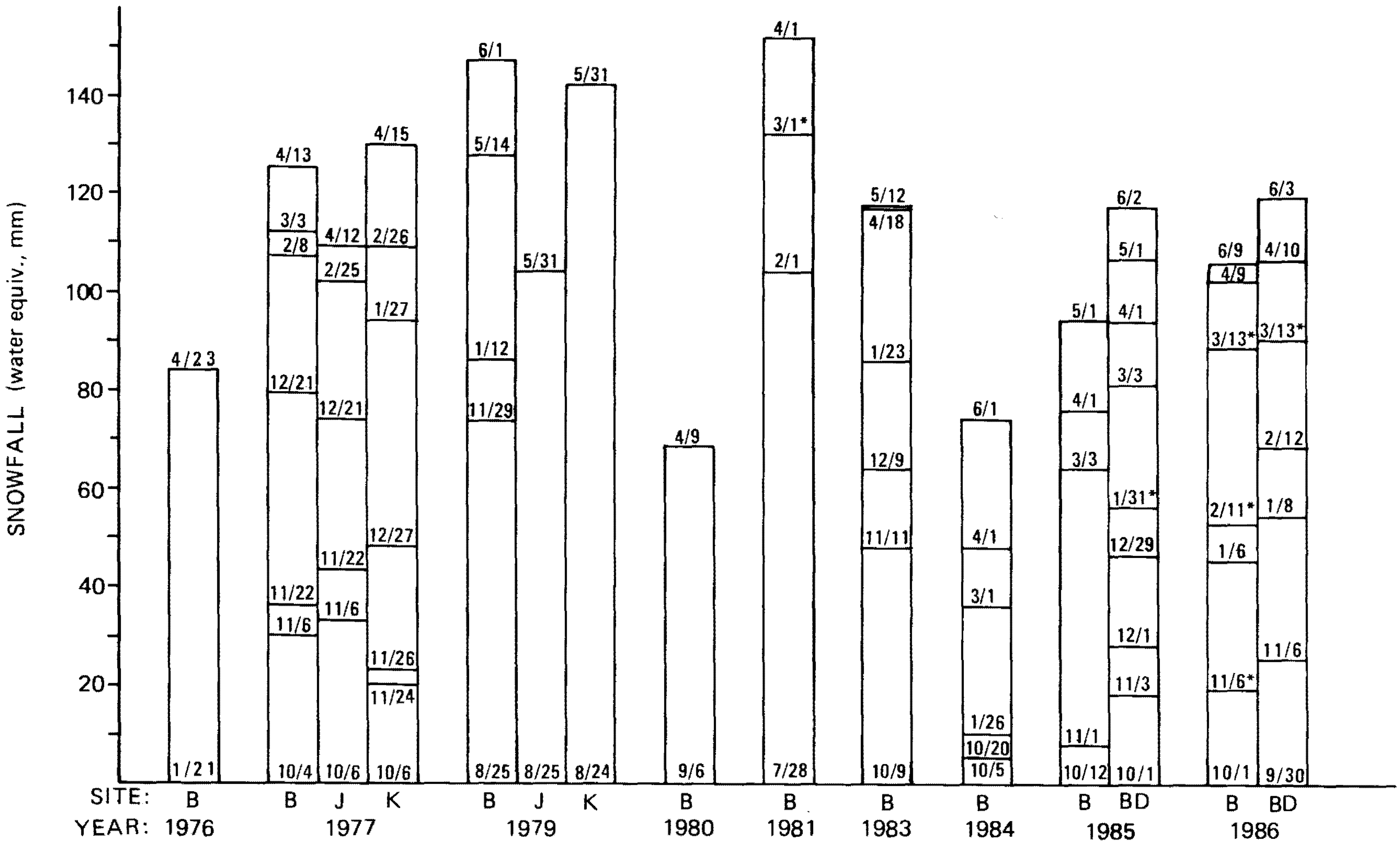


Fig. 1. Winter precipitation accumulated in Wyoming snow gauges at Barter Island Lake (B), Barter Island DEW line station (BD), Jago River (J), and Kavik (K), Alaska, 1976-1986. Sampling dates are noted. * signifies times when gauge was reported to be be capped over by snow or ice. Data are from U.S. Dept. of Agriculture, Soil Conservation Service (1976-1986) and Benson (1982).

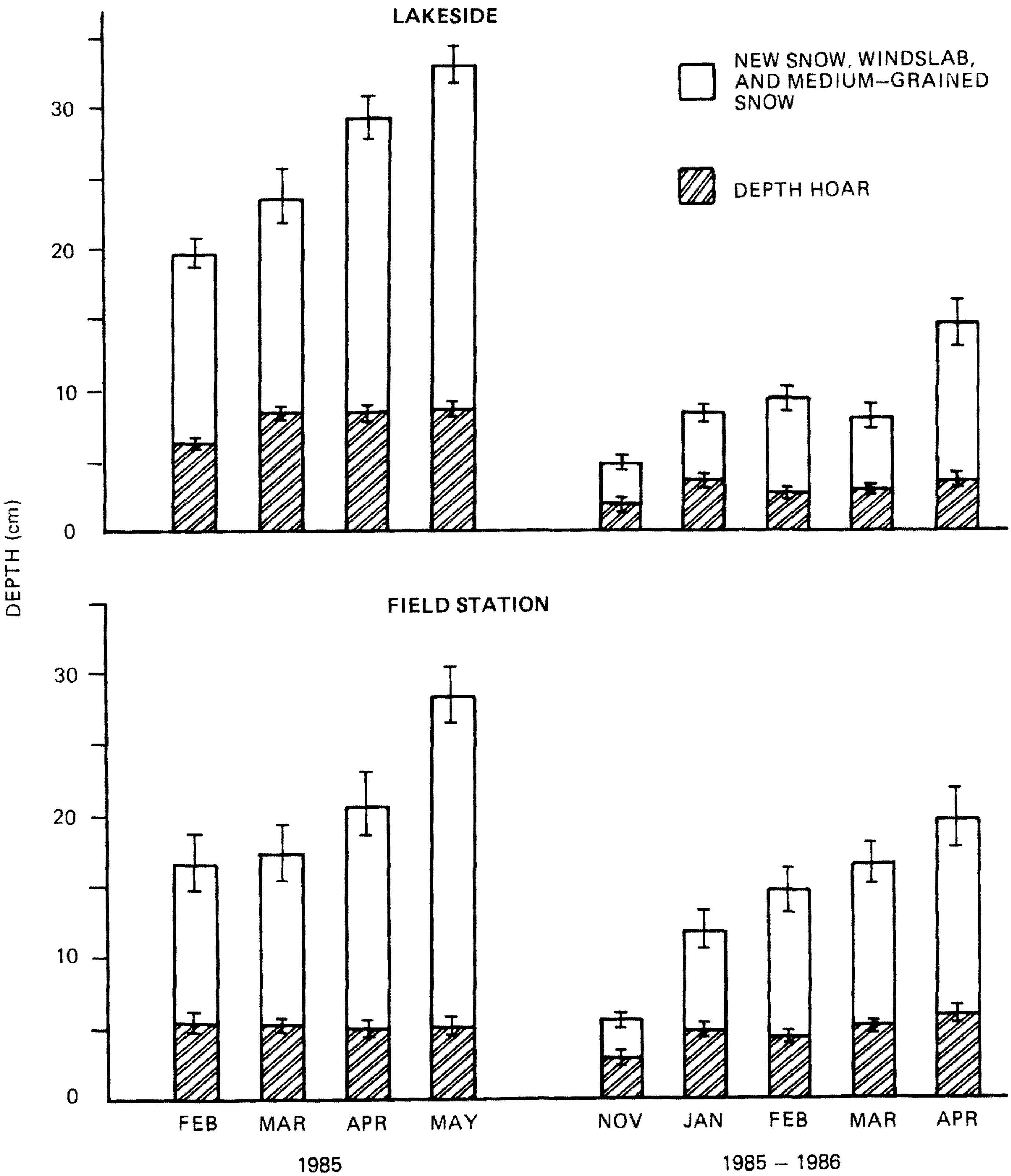


Fig. 2. Monthly snow depths on the lakeside and field station transects on Barter Island, Alaska, 1985-1986. Data are means ± SE, N=30.

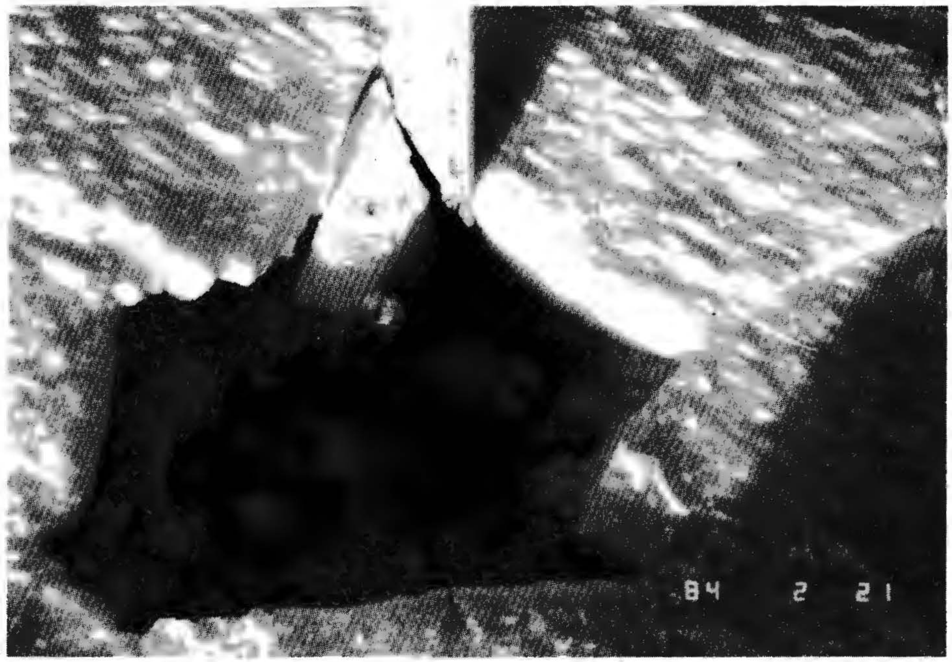


Plate 1. Snow profile showing loose depth hoar crystals under windslab.

Plate 2. Sculptured snow, known as sastrugi is formed by wind erosion of the snow surface.

layer is biologically important for arctic plants and animals, providing an area that is protected from wind abrasion and desiccation, and is somewhat insulated from air temperatures (Pruitt 1984). The loose layer of depth hoar offers little protection from surface disturbance due to winter vehicle travel.

The average depth hoar thicknesses at the 2 transects increased from November 1985 to January 1986, and were already well established by the time the sampling was initiated on 1 February 1985 (Fig. 2). Depth hoar thickness changed little over the remainder of both winters. The depth hoar was highly variable, ranging from 0 to 14 cm, at individual points along the 2 transects. As a percent of total snow depth, average depth hoar thickness decreased over time, since snow was added to the profiles and little additional metamorphosis to depth hoar occurred. The percent of depth hoar was also extremely variable, ranging from 0 to nearly 100%, at individual points along the 2 transects.

Monthly snow depth measurements at the permanent field station transect illustrate the variability of the wind drifted snow (Fig. 3). Snow accumulated in lower areas while higher microsites remain nearly bare, as was also commonly observed on the tundra. Snow was not evenly deposited over the transect each month but rather accumulated in drifts. This resulted in highly variable snow depths ranging from 7 to 49 cm at the last sampling date. Wind erosion and movement of the drifts along the transects was minor. However, some erosion did occur in the area which resulted in sculptured snow formations, known as sastrugi (Plate 2). The transect, which was oriented parallel to the sastrugi, probably showed less erosion than would a transect perpendicular to the sastrugi ridges.

Hardness of snow is a measure of the strength of the bonding between crystals. Rammsonde hardness at the 2 sites increased for the first part of both winters, then decreased after March (Fig. 4). Rammsonde hardness was higher during the winter of 1986 than 1985. Hardness was approximately the same for the lakeside transect and the field station transect in each year, except for April 1986 when the field station transect showed a large drop in hardness which did not occur at the lakeside transect. This large drop in hardness may have been partially due to the use of a 1-kg weight rather than the 0.5-kg weight which was used for other measurements in 1986. Measurements taken with both weights in 1985 suggested that the 1-kg weight gives lower hardness figures. Hardness was highly variable on each transect depending on whether a wind-packed drift or a layer with loose depth hoar was being measured. For example, hardness ranged from 3.5 to 90.0 along the field station transect on the last sampling date.

The average density of the snow for the season was 0.31 g/cm^3 in 1985 and 0.29 g/cm^3 in 1986. The density in November 1985 was low (0.26 g/cm^3), but had climbed to average levels by January, and then varied little over the rest of the season. Densities from individual cores ranged from 0.12 to0.49 g/cm^3. The average snow density found on ANWR is similar to that reported on NPR-A, 0.29 g/cm^2 in 1977, 0.32 g/cm^2 in 1978, and 0.34 g/cm^2 in 1979 (Sloan et al. 1979, Glude and Sloan 1980). Because average densities changed little over the season, the total water content of the snowpack was directly related to the increase in snow depth. The average

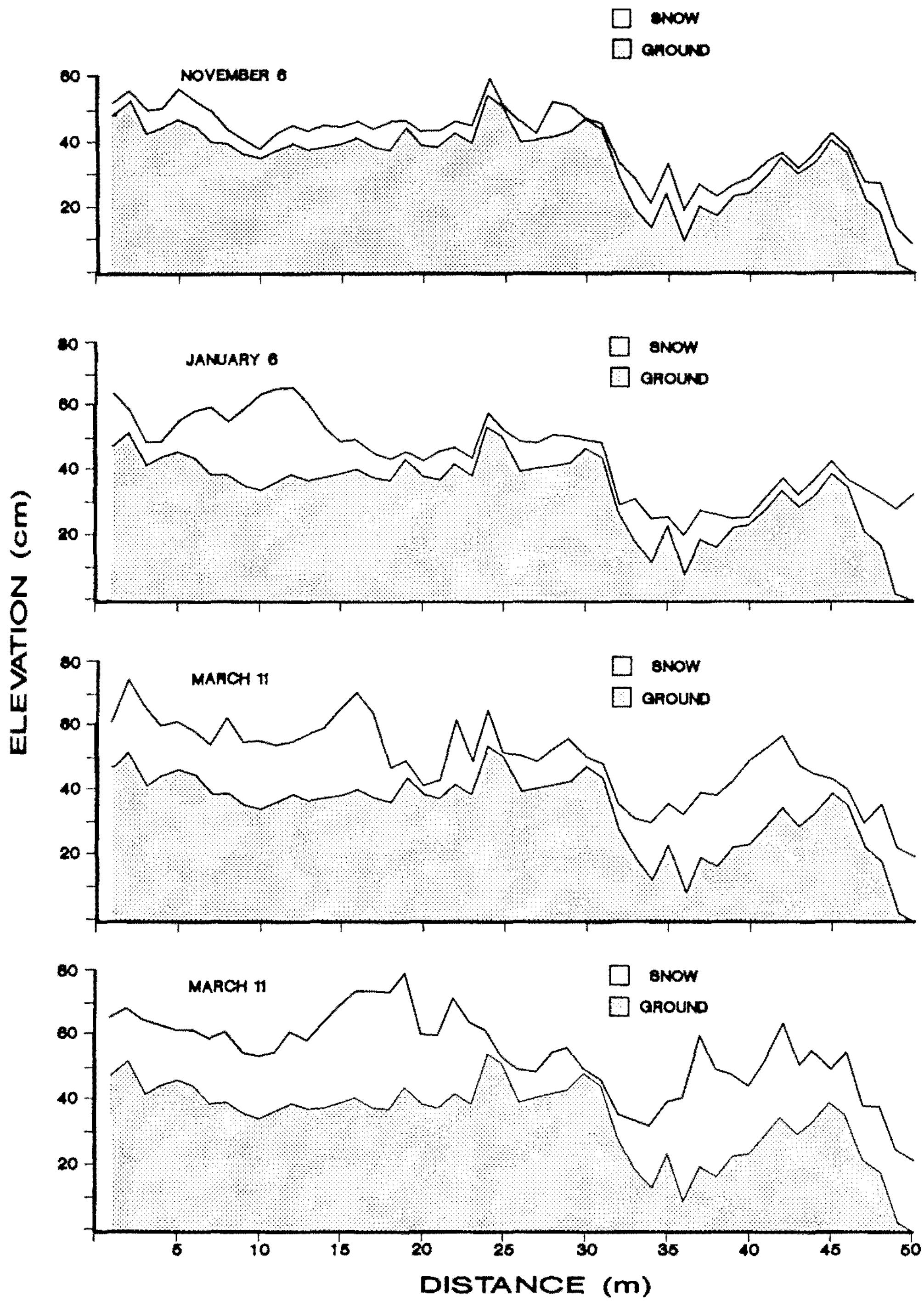


Fig. 3. Snow cover and ground elevations on the field station transect, Barter Island, Alaska, 1985-86.

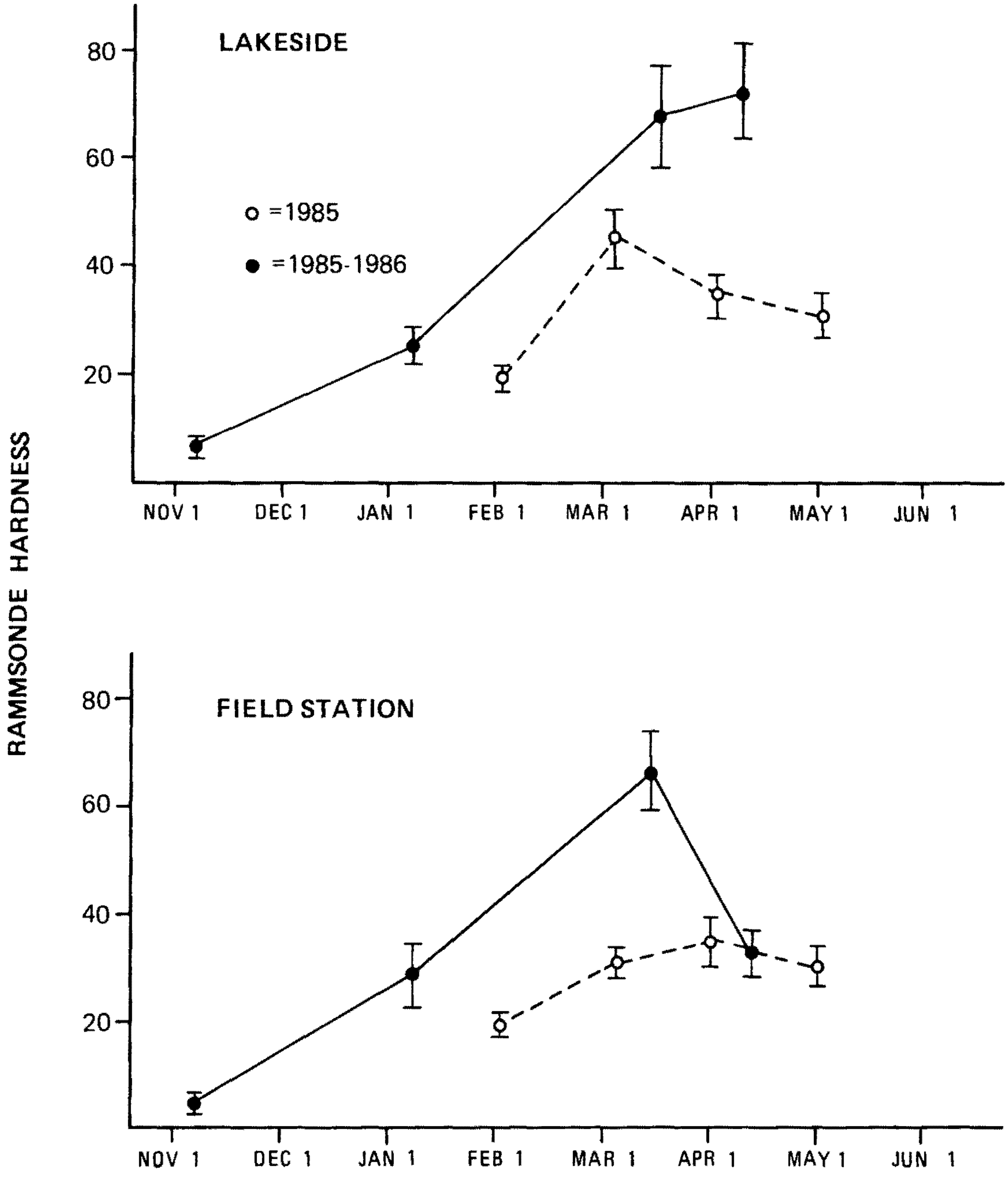


Fig. 4. Rammsonde hardness of snow on the lakeside and field station transects on Barter Island, Alaska, 1985-1986. Data are means ± SE, N=30.

total water content of the lakeside transect increased from 5.5 cm in February to 10.5 cm in May during 1985, and from 1.2 cm in November 1985 to 4.9 cm in April 1986. Total water content on the field station transect increased from 4.9 cm to 8.9 cm in 1985 and from 1.3 cm to 6.2 cm in 1986.

In 1985, the water content of the snowpack on the lakeside transect averaged 99% of the amount of water collected in the Wyoming snow gauge at the Barter Island DEW line station, and the average water content on the field station transect was 74% of the precipitation accumulated. The 1986 snowpack on the lakeside transect averaged only 43% of the water content collected in the gauge, while the field station transect had 58% as much water content as the gauge. The difference between the 2 years is most likely due to variations in wind direction and velocity, and resulting scouring and sublimation rates.

Snow Distribution on the Coastal Plain

Snow depths measured at the time of seismic exploration averaged 23 cm in 1984 and 30 cm in 1985. In 1984, 52% of the transects had average snow depths less than 20 cm and 85% had less than 30 cm, compared with 21% and 59% in 1985 (Fig. 5). These data agree with winter precipitation data from the Wyoming snow gauge at Barter Island where accumulation in 1984 was 63% of that in 1985.

The mean snow depth in 1985 was lower in January than in February, March, or April (Fig. 6). The mean snow depth in January was significantly different (Scheffe's test, $P < 0.05$) from February and March, but not April probably due to the low sample size in April. When 2-way analyses of variance were conducted with each site characteristic and month, no factor interactions were present. Therefore, each site characteristic was analyzed using the entire data set regardless of month.

Snow distribution on the coastal plain was extremely variable. Wind transport of snow resulted in little cover on hill crests or ridges, and deep accumulation in drainages (Plate 3). Hill crests had significantly less snow, ($\bar{x}$=21 cm, Scheffe's test, $P<0.05$) than basins associated with hilly terrain ($\bar{x}$= 43 cm) (Fig. 7). Drainages had significantly deeper snow ($\bar{x}$=70 cm, Scheffe's test, $P<0.05$) than all other landforms.

The area west of the Sadlerochit River had significantly less snow ($P<0.01$) than the eastern portion of the coastal plain. The western portion had an average snow depth of 25 cm, while in the eastern portion, the area north of 69° 45'N had an average snow depth of 31 cm and the area to the south had 33 cm (Plates 4, 5). The lower snow depths on the western portion were probably related to the windswept nature of the hilly topography and differences in regional deposition. In this area, the mountains are at their closest proximity to the coast and probably affect the movement of air masses, surface winds, and precipitation. One hypothesis was that this difference in snow depth was due to the presence of more drainages on the west side. However, drainage density, the number of drainages within 3 miles of each site, had no significant influence (analysis of variance, $P < 0.05$) on snow depths. Drainage density may not be a good index of the available wind traps in the area, since it does not include measures of the total extent and relief of available drainages.

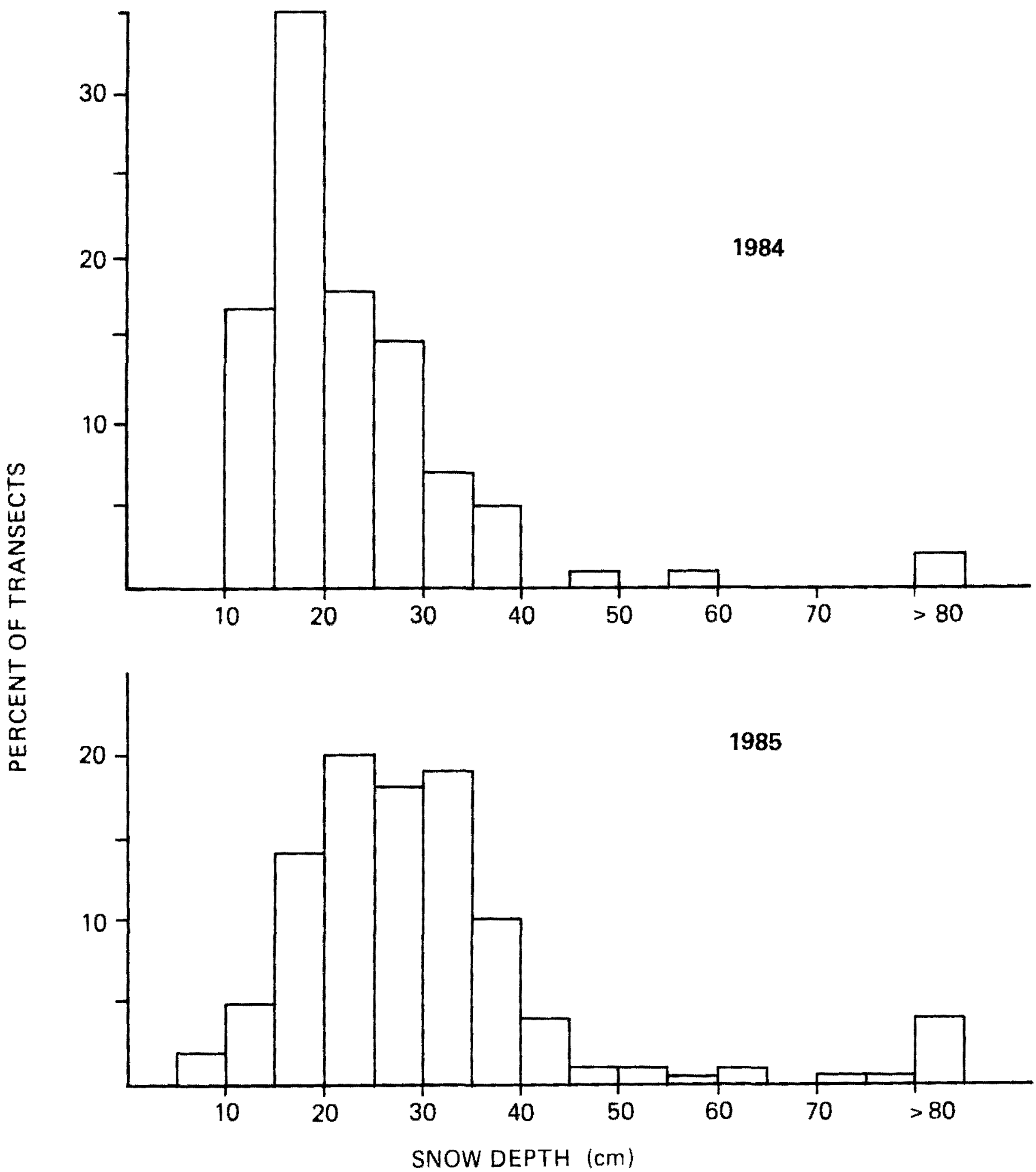


Fig. 5. Distribution of snow depths measured on transects across the coastal plain during seismic exploration in 1984 and 1985, Arctic NWR, Alaska.

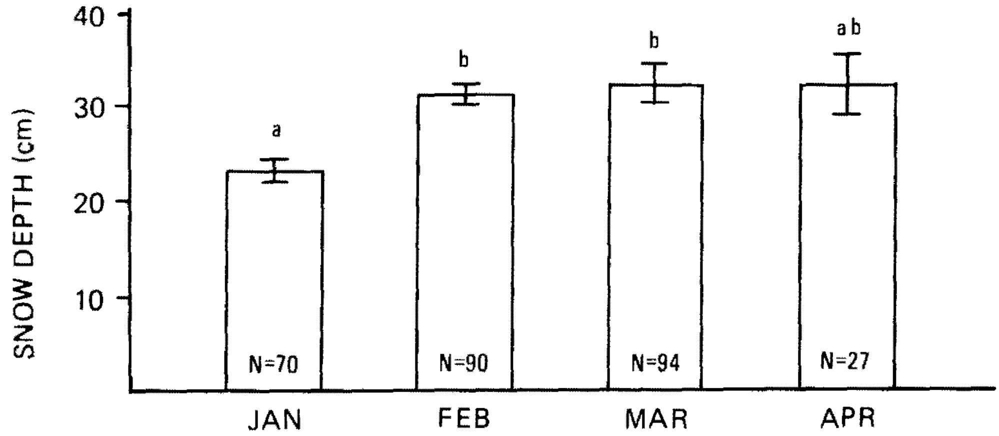


Fig. 6. Monthly snow depths on the coastal plain, Arctic NWR, Alaska, 1985. Data are means $\pm$ SE, N = number of transects. Bars with different letters are significantly different at $P < 0.05$ (Scheffe's test).

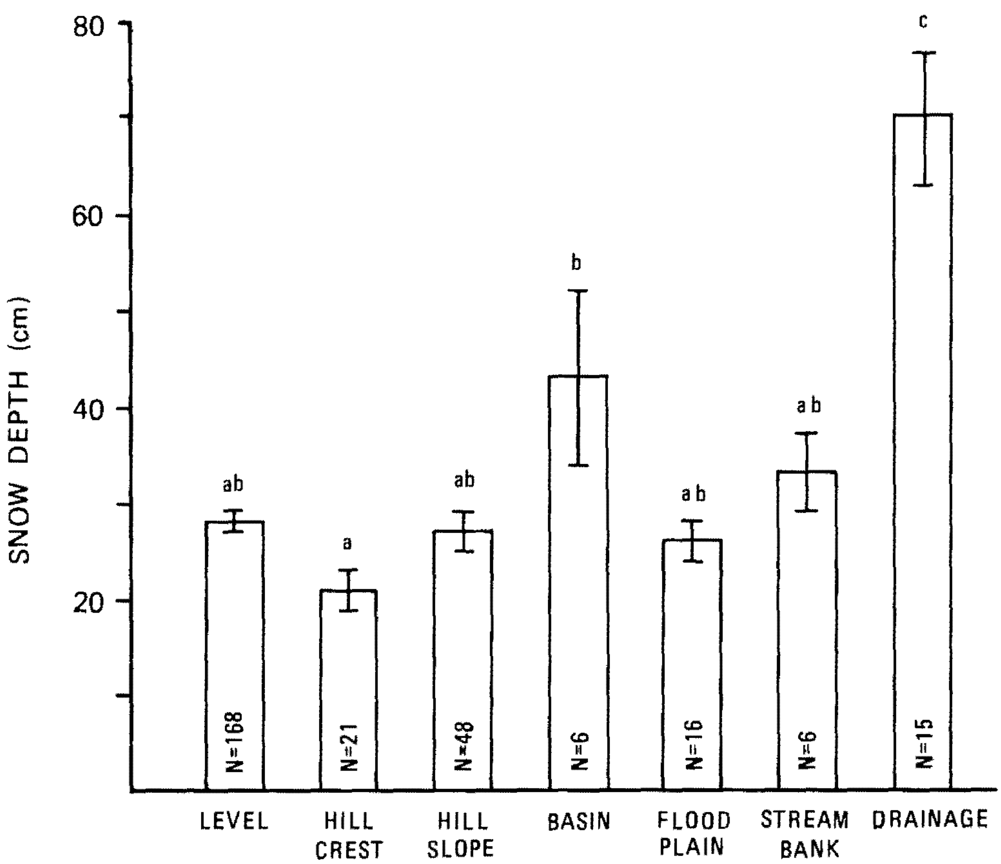


Fig. 7. Snow depths within landforms on the coastal plain, Arctic NWR, Alaska, 1985. Data are means $\pm$ SE, N = number of transects. Bars with different letters are significantly different at $P < 0.05$ (Scheffe's test).

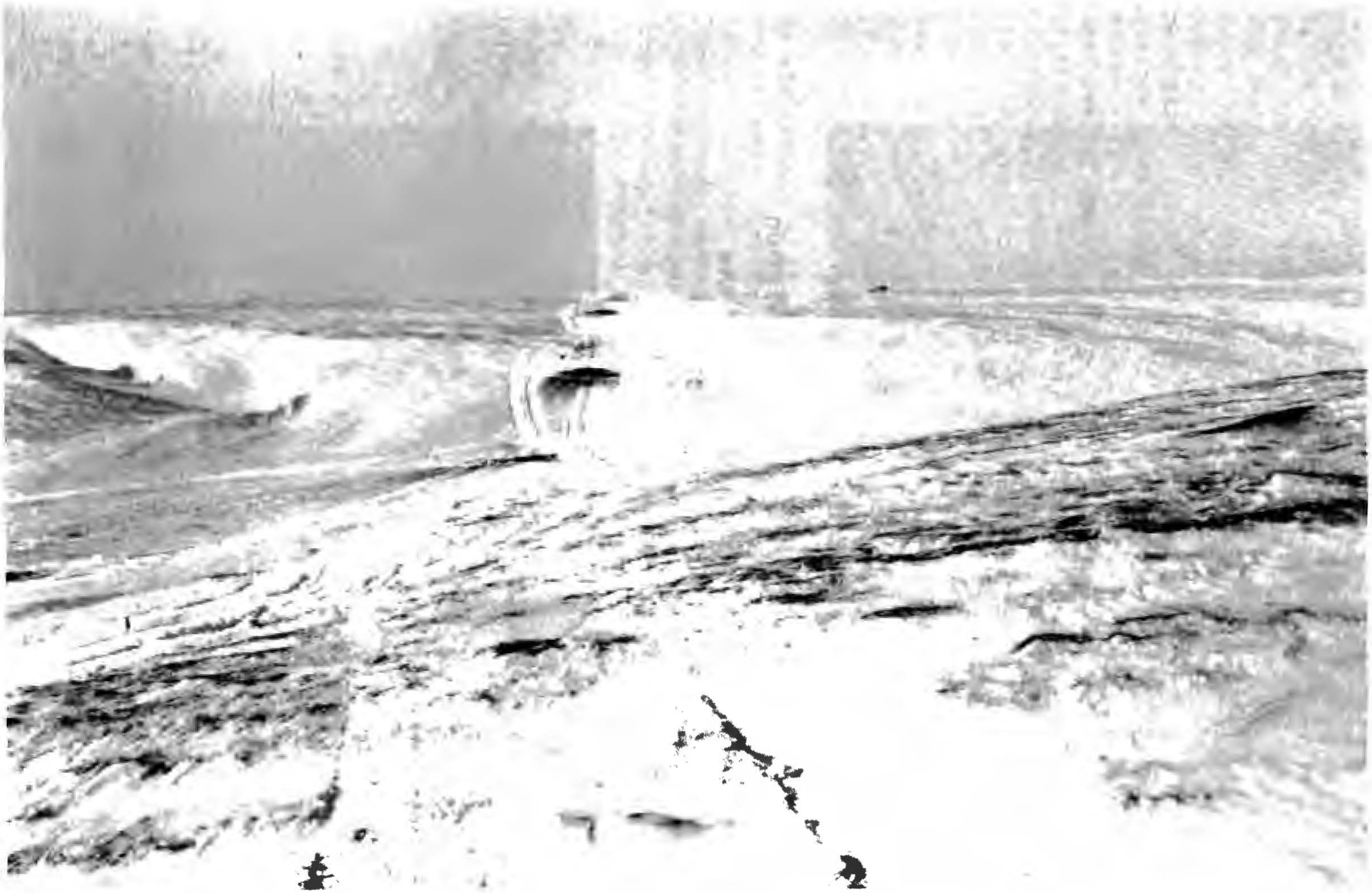


Plate 3. Variable snow cover is common on the coastal plain as shown by this barren ridgetop adjacent to a snow-filled drainage.

Plate 4. Good snow cover with little vegetation exposed was found in most areas east of the Sadlerochit River in 1985

Plate 5. Tussocks were often exposed through the lower snow cover west of the Sadlerochit River.

Snow depths differed among vegetation types (Fig. 8). Moist sedge tussock tundra and moist graminoid/barren tundra complex had significantly less snow ($\bar{x}$=19 cm, Scheffe's test, $P<0.05$) than wet graminoid tundra ($\bar{x}$=28 cm) on the western side of the coastal plain . Dryas terrace had an average snow depth of 17 cm, but was not significantly different from wet graminoid tundra, however the sample size was small. Wet graminoid tundra is generally located in basins or low areas where snow accumulates, while tussock tundra and barren complex are often found on windblown hills or ridges. The tops of tussocks and mounds often have little snow cover. Differences in snow depths among vegetation types on the east side were not statistically significant. Overall, wet graminoid tundra and closed riparian shrubland had the highest snow depths, while Dryas terrace and open riparian shrubland had the lowest snow depths (Plates 6, 7). The taller shrubs in closed riparian areas collect snow, while the wind blows snow away from the Dryas terraces and open riparian areas which are dominated by low-growing plants. Snow depths were found to be positively correlated with shrub height in a study of snow cover on the arctic tundra near Kotzebue (Brooks and Collins 1984). Sloan et al. (1979) found that average snow depths at willow sites were 41% higher than at other tundra sites on NPR-A.

No significant differences (analysis of variance, $P<0.05$) in average snow depths were observed between terrain types on the eastern or western portions of the coastal plain (Table 1). A map showing the location of these terrain types is included in Felix et al. (1987b). When all sites were tested together, the thaw lake plains had lower snow depths than the other terrain types, because the 8 sites sampled were located on the western side of the coastal plain. No significant difference (analysis of variance, $P<0.05$) in snow depths were found between elevations or aspects (Tables 2, 3). The absence of a significant difference between slopes of different aspects is consistent with the variable directions of blowing snow on Barter Island. During the period when snow measurements were made (11 Jan - 12 Apr), 55% of the days with blowing snow had predominantly easterly winds and 42% had westerly winds (U.S. Dept. of Commerce, NOAA 1985).

Table 1. Mean snow depths (cm) within terrain types on the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Snow depth								
	All sites			West			East		
Terrain types	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N
Thaw lake plain	25	2	8	25	3	8			
Hilly coastal plain	31	2	83	20	1	11	33	2	72
Foothills	28	1	127	27	2	65	30	2	62
Floodplain	31	2	63	22	2	11	33	2	52

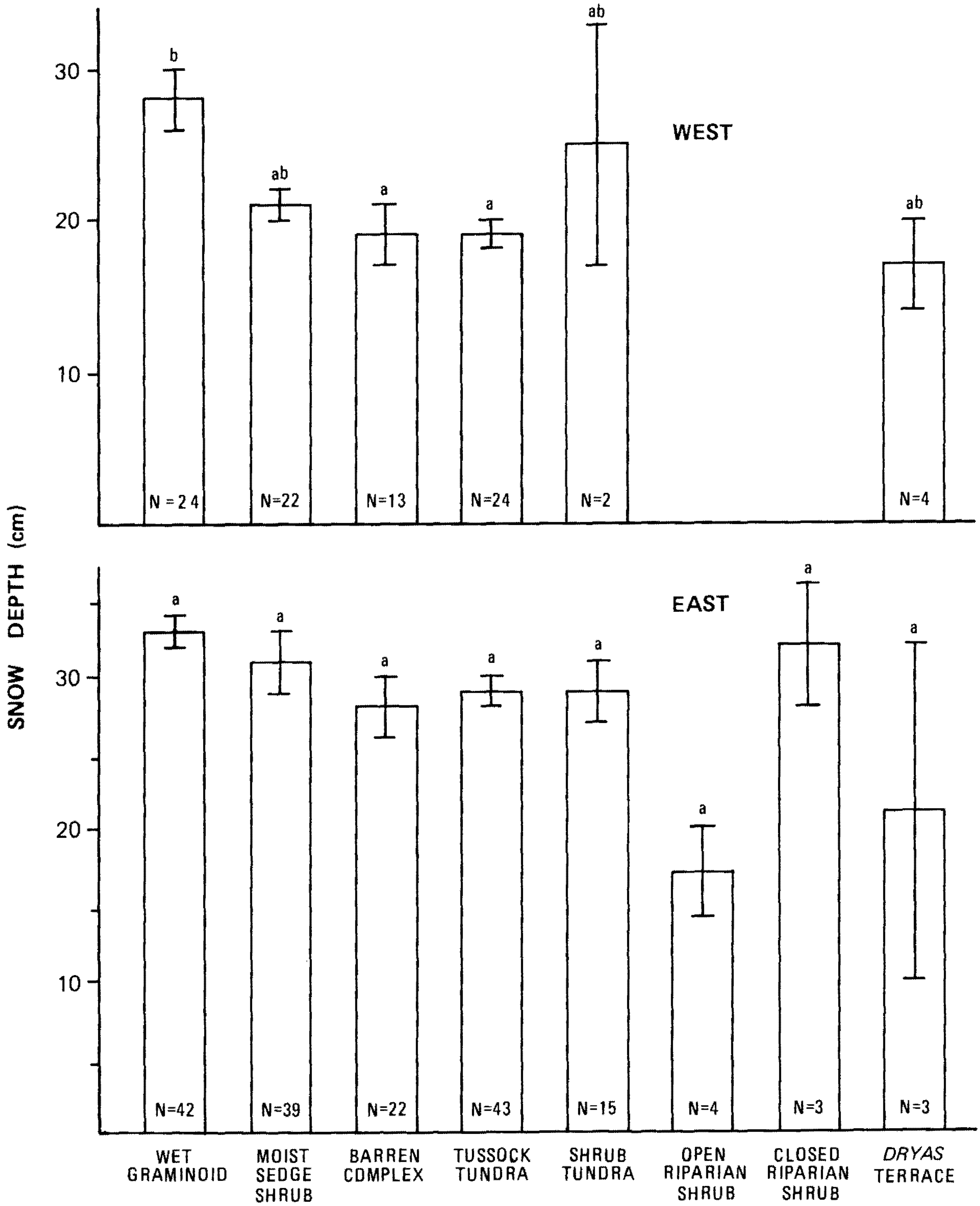


Fig. 8. Snow depths within vegetation types in the areas west and east of the Sadlerochit River, coastal plain, Arctic NWR, Alaska, 1985. Data are means ± SE, N = number of transects. Bars with different letters are significantly different at $P < 0.05$ (Scheffe's test).

Plate 6. Wet sedge tundra had higher snow cover than other vegetation types.

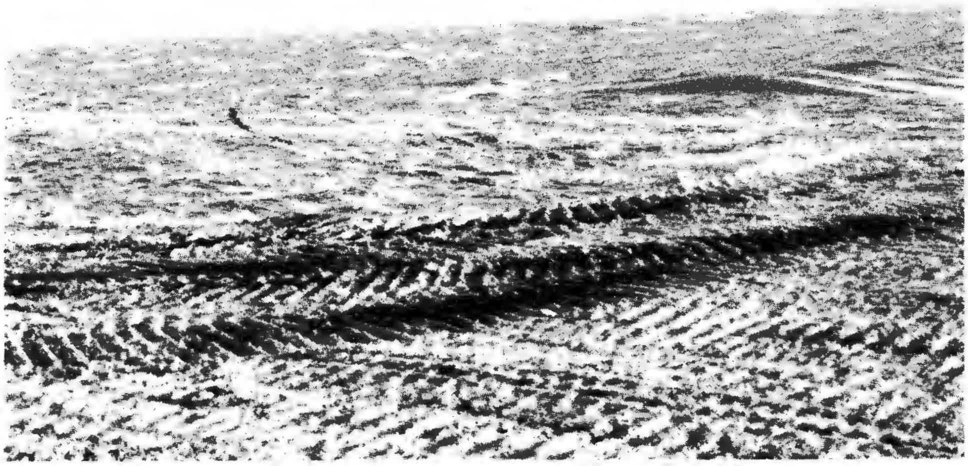


Plate 7. *Dryas* river terrace usually had very low snow cover.

Table 2. Mean snow depths (cm) by elevation (ft) on the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Elevation	Snow depth $\bar{x}$	SE	N
0 - 199	29	1	85
200 - 399	32	2	67
400 - 599	29	1	53
600 - 799	33	3	38
800 - 999	24	2	28
1000 - 1200	28	6	8

Table 3. Mean snow depths (cm) on slopes of varying aspect, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Aspect	Snow depth $\bar{x}$	SE	N
North	24	2	34
East	33	3	24
South	26	4	12
West	27	2	13

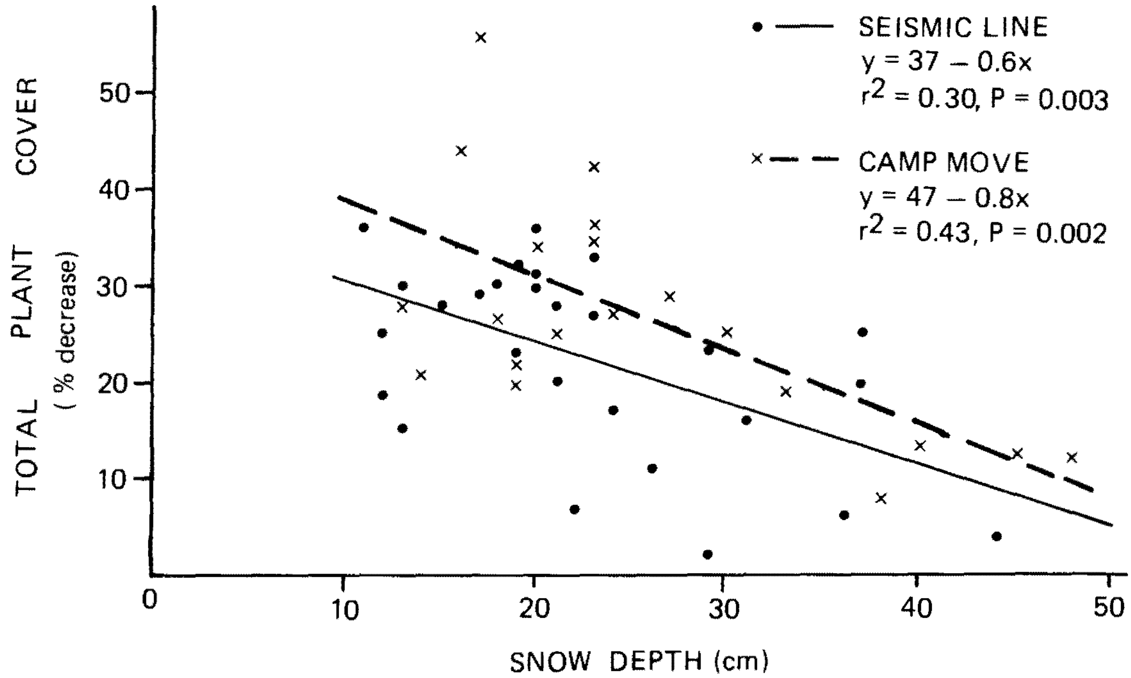
The Relationship of Snow Cover to Disturbance

Variable snow cover over the coastal plain provided tundra vegetation with little protection from disturbance in some places, and complete protection in other places. Higher microsites (tussocks and hummocks) often had thin snow cover, and were easily damaged by winter seismic vehicles (Plate 8). The deeper snow found in drainages greatly reduced impacts to underlying vegetation (Plate 9).

Tussock Tundra. The amount of disturbance on vehicle trails in tussock tundra was lower when snow depths were greater (Fig. 9, 10). This relationship between total snow depth and disturbance was significant for all disturbance measures when seismic lines and camp moves were considered together (Table 4). However, the coefficients of determination (R^2) were low, indicating that snow depth explained only a small portion of the total variation in disturbance. The strongest relationships occurred between snow depth and percent tussocks disturbed and destroyed with 74% and 60% of the variations explained by snow depth. Changes in vegetative ground cover, total plant cover, and bare ground were slightly greater on camp-move trails than on seismic lines at any given snow depth. This difference was statistically significant for total plant cover, but not for other measurements of disturbance (analysis of variance for comparison of 2 regression lines, $p=0.04$) (Fig. 9). Data transformations improved the fit of the regression model slightly in 2 cases. The relationship of the log of total plant cover vs. snow depth was stronger, especially for camp moves

Plate 8. Single cat-train trail through area with low snow cover. Crushed vegetation and micro-relief is visible in the trail.

Plate 9. Camp move through deep snow in drainage.



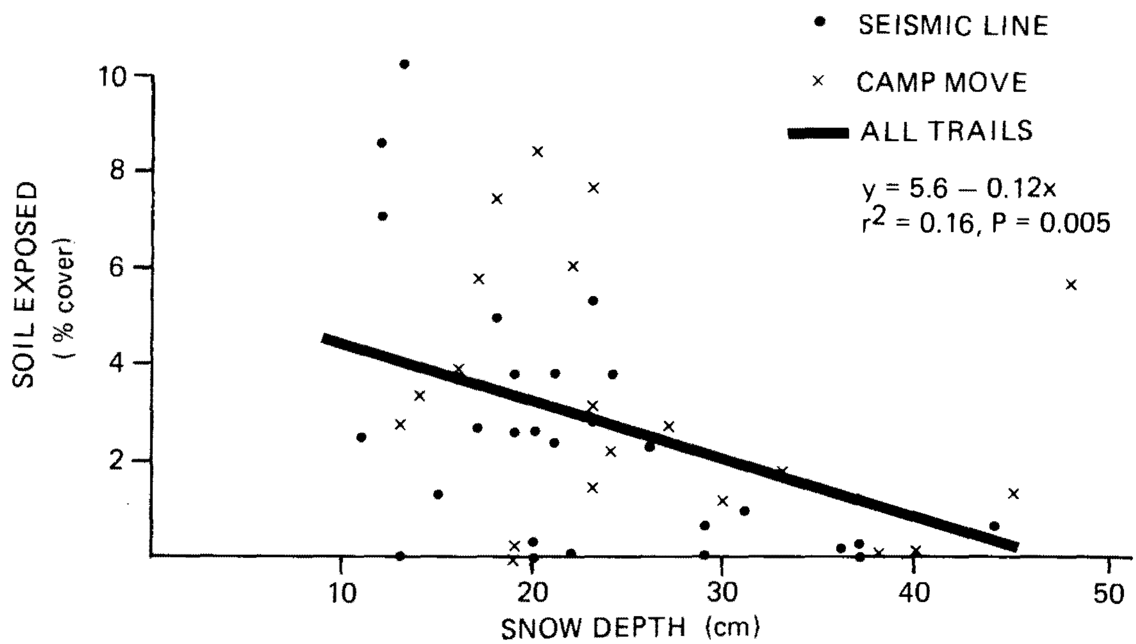


Fig. 9. Relationships of snow depth with percent decrease in plant cover ((D-C)/C x 100) and amount of soil exposed (D-C) in disturbed plots (D) compared to adjacent controls (C) in tussock tundra, coastal plain, Arctic NWR, Alaska, 1985.

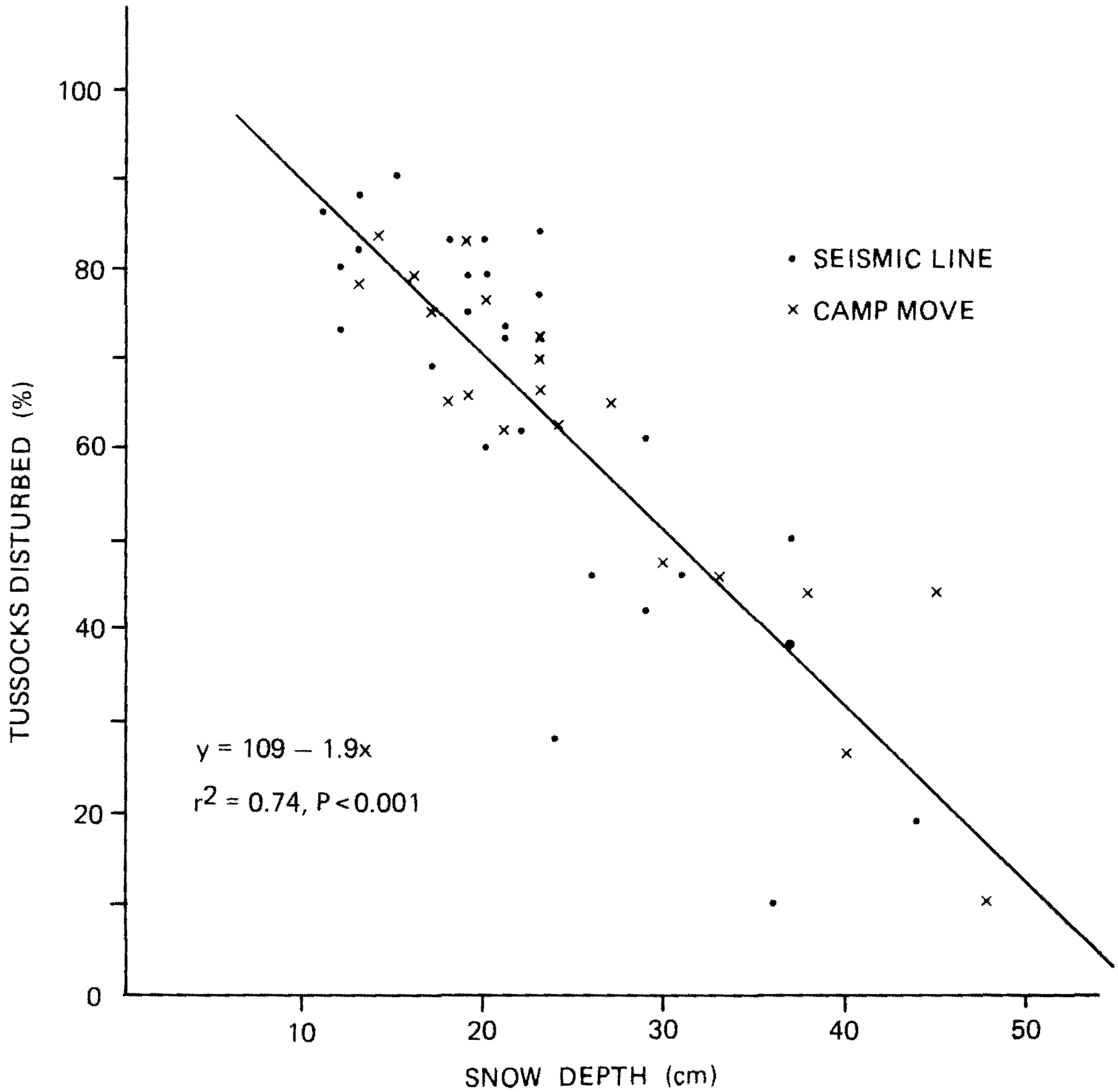


Fig. 10. Relationship between tussock disturbance and snow depth on winter seismic trails, coastal plain, Arctic NWR, 1985.

(all trails - $R^2 = 0.31$, $P < 0.001$; seismic lines - $R^2 = 0.31$, $P = 0.003$; camp moves - $R^2 = 0.55$, $P = 0.001$). The relationship of tussocks destroyed to snow depth was stronger with a square root transformation (all trails - $R^2 = 0.66$, $P < 0.001$; seismic lines - $R^2 = 0.68$, $P < 0.001$; camp moves - $R^2 = 0.70$, $P < 0.001$).

Table 4. Coefficients of determination (R^2) and significance levels (P) for relationships between total snow depth and disturbance on seismic lines and camp-move trails in tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	All trails[a]		Seismic lines[a]		Camp moves[a]	
Disturbance measures	R^2	P	R^2	P	R^2	P
Ground cover (% decrease)[b]	0.26	<0.001	0.31	0.003	0.30	0.013
Total plant cover (% decrease)[b]	0.30	<0.001	0.30	0.003	0.43	0.002
Soil exposed (%)[c]	0.16	0.005	0.31	0.003	0.08	0.223
Bare ground (%)[c]	0.27	<0.001	0.29	0.004	0.32	0.010
Tussocks disturbed (%)	0.74	<0.001	0.69	<0.001	0.85	<0.001
Tussocks destroyed (%)	0.60	<0.001	0.66	<0.001	0.57	<0.001

[a] N=47 for all trails; 20 for seismic lines; 27 for camp moves.
[b] The % decrease of ground cover and total plant cover is calculated as ((D-C)/C x 100), where D = % cover on the disturbed plot and C = % cover on the control plot.
[c] The % of soil exposed and bare ground is calculated as D-C.

The relationship between slab depth and disturbance was similar to that of total snow depth and disturbance. Slab depth excludes the depth hoar layer which appears to offer little protection from surface disturbance. However, slab depth did not appear to be a better measure of protective snow cover than total snow depth in tussock tundra.

There was less variation in most disturbance measures at greater snow depths (>25 cm) than at lower snow depths (≤25 cm) (Fig. 9). These 2 groups of data were analyzed separately to determine if the relationships between snow depth and the disturbance measures were stronger for the greater snow depths. The relationships of snow depth to ground cover, total plant cover, and bare ground were somewhat stronger for depths over 25 cm than for those under 25 cm, indicating that snow depth explained more of the decrease in disturbance at the greater snow depths (Table 5). However, these relationships were statistically significant only when all depths were considered together. The range of the greater snow depths alone was too limited and the sample size too small (n=15) to show statistically significant relationships with disturbance. The relationship between snow depth and tussocks destroyed was only significant at lower snow depths, indicating that the number of tussocks destroyed decreased with increasing snow depths up to 25 cm. Snow depths above 25 cm did not further decrease tussock destruction.

Mean levels of disturbance were significantly lower ($P < 0.01$) on vehicle trails with total snow depths over 25 cm than on those with snow depths below 25 cm (Table 6). In most cases, levels of disturbance on plots with

15 to 25 cm snow depths did not differ significantly from those on plots with 11 to 15 cm snow depths, indicating that at least 25 cm of snow was needed before a measurable decrease in disturbance occurred. No data were available to test levels of disturbance that would occur at snow depths below 11 cm.

Table 5. Coefficients of determination (R^2) and significance levels (P) for the relationship between total snow depth (all depths, ≤25 cm, and >25 cm) and disturbance in tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Total snow depth[a]					
	All depths		≤25 cm		>25 cm	
Disturbance measures	R^2	P	R^2	P	R^2	P
Ground cover (% decrease)[b]	0.26	<0.001	0.01	0.556	0.24	0.061
Total plant cover (% decrease)[b]	0.30	<0.001	0.01	0.822	0.14	0.173
Soil exposed (%)[c]	0.16	0.005	0.04	0.273	0.03	0.528
Bare ground (%)[c]	0.27	<0.001	0.01	0.754	0.24	0.065
Tussocks disturbed (%)	0.74	<0.001	0.28	0.002	0.46	0.006
Tussocks destroyed (%)	0.56	<0.001	0.44	<0.001	0.08	0.449

[a] N=47 for all depths; 32 for ≤25 cm; 15 for >25 cm.
[b] The % decrease of ground cover and total plant cover is calculated as ((D-C)/C x 100), where D = % cover on the disturbed plot and C = % cover on the control plot.
[c] The % of soil exposed and bare ground is calculated as D-C.

Table 6. Mean levels of disturbance which occurred under various snow depths on winter seismic trails in tussock tundra, Arctic National Wildlife Refuge, Alaska, 1985.

	Total snow depth[a]					
	11-15 cm		15-25 cm		>25 cm	
Disturbance measures	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Ground cover (% decrease)[b]	19ab[d]	3	25a	2	11b	2
Total plant cover (% decrease)[b]	25a	2	30a	2	15b	2
Soil exposed (%)[c]	5a	1	3a	1	1b	0
Bare ground (%)[c]	17ab	2	21a	2	9b	2
Tussocks disturbed (%)	83a	2	71a	2	40b	4
Tussocks destroyed (%)	48a	3	27b	3	5c	2

[a] N=8 for 11-15 cm snow depth; 24 for 15-25; and 15 for >25.
[b] The % decrease of ground cover and total plant cover is calculated as ((D-C)/C x 100), where D = % cover on the disturbed plot and C = % cover on the control plot.
[c] The % of soil exposed and bare ground is calculated as D-C.
[d] a,b,c, - means with the same letter do not differ significantly, pairwise t-tests adjusted with Bonferroni's probabilities, P < 0.01.

Visibility and disturbance levels of trails decreased significantly ($P < 0.01$) as snow cover increased (Table 7). Higher visibility ratings and disturbance levels occurred less frequently than would be expected for the total snow depth classes of 25.1 to 35.0 cm and over 35.0 cm, and the slab depth classes of 20.1 to 20.0 cm and over 30.0 cm. This indicated that snow depths above 25 cm and slab depths above 20 cm decreased the level of disturbance on the seismic lines and camp-move trails.

The distribution of total snow depths and slab depths at which each disturbance level occurred is shown in Fig. 11. A general trend of decreasing disturbance at greater snow depths is evident, although there are overlaps between snow depths at each disturbance level. Snow depths over 25 cm or slab depths over 15 cm were needed to prevent level 2 (moderate) disturbances from occurring on both seismic lines and camp moves (single cat-train trails). Level 1 disturbances occurred at snow depths as high as 45 cm and slab depths as high as 40 cm.

Table 7. Observed and expected () frequencies of visibility ratings and disturbance levels within total snow depth and slab depth classes on winter seismic trails in tussock tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

	Disturbance ratings							
	Visibility - air[a]		Visibility - ground[a]			Disturbance level[b]		
Depth (cm)	1	2	0	1	2	0	1	2
Total snow								
<15	0	8	0	0	8	0	2	5
	(2)	(6)	(1)	(2)	(5)	(1)	(4)	(2)
15 - 25	3	21	0	4	20	0	13	10
	(6)	(18)	(2)	(6)	(16)	(3)	(13)	(8)
25 - 30	2	5	0	4	3	1	6	0
	(2)	(5)	(0)	(2)	(5)	(1)	(4)	(2)
>30	6	2	3	4	1	4	4	0
	(2)	(6)	(1)	(2)	(5)	(1)	(4)	(3)
	X^2 = 16.0, 3 df		X^2 = 28.3, 6 df			X^2 = 25.2, 6 df		
	P = 0.001		P <0.001			P <0.001		
Slab								
<10	2	21	0	2	21	0	9	12
	(5)	(18)	(2)	(6)	(16)	(2)	(12)	(7)
10 - 20	3	12	0	5	10	1	11	3
	(4)	(12)	(1)	(4)	(10)	(2)	(8)	(5)
20 - 30	4	2	2	4	0	2	4	0
	(1)	(5)	(0)	(2)	(4)	(1)	(3)	(2)
>30	2	1	1	1	1	2	1	0
	(1)	(2)	(0)	(1)	(2)	(0)	(2)	(1)
	X^2 = 12.3, 3 df		X^2 = 26.1, 6 df			X^2 = 22.8, 6 df		
	P = 0.007		P <0.001			P <0.001		

[a] Visibility ratings: 0-not visible; 1-barely visible; 2-visible; 3-easily visible.

[b] Disturbance levels: 0-none; 1-low; 2-moderate; 3-high.

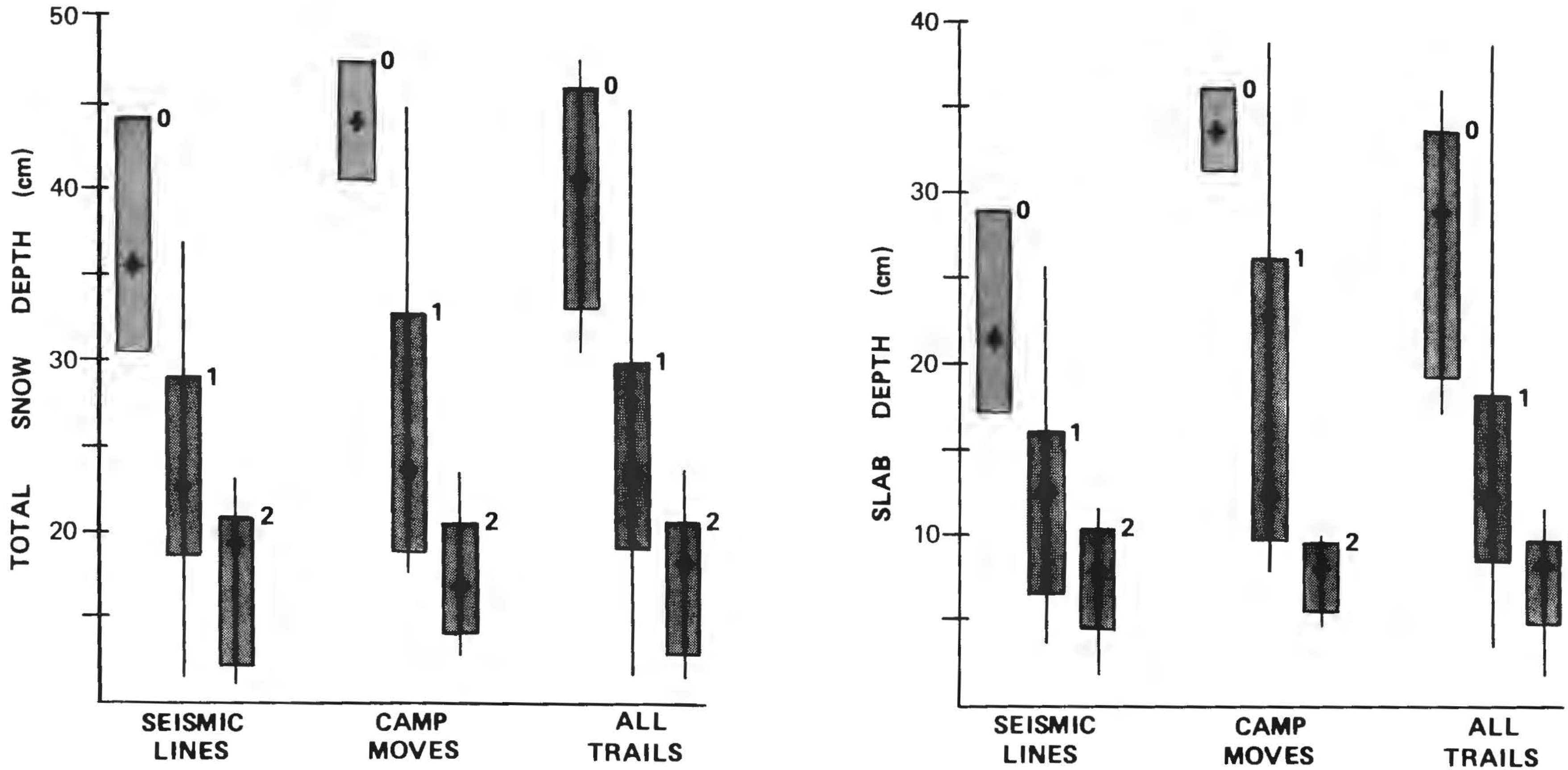


Fig. 11. Distribution of total snow and slab depths at which each level of disturbance due to winter seismic exploration occurred in tussock tundra, coastal plain, Arctic NWR, Alaska, 1985. 0, 1, 2 represent none, low, and moderate disturbance levels. + is at the median, the boxes are bounded by the first and third quartiles, and the lines extend to the minimum and maximum.

Moist Sedge-Shrub Tundra. Disturbance generally decreased with increasing snow cover on trails in moist sedge-shrub tundra. Shrub cover was the only disturbance measure which had a significant relationship with total snow depth (P 0.01) (Table 8). Slab depth appeared to be a better measure of protective snow cover, since the loss of vegetative ground cover, total plant cover, and shrub cover significantly decreased (P 0.05) as slab depth increased. As in tussock tundra, only a small portion of the variation in disturbance was explained by either total snow depth or slab depth as shown by coefficients of determination ranging from 0.10 to 0.22. Data transformations (logarithmic and square root) did not improve the fit of the regression models.

More of the relationships between total snow or slab depth and disturbance were significant for camp-move trails than for seismic lines (Table 8). Vegetative ground cover, total plant cover, and shrub cover generally showed larger decreases on camp moves than on seismic lines at any given snow depth. However, the regression lines for camp moves and seismic lines were not significantly different from each other (analysis of variance for comparison of 2 regression lines, P 0.05).

Table 8. Coefficients of determination (R^2) and significance levels (P) for the relationships between snow cover and disturbance on seismic lines and camp-move trails in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska 1985.

Disturbance measures	All trails[a]		Seismic lines[a]		Camp moves[a]	
	R^2	P	R^2	P	R^2	P
Total snow depth						
Ground cover (% decrease)[b]	0.05	0.174	0.04	0.450	0.04	0.358
Total plant cover (% decrease)[b]	0.07	0.083	0.05	0.358	0.07	0.200
Shrub cover (% decrease)[b]	0.18	0.008	0.22	0.052	0.14	0.101
Soil exposed (%)[c]	0.04	0.200	0.07	0.277	0.01	0.907
Bare ground (%)[c]	0.06	0.101	0.01	0.915	0.22	0.019
Slab depth						
Ground cover (% decrease)[b]	0.10	0.038	0.06	0.347	0.16	0.046
Total plant cover (% decrease)[b]	0.14	0.015	0.08	0.262	0.22	0.017
Shrub cover (% decrease)[b]	0.22	0.003	0.22	0.050	0.26	0.018
Soil exposed (%)[c]	0.05	0.133	0.08	0.252	0.15	0.565
Bare ground (%)[c]	0.06	0.103	0.01	0.994	0.25	0.012

[a] N=43 for all trails; 18 for seismic lines; 25 for camp moves. Except for shrub cover, where N=39 for all trails; 21 for camp moves.

[b] The % decrease of these disturbance measures is calculated as ((D-C)/C x 100), where D = % cover on the disturbed plot and C = % cover on the control plot.

[c] The % of soil exposed and bare ground is calculated as D-C.

Decreases in ground cover and total plant cover were less at total snow depths over 25 cm than at snow depths below 25 cm (Table 9). The mean changes for each snow depth class were similar to those in tussock tundra, but the differences were not statistically significant in moist sedge-shrub tundra. At snow depths over 35 cm, disturbance to shrub cover was less than at lower snow depths. Only small amounts of exposed soil and bare ground were present on vehicle trails in moist sedge-shrub tundra, and these measures changed little with increasing snow cover.

Table 9. Mean levels of disturbance which occurred under various snow depths on winter seismic trails in moist sedge-shrub tundra, Arctic National Wildlife Refuge, Alaska, 1985.

	Total snow depth[a]							
	9-15 cm		15-25 cm		25-35 cm		35 cm	
Disturbance measures	x	SE	x	SE	x	SE	x	SE
Ground cover (% decrease)[b]	17	4	23	4	14	4	14	4
Total plant cover (% decrease)[b]	22	4	27	4	17	4	17	5
Shrub cover (% decrease)[b]	36	10	48	6	38	7	20	8
Soil exposed (%)[c]	0.4	0.3	1.2	0.6	0.4	0.2	0.2	0.1
Bare ground (%)[c]	14	3	9	2	9	2	9	2

[a] N=6 for 9-15 cm snow depth; 15 for 15-25 cm; 13 for 25-35 cm; and 9 for 35 cm. Except for shrub cover where N=6 for 9-15 cm snow depth; 12 for 15-25 cm; 12 for 25-35 cm; and 9 for 35 cm. No statistical differences, analysis of variance, P 0.05.

[b] The % decrease of these disturbance measures is calculated as ((D-C)/C x 100), where D = % cover on the disturbed plot and C = % cover on the control plot.

[c] The % of soil exposed and bare ground is calculated as D-C.

Disturbance levels significantly decreased (P 0.05) as slab depths increased (Table 10). Disturbance levels were lower than would be expected for slab depths over 20 cm and higher than would be expected for slab depths less than 20 cm. No other significant relationships occurred between visibility or disturbance levels of trails and snow or slab depths (Table 11). Visibility ratings were not a good measure of disturbance in moist sedge-shrub tundra, since even low levels of disturbance left visible trails (Felix et al. 1986a).

The distribution of snow and slab depth measurements within disturbance levels shows the general trend of decreased disturbance with deeper snow cover, even though there is a large amount of overlap between disturbance levels (Fig. 12). Seventy-five percent of level 2 disturbances occurred at snow depths under 30 cm and slab depths under 15 cm and no level 2 disturbances occurred at snow depths over 35 cm and slab depths over 20 cm. Slight disturbance occurred on 1 seismic line plot which had a mean snow depth of 72 cm.

Table 10. Observed and expected () frequencies of disturbance levels on winter seismic trails within snow slab depth classes in moist sedge-shrub tundra, Arctic National Wildlife Refuge, Alaska, 1985.

Slab thickness (cm)	Disturbance level 1	Disturbance level 2	Total
<10	10 (13)	8 (5)	18
10 - 20	5 (6)	3 (2)	8
20 - 30	8 (6)	0 (2)	8
>30	7 (5)	0 (2)	7
Total	30	11	41

X^2 = 8.8, 3 df, p = 0.032

Table 11. Chi-square statistics for the distribution of visibility ratings and disturbance levels within total snow depth and slab depth classes in moist sedge-shrub tundra, coastal plain, Arctic National Wildlife Refuge, Alaska, 1985.

Disturbance ratings	N	Total snow depth		Slab depth	
		X^2	P	X^2	P
Visibility rating - air	43	3.58	0.734	2.92	0.819
Visibility rating - ground	43	7.94	0.243	10.85	0.093
Disturbance level	41	2.25	0.522	8.81	0.032

The lack of statistically significant relationships between snow or slab depth and disturbance measures in moist sedge-shrub tundra (Table 8, 11) could be due to problems associated with measuring disturbances in this vegetation type. Compression of the vegetative mat was one of the main impacts of higher disturbance levels, but was difficult to define. These estimates of change in plant cover and canopy cover on the trail were based on comparisons with equivalent undisturbed areas. An equivalent nearby area was often difficult to find as there was a high degree of variation in plant cover, especially shrubs and mosses, in this vegetation type. Soil exposed was not a good disturbance measure, since it rarely occurred.

General Conclusions. As snow and slab depths increased, disturbance due to winter seismic vehicles generally decreased. In tussock tundra, plots with snow depths over 25 cm had significantly less disturbance than those with less than 25 cm. The relationship between snow cover and disturbance was less clear in moist sedge-shrub tundra, and in a number of cases slab depth appeared to be a better measure of protective snow cover than total snow

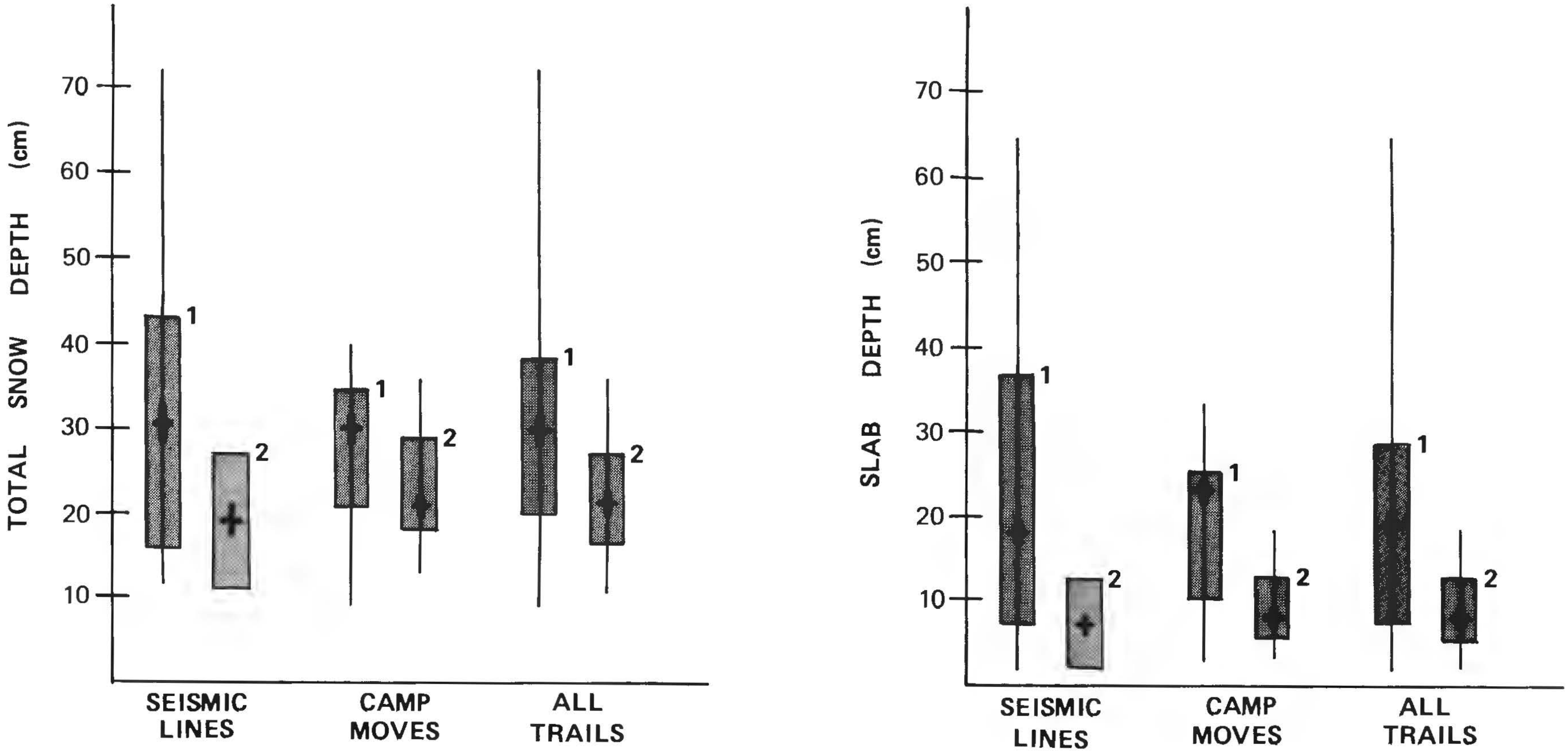


Fig. 12. Distribution of total snow and slab depths at which each level of disturbance due to winter seismic exploration occurred in moist sedge-shrub tundra, coastal plain, Arctic NWR, Alaska, 1985. 1, 2 represent low and moderate disturbance levels. + is at the median, the boxes are bounded by the first and third quartiles, and the lines extend to the minimum and maximum.

depth in this vegetation type. At total snow depths over 25 cm, less disturbance to vegetative ground cover and total plant cover occurred on trails in moist sedge-shrub tundra. Snow depths over 35 cm decreased damage to canopy cover and prevented moderate level disturbances from occurring. Low level disturbances (level 1) occurred at snow depths as high as 45 cm in tussock tundra, and 72 cm in moist sedge-shrub tundra.

Snow and slab depth explained only a small portion of the variation in disturbance, especially at lower snow depths. Many other factors influenced the amount of disturbance that occurred during winter seismic exploration. In this study, traffic pattern and vegetation type were held constant by limiting the study to seismic lines and camp moves in tussock tundra and moist sedge-shrub tundra. However, there was much variation in the numbers and types of vehicles that traveled on a seismic line. For camp moves, individual passes of cat-trains were selected for the analysis, but even these differed in the total weight of the camp trailers. Within tussock tundra and moist sedge-shrub tundra, there were a variety of plant communities with differing species compositions. Individual plant communities may be impacted differently depending on the presence of sensitive species, the amount of canopy cover, the amount of moss cover, and the moisture level. The micro-relief of an area is important in determining its susceptibility to disturbance, because high mounds or tussocks have less snow cover and are easily crushed or scuffed by vehicle tracks. Temperature is also important in determining the impact of vehicles on shrub canopies. Shrubs are more brittle and break easily at sub-zero temperatures, but will bend rather than breaking at higher temperatures. Other factors which may influence the amount of disturbance due to winter vehicle travel include slope, slope position, soil texture and ice content, and the speed of vehicle travel.

Acknowledgments

We wish to thank ERA helicopter pilot Bob Dunbar for his safe and skillful logistical support as well as his entertaining insights into tundra ecology. We also thank all of the field monitors who helped with winter data collection, including K. Moitoret, P. Miller, G. Weiler, D. LaPlant, P. Garrett, L. Martin, E. Snyder-Conn, A. Rappoport, P. Rost, and J. Hall.

Literature Cited

Abele, G. 1963. A correlation of unconfirmed compressive strength and Ram hardness of processed snow. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Technical Rep. 85, 18pp.

Abele, G. 1976. Effects of hovercraft, wheeled and tracked vehicle traffic on tundra. Pages 186-201 <u>in</u> Proc. Sixteenth Muskeg Res. Conf., Natl. Res. Counc. of Canada, Assoc. Comm. on Geotechnical Res., Tech. Memo. 116.

Adam, K.M., and H. Hernandez. 1977. Snow and ice roads: ability to support traffic and effects on vegetation. Arctic 30:13-27.

Benson, C.S. 1982. Reassessment of winter precipitation on Alaska's arctic slope and measurements on the flux of wind blown snow. Geophysical Institute, Univ. Alaska, Fairbanks. UAG R-288, 26pp.

Brooks, J., III, and W.B. Collins. 1984. Snow cover and interpretation of vegetation/habitat inventories. Pages 203-210 in V.J. LaBau and C.L. Kerr, eds. Inventorying forest and other vegetation of high latitude and high altitude regions. Proc. Int. Symp., Soc. of Am. For. Reg. Tech. Conf., Fairbanks, Ak. Soc. of Am. For., Bethesda, Maryland.

Dixon, W.J., M.B. Brown, L. Engelman, J.W. Frane, M.A. Hill, R.I. Jennrich and J.D. Toporek. 1981. BMDP Statistical Software. Univ. Calif. Press, Berkeley. 725pp.

Envirosphere Company. 1985. Effects of dynamite and vibrator seismic exploration on visual quality, soils, and vegetation of the Alaskan north slope. Final Rep. prepared for Geophysical Service Inc., Anchorage, Ak. 82pp & Appendices.

Felix, N.A., M.T. Jorgenson, M.K. Raynolds, R. Lipkin, D.L. Blank, and B.K. Lance. 1987a. Effects of winter seismic exploration on visual resources, vegetation, and surface stability of the coastal plain of the Arctic National Wildlife Refuge, Alaska, 1985. In G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitat. U.S. Fish and Wildl. Serv., Anchorage, Ak.

Felix, N.A., M.T. Jorgenson, M.K. Raynolds, R. Lipkin, D.L. Blank, and B.K. Lance. 1987b. Airphoto analysis of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge. Alaska, 1985. In G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitat. U.S. Fish and Wildl. Serv., Anchorage, Ak.

Geophysical Service Inc. 1983a. Exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Ak.

Geophysical Service Inc. 1983b. Plan of operation supplementing the GSI exploration plan for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1983. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Ak.

Geophysical Service Inc. 1984. Plan of operation for seismic exploration of the coastal plain, Arctic National Wildlife Refuge, 1984. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Ak.

Glude, J.W., and C.E. Sloan. 1980. Reconnaissance snow survey of the National Petroleum Reserve in Alaska, April-May 1979. U.S. Geol. Survey, Anchorage, Ak. Water Resour. Invest. 80-49, 13pp.

Johnson, P.R., and C.M. Collins. 1980. Snow pads used for pipeline construction in Alaska, 1976: construction, use and breakup. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Tech. Rep. 80-17, 28pp.

Joint Snow Compaction Program. 1954. Report on snow compaction trials 1952-53. Canada, Defense Res. Board, Defense Sci. Inf. Serv. Doc. L7167.

Keyes, D.E. 1977. Ice and snow construction; workpads, roads, airfields, and bridges. Pages 369-382 in Proc. of the 2nd Int. Symp. on Cold Regions Engineering, 12-14 August 1976, Fairbanks, Ak.

Minitab, Inc. 1985. Minitab reference manual. State College, Pa. 232pp.

Mueller-Dombois D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York City.

Pruitt, W.O., Jr. 1984. Snow and living things. Pages 51-77 in R. Olson, R. Hastings, and F. Geddes, eds. Northern ecology and resource management. Univ. of Alberta Press, Edmonton.

Reynolds, P.C. 1982. Some effects of oil and gas exploration activities on tundra vegetation in northern Alaska. Pages 403-417 in P.J. Rand, ed. Land and water issues related to energy development. Ann Arbor, Mich.

SPSS Inc. 1986. SPSS^{X} user's guide. McGraw-Hill Book Company, New York. 988pp.

Sloan, C., D. Trabant, and W. Glude. 1979. Reconnaissance snow surveys of the National Petroleum Reserve in Alaska, April 1977 and April-May 1978. U.S. Geol. Survey, Anchorage, Ak. Water Resour. Invest., Open-File Rep. 79-1342, 31pp.

U.S. Dep. of Agric., Soil Conservation Service. 1976-1986. Alaska snow surveys. Monthly bulletins. Anchorage, Ak.

U.S. Dep. of Commerce, National Oceanic and Atmospheric Administration. 1985. Local climatological data; monthly summary, Barter Island, Alaska. National Climate Data Center, Asheville, N.C.

Walker, D.A., K.R. Everett, W. Acevedo, L. Gaydos, J. Brown, and P.J. Webber. 1982. Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. CRREL Rep. 82-27, 59pp.

Walker, D.A., P.J. Webber, and K.R. Everett. 1983. 1:63,360 scale geobotanical mapping studies in the Arctic National Wildlife Refuge, Alaska. Final Rep. by Institute of Arctic and Alpine Research, Univ. Colorado, Boulder. Prepared for U.S. Fish and Wildl. Serv., Anchorage, Ak. 125pp.

ANWR Progress Report FY86-4-Impacts

Effects of winter seismic exploration activities on muskoxen in the Arctic National Wildlife Refuge January-May, 1984-1985

Patricia E. Reynolds
Daniel J. LaPlant

Key words: Muskoxen, seismic exploration, distribution, movements, response, Alaska, north slope, Arctic National Wildlife Refuge.

Arctic National Wildlife Refuge
U.S. Fish and Wildlife Service
101 12th Avenue, Box 20
Fairbanks, Alaska 99701

December 1986

Effects of winter seismic exploration activities on muskoxen in the Arctic National Wildlife Refuge, January-May, 1984 and 1985.

Patricia E. Reynolds, U.S. Fish and Wildlife Service, Arctic National Wildlife Refuge, Fairbanks, Alaska.

Abstract: Effects of winter seismic exploration activities on muskox (*Ovibos moschatus*) distribution and movements in the Arctic National Wildlife Refuge were documented by relocating radio-collared animals between early January and late May 1984 and 1985 when seisimic crews were operating in the study area. Aerial observations of muskoxen were also obtained during over-flights of the coastal plain. Field monitors traveling with seismic trains provided locations of muskoxen near seismic activities as well as responses of groups to seismic vehicles. Distribution of muskoxen was the same during and before or after seismic activities and did not differ from muskox distribution observed in 1982-1985. No long range movements of radio-collared muskoxen occurred during seismic activities and muskoxen did not leave areas of traditional use. Muskoxen responding to seismic vehicles showed a variety of responses. Some animals showed no observable response to moving vehicles until approached within 100-300 m. Other animals grouped and ran from moving vehicles which were more than 3 km away. In 1984 and 1985, productivity of muskoxen was 75 calves per 100 cows older than 3 years compared with 66 calves per 100 cows in 1983

Effects of winter seismic exploration activities on muskoxen in the Arctic National Wildlife Refuge, January-May 1984 and 1985.

Muskoxen (Ovibos moschatus) are year-round residents of the coastal plain of the Arctic National Wildlife Refuge (ANWR) and are one of the few species which may be directly affected by the seismic exploration activities conducted during winter. Potential effects include increased energy expenditures or injuries associated with escape responses, disruption of normal activity patterns, and the avoidance of important winter habitat in areas of seismic exploration activity. These factors may cause increased mortality, decreased productivity or increased dispersal. This report summarizes data collected during the winter and spring of 1984 and 1985 when a winter seismic exploration program was conducted on the coastal plain of ANWR.

The objective of this study was:

1. Document the effects of winter seismic exploration activities on distribution and movements of muskoxen in ANWR.

Methods and Materials

The study area was located in northeast Alaska between the Canning River and the Canadian border, from the arctic coast south to 69° 30' N latitude (Fig. 1). A detailed description of this area was presented in the initial report of the ANWR coastal plain (U.S. Fish and Wildlife Service 1982). For purposes of this study, the principle study area was subdivided into the Tamayariak area, the Sadlerochit area and the Okerokovik area (Fig. 1).

Between late January and early May 1984 and 1985, a seismic exploration program was conducted on the coastal plain of ANWR. A total of 200 km of seismic line arranged in an approximately 10 x 19 km grid was completed during the 2 year program (Fig. 2). The shothole technique, in which dynamite is detonated below the surface, was used for most of the 1984 program. The Vibroseis technique (registered trademark of Conoco), which utilizes a surface sound source of vibrating plates carried by track-mounted vehicles, was used along coastal tie lines in 1984 and for the entire 1985 program. Large tracked vehicles were used to carry drills, vibrators, recording equipment, dynamite, and geophones. The 2 seismic crews also used smaller, tracked-mounted vehicles (Bombardiers) for surveying and other activities. Strings of ski-mounted trailers pulled by tractors ("cat-trains") provided logistical support. Fuel and explosives were brought overland in ski-mounted magazines or tanks pulled by tractors. Other supplies and personnel were flown in by turbine Beaver or twin Otter aircraft landing on snow or ice near camps.

Forty-three muskoxen were radio-collared between April 1982 and April 1984 as part of a baseline study of muskox ecology on ANWR (Reynolds et al. 1983, 1984, 1985, and 1987). Radio-collared muskoxen were relocated using fixed-wing aircraft outfitted with wing-mount "H" antennas and a scanner-receiver (Telonics, Mesa, Az). From January to May when seismic crews were operating on the coastal plain, radio-collared muskoxen were relocated 11 times in 1984 and 5 times in 1985 Miscellaneous observation of muskoxen were also obtained during other overflights of the coastal plain. U.S. Fish and Wildlife Service (USFWS) field monitors traveling with the seismic crews recorded observations of muskoxen seen near seismic exploration activities. Behavior, responses to activities, and winter habitat use were summarized on field form sheets by monitors. All locations were plotted on USGS quad maps at 63,360 scale.

Following the completion of the winter seismic exploration activities, the location of seismic lines, associated trails and dates of activity were summarized on 63,360 scale maps, using data obtained by seismic crew monitors. Observations of muskoxen between January and May were also mapped. Movements by groups containing marked individuals were delineated. Daily movements were calculated by measuring the linear distance (in km) between 2 consecutive sightings which occurred more than 5 days apart and dividing this distance by the number of days between 2 sightings. Daily movements of a satellite-collared muskox in the Okerokovik area in 1985 were calculated from observations made at 1-3 day intervals. Dates of seismic exploration activity within a given area were estimated by camp location dates and monitor field notes. Movements based on muskox locations within a 5 km radius of a seismic line being shot or surveyed, a camp site location, or an active camp-move trail, were defined as movements which occurred during seismic exploration activities. Other movements were defined as taking place before or after exploration activities were present.

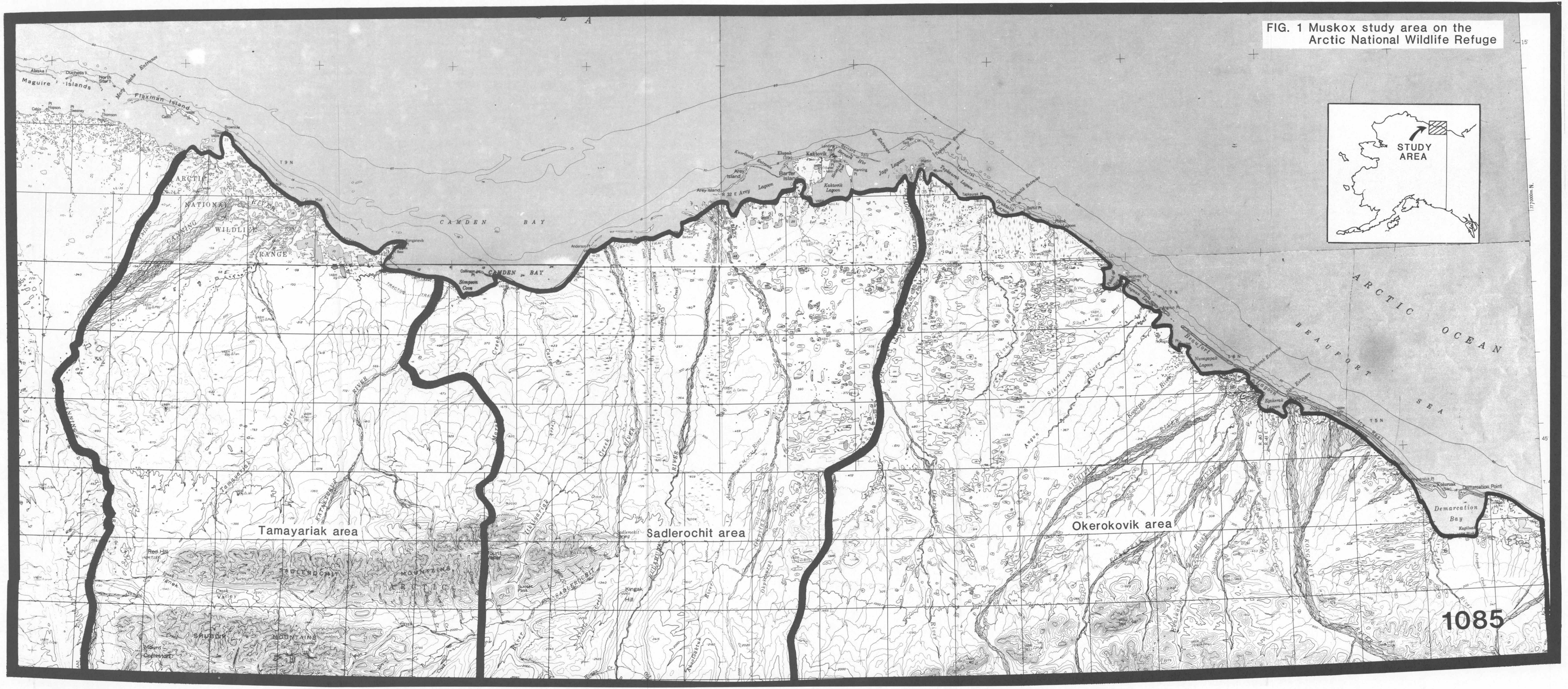
Results

Winter and spring (Jan-May) distribution of muskoxen in the ANWR study area, based on the relocations of radio-collared animals, was similar in 1984 and 1985 when seismic crews were present, and in 1982 and 1983 when seismic crews were absent (Fig. 2). All groups observed during the seismic exploration program were located in or near areas used by muskoxen from 1982 to 1985 (Reynolds et al. 1987).

Tamayariak Area

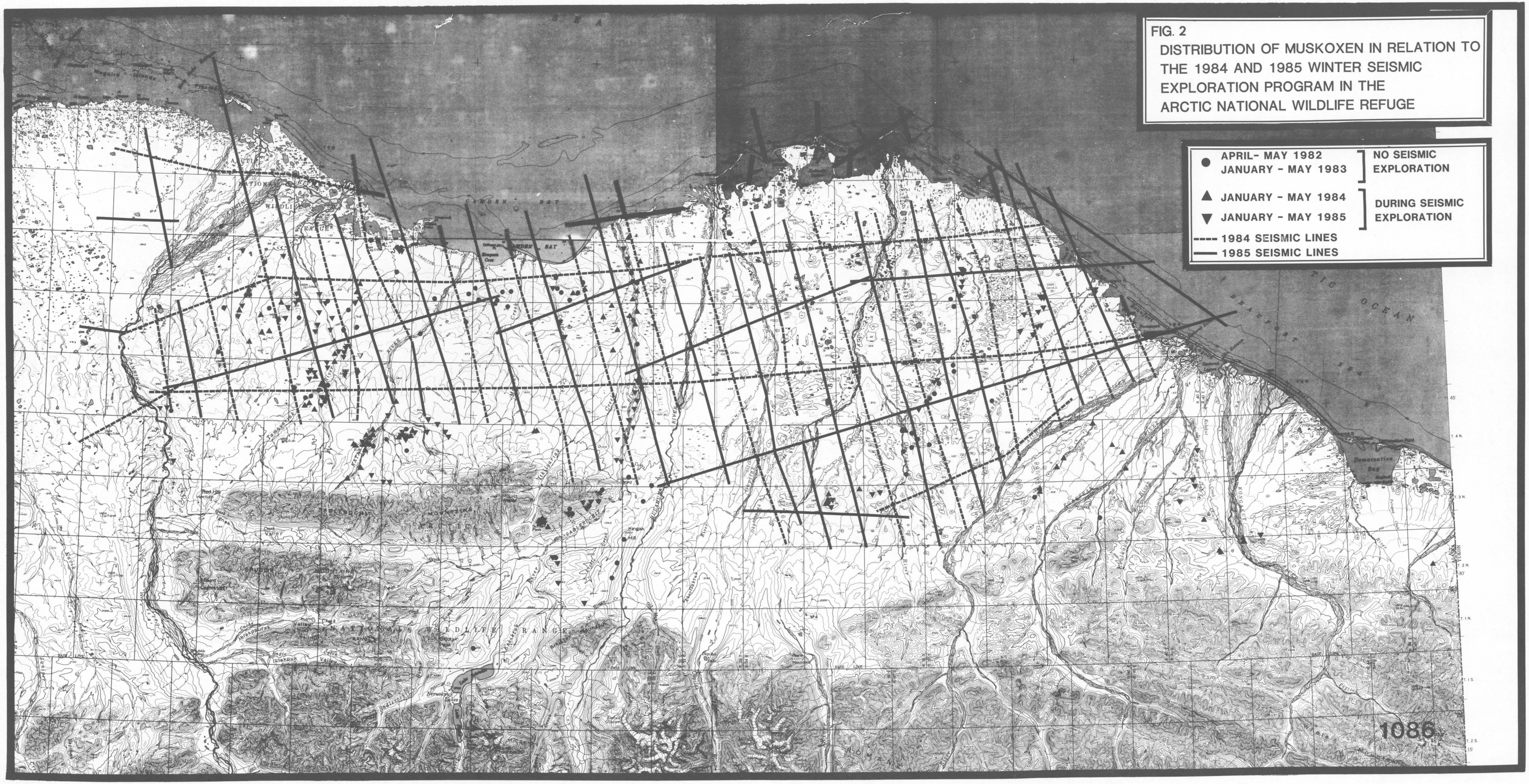
In the Tamayariak area, portions of 9 seismic lines traversed areas of high muskox use between the Canning and Katakturak Rivers (Fig. 2). At least 3-5 mixed-sex groups were present in this area when seismic exploration was being conducted from January through April 1984 and 1985. In 1984, 1 group of 9 muskoxen was seen in an area about 1 km west of a trail and 4 km north of a seismic line. On 25 January a seismic vehicle traveled within 1 km of the animals, which responded by grouping and running about 1.6 km. Between 25 January and 12 February this group moved 18 km west, crossing portions of 2 seismic lines along which vehicles had been present from 1-8 and 14-19 February. The group may have encountered seismic vehicles before or during either one of these movements. By 19 February this group had joined a second group of 9 muskoxen which had also moved west across one of the same seismic lines between 25 January and 12 February, before the line was shot on 14-16 February. A third group of 15 muskoxen moved northwest and joined these groups by 19 February. On 28 February, this group, now containing 39 muskoxen, was located within 1.5 km of a cat train camp near a seismic line. The group moved 10 km between 28 February and 6 March in approximately the same direction of travel as vehicles moving along the seismic line, but diverging from it by a distance of 1 to 9 km. Muskox mixed-sex groups

FIG. 1 Muskox study area on the Arctic National Wildlife Refuge



1085

FIG. 2
DISTRIBUTION OF MUSKOXEN IN RELATION TO THE 1984 AND 1985 WINTER SEISMIC EXPLORATION PROGRAM IN THE ARCTIC NATIONAL WILDLIFE REFUGE



remained on the main fork of the Tamayariak River when seismic trains were working in the area from 11-15 February, 29 February, and 2 March. Because of the topography of the area, these muskoxen were out sight of the seismic crews, with one exception. On 13 February, at least 40 muskoxen were observed about 1 km from a seismic line, along which crews were working. This group moved 6 km to the southwest by 19 February.

In 1985, 1 group of 16-20 muskoxen may have encountered seismic vehicles on the upper Tamayariak River in mid-April. This group remained within a relatively small area from January until late April and did not leave this area when seismic crews were working about 4 km away. A group of 5 muskox also did not leave the middle Tamayariak River when seismic crews were working on lines 3.5 to 5.0 km from this group in January and April. A group of 53 muskoxen observed by seismic crews in early April, moved 3.5 km from where they had been observed 3 days earlier. The group formed a tight aggregation when approached by surveyers in Bombardiers within 1.5 km.

Further east in the upper Katakturuk drainage between the Nularvik and Katakuruk Rivers, 2 mixed-sex groups and several bulls were observed from January through April in 1984 and 1985. In both years 1 seismic line ended in this area. Bombardiers encountered 1 group of 25 muskoxen on 6 February, 1984 at a distance of 3.0 km. The animals ran into a group and ran at least 1.0 km out of sight. When relocated on 12 February, they were 2.0 km to the southwest of the area in which they were observed before and after seismic exploration activities were present. In 1985, 1 muskox group which included at least some of these same animals, remained on the same ridge before, during and after seismic crews were working within 3 km.

Mean movements of radio-collared muskoxen did not differ (1984: $t=0.69$, $df=24$, $p=0.50$; 1985: $t=1.14$, $df=7$, $p=0.30$) during times when seismic activities were present and absent in the Tamayariak area (Table 1).

Table 1. Movements of radio-collared muskoxen when seismic survey crews were present and absent in the Tamayariak area, January-April 1984 and 1985.

Seismic survey activity	Mean no. days between sightings	Distance moved (km/day) N	Mean	SD	Range
1984					
Crews absent	13.0 ± 3.8 SF	15	0.5	0.7	0.0 - 2.2
Crews present	11.3 ± 4.5 SD	11	0.6	0.5	0.9 - 1.7
1985					
Crews absent	31.4 ± 5.8 SD	7	0.2	0.1	0.0 - 0.4
Crews present	24.0 ± 0.0 SD	2	0.1	0.0	---

Behavior of muskoxen in response to seismic vehicles was observed by USFWS seismic field monitors 3 times in the Tamayariak area in 1984 and 3 times in 1985 (Table 2). In 1984, a group of 32-40 animals did not respond to a Bombardier about 800 m away during 3.5 h of observation. A moving Bombardier at the same distance caused the animals to look up from where they were resting. When a Bombardier approached within 200 m, the animals ran into a group and faced the vehicle. The animals then ran to the southwest and out of view approximately 1 km away. When radio-collared animals were relocated from the air 6 days later the group had moved a total of 6.5 km in the same direction. A group of 28 muskoxen did not respond to the presence of a Bombardier parked 300 m away for 45 min. When the vehicle approached within 100m, the animals ran together into a group and ran east from the disturbance. When radio-collared animals were relocated from the air the following day, the group had apparently moved 4.5 km southwest. A group of 25 muskoxen ran at least 1 km southwest when Bombardiers were operating about 3.0 km northeast of them. In 1985, a group of 11 muskox formed a loose aggregation when a Bombardier was 3 km distance. Groups of 15 and 30 formed tight aggregations when a Bombardier approached to within 1 to 1.5 km.

Table 2. Behavioral responses of muskoxen to activities associated with seismic surveys in the Tamayariak area, February-March 1984 and April 1985

		Number of herds responding in each category					
Type of disturbance	Distance from herd (km)	Group and run	Group and stand	Form loose group or walk away	Look up or rise	None seen	Total
Bombardier parked	0.3					1	1
	0.8					2	2
Bombardier moving	0.1-0.3	2	1			1	4
	0.8	1			1		2
	2.8-3.2	1	1	1			3
Beaver aircraft							
landing	4.8				1		1
departing	4.8					1	1
Total		4	2	1	2	5	14

Sadlerochit Area

In the Sadlerochit area, portions of 8 seismic lines crossed areas of high muskox use (Fig. 2). In 1984, 1 east-west line crossed the Carter Creek hills where muskoxen calved in 1982 and 1983 (Reynolds et al. 1984) and continued across the lower Sadlerochit River. Work along this portion of the line occurred on 19-23 February 1984, when muskoxen were located at least 18 km south on the mid-Sadlerochit River. A portion of an east-west line crossing the middle Sadlerochit River was shot on 10-13 April 1984, after the animals had moved to Carter Creek hills in early March. A line which paralleled the lower Sadlerochit River within 1.5 km was also shot in late April when the muskoxen were in Carter Creek hills. In 1985, lines crossing or running parallel to the Sadlerochit River were shot in late January and early February and early March. Seismic trains intentionally avoided the Carter Creek hills from mid-April to mid-May during the muskox calving season.

Muskox mixed-sex groups moved from the Sadlerochit River to Carter Creek hills prior to calving in 1982, 1983, 1984 and 1985 (Reynolds et al. 1985, 1987). In 1984 and 1985 this movement occurred in early March, at least 1 month before similar movements were seen in 1982 and 1983. By late March 1985, 3 different mixed-sex groups had converged in Carter Hills, forming a large group of over 100 muskox. No seismic trains were present in the area during the time the animals moved, but some of these animals were hunted by people on snow machines on 6 March 1984 and 6 March 1985.

In 1984, muskoxen may have encountered seismic activities near the Carter Creek hills in late April. On 23 April work on a line was within 4.0 km of a group of 95 muskoxen. Between 11-23 April, the animals moved to the creek bottom from the hills where they had been since 19 March. During the following 2 weeks they continued to travel along Carter Creek after splitting into 2 different groups. In 1985, 1 group of muskoxen was seen by seismic crew monitors prior to moving to the Carter Hills.

During both years, one old cow (#14j) left the mixed-sex group prior to or during the movement to Carter Hills. In 1984, this animal traveled at least 25 km southwest to the ridges above Arctic Creek in the upper Sadlerochit drainage. In 1985, this same cow, accompanied by a 3 year old cow, moved to hills above upper Carter Creek, where it died, apparently of old age, later in the spring.

No observed encounters with muskox in the Sadlerochit River were documented in 1984. In 1985, movements of marked animals made when seismic crews were present were not different ($t=-0.18$, $df=6$, $p > 0.05$) from movements made when seismic crews were absent (Table 3).

Table 3. Movements of radio-collared muskoxen when seismic crews were present and absent in the Sadlerochit area in 1985.

Seismic survey activity	Mean no. days between sightings	Distance moved (km/day) N	Mean	SD	Range
Seismic crews absent	19.0 ± 12.9 SD	4	0.5	0.6	0.1 - 1.4
Seismic crews present	21.3 ± 10.8 SD	4	0.4	0.1	0.3 - 0.5

In the Sadlerochit area, no observations were made of muskoxen responding to vehicles associated with seismic surveys in 1984, but in 1985, monitors recorded responses of muskoxen to Bombardiers and hunters on snow machines (Table 4).

Table 4. Behavioral responses of muskoxen to vehicle in the Sadlerochit area, February and March 1985.

		Number of herds responding in each category		
Type of disturbance	Distance from herd (km)	Group and run	Group and stand	Form loose aggregation
Moving	2.4	1		
Bombardier	1.6		3	1
Hunters on	1.0		1	1
snowmachines	0.5	2		

Okerokovik Area

In the Okerokovik area, portions of 11 seismic lines crossed areas of high muskox use (Fig. 2). In 1984, seismic lines traversing areas used concurrently by muskoxen were shot in late March. Muskox groups observed in January remained in a small area along the Sikrelurak and Angun Rivers from mid-February until late April. These animals were present prior to the arrival of seismic trains in early March and did not leave the area until after the vehicles had left. No major movements of groups containing radio-collared animals occurred during the time when seismic trains were operating in the area.

In January 1984, the lower Niguanak River was used by mixed-sex groups prior to the arrival of seismic trains. One group of 14 moved southwest along the river in February and March and may have encountered seismic vehicles on or near Okerokovik River in late March. On 27-28 March when a seismic crew was in the area, groups of 10 and 2 were seen on hills southwest of the Okerokovik River about 7 km southwest of areas in which they were normally seen. A radio-collared cow and 3-year old cow apparently left a large mixed-sex group and moved 7 km further west to Pilak bluffs. These movements may have been the result of animals being disturbed by seismic vehicles or normal movements into wintering areas.

In 1985, movements of a large mixed-sex group were followed throughout the winter with the use of satellite telemetry. One cow in this group carried an experimental satellite collar (Reynolds 1987). The animals were present on the Okerokorik River from mid December 1984 until at least early February 1985. Seismic crews working in this area in early February observed a group of 15 muskoxen on 9 February. Between 9 February and 1 March, this group which included the satellite-collared muskox moved 11 km southwest to a ridge. This movement may have been in response to the presence of seismic crews near the muskoxen on 9 February or may have been a normal movement into a wintering area. The animals eventually moved further west to Pilak bluffs, where they remained until late May.

In 1984, in the Okerokovik area, distances moved by radio-collared muskoxen when seismic crews were present were slightly greater (t=1.93, df=16, p=0.03) than movements made when seismic activities were absent (Table 5). The maximum movement observed occurred when a group traveled the Niguanak River to hills southwest of the Okerokovik River on 19-27 March 1984. Although seismic vehicles were in the area on 27 March 1984, it is not known if the group encountered and/or was disturbed by the activity. In 1985, movements of a satellite-collared cow muskox were not different (t=0.65, df=24, P > 0.50) when seismic crews were present and absent.

Table 5. Movements of radio-collared or satellite-collared muskoxen when seismic survey crews were present and absent in the Okerokovik area, January- May 1984 and 1985.

Seismic survey activities	Mean no. days between sightings	Distance moved (km/day) N	Mean	SD	Range
1984					
Crews absent	14.9 ± 5.2 SD	16	0.4	0.4	0.0 - 1.3
Crews present	13.5 ± 2.1 SD	2	1.0	1.0	0.3 - 1.8
1985					
Crews absent	1.5 ± 0.7 SD	13	1.5	1.0	0.3 - 3.1
Crews present	1.8 ± 1.0 SD	4	1.3	1.3	0.2 - 3.2

Response of muskox mixed-sex groups near seismic vehicles in the Okerokovik area were recorded by USFWS seismic field monitors in 1984 and 1985 (Table 6). In 1984, 1 group was observed for 3 consecutive days. This group ran from 3 Bombardiers which approached within 0.4 km. Within 24 h, the group moved 3.0 km. On 17 March, 4 of 17 animals in this group ran into a defense formation once during 40 min of observation. Some individuals formed loose aggregations as 4 Bombardiers traveled along a seismic line 2 to 4 km away. A lone bull ran toward this group when 4 Bombardiers approached within 0.8 km. More than 9 h later this group was observed in the same location and showed similar behavior when 1 Bombardier and 6 drill trucks were within 2.0 to 3.0 km. On 18 March, the group, which had moved less than 1 km in 24 h, grouped together in a loose formation as 7 drill trucks traveled along the seismic line 3.6 km to the west. On 19 March, the group was relocated from the air and had moved about 2.0 km closer to the seismic line.

From 15-16 March 1984, part of another mixed-sex group moved together into a loose aggregation as single vehicles passed within 2.0 to 3.0 km. Other individuals in the group showed no change in behavior. Animals were seen again in the same location about 3 h later while seismic recording was taking place. Although detailed response to the activity was not noted, the animals remained in the area. The muskoxen moved about 1.0 km between March 15 and 16 1984. On 24 March, an unmarked group of 4 showed no response to a Bombardier 4.0 km away, but ran when 5 trucks were within 3.2 km of them. Two muskoxen did not change their behavior as 3 vehicles were operating 3.0 km from them on March 27. Similarily, mixed-sex group of 10 showed little response to a Bombardier at 1.2 - 2.4 km.

Table 6. Behavioral responses of muskox herds to seismic vehicles in the Okerokovik area, March 1984 and February 1985.

		Number of herds responding in each category					
Type of disturbance	Distance from herd (km)	Group and run	Group and stand	Form loose group or walk away	lookup or rise	None seen	Total
Bombardier parked	1.0			1[a]			1
	1.6			1			1
Bombardier moving	1.0		1				1
	1.6			1[a]	1	2	4
	2.4			1	1		2
	3.0			1		2	3
2-4 vehicles moving	1.0	2		1			3
	1.6	1[b]		1			2
	2.4			2[a]			2
	3.0		1	1[a]		2	4
5-8 vehicles moving	3.0	1		1			2
Total		4	2	11	2	6	25

[a] more than 70% of herd responding.
[b] less than 30% of herd responding.

In 1985, responses to moving bombardiers ranged from no response by a herd of 15 when vehicles were 1.6 km to 4.8 km distant to a herd of 8 grouping together when a vehicles approached to within 900 m.

Discussion

In 1984 and 1985, general distribution of muskoxen was similar before, during and after seismic survey were completed and did not differ from winter-spring distributions in 1982 and 1983. Muskoxen apparently were not displaced from areas of traditional use during geophysical surveys. All muskoxen observed were within or near use areas documented in 1982-1985.

Information from movements of radio-collared animals also showed that muskoxen did not move long distances in response to seismic surveys. Observed movements possibly caused by a negative response to the presence of seismic vehicles did not exceed 5.0 km. In undisturbed conditions muskoxen often remain in a small area for several days or weeks before moving to a different area (Reynolds 1987). Daily rates of movements of a satellite-collared cow in January-April 1985, calculated from all observations at least 16 h apart, ranged from 0.0 km/day to 3.4 km/day with a mean of 1.3 $\pm$ 1.0 km/day (N = 29). Daily rates of movement for the entire year ranged from 0.0 km/day to 20.0 km/day. Any movements caused by the presence of seismic activities probably did not greatly exceed the range of daily movements which occur in undisturbed conditions.

Ground observations of muskoxen near seismic vehicles suggest that variability in response to disturbance existed. For example, 2 groups did not respond by running into groups and facing the disturbance or running from the disturbance until they were approached within 100 to 300 m. Two other groups ran when vehicles were at least 2.8 away.

Muskox herds encountered seismic crews infrequently in 1984 and 1985. Although the seismic program covered several areas of high muskox use, activities were present within each area for only a few days. Even if disruptions in normal movements and activity patterns occurred, effects on the population were probably not substantial, because of the transitory nature of the program. Productivity, determined by the number of calves born to cows older then three years, was 0.75 calves per cow in 1984 and 1985 compared with 0.66 calves per cow in 1983 (Reynolds et al. 1987).

Results of this study were similar to studies documenting the effects of seismic exploration on muskoxen in Canada which found that animals responded to vehicles by forming defensive groups and running, or gradually moving away from the vicinity of a seismic line (Urquahart 1973, Beak Consultants Ltd. 1976, Russell 1977, Jingfors and Lassen 1984). Movements away from lines were apparently of relatively short duration and herd or population size did not appear to be affected.

Acknowledgements

N. Felix, P. Miller, and K. Moitoret provided winter observations of muskoxen and behavioral information on animals' response to seismic vehicles. C. Curby prepared computer maps and graphics. K. Davis, J. Stoddard, and S. Brown typed the manuscript. G. Garner provided guidance in study design, data analysis and editorial review.

Literature Cited

Beak Consultants Limited. 1976. A study of the influence of seismic exploration on muskoxen and caribou on Banks Islands, N.W.T. Panarctic oils Limited, Calgary, Alberta. 67pp.

Jingfors, K.T., and P. Lassen. 1984. Muskox responses to a seismic test operation:preliminary observations. Page 127 in D.R. Klein, R.G. White and S. Keller, eds. Biol. Pop. Univ. Alaska Spec. Rep. No. 4., Fairbanks, AK. 218pp. (Abstract only).

Reynolds, P.E. 1987. Movements and activity patterns of a satellite-collared muskoxen in the Arctic National Wildlife Refuge, 1984-1985. in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the Fish and Wildlife and their habitats. U.S. Fish and Wildl. Ser., Anchorage, Ak. pp.

Reynolds, P.E., L.D. Martin, and G.J. Weiler. 1983. Population size, productivity and distribution of muskoxen in the Arctic National Wildlife Refuge, Alaska. Pages 248-274 in G.W. Garner and P.E. Reynolds, eds. 1982 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, Ak. 379pp.

Reynolds, P.E., L.D. Martin, T.J. Wilmers, and T.J. Doyle. 1984. Population dynamics and distribution of muskoxen in the Arctic National Wildlife Refuge, Alaska. Pages 293-329 in G.W. Garner and P.E. Reynolds, eds. 1983 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, Ak. 614pp.

Reynolds, P.E., L.D. Martin, G.J. Weiler, J.M. Noll, and J.M. Morton. 1985. Population and herd dynamics, distribution, movements, and habitat use of muskoxen in the Arctic National Wildlife Refuge, Alaska, 1982-1984. Pages 42-95 in G.W. Garner and P.E. Reynolds, eds. 1984 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, Ak. 777 pp.

Reynolds, P.E., J.A. Herriges, and M.A. Masteller. 1987. Ecology of muskoxen in the Arctic National Wildlife Refuge, 1982-1985. in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak.

Russell, J. 1977. Some overt responses of muskoxen and caribou to seismic activities, northeastern Banks Island. Unpubl. rep. Canadian Fish and Wildlife Service. Yellowknife, Northwest Territories. 85pp.

Urquart, D.R. 1973. The effects of oil exploration activities on the caribou, muskoxen and arctic foxes on Banks Island N.W.T. Unpub. rep. Northwest Territories Game Management division. 147pp.

U.S. Fish and Wildlife Service. 1982. Arctic National Wildlife Refuge coastal plain resource assessment - initial report. Baseline Study by the fish, Wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, Ak. 507pp.

ANWR Progress Report No. FY 86-5-Impacts

RESPONSES OF MUSKOX GROUPS TO AIRCRAFT OVERFLIGHTS IN THE ARCTIC NATIONAL WILDLIFE REFUGE 1982-1985

Patricia E. Reynolds

Key words:muskoxen, disturbance, fixed-wing aircraft, helicopter, response, season, above ground altitude, sex, habituation, Arctic National Wildlife Refuge

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

December 1986

Responses of muskox groups to aircraft overflights in the Arctic National Wildlife Refuge, 1982-1985.

Patricia E. Reynolds, U.S. Fish and Wildlife Service, Arctic National Wildlife Refuge, Fairbanks, Alaska.

Abstract: Responses of muskox groups (Ovibos moschatus) to overflights of small single engine fixed-wing aircraft and helicopters were recorded during radio relocation flights, spring and fall population surveys, and summer composition counts. Responses were defined as: run, group, partial group, alert, and none observable. A total of 1744 responses to fixed-wing overflights and 187 responses to helicopter overflights were recorded. Muskoxen ran and grouped more frequently in response to helicopter overflights than fixed-wing overflights. Bulls grouped less frequently than did mixed-sex herds in response to fixed-wing aircraft. Groups were less responsive to fixed-wing overflights during summer and fall (late June to early November) than winter and calving (mid-November through mid-June) and showed less response as aircraft flight altitude increased. Similar results were seen during ground observation of 3 muskox herds. The percentage of mixed-sex groups showing no response to fixed-wing overflights, increased between 1982 and 1985.

Responses of muskox groups to aircraft overflights in the Arctic National Wildlife Refuge, 1982-1985.

Muskoxen (Ovibos moschatus) are year-round residents of the coastal plain of the Arctic National Wildlife Refuge (ANWR) and are vulnerable to impacts resulting from petroleum exploration or development activities which may occur in winter as well as summer. Continued exploration and development of the ANWR coastal plain will result in high levels of aircraft traffic in areas of construction and development as equipment and supplies must be brought into this remote roadless region by air. Aircraft overflights are a source of potential disturbance to muskoxen. Miller and Gunn (1979) recorded overt behavioral responses by muskoxen during helicopter overflights simulating aircraft activity associated with construction of an arctic gas pipeline. Gray (1974) reported responses of muskoxen to isolated aircraft overflights. Jingfors and Lassen (1984) observed responses of muskoxen to overflights during summer seismic activities in northeast Greenland. Lent (1974) speculated that muskox calves may be trampled if animals ran in response to aircraft overflights.

The objectives of this study were:

1. Determine the response of muskox groups on the ANWR coastal plain to overflights of small single engine fixed-wing aircraft and helicopters during radio relocation, survey flights, and capture.

2. Determine the relationship between muskox responses to aircraft overflights and type of aircraft, altitude above animals, season of the year, and type of group.

METHODS

The study area is in northeast Alaska on the coastal plain of the ANWR between the Canning River and the Aichilik River (U.S. Fish and Wildlife Service 1982). The majority of observations of muskoxen were made within this area, although a few observations were recorded west of the Canning River along the Kavik River, and east of the study area, from the Aichilik River to the Canadian border and along a few rivers in Canada.

During this study, the seasons were defined as: 1. Winter (mid-November to early March), 2. Precalving (mid-March to mid-April), 3. Calving (late April to mid-June), 4. Summer (late June through July), 5. Rut (August to mid-September), and 6. Fall (late September to early November).

For purposes of analysis, a "group" was defined as 1 or more muskoxen associated during the period of the observation. Mixed-sex groups contained bulls, cows, and calves. Groups containing only cows and calves were included in this mixed-sex group category. Bull groups were comprised of 1 or more bulls older than 2 years of age.

From 1982-1985, 45 muskoxen were captured and radio-collared as part of an ecological study of muskoxen on the ANWR coastal plain (Reynolds et al. 1983, 1984, 1985, 1987). Animals were relocated every 2-3 weeks during summer and about once a month during winter. Spring and fall population surveys were conducted each year using the small fixed-wing aircraft. Muskox groups were overflown with helicopters during summer composition counts, and during tagging operations, which occurred primarily in late March and early April. During these aircraft overflights, responses of the groups to the aircraft, horizontal distance from the group, above ground elevation, type of aircraft, type and size of group, and type of aircraft were recorded.

Above ground elevation (AGL) was estimated by subtracting the elevation of the animals' location from the aircraft altimeter reading obtained during the time of the overpass. Horizontal distance from the animals was estimated from the air at intervals of 200 m. Aircraft type was either fixed-wing or helicopter. Fixed-wing aircraft were all small single-engine airplanes ranging in size from a Supercub to a DeHaviland Beaver. Cessna 185 and 207 were the most commonly used aircraft in radio-relocation flights. Helicopters used for tagging and composition counts were single rotor craft, primarily Bell 206 Jet Rangers.

Reactions to aircraft were categorized as: 1) run (animals grouped into a defensive formation, then ran in a group; single animals ran), 2) group (animals grouped into a defensive formation, but did not run), 3) partial group (animals moved toward one another forming a loose aggregation), 4) alert (animals lifted heads and/or stood up, if lying down, 5) none (no observable response). Although the absence of an observable response does not preclude disturbance to an animal from physiological stress (e.g. increased heart and/or respiration rate) this type of response is energetically less draining to animals than running into groups or running from disturbances.

In addition to aerial observations during aircraft overflights, responses to aircraft were recorded during ground observations of 3 different mixed-sex muskox groups during the summers of 1984 and 1985. Prior behavior, local environmental conditions, and behavior after departure of the aircraft were all recorded during ground observations in addition to type of response, estimated vertical and horizontal distance and type of aircraft.

Statistical analysis was done using CROSSTAB and REGRESSION procedures (SCSS Conversational System, Nie et al. 1980).

Results and Discussion

Aerial Observations

A total of 1931 observed responses of muskox groups or solitary to aircraft overflights were recorded between 1982 and 1985. Of these, 1744 were fixed-wing overflights and 187 were helicopter overflights.

Muskoxen responded differently to helicopter overflights than to fixed-wing overflights ($P < 0.01$, $x^2 = 250.9$) (Fig. 1). Over 36% of all helicopter overflights resulted in animals running, compared to 5% of all fixed-wing overflights. Animals showed no observable response to 49% of fixed-wing overflights compared to 24% of helicopter overflights. Helicopter overflights

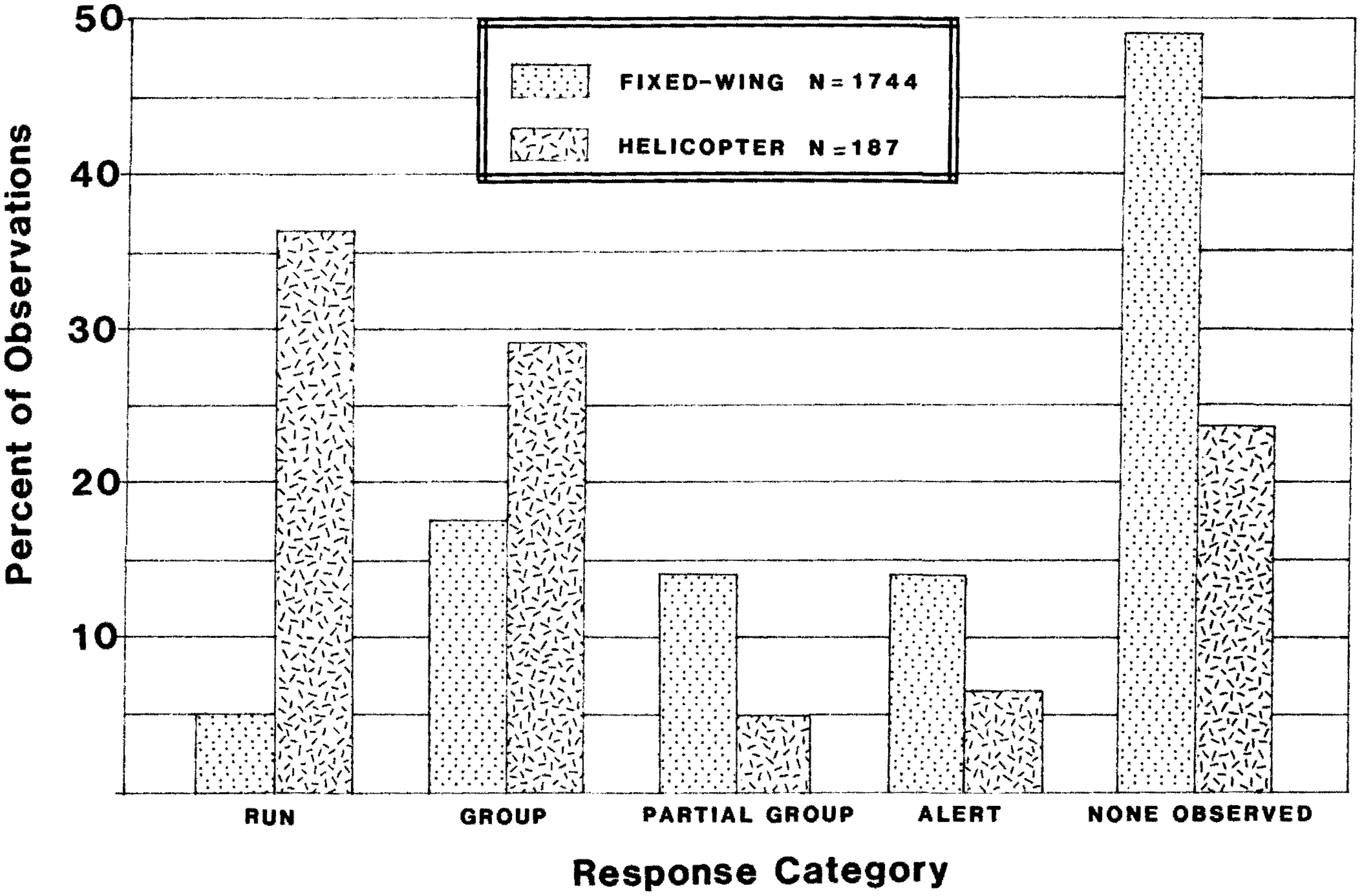


Fig. 1. Responses of muskox groups to fixed-wing and helicopter overflights in the Arctic National Wildlife Refuge, Alaska, 1982-1985.

were closer to the ground than fixed-wing flights. Mean helicopter flight elevation was 82 m. By contrast, mean elevation of 1653 fixed-wing overflights was 332 m AGL and 46% of these flights were 300-600 m. But at helicopter overflights of altitudes of 300-600 m, 63% of 16 muskox groups ran or grouped up compared to 17% of 768 groups overflown with fixed-wing aircraft at the same altitudes. This suggests that helicopters caused a more intensive response than fixed-wing aircraft.

Bull groups (including single bulls) showed different ($P < 0.01$, $x^2 = 50.1$, 4df) response patterns to fixed-wing overflights than did mixed-sex groups (Fig. 2). Bulls moved into defensive formations less frequently and showed no observable response more frequently than did mixed-sex groups. Single bulls rarely ran. A commonly observed response of bulls to fixed-wing overflights was for bulls to approach one another, and then turn and hit heads. This behavior may be the result of 2 conflicting drives: the drive which causes the animals to group into the defensive formation, a distinctive feature of this species' behavioral repertoire (Gray 1973, 1984), and the drive which results in the spectacular fights observed between bulls during the rut (Smith 1976). Prior to and during the rut, bulls may have threshold distances at which they respond by agonistic displays, including head clashing (Smith 1976). As the bulls are disturbed by the approaching aircraft, they run toward one another as a prelude to grouping into a defensive formation, but as they approach one another, the critical distance at which agonistic behavior is elicited is met and the animals whirl and clash heads instead of forming or joining a group.

Miller and Gunn (1979), during their study of helicopter overflights, concluded that muskox cows and calves were usually more responsive than other sex/age classes and that solitary bulls and bull groups tended to be more responsive than individual bulls in mixed-sex groups.

Seasonal differences in group response to fixed-wing overflights were also apparent (Fig.3). Groups were less responsive during the summer, rut and fall period, then during the winter and calving when high percentages of the group response were seen. Winter may be a critical period in the annual cycle of the muskox. Activity and movements may be restricted in late winter as an energy-conserving strategy (Reynolds 1987).

Responses of muskox groups to fixed-wing aircraft varied with flight altitude (Fig. 4). At flight altitudes below 150 m, 39% of 257 groups ran or grouped and 22% showed no observable response. By contrast, 43% of 209 groups showed no observable response to fixed-wing aircraft at altitudes of 150-300 m and 63% of 768 groups showed no observable response to fixed-wing aircraft at elevations greater than 300-610 m. However, 31 of 154 groups responded by running or grouping during fixed-wing overflights at altitudes greater than 610 m suggesting that a certain percent of groups will response to aircraft overflights at even relatively high flight altitudes. Similar results were obtained when only mixed-sex groups in summer were used in the calculation. At flight altitudes below 150 m, 44% of 117 mixed-sex herds responded by running or grouping and 16% showed no response. At altitudes of 300 m or more, 70% of 407 mixed-sex herds showed no response.

Miller and Gunn (1979) found an inverse relationship between helicopter flight altitude and levels of muskox responses in July and August. Less than 45% of all individual response samples showed an observable response to helicopter

Fig. 2. Responses of bull groups and mixed-sex herds to fixed-wing aircraft overflights in the Arctic National Wildlife Refuge, Alaska, 1982-1985.

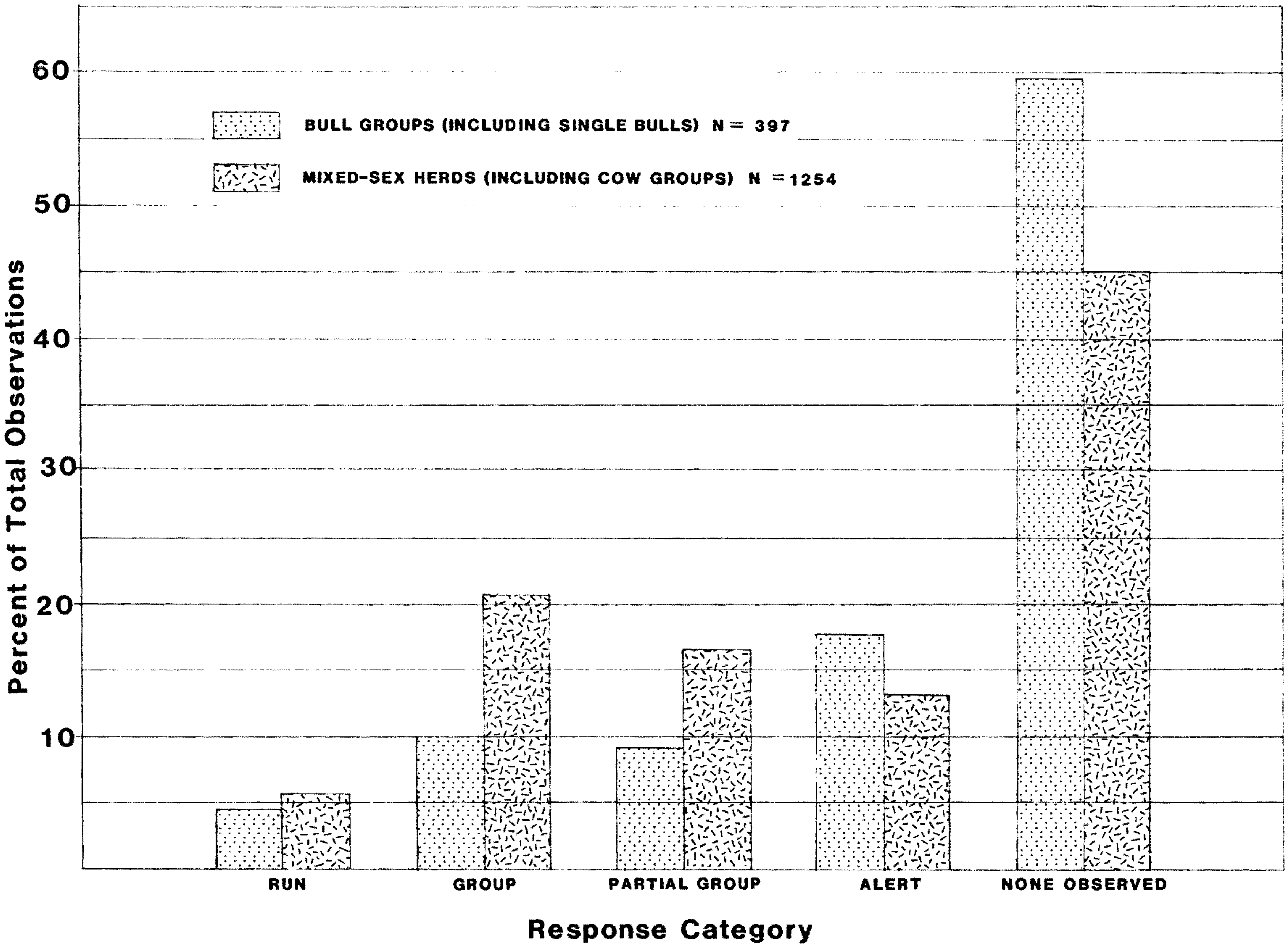


Fig. 3. Responses of muskox groups of fixed-wing aircraft overflights during different seasons of the year in the Arctic National Wildlife Refuge, Alaska, 1982-1985.

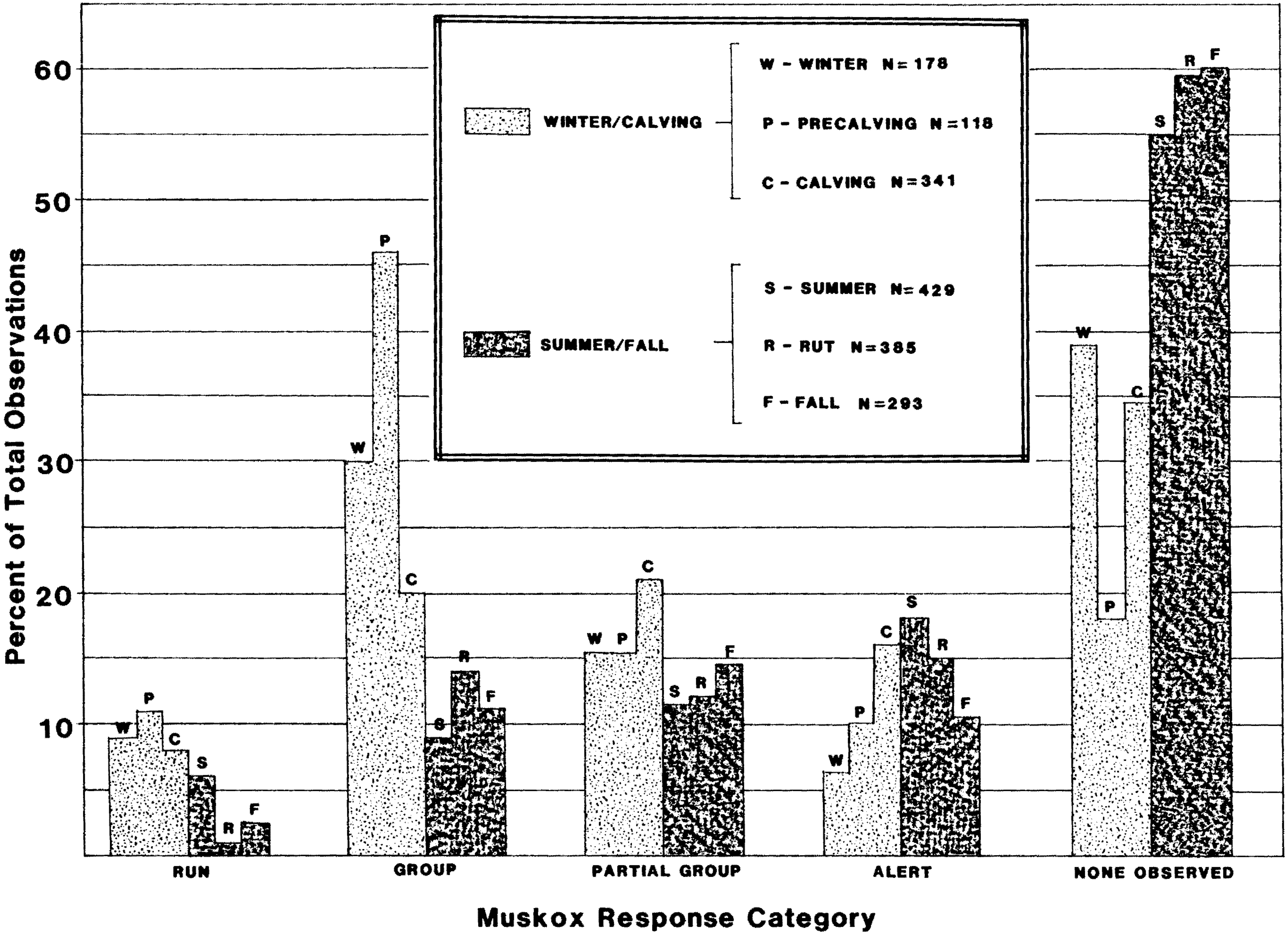
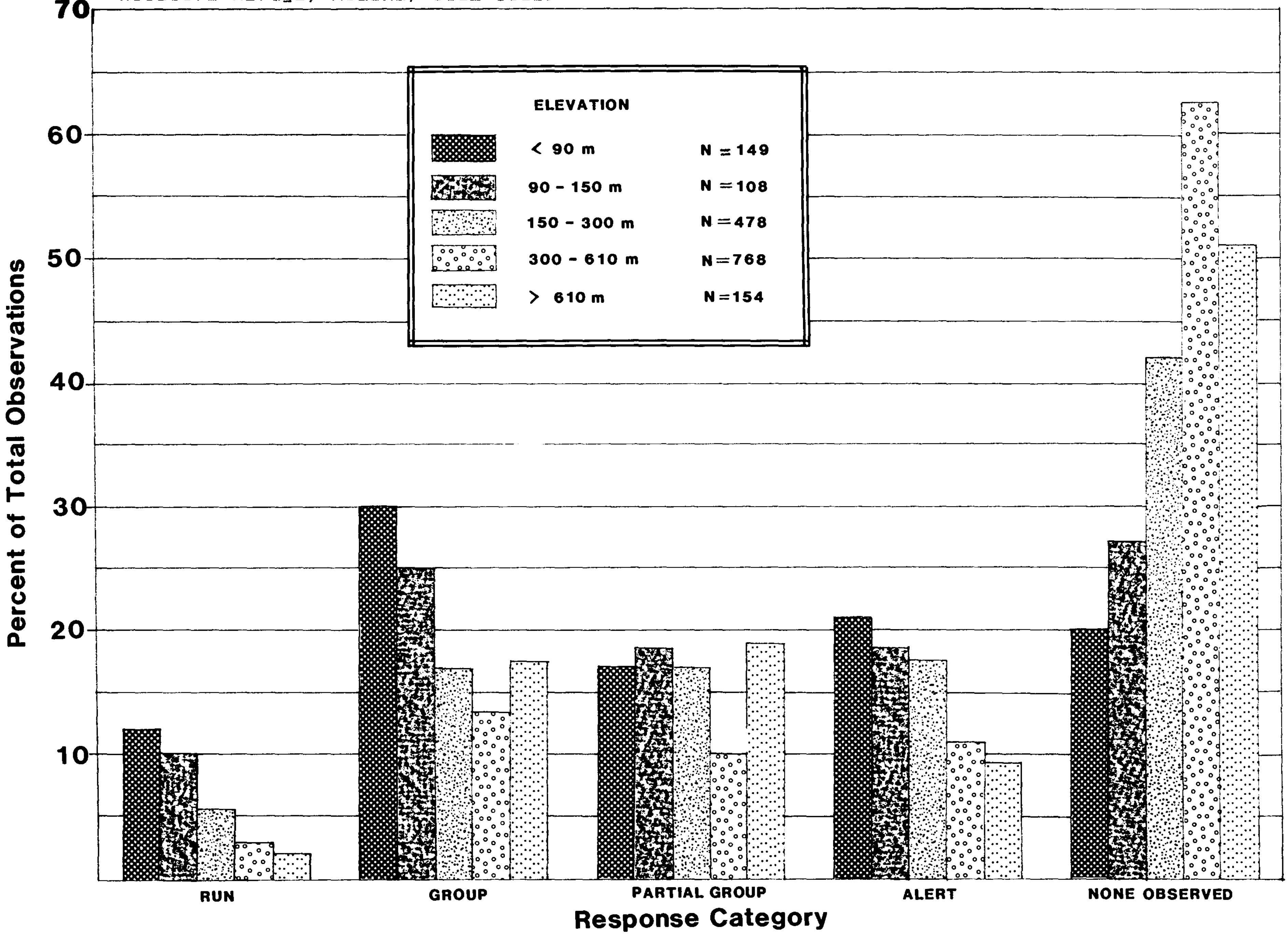


Fig. 4. Responses of muskox groups to fixed-wing aircraft overflights at different flight altitudes in the Arctic National Wildlife Refuge, Alaska, 1982-1985.



overflights. Of these, almost 70% ran into defensive formations when overflights were at 50-100 m AGL. At flight altitudes of 200-400 m, the percentage running into defensive formations declined to about 30%.

Responses of muskox groups in summer to fixed-wing aircraft apparently changed between 1982 and 1985 (Fig. 5). The percentage of groups showing no observable response was higher in 1984 and 1985 and percentages of groups running, grouping and becoming alert declined. Similar results were seen when only mixed-sex herds overflown at flight altitudes of 150-610 m in summer were used in the calculations. In 1982, 35% of 49 mixed-sex herds showed no response. This percentage increased to 75% of 99 observations in 1984 and to 82% of 296 observations in 1985. Small fixed-wing aircraft repeatedly flew over the same groups of animals during this 4 year period, and these results suggest that at least some animals habituated to the presence of these aircraft. Marler and Hamilton (1966) defined habituation as the process by which responsiveness to innocuous stimuli becomes temporarily or permanently eliminated. Miller and Gunn (1984) stated that habitation may have occurred during their study, but tolerances apparently varied among individuals or herds.

Jingfors and Lassen (1984) observed 11 overflights of helicopters during summer seismic activities in northeast Greenland. Two herds ran from the disturbance, 3 herds grouped into defensive formation, and 6 herds showed no response.

Ground Observations

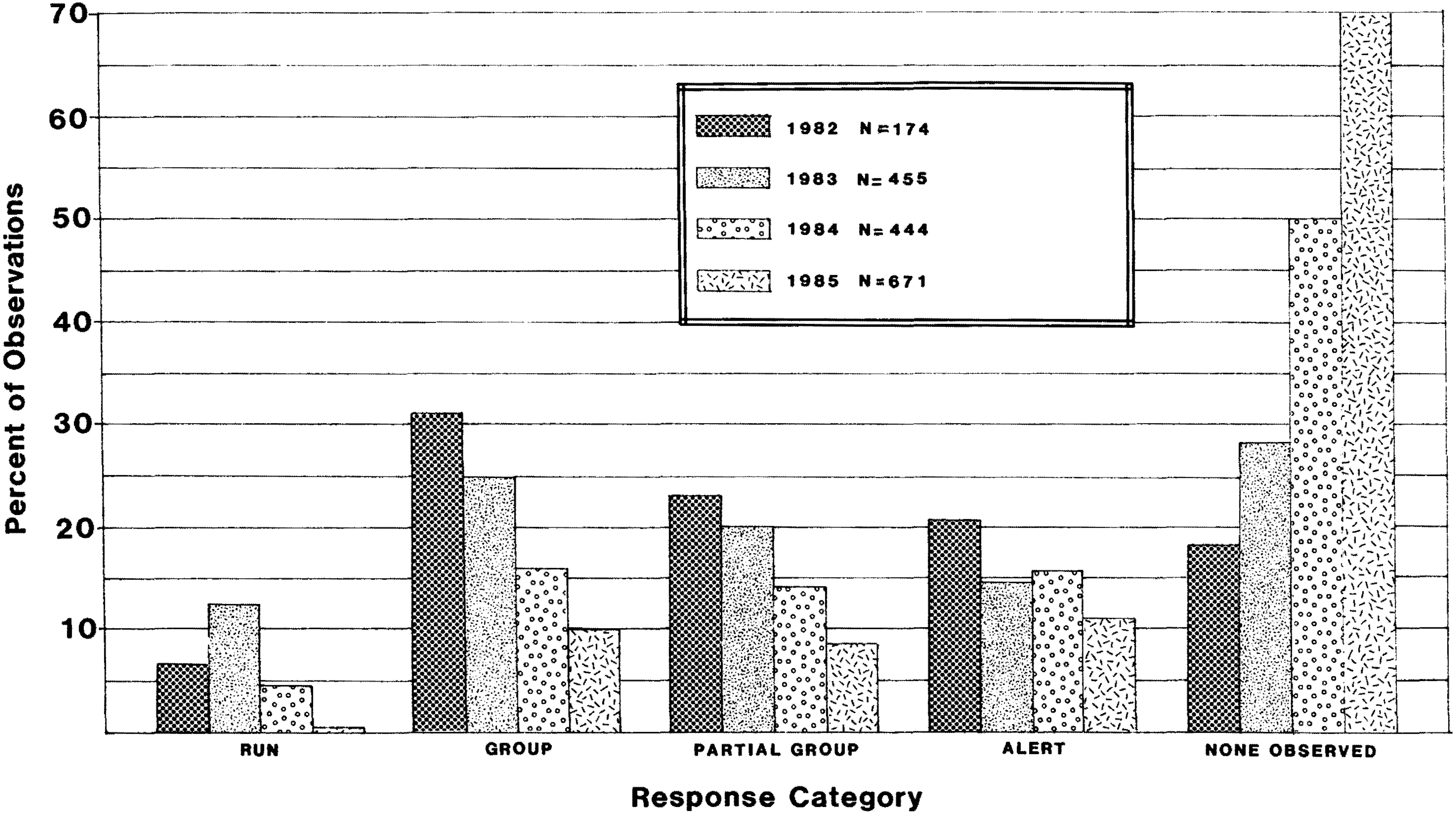
Responses of 3 mixed-sex muskox groups to aircraft overflights were similar during ground observations in July and August 1984 and 1985. A total of 16 observations of helicopter overflights, takeoffs or landings and 5 observations of fixed-wing overflights were recorded. Muskoxen showed no observable response in 12 of 21 observations (57%), including 1 helicopter landing within 800 m of the animals. Animals responded to helicopters by running on 3 occasions: twice when a helicopter landed or took off 400-800 m from the herd and once when a helicopter flew directly over the animals at 300 m AGL. No aircraft overflights resulted in animals running.

Muskox response of aircraft appeared to be dependent upon vertical and horizontal distance from the aircraft, although sample sizes in each category were very small (Table 1).

Table 1. Reaction of muskoxen to helicopter and fixed-wing aircraft during ground observations.

Response category	Type of aircraft	N	Aircraft altitude (m)			Distance from muskox (m)		
			Mean	SD	Range	Mean	+SD	Range
Run	Helicopter	3	100	173	0-300	400	400	0-800
Group	Helicopter	2	150	212	0-300	300	141	200-400
Partial group	Helicopter	4	150	106	0-300	550	191	400-800
	Fixed-wing	1			300			0
No response	Helicopter	7	271	125	0-400	234	2122	800-6400
	Fixed-wing	4	438	197	150-600	1000	1514	0-3200

Fig. 5. Responses of muskox groups to fix-wing aircraft overflights during different years in the Arctic National Wildlife Refuge, Alaska.



On 7 of 9 occasions when muskoxen reacted to aircraft overflights, animals returned to the same activity they had been engaged in prior to being disturbed. Twice muskoxen began feeding after reacting to an overflight by rising from rest and grouping into a defensive formation. Muskoxen returned to prior activities or began feeding within 10 min. of reacting to the aircraft overflight ($x = 6.9 \pm 3.4$ min., $N = 8$).

Discussion

Preliminary analysis of muskox group responses to small fixed-wing and single rotor helicopter overflights suggest that responses may be variable and apparently are dependent upon the type of aircraft, distance above the animals, season of the year and type of group. Some habituation to aircraft overflights may occur over time. Overflights during this study occurred at a maximum of a few times each week by small aircraft. Aircraft overflights during construction phases of exploration or development of petroleum resources on the coastal plain would probably occur many times each day and would include large multi-engine airplanes ranging from Twin Otters and Hercules to large jet aircraft.

Responses of muskoxen to high levels of multi-engine aircraft traffic are not known. Although some animals will probably habituate to almost any levels of aircraft traffic, other animals may move out of the immediate vicinity of areas of high activity. But displacement distances are not known. Muskoxen in the ANWR study area have shown a high fidelity to specific areas (Reynolds et al. 1987) which may decrease the likelihood of long distant displacement.

Acknowledgements

L. Martin, G. Weiler, J. Herriges, T. Wilmers, T. Doyle, J. Noll, J. Morton and M. Masteller all assisted in collection of data. S. Waln and L. Callender typed the manuscript and B. Swift drafted the figures. G. Garner provided guidance for study design, and analysis as well as editorial review.

Literature Cited

Gray, D.R. 1973. Social organization and behavior of muskoxen (Ovibos moschatus) on Bathurst Island, N.W.T. Ph.D. Thesis, Univ. Alberta, Edmonton. 212pp.

Gray, D.R. 1974. The defense formation of the musk-ox. The Musk-ox 14:25-29.

Gray, D.R. 1984. Dominance fighting in muskoxen of different social status. Pages 118-122 in D.R. Klein, R.G. White, and S. Keller, eds. Proc. First Int. Muskox Symp. Biol. Pap. Univer. Alaska Spec. Rep. No. 4. Fairbanks. 218pp.

Jingfors, K.T., and L. Lassen. 1984. Muskox responses to a seismic test operation: preliminary observation. Page 127 in D.R. Klein, R.G. White, and S. Keller, eds. Proc. First Int. Muskox Symp. Biol. Pap. Univ. Alaska Spec. Rep. No. 4, Fairbanks, Ak. 218pp (Abstract).

Lent, P.C. 1974. Mother-infant relationships in ungulates. Pages 14-55 in V. Geist and F. Walther, eds. The behavior of ungulates and its relation to management. New Ser. No. 24 Int. Union Conserv. Nat. Resour. Morges, Switz. 940p.

Marler, P.R., and W.J. Hamilton III. 1967. Mechanisms of animal behavior. John Wiley and Sons, Inc. 771p.

Miller, F.L., and A. Gunn. 1979. Responses of peary caribou and muskoxen to turbo-helicopter harassment, Prince of Wales Island, N.W.T. 1979-1977. Can. Wildl. Serv. Occ. Pap. No. 40. 90pp.

Miller, F.L., and A. Gunn. 1980. Behavioral responses of muskox herds to simulation of cargo slinging by helicopter, N.W.T. Can. Field-Nat. 94:52-60.

Miller, F.L, and A. Gunn. 1984. Muskox defense formations in response to helicopters in the Canadian high arctic. Pages 123-126 in D.R. Klein, R.G. White, and S. Keller, eds. Proc. First Int. Muskox Symp. Biol. Pap. Univ. Alaska. Spec. Rep. No. 4. Fairbanks, Ak. 218pp.

Nie, N.H., C.H. Hull, M.N.Franklin, J.C. Jenkins, K.J. Sours, M.J. Norusis, and V. Beadle. 1980. SCSS: A users guide to the SCSS conventional system. McGraw-Hill Book Company, New York. 595pp.

Reynolds, P.E. 1987. Movements and activity patterns of a satellite-collared muskoxen in the Arctic National Wildlife Refuge, 1984-1985. in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish and wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak.

Reynolds, P.E., L.D. Martin, and G.J. Weiler. 1983. Population size, productivity and distribution of muskoxen in the Arctic National Wildlife Refuge, Alaska. Pages 248-274 in G.W. Garner and P.E. Reynolds, eds. 1982 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Serv., Anchorage, Ak. 379pp.

Reynolds, P.E., L.D. Martin, T.J. Wilmers, and T.J. Doyle. 1984. Population dynamics and distribution of muskoxen in the Arctic National Wildlife Refuge, Alaska. Pages 293-329 in G.W. Garner and P.E. Reynolds, eds. 1983 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Serv., Anchorage, Ak. 614pp.

Reynolds, P.E., L.D. Martin, G.J. Weiler, J.M. Noll, and J.M. Morton. 1985. Population and herd dynamics, distribution, movements, and habitat use of muskoxen in the Arctic National Wildlife Refuge, Alaska, 1982-1984. Pages 41-95 in G.W. Garner and P.E. Reynolds, eds. 1984 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Serv., Anchorage, Ak. 777 pp.

Reynolds, P.E., J. Herriges, and M. Masteller. 1987. Muskox ecology on the Arctic National Wildlife Refuge, 1982-1985. in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish & Wildl. Serv. Anchorage, Ak.

Smith, T.E.. 1976. Reproductive behavior and related social organization of the muskox on Nunivak Island, M.S. Thesis, Univ. Alaska, Fairbanks. 138pp.

U.S. Fish and Wildlife Service. 1982. Initial report baseline study of the fish, wildlife, and their habitats. Arctic National Wildlife Refuge Coastal Plain Resource Assessment. U.S. Fish and Wildl. Serv. Anchorage, Alaska. 507pp.

ANWR Progress Report Number FY86-6-Impacts

EFFECTS OF AIRCRAFT DISTURBANCE ON THE ENERGETICS OF STAGING LESSER SNOW GEESE: A MODEL

Alan W. Brackney

Key words: Snow goose, _Anser caerulescens_, Anseridae, energetics, behavior, aircraft disturbance, Arctic National Wildlife Refuge.

Arctic National Wildlife Refuge
U.S. Fish and Wildlife Service
101 12th Avenue, Box 20
Fairbanks, Alaska 99701

1 September 1986

Effects of aircraft disturbance on the energetics of staging lesser snow geese : A model.

Alan W. Brackney, U.S. Fish and Wildlife Service, Arctic National Wildlife Refuge, Fairbanks, Alaska.

Abstract: Energetics of fall staging snow geese (*Anser caerulescens caerulescens*) on the coastal plain of the Arctic National Wildlife Refuge (ANWR) were examined in 1984-1985 with special emphasis on the effects of aircraft disturbance. A comprehensive model of energy intake and expenditure predicted a daily energy expenditure of 1623.5± 19.9 kj/day (mean± Sd) by adult females and 1759.8± 21.4 kj/day by adult males. In juveniles, 1302.4± 15.5 kj/day and 1361.4± 16.2 kj/day were expended by males and females, respectively. While adult females expended 1156± 215.7 kj/day and males 1220± 167.7 kj/day on tissue gain, juvenile males and females expended only 570.8± 156.5 and 627.9± 148.5 kj/day, respectively. Simulated aircraft disturbance had little effect on daily energy expenditure or activity cost under the base model which assumed limited nonflight habituation. Without the inclusion of behavioral substitution for lost feeding time (compensation), the model predicted a 50% reduction in true metabolizable energy intake and fat gain at aircraft overflights of 25 and 38 per day in juveniles and adults, respectively. Within the base model, the loss of feeding time and reduced energy intake, rather than increased energy expenditure, was relatively more important in regard to the detrimental effects of aircraft disturbance. The ameliorating effects of high levels of compensation indicated that the behavior of the geese when they are not being disturbed may be the most critical determinant of impacts from aircraft overflights.

Effects of aircraft disturbance on the energetics of staging lesser snow geese: A model.

Proposed petroleum development on the coastal plain of the Arctic National Wildlife Refuge may potentially impact lesser snow geese staging there during late August through September of each year. One source of detrimental impacts may be the disruption of normal behavior from aircraft disturbance. Fall staging snow geese react severely to aircraft flying at altitudes up to 10,000 feet (Davis and Wisely 1974). Such aircraft disturbance may be common in the vicinity of an oil field with aircraft traffic repeatedly disturbing geese over a much larger area than the total area of direct habitat loss from oil field facilities.. The Federal Aviation Administration (FAA) recorded over 3600 non-carrier aircraft contacts (120/day) in the Prudhoe Bay area in September 1985 (L. Carter, pers comm.).

The effects of frequent aircraft disturbance on the ability of the geese to acquire sufficient body fat reserves must be understood before an assessment can be made of the impacts of a Prudhoe Bay type facility within or next to the staging area. The objective of this study was to develop a model of energy expenditure and intake by snow geese and predict the consequences of varying levels of disturbance.

Energetics modeling in birds is a young discipline subject to many assumptions on the mechanics of energy flow through the avian body. The model presented in this study is based, by necessity, not only on data collected on snow geese on the ANWR coastal plain, but also on laboratory and field studies of other avian species. The accuracy of those studies in regard to snow geese is not known. Furthermore, many equations used in the model and developed by others to express certain energy pathways may be oversimplified. No data are presented here to verify the accuracy of the model. Consequently, the results of the model should not be viewed as a mirror of the real world but as a means to narrow the range of possible outcomes of disturbance to snow geese as a result of petroleum development, and as a guide to identify where further studies are needed.

Methods

In the model, the energy budget was partitioned along physiological pathways (Owen and Reinecke 1979) (Fig. 1). Estimated energy costs of activity, tissue production, thermoregulation, basal metabolic rate, metabolic fecal energy, endogenous urinary energy, and heat increment of feeding (specific dynamic effect) (Brody 1945, Owen and Reinecke 1979) were added to derive a true metabolizable energy (TME) intake value. TME was divided by a metabolizability coefficient to estimate gross energy intake. The definitions of abbreviated terms are listed in Appendix A. Variances in the energetics model were carried through the calculations by the methods of Goodman (1960) and Sokal and Rohlf (1969).

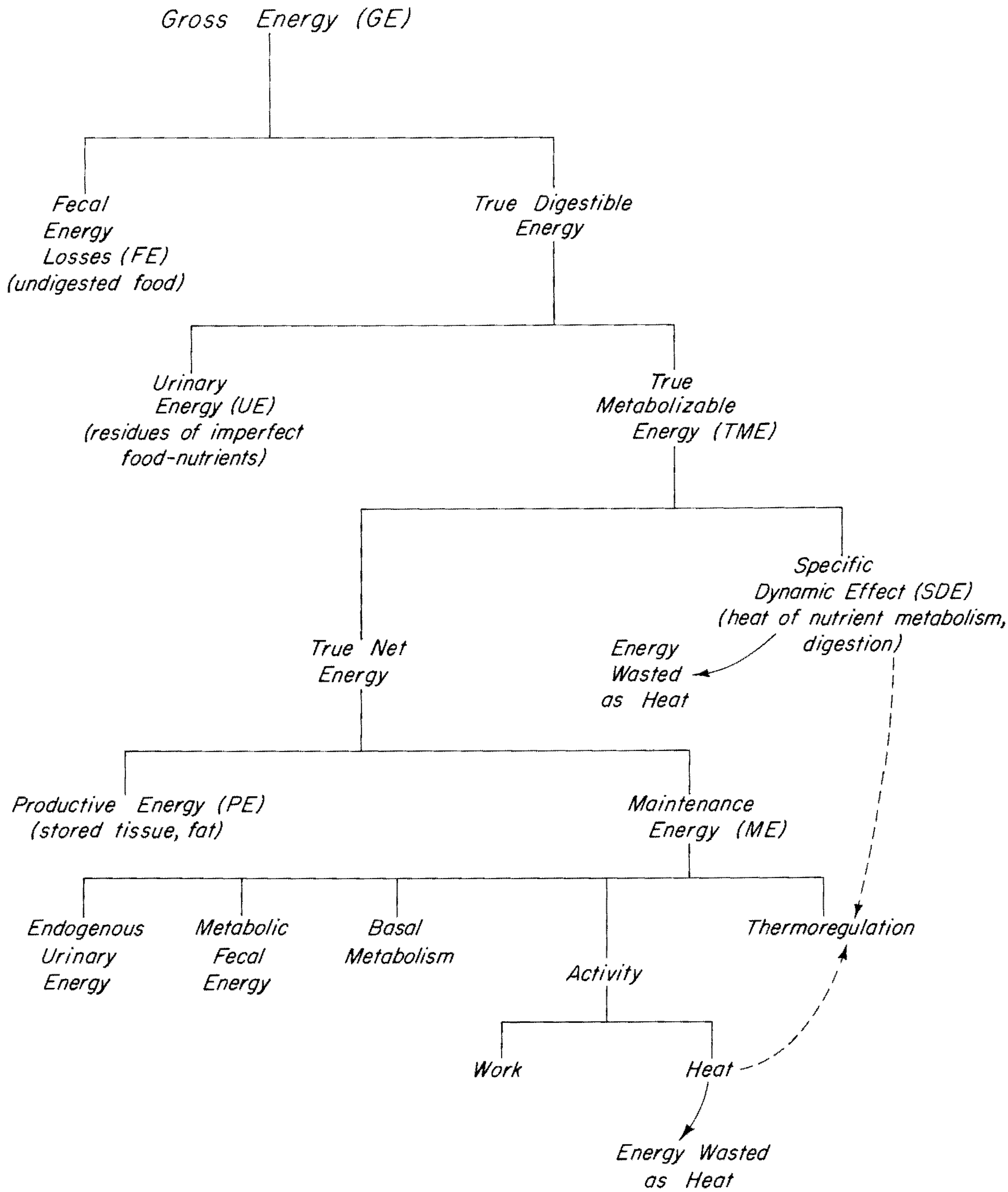


Fig. 1 Partitioning of avian energy flow taken from Crampton and Harris (1969).

Basal metabolic rate: Since no published values of basal metabolic rate (BMR) were available for snow geese, the nonpasserine nighttime (beta) formula of Aschoff and Pohl (1970) was used:

$$BMR = 307\ Wt^{0.743} \quad (1)$$

Where Wt equals body weight in kg and BMR is expressed in kj/day.

Activity Costs: Daily activity costs were estimated from multiples of basal metabolic rate (Wooley and Owen 1978) (Table 1) for each activity, times the estimated proportion of the 24 hour day spent in that activity (Brackney et al 1987). Since Wooley and Owen's estimates also included costs of specific dynamic effect (SDE) (Gauthier et al. 1984), 0.1 times BMR was subtracted from each value (the increment over BMR of the resting black ducks) to delete the extraneous energy expenditure. SDE was estimated independently of activity. Energy estimates of flight in birds vary from 4.7 to 15.0 BMR (Berger and Hart 1974, Flint and Nagy 1984) and the value used in the model was the most recent wind tunnel measurement for a large flapping bird (Hudson and Bernstein 1983). Nighttime resting activity was assumed to be 1.3 BMR (after King and Farner 1961, Wooley and Owen 1978).

Table 1. Multiples of basal metabolic rate used to calculate activity costs in the snow goose energetics model.

Activity	Cost (multiple BMR)
Resting	1.0
Preening	1.5
Alert	2.0
Grubbing	1.6
Searching	1.5
Loafing	1.5
Social Interaction	2.7
Walking	1.5
Flying	11.0
Nighttime roosting	1.3

Specific dynamic effect: SDE is the heat produced during digestion and nutrient absorption of foods (Brody 1945). SDE was estimated from a modified formula of Owen and Reinecke (1979) based on SDE heat production values of diet composition in Ricklefs (1974:168).

$$SDE = GE\ [(\%\ Crude\ Fat/100)\ 0.13 + (\%\ Crude\ Protein/100)\ 0.31 + (\%\ TNC/100)\ 0.23] \quad (2)$$

Where GE is gross energy intake, and TNC is total nonstructural carbohydrates.

Thermoregulation: Thermoregulatory costs (H_t) were a minor component of the energy costs, but were the most detailed to derive and involved a considerable number of assumptions. The basic approach was taken from thermal resistance models (Campbell 1977, Robinson et al. 1976 as modified by Walsberg et al. 1978) where the energy budget of an animal is expressed as the difference between the body temperature of the animal (T_b) and the black-body temperature of the surroundings (T_e), divided by the resistance of the plumage and body to heat loss. The derivation of H_t is summarized in Appendix B.

<u>Endogenous energy losses</u>: Estimates of metabolic fecal energy (MFE), endogenous energy lost from the digestive tract, and endogenous urinary energy (EUE) followed the procedures of Owen and Reinecke (1979:78):

$$MFE = [(0.08g\ N\ \ Wt^{0.734})\ (34.4\ Kj/g\ N\ excreted)]$$
$$[(\%\ Dietary\ fiber)\ (100/23.0) + 0.96] +$$
$$[D.M.\ Intake\ (Date - 1)(g)/\ Maintenance\ D.M.\ Intake\ (Date - 1)\ (g)] \quad (3)$$

where N = nitrogen, D.M. = dry matter, and Maintenance D.M. Intake = [maintenance energy/gross energy intake] D.M. Intake. Maintenance energy is the sum of BMR, activity costs, thermoregulation, MFE and EUE.

Endogenous urinary energy was calculated as:

$$EUE = [(0.2g\ N)\ \ 34.4\ Kj/g\ N\ excreted]\ [Wt^{0.734}]$$
$$[Net\ energy(Date - 1)/BMR] \quad (4)$$

where Net energy is the sum of maintenance and productive energy (PE).

<u>Productive energy</u>: The energy cost of tissue gain was derived from:

$$PE = [39.54\ (Fat\ wt)]/P_e \quad (5)$$

Where 39.54 is the energy value of body fat in Kj/g (Odum et al. 1964) and P_e is the efficiency of tissue production. P_e was calculated from the product of the contribution to digestible energy (DE) of the major nutrients of the diet (protein, fat, carbohydráte) (Brackney et al. 1987) and theoretical efficiency values for conversion of those nutrients to fat (Van Es 1977) where:

$$P_e = [(\%DE_{fat}/100)\ 0.90] + [(\%DE_{protein}/100)\ 0.75)] + [(\%DE_{carbohydrate}/100)\ 0.65)] \quad (6)$$

Digestible energy of each nutrient was estimated from components of an equation of Miller (1974) and Owen and Reinecke (1979:81):

$$DE_{fat} = \%\ Fat\ [0.95 - (3.0\ (\%Fiber)^2)]\ 39.54\ Kj/g \quad (7)$$

$$DE_{protein} = \%\ Protein\ [0.88 - \%\ Fiber]\ 23.64\ Kj/g \quad (8)$$

$$DE_{carbohydrate} = \%\ Carbohydrate\ [0.96 - (6.0\ (\%\ Fiber)^2)]\ 17.36\ Kj/g \quad (9)$$

These values were added and percentages were derived for use in Eq. 6.

Computer Simulations

Simulations of snow goose energy budgets were programmed in double precision basic and run on a microcomputer. The program (Fig. 2) calculated thermoregulatory costs on an hourly basis from daily minimum temperature, maximum temperature, average wind velocity, average cloud cover and 3 levels of fog intensity. Hourly

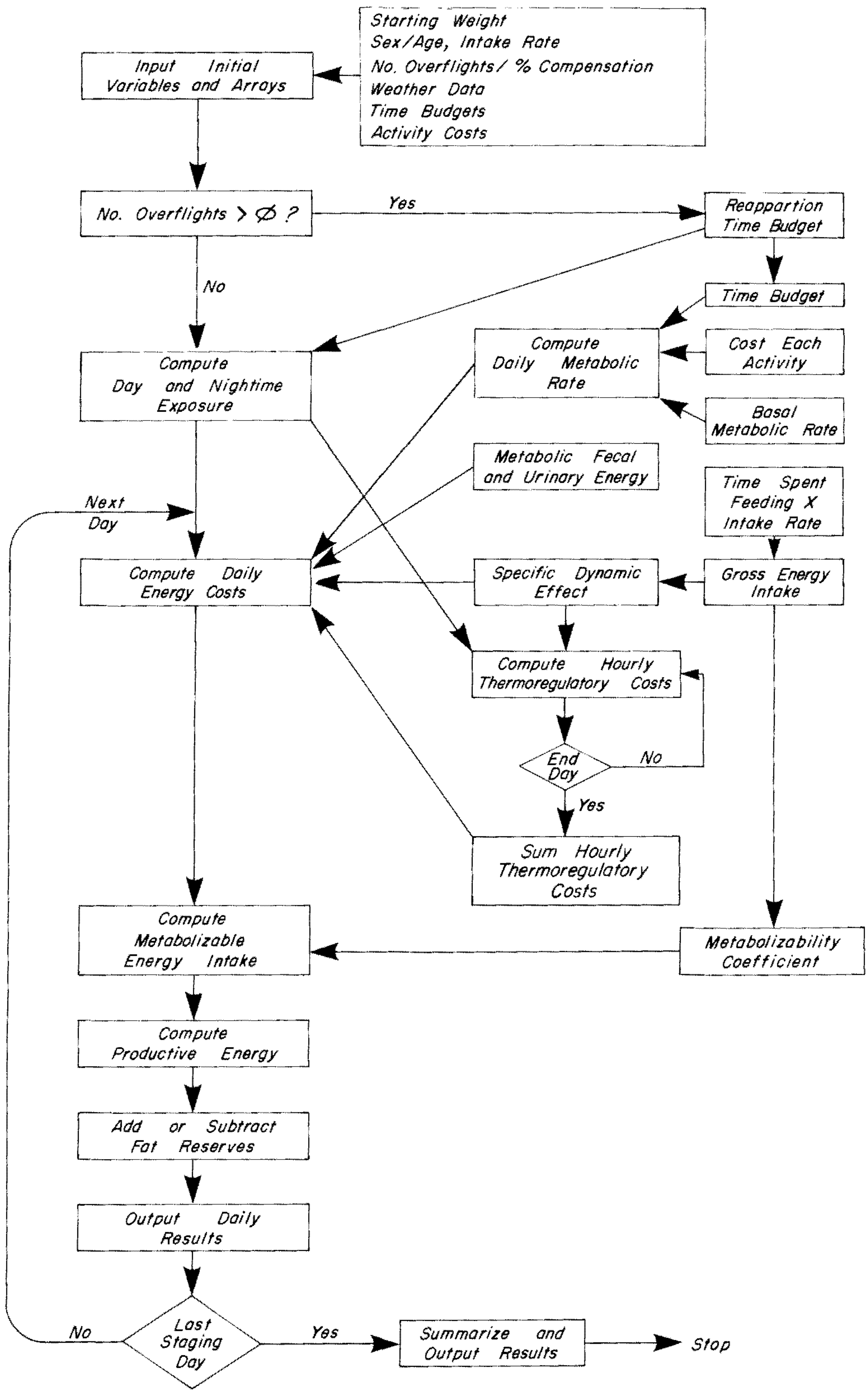


Fig. 2 Computer model used in the prediction of snow goose energy budgets.

temperatures were simulated from a sine curve (Fig. 3) (Owen and Reinecke 1979).

For each day of the staging period the model calculated daily energy expenditure (DEE) from the sum of activity costs, thermoregulatory costs, metabolic fecal energy (MFE), endogenous urinary energy (EUE), and SDE. TME was calculated from the sum of DEE and productive energy (PE) and gross energy was back-calculated from the TME intake estimates with a digestibility coefficient. Body weights of arriving geese in 1985 were used as initial input for BMR estimates, and daily recalculations of body weight were made from the addition or subtraction of body fat times 1.1 to account for changes in body water.

Disturbance Model

The hourly intake rates of gross energy and TME were estimated from the model on undisturbed geese for each age and sex class and used in the calculation of intake for time budgets altered by the disturbance. PE was estimated as the difference between TME and DEE.

Davis and Wisely (1974) timed the reactions of snow geese to aircraft overflights, both experimental and nonexperimental, and documented total reaction times of 3.8 to 10.3 minutes per overflight. Flying response varied from 100% in small experimental aircraft overflights at 120 min intervals to 24% in overflights at 30 min intervals. A mean of Davis and Wisely's estimates of snow goose responses to nonexperimental aircraft, 5.7 min total reaction time and 2.3 min flying time, were used as disturbance times in the base model. All reaction times other than flying were considered to be alert behavior.

It was assumed the geese would adapt to disturbance in 2 ways. The geese would habituate to the disturbance by taking flight on a lower percentage of overflights as disturbance levels increased (nonflight habituation) , and they would also compensate for the lost feeding time by increasing feeding during undisturbed periods at the expense of other activities. Since the rate of change in nonflight habituation with increased disturbance levels was not known, the percentage of overflights in which the birds flew was modeled along a negative exponential (Fig. 4) from 89% at 1 overflight/day to 36% at 40 overflights/day. Compensation was modeled for lost feeding time and additional flight and alert times by increasing feeding behavior by various proportions of the loss caused by disturbance. The change in feeding behavior was taken at the expense of other normal behaviors. In the model, hours of darkness were free of aircraft disturbance.

Results

Daily Energy Budget

The energetics model was initially run with 1985 weather data and 1985 daily fat gain (Brackney et al. 1987). The rate of gross energy and metabolizable energy intake was estimated in this initial run and energy budgets were compared by age and sex class (Table 2). The model predicted that adults metabolized 849.4-1039.5 Kj/day more energy than juveniles but expended only 262.1 to 457.3 Kj/day more energy than juveniles. Energy expended on tissue gain by adults was nearly double that of juveniles. Adults utilized 41%-42% of their true metabolizable energy (TME) intake in fat production (PE) and juveniles put 30-33% of their TME intake into fat reserves. Activity costs were slightly higher in adults

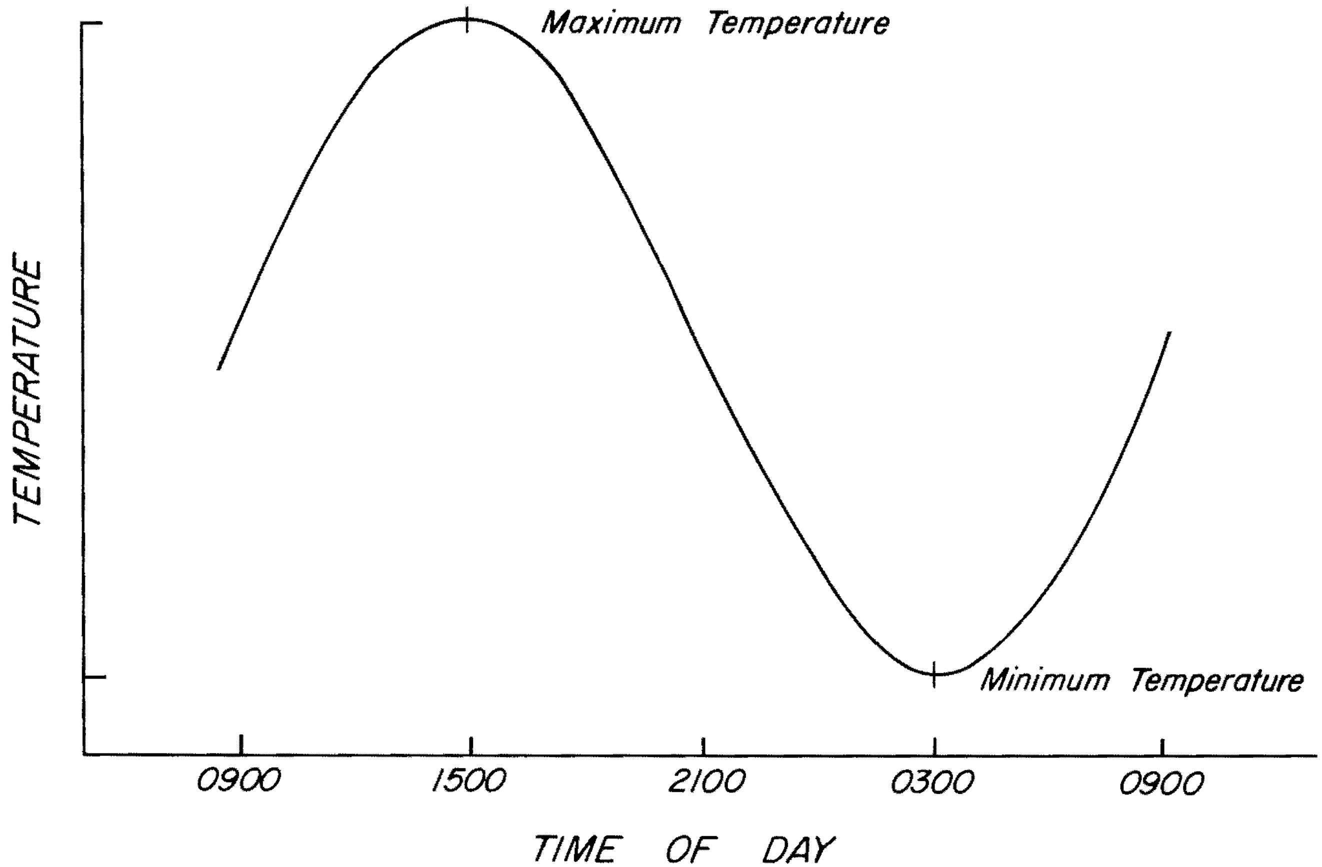


Fig. 3 Daily air temperature simulated by a sine curve for the calculation of snow goose thermoregulatory costs.

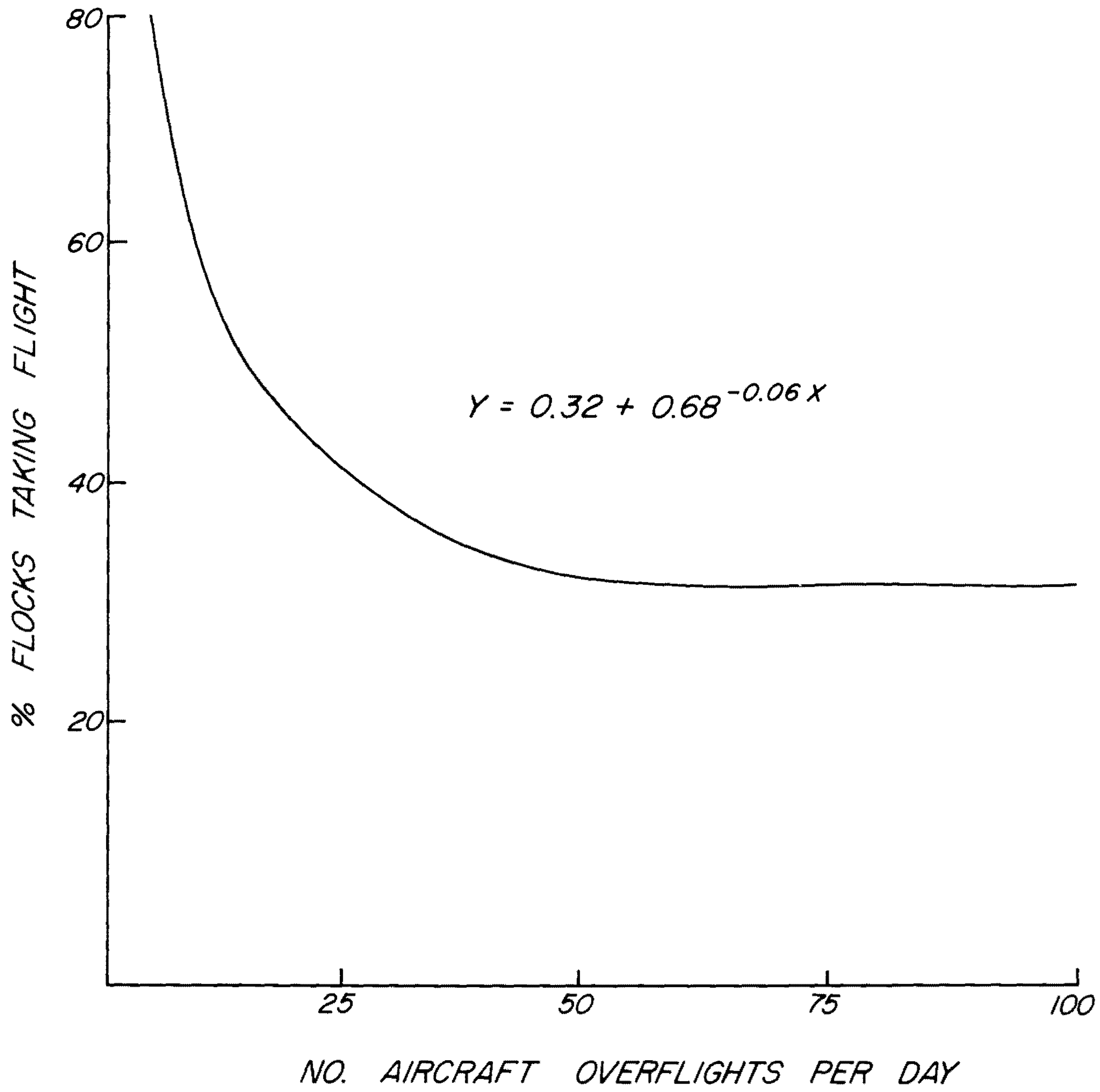


Fig. 4 Simulated flight response of snow geese to aircraft disturbance used in the base disturbance model.

(1064.1-1164.7 Kj/day) than juveniles (906.7-964.8 Kj/day) and higher in males than females in the respective age classes. Estimated energy costs and intake were similar between sexes in juveniles.

Predicted mean daily thermoregulatory costs in 1985 were small (17.2 - 16.5 Kj/day) and accounted for only 0.6% - 0.8% of daily metabolized energy. The predicted endogenous energy losses (metabolic fecal + endogenous urinary energy), 2.6% of TME in adults and 4.1% of TME in juveniles, agreed with Miller and Reinecke's (1984) suggestion that endogenous energy losses should approach 3% of TME at high levels of energy intake.

Table 2. Predicted daily energy budgets of undisturbed staging snow geese during the fall of 1985, Arctic National Wildlife Refuge, Alaska.

Energy Costs		Adults		Juveniles	
		Males	Females	Males	Females
Maintenance					
Thermoregulatory	mean	17.2[a]	17.1	16.7	16.5
	Sd	0.2	0.2	0.3	0.3
Activity Costs	mean	1164.7	1064.1	964.8	906.7
	Sd	15.4	14.0	12.6	11.8
Metabolic Fecal	mean	21.3	20.4	17.3	17.1
	Sd	0.9	0.8	0.5	0.6
Endogenous Urinary	mean	55.2	51.7	35.9	35.9
	Sd	0.4	0.4	0.2	0.2
Specific Dynamic Effect	mean	515.4	483.0	333.4	334.2
	Sd	47.1	44.2	30.6	30.6
Daily Energy Expenditure[b]	mean	1759.8	1623.5	1361.4	1302.5
	Sd	21.4	19.9	16.2	15.5
Productive Energy	mean	1210.0	1156.2	570.8	627.9
	Sd	167.7	215.7	156.5	148.5
True Metabolizable Energy Intake[c]	mean	2969.8	2779.7	1932.2	1930.3
	Sd	169.0	216.6	157.3	149.3
Gross Energy Intake[d]	mean	6614.3	6190.9	4303.5	4299.2
	Sd	376.5	482.4	350.4	332.5

[a]Kj/day
[b]Daily energy expenditure (DEE) = Maintenance energy (H_t + activity + MFE + EUE) + SDE
[c]True metabolizable energy (TME) intake = DEE + PE
[b]Gross energy Intake = TME intake / digestibility coefficient (0.4489)

For 1985, the model predicted a departure weight of 2856 g for adult males, 2544 g for adult females, 2156 g for juvenile males and 1999 g for juvenile females. This represents a slight overestimate of 5.5% from observed mean departure weights in adult males and a 4.4% overestimate from observed mean adult female departure weights (Brackney et al. 1987) Juveniles weights were underestimated by only 1.4% in males and overestimated by 1.2% in females.

Sensitivity of the Model

The sensitivity of the model to possible errors in assumptions and critical variables was investigated with the method of Fancy (1986). Thirteen variables were altered by ±10% of the original value (Table 3). Sensitivity tests were run with the 1985 arrival weights of adult and juvenile females. The model exhibited the most sensitivity to the variable expressing the conversion efficiency of productive energy (PE) to fat, originally estimated at 73.5%. A 10% change in this variable produced a possible change of 5.4% in estimates of true metabolizable energy (TME) intake for adult females and a 4.2% change for juvenile females. PE efficiency conversion may vary from 65% to 85% (Van Es 1977) with changes in TME estimates of +13% and -16%, respectively at the extreme values.

Table 3. Sensitivity of predicted metabolizable energy intake by fall staging snow geese to ±10% variation in 13 variables used in the model.

	Change in Initial Variable			
	Adult Females		Juvenile Females	
Variable	-10%	+10%	-10%	+10%
Basal metabolic rate	-103.1[a]	108.0	-88.5	92.0
PE conversion efficiency[b]	149.5	-122.6	81.3	-66.5
SDE, % of GE[c]	-54.9	57.1	38.2	39.7
SDE offset of H_t[d]	0	0	0	0
Resting cost	-5.4	5.4	-1.8	1.8
Preening cost	-1.8	1.8	-1.1	1.1
Alert cost	-13.4	13.4	-1.8	1.8
Grubbing cost	-30.4	30.4	-31.2	31.2
Searching cost	-8.0	8.0	-14.5	14.5
Social interaction cost	-0.7	0.7	-0.2	0.2
Walking cost	-3.9	3.9	-4.5	4.5
Flying cost	-30.1	30.1	-25.8	25.8
Nighttime roosting cost	-30.3	30.3	-25.9	25.9

[a] Change from baseline value (Kj/day)
[b] Efficiency (%) of conversion of productive energy (PE) to fat
[c] Percentage of gross energy (GE) converted to heat in SDE
[d] Percentage of SDE heat utilized for thermoregulation (H_t)

Basal metabolic rate (BMR) was another variable to which the model was sensitive. A 10% change in BMR produced a 3.7-3.9% and 3.4-4.2% change in TME intake estimates for adult females and juvenile females, respectively. Aschoff and Pohl's 1970 equation may have underestimated BMR (see Morehouse 1974, West and Norton 1975), but it is unlikely it overestimated BMR. Considering the very high TME intake estimates by the baseline model, basal metabolic rates in these snow geese are probably not higher than that estimated by the model.

A 10% change in SDE, derived as a percentage of gross energy (GE) intake, caused variations of 2.0-2.1% in the model. SDE estimates may be lower if estimated available protein is substituted for crude protein (12.0%) in Eq. 2. Since all nitrogen assayed from plants are not available as protein (Sedinger and Raveling 1984), a linear regression of true available protein content against percent nitrogen (Sedinger and Raveling 1984) was used to estimate an available protein level (8.6%) in cottongrass. This reduced SDE from 7.6% to 6.6% of GE; a 13% reduction.

Variations in activity costs exerted little influence on TME intake estimates. Ten percent variations in the costs of grubbing, flying, and nighttime roosting each altered the TME intake estimates by 1.1% to 1.6%. Cost of grubbing for roots could be as high as 3.0 times BMR (Gauthier et al. 1984). Such an assumption would raise TME intake estimates by 270-280 Kj/day, or up to 10.0% and 14.5% in adult females and juvenile females, respectively. Flight costs may lie between 4.0 and 15.0 times BMR (see earlier discussion) with corresponding variations in TME of the same magnitude as grubbing. An assumption that the geese rested the entire night could place nighttime costs as low as 1.0 times BMR with corresponding TME reductions of 60 Kj/day (3.1%) in juvenile females and 70 kj/day (2.5%) in adult females.

Since errors can be either additive or offsetting, two additional models were run with minimum and maximum values for 5 variables. Maximum values for the 5 variables produced estimates of true metabolizable energy (TME) intake that were 20% higher in adults and 24-25% higher in juveniles than the base model (Table 4). Likewise, the minimum values for the 5 variables resulted in TME intake estimates that were 16% and 15% lower than the base model in adults and juveniles, respectively.

Table 4. The additive effect on estimated metabolizable energy intake of maximum and minimum values of 5 variables in the snow goose energetics model.

	Adults		Juveniles	
	Males	Females	Males	Females
Maximum values[a]	3567.5[b]	3334.7	2410.6	2394.2
Base values	2969.7	2779.7	1932.2	1930.3
Minimum values[b]	2568.6	2403.3	1681.1	1676.9

[a]Maximum values, SDE = 0.076 GE, 65% PE efficiency, Flying = 15.0 BMR, Grubbing = 3.0 BMR, Nighttime roosting = 1.3 BMR.
[b]Predicted True metabolizable energy intake
[c]Minimum values, SDE = 0.066 GE, 85% PE efficiency, Flying = 9.0 BMR, Grubbing = 1.6 BMR, Nighttime roosting = 1.0 BMR.

These sensitivity tests do not probe the accuracy of the model but only verify that the model is sensitive to the additive effects of possible errors in certain variables. Although such errors may be offsetting and result in accurate estimates of some energy parameters, the predictive power of the model would be reduced if errors occurred in the sensitive variables. Therefore, independent estimates of energy costs and intake may be necessary to confidently predict the actual energy expense of aircraft disturbance through an energetics model.

Disturbance Simulations

The base model (Model I) and 3 alternative disturbance scenarios were run to examine the consequences of other possible snow goose responses. These included the base disturbance model without nonflight habituation (Model II); a model with the maximum response of 10.3 min. total response time to each disturbance, 3.0 min. in flight (Davis and Wisely 1974), and nonflight habituation (Model III); and the maximum response without nonflight habituation (Model IV). For a comparison of model simulations of aircraft disturbance, daily fat gain (DFG) was plotted against the number of aircraft disturbances for adult and juvenile females at compensation levels of 0, 50%, and 100% (Figs 5-8)

Simulated aircraft disturbance, without compensation, greatly reduced predicted DFG at all levels of aircraft disturbance in each model. Increased percentages of behavioral substitution (compensation) progressively ameliorated the effect of disturbance such that adults could tolerate up to 53 overflights per day at 50% compensation and over 80 overflights per day at 100% compensation without a reduction in DFG in Model I. However, because of the longer daily feeding time and lower intake rates in juveniles, they could tolerate only about 25 overflights per day at 50% compensation or 45 overflights per day at 100% compensation before DFG was reduced. The model predicted that juvenile DFG would be cut in half at 25, 50, and 66 aircraft overflight/day at 0%, 50% and 100% compensation, respectively. Adult DFG would be halved at 38, 78, and 98 aircraft overflights per day at compensation of 0%, 50%, and 100%.

The behavioral response assumed in the Model I allowed the smallest reduction in DFG of the 4 scenarios. In the base model without nonflight habituation (Model II), the same DFG occurred at 15-20 fewer overflights/day than in Model I. Fat gains were as low as 5% of those predicted by the base model at 60 overflights per day. The increased alert and flight time assumed by the maximum response scenario with nonflight habituation (Model III) predicted much lower levels of DFG than the base model at similar disturbance levels. Likewise, the maximum response model without habituation (Model IV) predicted a DFG equivalent to Model III at 6 to 10 fewer overflights/day. Therefore, the additional flying time and associated increase in daily energy expenditure (DEE) had profound negative effects on the predicted fat gain. The worst possible behavioral response that could be taken by the geese (0% compensation and maximum response without habituation) was used by Davis and Wisely (1974) to estimate a 20.4% decrease in fat gain by juveniles on the Yukon north slope at 2 aircraft overflights per hour (28-32/day). In our model, this level of response by the geese (Model IV) would result in a 34.6% reduction in DFG. A 50% reduction in daily fat gain would occur at 12 overflights per day (0.75/ hour) and compensation would be relatively less beneficial.

Discussion

High levels of aircraft disturbance as a result of oilfield development on the coastal plain could potentially affect the accumulation of adequate body fat reserves by snow geese for migration. Two factors, the intensity of aircraft disturbance and the behavioral response of the geese to the aircraft, will ultimately determine the severity of the impacts.

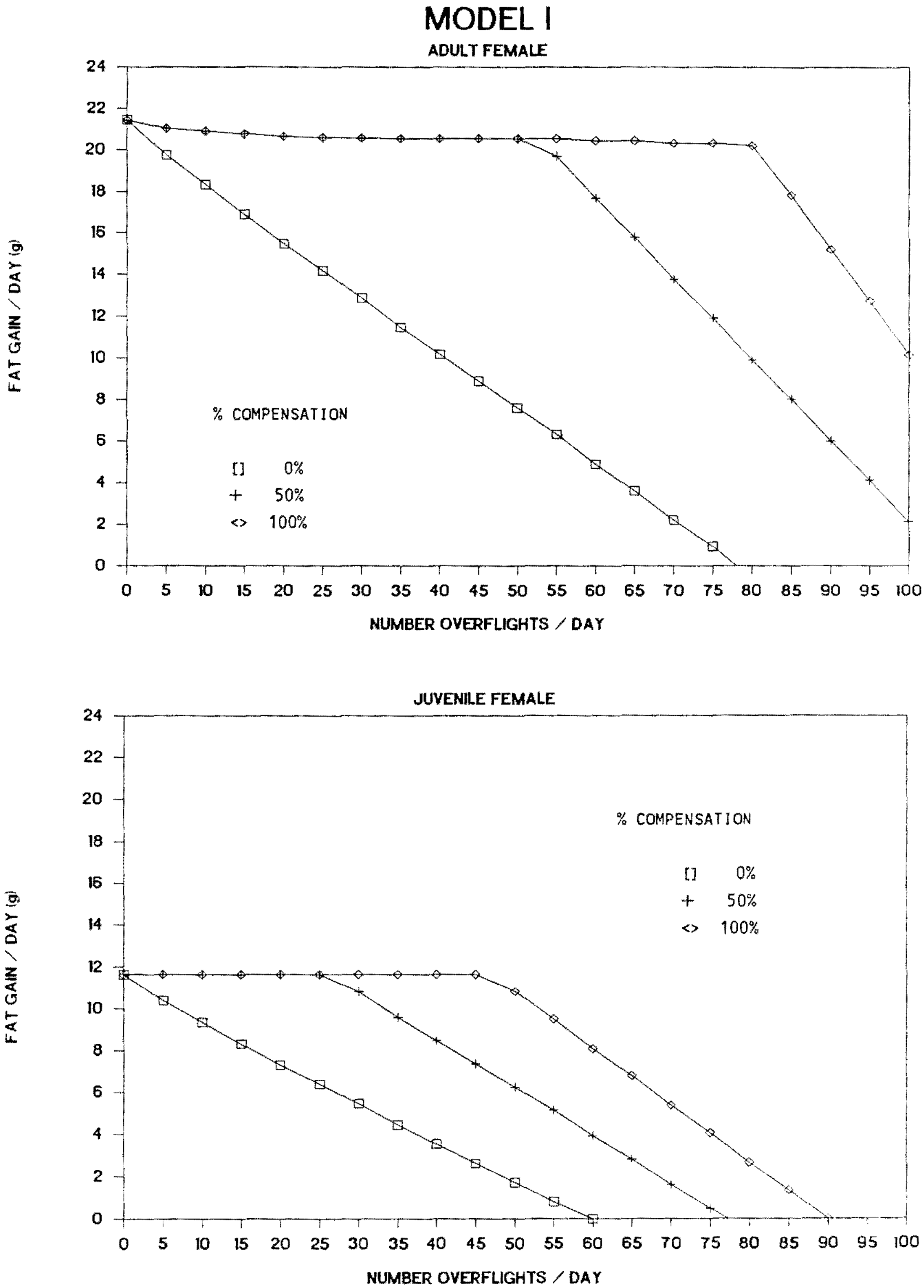


Fig 5. Simulated daily fat gain (g) of female snow geese with an average response to disturbance and nonflight habituation.

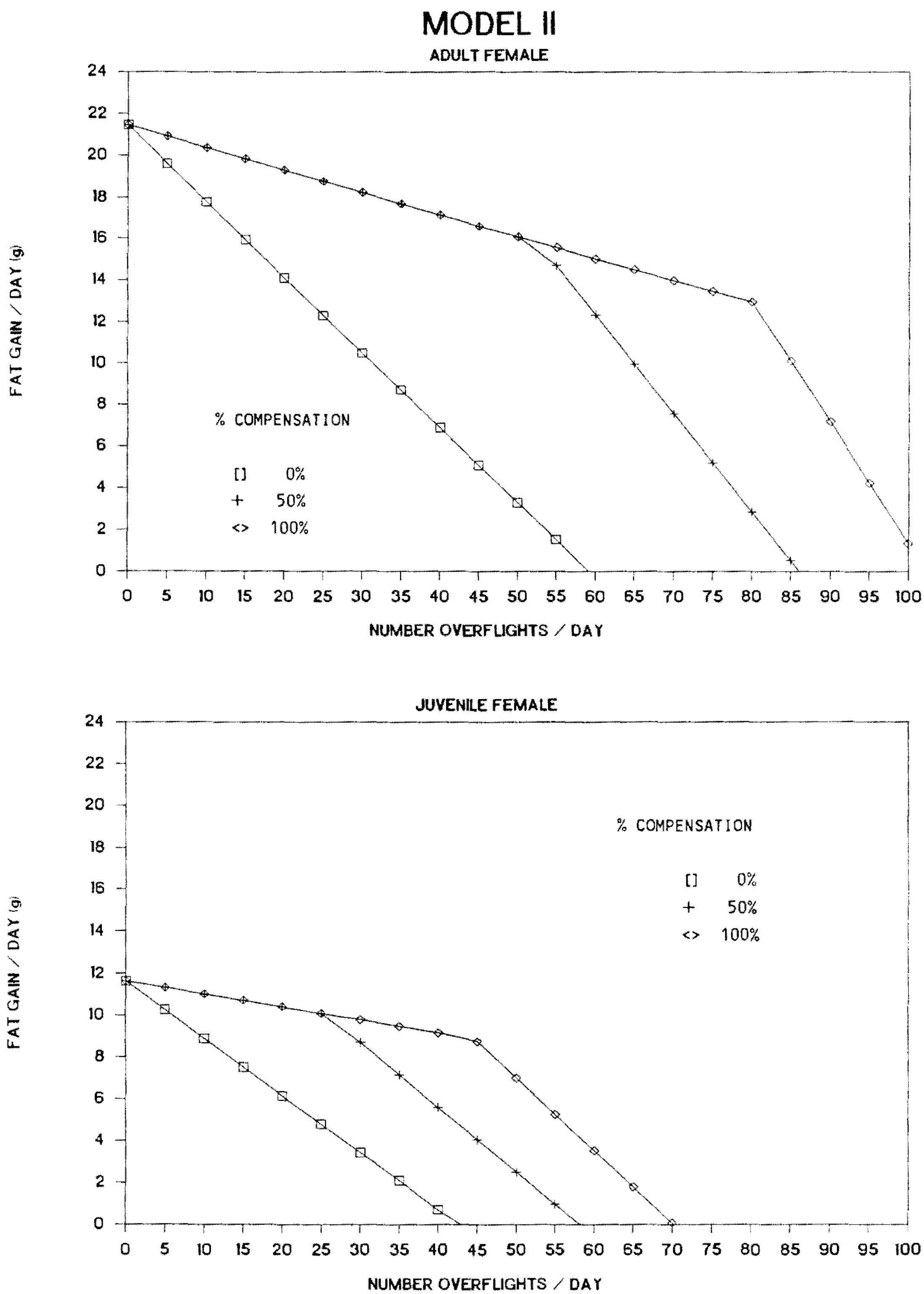


Fig 6. Simulated daily fat gain (g) of female snow geese with an average response to disturbance and no habituation.

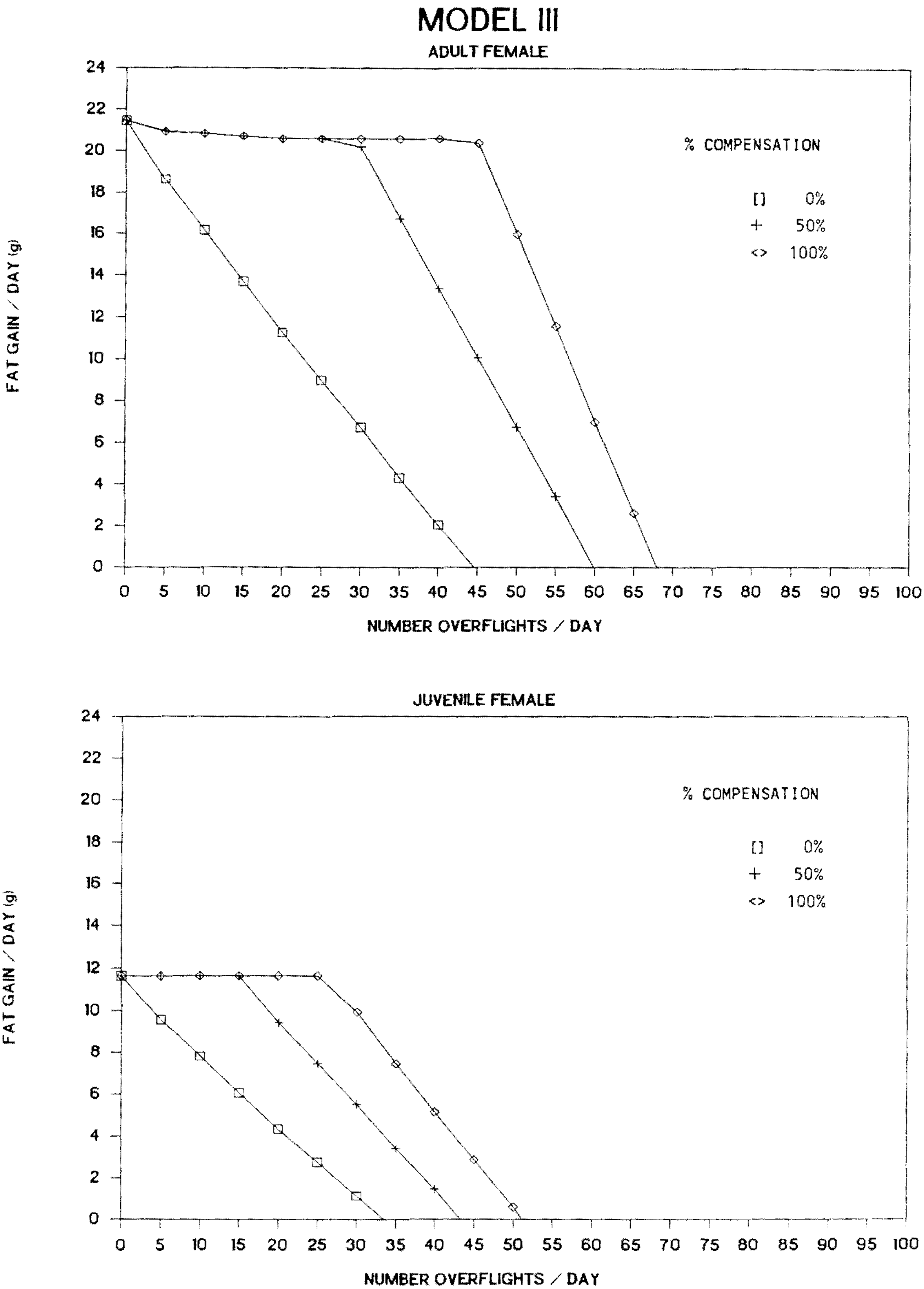


Fig 7. Simulated daily fat gain (g) of female snow geese with a maximum response to disturbance and nonflight habituation.

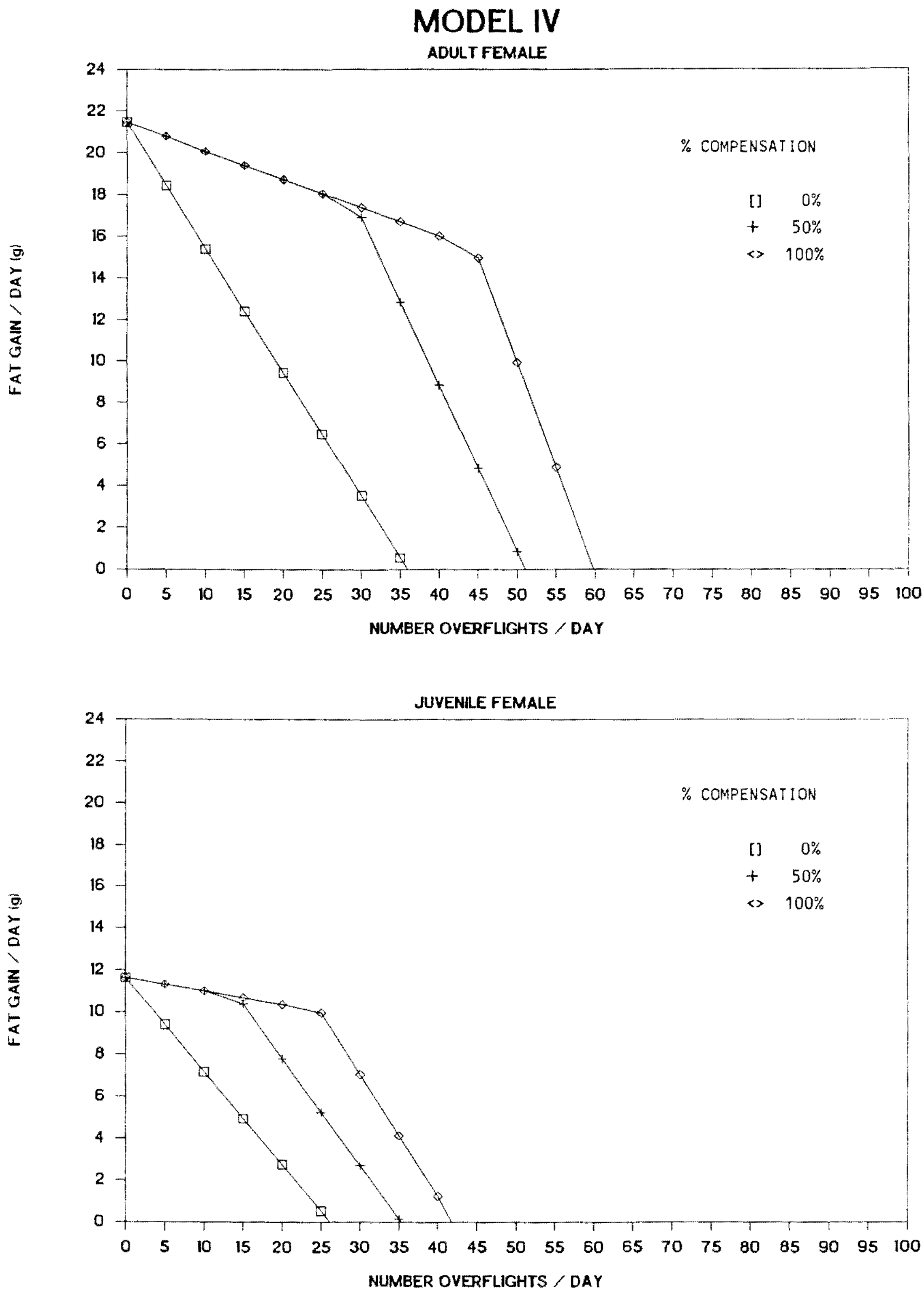


Fig 8. Simulated daily fat gain (g) of female snow geese with a maximum response to disturbance and no habituation.

The model developed in this study predicted the energetic consequences of various numbers of aircraft overflights at several possible behavioral responses by the geese. However, the actual intensity of possible disturbance and the behavioral response of the geese to the disturbance is not sufficiently known to explicitly define the impacts. Large numbers of aircraft (120/day) may fly through and around an active oilfield each day, some making several passes through the same area. The size, altitude, and noise level of the aircraft can affect the distance at which the geese react and their level of response (Davis and Wisely 1974). The number of overflights through a particular segment of the staging area cannot be predicted from available information. Once development scenarios are known, further studies are needed to define and predict the number and intensity of disturbances to geese using particular areas of the coastal plain. Studies of aircraft flight patterns through the Prudhoe Bay area may be instructive in the prediction of aircraft flight patterns on ANWR if petroleum development proceeds.

The model clarifies the importance of various aspects of snow goose response to aircraft disturbance. Although the energetic costs of flight-escape and alert responses to disturbances are important without nonflight habituation, the most sensitive question is how the geese will behave between disturbances. Since the loss of feeding time and reduced energy intake is the most critical aspect of disturbance, their ability to substitute feeding for other behaviors and maintain feeding time at a high level will ultimately determine the extent of the impacts on the geese. Nonflight habituation was observed by Davis and Wisely (1974) and further studies should attempt to define the level of this habituation at different intensities of disturbance. Total habituation may also be a factor. With increased disturbance, the geese may ignore aircraft up to higher thresholds of stimuli before discontinuing feeding behavior and reacting with an alert posture. Finally, it is possible that at very high levels of disturbance the geese may abandon the area, or initially avoid it, and be denied use of a portion of the staging grounds. Such a situation would be equivalent to a direct habitat loss.

If substantial habitat loss from petroleum development occurs, additional information on habitat-use, daily food intake, and reestablishment of food sources depleted by feeding geese will be necessary to assess the effect of such losses.

Literature Cited

Aschoff, J. and H. Pohl. 1970. Rhythmic variations in energy metabolism. Fed. Proc. Fed. Amer. Soc. Exp. Biol. 29:1541-1552.

Bennett, F.G. and R.C. Lee. 1937. Lipogenesis in the animal body, with special reference to the physiology of the goose. Carnegie Inst., Washington D.C. 232pp.

Berger , M., and J. S. Hart. 1974. Physiology and energetics of flight. Pages 415-477 _in_ D. S. Farner, J. R. King, and K. C. Parkes, eds. Avian biology Vol IV. Academic Press, London. 504pp.

Berger, M., J.S. Hart, and O.Z. Roy. 1971. Respiratory water and heat loss of the black duck during flight at different ambient temperatures. Can. J. Zool. 49:767-774.

Best, R.G. 1981. Infrared emissivity and radiant surface temperatures of Canada and snow geese. J. Wildl. Manage. 45:1026-1029.

Brackney, A. W., R. M. Platte, J. M. Morton, and D. Whiting 1987. Ecology of lesser snow geese staging on the coastal plain of the Arctic National Wildlife Refuge, Alaska, fall 1985. in G.W. Garner and P.E. Reynolds, eds. 1984 update report baseline study of the fish, wildlife and their habitats. Vol I. U.S. Fish and Wildl. Serv., Anchorage, Ak. 777pp.

Brody, S. 1945. Bioenergetics and growth. Reinhold Publ. Corp. N.Y. 1023pp.

Calder, W.A., and J.R. King. 1974. Thermal and caloric relations of birds. Pages 259-413 in D.S. Farner, J.R. King, and K.C. Parkes. eds. Avian Biology Vol. IV. Academic Press. 504pp.

Campbell, G.S. 1977. An introduction to environmental biophysics. Springer-Verlag. New York. 159pp.

Crampton, E. W. , and L. E. Harris 1969. Applied animal nutrition. 2nd ed, W. H. Freeman and Co., San Francisco, 753pp.

Davis, R.A., and A.N. Wisely. 1974. Normal behavior of snow geese on the Yukon-Alaska north slope and the effects of aircraft-induced disturbance on this behavior, September, 1973. Chapter II, 35pp in W.W.Gunn, W.J. Richardson, R.E. Schweinsburg, T.D. Wright, eds. Studies on snow geese and waterfowl in the northwest Territories, Yukon Territory and Alaska, 1973. Arctic Gas Biol. Rep. Ser. 27. 203 pp.

Fancy, S.G. 1986. Daily energy budgets of caribou: a simulation approach. Phd. dissertation. University of Alaska-Fairbanks 226pp.

Flint, E.N., and K.A. Nagy. 1984. Flight energetics of free-living sooty terns. Auk 101:288-294.

Gauthier, G., J. Bedard, and Y. Bedard. 1984. Comparison of daily energy expenditure of greater snow geese between two habitats. Can. J. Zool. 62:1304-1307.

Goodman, L.A. 1960. On the exact variance of products. J. Amer. Stat. Assn. 55:708-713.

Hammel, H.I. 1956. Infrared emissivities of some arctic fauna. J. Mammal. 37:375-378.

Hudson, D.M., and M.H. Bernstein. 1983. Gas exchange and energy cost of flight in the white necked raven, Corvus cryptoleucus. J. Exp. Biol. 103:121-130.

Isado, S.B, and R.D. Jackson. 1969. Thermal radiation from the atmosphere. J. Geophy. Res. 74:5397-5403

Irving, L., H. Krog, and M. Monson. 1955. The metabolism of some Alaskan animals in winter and summer. Physiol. Zool. 28:173-185.

King, J.R. and D.S. Farner. 1961. Energy metabolism, thermoregulation and body temperature. Pages 215-288 in A.J. Marshall, ed. Biology and comparative physiology of birds. Vol II, Academic Press, N.Y.

Kleiber, M. 1961. The fire of life. Wiley Press. N.Y.

Mahoney, S.A., and J.R. King. 1977. The use of the equivalent black-body temperature in the thermal energetics of small birds. J. Thermal Biol. 2:115-120.

Midtgard, U. 1978. Resting postures of the mallard Anas platyrhynchos. Ornis Scan. 9:214-219.

Miller, M.R. 1974. Digestive capabilities, gut morphology, and cecal fermentation in Wild Waterfowl, (Genus Anas) fed various diets. M.S. Thesis. Univ of California. Davis. 87pp.

Miller, M.R., and K.J. Reinecke 1984. Proper expression of metabolizable energy in avian energetics. Condor 86:396-400.

Morehouse, K.A. 1974. Development, energetics and nutrition of captive pacific brant (Branta bernicla orientalis Tougarinov). Ph.d. dissertation Univ. Alaska, Fairbanks. 104pp.

Mugaas, J.N., and J.R. King. 1981. Annual variation of daily energy expenditure by the black-billed magpie: A study of thermal and behavioral energetics. Studies Avian Biol. No. 5, 78pp.

Odum, E.P., D.T. Rogers, and P.L. Hicks. 1964. Homeostasis of the nonfat components of migrating birds. Science 143:1037-1039.

Owen, R.B. and K.J. Reinecke. 1979. Bioenergetics of breeding dabbling ducks. Pages 71-93 in T.A. Bookhout, ed. Waterfowl and wetlands - An integrated review. Proc. Symp. 39th Midwest Fish and Wildl. Conf. LaCross Printing Co. 152pp.

Ricklefs, R.E. 1974. Energetics of reproduction in birds. Pages 152-292 in R.A. Paynter, ed. Avian energetics. Nuttall Ornith. Club, Cambridge. 334pp.

Robbins, C.T. 1983. Wildlife feeding and nutrition. Academic Press, N.Y. 342pp.

Robinson, D.E., G.S. Campbell, and J.R. King. 1976. An evaluation of heat exchange in small birds. J. Comp. Physiol. 105:153-166.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. 776pp.

Sedinger, J.S., and D.G. Raveling. 1984. Dietary selectivity in relation to availability and quality of food for goslings of cackling geese. Auk 101:295-306.

Torre-Bueno, J.R. 1976. Temperature regulation and heat dissipation during flight in birds. J. Exp. Biol. 65:471-482.

Torre-Bueno, J.R. 1978. Evaporative cooling and water balance during flight in birds. J. Exp. Biol. 75:231-236.

Unsworth, M.H., and J.L. Monteith. 1975. Long-wave radiation at the ground. I. Angular distribution of incoming radiation. Quart. J. Roy. Met. Soc. 101:13-24.

Van Es, A.J.H. 1977. The energetics of fat deposition during growth. Nut. Metab. 21:88-104.

Walsberg, G.A., and J.R. King. 1978. The relationship of the external surface area of birds to skin surface area and body mass. J. Exp. Biol. 76:185-189.

Walsberg, G.E., G.S. Campbell, and J.R. King. 1978. Animal coat color and radiative heat gain: a re-evaluation. J. Comp. Physiol. 126:211-222.

West, G.C., and D.W. Norton. 1975. Metabolic adaptations of tundra birds. Pages 301-329 in V.F.J. Vernberg, ed. Physiological adaptations to the environment. Intext Educational Publishers, N.Y. 576pp.

Wooley, J.B., and R.B. Owen. 1978. Energy costs of activity and daily energy expenditure in the black duck. J. Wildl. Manage. 42:739-745.

APPENDICIES

APPENDIX A: Definition of abbreviations presented in the text.

a	Coefficient in the general equation for BMR aWt^b
a_l	Absorptivity of the animal to long-wave radiation
a_s	Absorptivity of the animal to short-wave radiation
A	Surface area of the body
A_d	Body surface area exposed to scattered short-wave radiation
A_e	Body surface area exposed to convective and radiant heat exchange
A_r	Body surface area exposed to reflected short-wave radiation
A_t	Body surface area exposed to direct short-wave radiation
AME	Apparent metabolizable energy, GE - (fecal + urinary + EUE + MFE)
BMR	Basal metabolic rate
d	Characteristic dimension of the animal
DE	Digestible energy, GE - fecal energy
DEE	Daily energy expenditure, EUE + MFE + activity cost + BMR + H_t + SDE
E	Skin evaporative heat loss
E_r	Respiratory evaporative heat loss
EUE	Endogenous urinary energy
GE	Gross energy
H_t	Energy expended on thermoregulation
K	Thermal conductivity constant
l	Plumage thickness
L	Long-wave radiation incident on the body
LCT	Lower critical temperature
M	Metabolic heat loss
MFE	Metabolic fecal energy
p	Probability a solar ray will strike a feather barbule
P_{cp}	Volumetric specific heat of air (1200 j/m^3)
P_e	Energy efficiency of tissue production
PE	Productive energy expenditure, energy expended on tissue production
r_b	Total resistance of the body to heat transfer, $r_t + r_c$ (s/m)
r_c	Plumage thermal resistance to heat transfer (s/m)
r_e	External resistance to convective and radiant heat transfer (s/m)
r_{ha}	Resistance of the boundary layer to convective heat transfer (s/m)
r_r	Thermal resistance to radiant heat transfer (s/m)
r_t	Thermal resistance of the tissue to heat transfer (s/m)
R_{abs}	Short and long wave radiation absorbed by the animal
S	Short-wave radiation incident on the body
S_b	Direct solar (short-wave) irradiance on a horizontal surface
S_f	Diffuse sky (short-wave) irradiance
S_p	Short-wave flux density perpendicular to the beam
S_{po}	Solar constant (1.36 kW/m^2)
S_r	Reflected short-wave radiation
S_t	Direct solar (short-wave) irradiance perpendicular to the solar beam
SDE	Specific dynamic effect
t	Time of day
t_o	Time of solar noon
T_a	Ambient air temperature in °C
T_b	Core body temperature in °C
T_e	Equivalent black-body temperature in °C
T_k	Ambient temperature in °K

TME	True metabolizable energy, GE - (fecal energy + urinary energy)
TNC	Total nonstructural carbohydates
u	Wind velocity (m/s)
Wt	Body weight
w	watts (1 j/sec)
ϵ_a	Emissivity of a clear sky
ϵ_c	Emissivity of a cloudy sky
β	Latitude
τ	Latent heat of vaporization of water (2030 j/g)
σ	Stephan-Boltzman constant ($5.67 \times 10^{-8} Wm^{-2}k^{-4}$)
δ	Solar declination
ϕ	Solar elevation angle

APPENDIX B. Thermal resistance model (Campbell 1977, Robinson et al. 1976 as modified by Walsberg et al. 1978) used in the estimation of thermoregultory costs (H_t) in the snow goose energetics model.

Th metabolic rate of an animal can be expressed as:

$$M - \tau E = Pcp\ (T_b - T_e)/(r_b + r_e) \qquad (11)$$

Where M and E are metabolic heat production and evaporation per m^2 of animal surface area, respectively, and τ is the latent heat of vaporization of water (2030 j/g). Pcp is the volumetric specific heat of air (1200 j/m^3 °C). The core body temperature of the goose is T_b (41.5 °C, Bennett and Lee 1937) and T_e is the equivalent black-body temperature. The whole body thermal resistance (r_b) is the sum of plumage resistance (r_c) and tissue resistance (r_t). The external resistance to convective and radiant heat transfer (r_e), is derived from the equation of two resistances in parallel series:

$$r_e = r_r r_{ha}/(r_r + r_{ha}), \quad \text{and} \quad r_r = Pcp/(4\epsilon\sigma T_k^{3\circ}) \qquad (12)\ (13)$$

here ϵ is the emissivity of the goose, σ is the Stephan Boltzman constant (5.67 x $10^{-8} Wm^{-2}\ {}^\circ K^{-4}$) and T_k is ambient temperature in degrees Kelvin. Emissivities in snow geese are 0.963 in adults and 0.959 in juveniles (Best 1981). The boundary layer resistance r_{ha} is:

$$r_{ha} = K\ (d/u)^{1/2} \qquad (14)$$

Where d is the characteristic dimension defined as the diameter perpendicular to air flow. Dimensions of 2 snow geese measured for this study averaged 0.534 m on the long axis and 0.138 m across the short axis of the body. Average values of the 2 dimensions were used in the model to estimate the diameter. The variable u is the wind velocity (m/sec) and k is a constant (310, Robinson et al. 1976).

The equivalent black body temperature T_e equals the ambient temperature T_a (°C) plus an increment for radiant loss or gain:

$$T_e = T_a + (r_e/Pcp)\ (R_{abs} - \epsilon\sigma T_a^{4\circ}). \qquad (15)$$

Where R_{abs} is the average long and short wave radiation absorbed by the animal. The derivation of R_{abs} is :

$$R_{abs} = a_l L + S\ [a_s + (r_c/r_e)\ (1/pl)\ (2-a_s)] \qquad (16)$$

Here a_l is the absorptivity of the animal to long wave radiation (0.98, Hammel 1956), L is the long wave radiation incident on the bird, and S is the short wave radiation incident on the bird. The absorptivity of the plumage to short wave radiation (a_s) was taken as 0.3 for white feathers (Mugaas and King 1981) and 0.48 for gray feathers (Campbell 1977). The variables p and l are the probability per unit depth of plumage that a ray will strike a feather (p), times the plumage thickness (l). The variable pl is approximately 34 (Walsberg et al. 1978). A tissue resistance, r_t, of 100 s/m (Robinson et al. 1976) was assumed, and $r_c = r_b - r_t$.

Body resistance r_b was estimated from the equation:

$$r_b = [Pcp\ (T_b - T_a)/(M - \tau E)] + r_e$$

where T_e equals T_a such as occurs in a metabolic chamber. Maximum resistance occurs in the chamber at low wind speeds at or just above the lower critical temperature (LCT). The LCT for snow geese is not known, but temperatures for other waterfowl have included -2 °C in Emperor goose (Anser canagicus, West and Norton 1975), 6 °C in black brant (Branta bernicla nigricans, Irving et al. 1955) and 0° C in the mallard (Anas platyrhynchos, Owen and Reinecke 1979). We assumed an LCT of 0 °C to estimate r_b in a metabolic chamber at an airflow velocity of 0.2 m/sec (Mahoney and King 1977). E was assumed to be zero. A metabolic rate (M) of 51.02 W was estimated for a 2100 g goose from the equation of Aschoff and Pohl (1970). Whole body resistance was estimated at 800.15 sec/m with this procedure.

Long wave irradiance (L) was estimated with the following equation (Campbell 1977):

$$L = (\epsilon_c \sigma T_a^4)0.5 + (0.98T_a^4)0.5. \qquad (17)$$

The value 0.98 in Eq. 17 is the emissivity of the surroundings. The two sides of Eq. 17 were partitioned over one half of the body.

The emissivity of the sky ϵ_c is dependent on cloud cover and estimated from Eq. 11 of Unsworth and Monteith (1975:22):

$$\epsilon_c = (1 - 0.84c)\epsilon_a + 0.84c \qquad (18)$$

where c equals the proportion of the sky covered with clouds and ϵ_a is the emissivity of a clear sky.

Short wave radiation (S) was estimated after Campbell (1977) and reduced proportionally by % cloud cover:

$$S = A_t S_t + A_b S_d + A_r S_r \qquad (19)$$

Where S_t is direct irradiance perpendicular to the solar beam, A_t is the area of the body subject to direct irradiance (0.25, Mugaas and King 1981), S_b is scattered short wave radiation over the upper half of the body (A_d = 0.5) and S_r is reflected shortwave radiation incident on the low half of the bird (A_r = 0.5). Shortwave radiation incident on the substrate is partially absorbed and only a fraction (24% for grass, Campbell 1977), termed albedo, is reflected.

Direct irradiance S_t is the sum of direct irradiance on the horizontal surface (S_b) and diffuse sky irradiance: (S_d) Isado and Jackson (1969) :

$$S_t = S_b + S_d \qquad (20)$$

Direct irradiance on the horizontal surface is:

$$S_b = S_p \sin \phi \qquad (21)$$

where ϕ is the sun angle from the horizon.

Sun angle is determined from:

$$\sin \phi = \sin \beta \ \sin \delta + \cos \beta \ \cos \delta \ \cos 15(t-t_o) \qquad (22)$$

where β is the latitude (69.8°N), δ is the solar declination corresponding to the time of day and month (+8.6° for September 1), t is the time of day, and t_o is the time of solar noon (1300 hrs).

The value S_p is a function of the distance traveled by the solar beam through the atmosphere, transmissivity of the atmosphere, and the incident flux density:

$$S_p = a^m S_{po} \qquad (23)$$

where $S_{po} = 1.36$ kW/m^2, a is atmosphere transmission coefficient (0.9 for clear day, 0.6 for foggy day), and $m = 1/\sin \phi$.

The value of S_d, diffuse sky irradiance, is estimated from:

$$S_d = 0.5 \ S_{po} \ (1 - a^m) \sin \phi \qquad (24)$$

In the model, skin evaporative heat loss (τE) was assumed to be zero at the temperatures encountered during the study (Robbins 1983, Calder and King 1974) and respiratory evaporative heat loss (E_r) was estimated from Eq. 56 of Calder and King (1974):

$$E_r = \text{BMR} \ [0.05 + (0.0148 \ e^{(0.087Ta)}] \qquad (25)$$

Total heat production was estimated from the product of M and surface area (A). Surface area was estimated from Eq. 2 of Walsberg and King (1978):

$$A = 8.11 \ Wt^{0.667} \qquad (26)$$

Here A is expressed in cm^2 and Wt is body weight in grams. The validity of this estimate was examined by measuring the surface area of 2 adult male snow geese. The geese were skinned and the wings, including bone and muscle, were maintained intact with the skin. The flat skin, with the wings folded, was traced on paper and the surface area was measured with a planimeter. We entered the surface area (A) and weight of each goose into the equation $A = aWt^{0.667}$ and solved for a. The coefficient (a) for the two males averaged 8.46 and was similar to 8.11.

In the wild, the actual surface area exposed to convective and radiant heat transfer depends on the posture of the goose. surface exposure (A_e) was estimated as an average value and % exposure estimated from the sum of the proportion of surface area exposed in a given activity times the proportion of time spent in that activity. Proportions of surface exposure were 0.88 for resting, 0.96 for loafing, and 1.0 for other activities (Midtgard 1978).

In the absence of work, only a small fraction of the energy produced in metabolism is not lost as heat (King and Farner 1961), therefore, thermoregulatory costs (H_t) were calculated from the difference of total heat loss, including respiratory evaporation ($M + E_r$), and BMR. Theoretically, thermoregulatory costs are offset by SDE (Brody 1945, Calder and King 1974, Kleiber 1961), so we applied 80% of SDE heat production (Owen and Reinecke 1979) to H_t such that:

$$H_t = A_e [M + E_r] - BMR - (0.8\ SDE). \qquad (27)$$

Because heat production from SDE is only possible during digestion and absorption/metabolism of foods, SDE offset H_t in the model only during the 16 hr period of digestion, from 1 h after feeding began to 1 hr after feeding ceased. Although heat production from exercise should reduce thermoregulatory costs, this has not been found in birds (Mugaas and King 1981, Robbins 1983) and may be a function of the disruption of feather insulation during movement as well as increased surface exposure during activity (Calder and King 1974, Robbins 1983). Since flight results in high heat production, (Torre-Bueno 1978, Berger and Hart 1974, Berger et al. 1971, Torre-Bueno 1976), H_t in the model was calculated for nonflying time only.

Appendix VI

OTHER STUDIES

Appendix VI OTHER STUDIES

Contents | Page

ADFG Interim Report
Population status and trend of the Porcupine caribou herd, 1982-1985.. 1139

CWS Report
Distribution, movements and juvenile mortality of the Porcupine caribou herd in northern Yukon.................. 1147

APPENDIX I:

Distribution, activity and range use of male caribou in early summer in northern Yukon, Canada.................... 1184

AFWRC Progress Report: Subwork Unit 4
Caribou use of potential oil and gas development areas in the 1002 region of the Arctic National Wildlife Refuge.... 1205

AFWRC Progress Report: Subwork Unit 3
A sampling method to determine caribou use of coastal tundra on the Arctic National Wildlife Refuge : caribou use of the area surrounding the Kaktovik Inupiat Corporation (KIC) exploratory well No. 1 site............. 1217

AFWRC Progress Report: Subwork Unit 5
Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the Arctic National Wildlife Refuge...................... 1236

POPULATION STATUS AND TREND OF THE PORCUPINE CARIBOU HERD, 1982-1985

Kenneth R. Whitten

An interim report to the Arctic National Wildlife Refuge
U.S. Fish and Wildlife Service

Alaska Department of Fish and Game
Fairbanks, Alaska

April 1986

POPULATION STATUS AND TREND OF THE PORCUPINE CARIBOU HERD, 1982-1985.

Kenneth R. Whitten, Alaska Department of Fish and Game, Fairbanks, Alaska.

Background

Status of the Porcupine caribou herd prior to the early 1970's was not well known. Skoog (1968) reviewed a large body of mostly anecdotal and qualitative historical accounts and concluded that Porcupine herd numbers and distribution had fluctuated from the late 1800's through about 1960, but that a large caribou herd had been present during the entire period.

The first rigorous census of the Porcupine herd was conducted in 1972 (LeResche 1975) using the aerial photo-direct count-extrapolation (APDCE) technique (Hemming 1972). The APDCE technique involved: 1) photographing most of the herd while it was in large post-calving aggregations during July; 2) counting the caribou on the photos; 3) estimating the number of adult cows in the aggregations; and 4) estimating the composition of the entire herd during the rut in October. The number of adult cows in the herd was determined by multiplying the number of caribou in the photos by the proportion of cows estimated to be in the aggregations, and the population was estimated by dividing this figure by the proportion of cows in the entire herd. Needless to say, this stepwise process had many implicit assumptions and was subject to error and uncertainty at each step (Davis et al. 1979). LeResche (1975) estimated 100,000 caribou in the Porcupine herd in 1972 and concluded that, while numbers had probably not fluctuated much since at least 1950, there was really no sound basis for determining any overall population trend.

A second APDCE census was conducted in 1977. In this case some replicate counts were made during composition surveys, and it was possible to place confidence limits on the final estimate; 105,000 ± 28,000 caribou were estimated to be in the herd (Bente and Roseneau 1978, Davis 1978). There was an apparent reduction in the number of adult females from 1972-1977 (Davis 1978), but the difficulties in obtaining reliable herd composition data made it impossible to conclusively determine whether either numbers or composition had actually changed.

Problems with the standard APDCE technique were widely recognized by the late 1970's in Alaska, and a more reliable modified APDCE was developed (Davis et al. 1979). In this method, all post-calving aggregations are photographed, giving a direct photographic count of most of the herd. Remaining animals in the herd are then estimated through a peripheral area search in which line-transect and/or block quadrats are randomly or systematically sampled over the herd's range outside the aggregation area. Thus most of the herd is counted directly, and only a small portion of the overall estimate is subject to extrapolation errors.

A modified APDCE census of the Porcupine herd was conducted in 1979 (Whitten and Cameron 1980); 105,683 caribou were counted from photos, and only 3 more were located in a peripheral area search of most of the rest of the herd's range. Peripheral searches had to be terminated when caribou dispersed from the aggregation area during inclement weather. It was clear, however, that essentially all caribou had been accounted for on photos. The final estimate was rounded to 110,000 under the assumption that some caribou (primarily calves) were hidden behind other caribou on the photos, and that a few probably were not photographed at all (Whitten and Cameron 1980).

The Alaska National Interest Lands Conservation Act (ANILCA) of 1980 opened part of the Porcupine herd calving grounds in the Arctic National Wildlife Refuge (ANWR) to oil and gas exploration. ANILCA also mandated that baseline data on biological resources in the affected area be collected. As part of this program, population status and trend of the Porcupine caribou herd has been monitored jointly by the U.S. Fish and Wildlife Service (ANWR staff), the Alaska Department of Fish and Game (ADFG), the Yukon Territory Government (YTG), and the Canadian Wildlife Service (CWS). Results of censuses and population projections based on recruitment and mortality data are summarized in this report for the period 1982-1985.

Methods

Census Design

The modified APDCE technique (Davis et al. 1979) was used to census the Porcupine herd in July 1982. Tracking 29 active radio-collars assisted in locating post-calving aggregations. In 1983, intensive aerial surveys and tracking of 140 radio-collars indicated that very few, if any, caribou were not included in the post-calving aggregations; therefore, no peripheral area searches were flown to estimate caribou not in the photo-groups. Effectiveness of this "Radio-collar Census" technique has been discussed by Valkenburg et al. (1985).

Photography

In 1982, color-transparency photographs of some aggregations were taken with hand-held 35mm cameras from the side window of a Cessna 185 aircraft. Photos were taken from 120-300m above and 100-400m to the side of each group. Thus the camera angle was oblique, and some caribou (especially small calves) were potentially hidden from sight behind others. Two cameras, both with automatic film-winders, were available so that one could be reloaded while the other was in use. Even large groups could be covered with a single series of overlapping photographs using this method.

The remainder of the aggregations in 1982, and all groups in 1983, were photographed with a Fairchild T-11 aerial camera mounted in the belly of a DeHavilland Beaver aircraft, using black and white print film. Photo angle was vertical, but still some calves could be obscured beneath their mothers. Several overlapping transects were required to photograph some large groups. Transects were oriented along the long axis (usually the direction of movement) of each group. Overlap between photos within a transect was approximately 60%, and overlap between transects was about 30%. In a few cases, however, inadvertent navigation errors resulted in portions of transects that did not overlap.

Counting Caribou on Photos

Color prints prepared from the 35mm transparencies were used to determine overlap lines between photos. The original transparencies were then individually projected onto white sheets of paper, and with reference to the prints, overlap lines were drawn on the paper. Caribou were enumerated by marking each image with a pencil connected to an electric switch which kept a running tally. Whenever the observer marked the image of a calf, he also depressed a hand-held mechanical tally register. The difference between the electric tally count and the mechanical tally gave the total number of caribou 1 year of age or older on each photograph. Each frame was counted twice, either by the same person or by two different people; the two pencil-marked sheets of paper from each frame could then be compared to each other and to the original transparency if the counts disagreed.

Overlap lines were drawn directly on the black and white prints (ca. 23cm x 23cm) taken with the Fairchild camera. To facilitate counting, a transparent acetate grid was taped to each photo, and its position was marked on the photo so that the grid could be replaced in the same position for replicate counts. Magnifying lenses (8 or 10x "Lupe" viewers) and hand-held tally registers were used to count caribou. Subtotals were entered on a data sheet by photo number and grid row number. The same or different observers could thus compare total counts and/or row counts for each photo as a means of assessing accuracy and consistency in counting. No attempt was made to distinguish calves from adults on the black and white prints.

Estimation of Population Trends

From 1983-1985, initial productivity, calf survival/yearling recruitment, and adult mortality data were available from large samples of radio-collared caribou. Population change (expressed as a percent) was calculated as the difference between recruitment and mortality. Population size in 1984 and 1985 was estimated by applying these changes to the 1983 census figures.

Results and Discussion

1982 Census

In July 1982, the Porcupine herd formed post-calving aggregations in 2 areas within ANWR. Eleven caribou groups in the Brooks Range between the Egaksrak and Clarence Rivers were photographed with 35mm cameras on 6 and 7 July. Eight groups on the coastal plain between the Okpilak and Aichilik Rivers were photographed with the Fairchild aerial camera on 13 July. Daily tracking of 29 radio-collar caribou during the intervening period indicated that the mountain and coastal plain groups remained separated, with 1 exception. Some caribou (including 2 of 4 with radio-collars) from the lowest elevation and westernmost mountain group later joined with the coastal groups.

There were 46,107 caribou counted on the photos from the mountains, and 81,473 from the coast. To adjust for the mixing of part of 1 mountain group with the coastal groups, the total count was adjusted downwards by 2,287 caribou (one-half of that particular mountain group count). An additional 46 caribou were observed during 10 hrs. of intensive aerial survey in a 5,000 km^2 area surrounding the aggregation areas. No caribou were observed in 14 quadrat search areas (each 92.4 km^2) located randomly over the remainder of the Porcupine herd summer range. Thus the Porcupine herd population, based solely on caribou observable on photos or counted directly from aircraft, was 125,339 caribou.

Calves not visible in the oblique angle photos of the mountains were estimated by comparing the percentage of calves identifiable in the photos with the percentage observed in composition counts of the same groups. There were 2.1% calves in the photos. Of 8,082 caribou in the mountains which were classified by ground based observers using binoculars or spotting scopes, 8.2% were calves. Thus nearly 3 calves may have been missed for each calf counted on the photos.

The vertical photo angle used for coastal groups should have prevented concealment of calves behind their mothers. Nevertheless, comparison of some particularly high quality prints (sharp focus) with lower quality prints (hazy focus) suggested that calves standing very close to, touching, or partially under their mothers would not be discernible as separate from their mothers in the poorer focus photos. Composition counts of 11,636 caribou on the coastal plain indicated 20% calves. It was estimated that discernability of calves was greater in the coastal group photos than in the mountain group photos, but that about half the calves may still have been missed. In all, there may have been about 3,000 undetected calves in the mountains, and 9,000 on the coastal plain. Thus the photo count may have actually represented about 137,000 caribou.

1983 Census

The Porcupine herd formed dense post-calving aggregations during the first week of July in 1983. Thirteen groups were located on the coastal plain between the Aichilik and Niguanak Rivers. In the mountains, 10 groups were in the Egaksrak Valley and 1 was in the Kongakut Valley. All groups were photographed with the vertical angle Fairchild camera on 6 July. There were 140 radio-collared caribou distributed among the groups. Daily tracking of these animals prior to the census was combined with visual search for groups of caribou without radio-collars. By the time photographs were taken, all radio-collared caribou were in the aggregations, and no other groups could be found away from the aggregation areas. Peripheral area searches in 1982 had not located any additional caribou outside the immediate aggregation area. Thus it was determined that peripheral area searches in 1983 would also add inconsequentially to the total count, and none were flown.

There were 93,645 caribou counted on photos of the coastal groups, including 80,651 in a single group. In the mountains, there were 41,639 caribou, with 12,396 in the largest group. The total count from photos was thus 135,284. Composition counts were conducted in the coastal area only, and sample size was small (2584 caribou). No attempt was made to estimate additional caribou not discernible on photos.

1984 and 1985 Population Projection

No censuses were conducted in 1984 or 1985, but the changes in population size can be estimated from recruitment, mortality, and herd composition data. Yearling recruitment and adult mortality estimates are available from studies of radio-collared caribou. Composition data have been collected from aerial and ground counts and from radio-collaring studies.

A sex ratio of 60 bulls per 100 cows was observed during an intensive aerial and ground based composition survey of the entire range of the Porcupine herd in fall 1980 (Whitten and Cameron 1981). This skew in adult sex ratio toward females is consistent with most other lightly hunted or unhunted caribou populations in North America (Bergerud 1978), and is presumably due to relatively higher natural mortality among males (Davis and Valkenburg 1985). In the absence of any known selective harvest pressure toward either sex in the Porcupine herd during the past 5 years, adult sex ratio is presumed to have remained unchanged since 1980.

For purposes of calculating population change, an initial productivity of 70% was assumed, based on the following observations. Productivity among radio-collared cows aged three years or older was 78% in 1983 (Whitten et al. 1984), and 74% in 1984 (Whitten et al. 1985b). However, very few radio-collared two year old cows from the Porcupine herd (1 of 42) produced calves from 1983-1985 (Whitten et al. 1986b). Thus the productivity observed among older radio-collared cows would likely overestimate herd productivity. Similarly, aerial surveys of a high density calving area in 1983 estimated a productivity of 74% (Whitten et al. 1984), but many barren cows were known to be distributed away from the core calving area, based on both radio-collar and aerial survey data, and this ratio would likely also overestimate herd productivity. Thus the slightly lower figure of 70% productivity was used.

First year mortality among calves radio-collared in 1983 was between 39 and 57%, and was most probably about 43% (Whitten et al. 1985a). First year mortality in the 1984 calf cohort was 40% (Whitten et al. 1986a). A mean rate of 41.5% for both years is assumed here for calculating population change. Mortality among radio-collared adult females and yearlings (both sexes, but predominantly females) was 8-12% from June 1983 to May 1984 (Whitten et al. 1985a), and 11% over the next year (Whitten et al. 1986a). The mean rate for the two years was assumed to be 10.5%.

In this hypothetical context, age/sex structure would be stable and the entire population (including calves) would increase at the same rate. There would be 37 yearlings per 100 cows each year. Observed yearling composition on the core calving grounds was 24 yearlings per 100 cows in June 1983 (Whitten et al. 1984b). However, many yearlings, particularly males, were known to occur away from the core calving area, based on radio-collar locations and aerial surveys. Thus the calculated ratio of 37 yearlings per 100 cows is not unreasonable.

With these data and assumptions, the population changes from 1983 to 1984 and 1985 can be calculated. The 70 calves produced for every 197 adults (ie., 100 cows, 60 bulls, and 37 yearlings) in 1983 and 1984 would result in 41 yearlings recruited the next year, or a potential increase of 20.8% to the previous year adult base population. However, that adult base would have decreased 10.5% from mortality, and the realized increase in the adult population would be 10.3%. Expressed in slightly different terms, for every 197 adults alive in one year, 176.3 would survive to the next June. These would be supplemented by 41 new yearlings, yielding 217.3 adults altogether, or an increase of 10.3%. At this rate, the 135,284 caribou counted from photos in July 1983 would have grown to approximately 149,000 in July 1984 and 165,000 in 1985.

The assumptions used to derive these estimates are based on mean values, or in some cases on what may be termed as "informed guesses" based on partial and incomplete data. Slight changes in these assumptions would produce different results. For example, a calf mortality of 45% (which is higher than actually observed) and an adult mortality of 15% (higher than the value of 10.5% used above, which was calculated mostly from females) would yield an annual increase rate of only 5.8% and only about 151,000 caribou in 1985. However, considering that the 1983 population figure was a direct count from photos and likely underestimated the actual population, the "best guess" estimate of about 165,000 caribou in 1985 would still be a reasonable figure. Assuming a continued increase rate of 10.3% per year, there should be about 182,500 caribou in the Porcupine herd in 1986. Only another census, such as planned for July 1986, can verify this projection.

The current estimate of a 10.3% yearly increase rate is higher than the rate of 6-8% derived emperically from census results from 1979-1983 (Whitten and Cameron 1984). This accelerated rate of increase is reasonable, considering that harvest has remained fairly constant while the herd has been growing, resulting in a lower proportion of the herd being shot each year and a decrease in the contribution of hunting to overall mortality. Furthermore, initial productivity rates apparently increased after 1982 and have remained high since. There is little doubt that the Porcupine Herd is growing and is probably growing faster now than it was a few years ago.

Literature Cited

Bente, P.J., and D.G. Roseneau. 1978. An aerial photo-estimate of the 1977 Porcupine caribou herd population. Renewable Resources Consulting Serv. Ltd. Fairbanks, Alaska. 84pp.

Bergerud, A.T. 1978. Caribou. Pages 83-101 in J.L. Schmidtz and D.L. Gilbert, eds. Big game in North America. Stackpole Books, Harrisburg, Pa. 494pp.

Davis, J.L. 1978. Sex and age composition of the Porcupine caribou herd. Alaska Dep. of Fish and Game, Fed. Aid Wildl. Rest. Proj. Final Rep. W-17-9 and W-17-10, Job 3.23R. Juneau, Ak. 23pp.

Davis, J.L., and P. Valkenburg. 1985. Qualitative and quantitative aspects of natural mortality of the Western arctic caribou herd. Alaska Dep. Fish and Game. Fed. Aid in Wildl. Rest. Final Rep. Juneau, Ak. 71pp.

Davis, J.L., P. Valkenburg, and S.J. Harbo, Jr. 1979. Refinement of the aerial photo-direct count-extrapolation caribou census technique. Alaska Dep. of Fish and Game, Fed. Aid. Wildl. Rest. Proj. Final Rep. W-17-11, Job 3.25R. Juneau, Ak. 23pp.

Hemming, J.E. 1972. Techniques for aerial photo censusing of caribou. Alaska Dep. of Fish and Game, Fed. Aid. Wildl. Rest. Proj. Progress Rep. W-17-2 and W-17-3, Job No. 3.1R. Juneau, Ak. 4pp.

LeResche, R.E. 1975. The international herds: present knowledge of the Forty-mile and Porcupine caribou herds. Pages 127-134 in J.R. Luick, P.C. Lent, D.R. Klein and R.G. White, eds. Proc. First Int. Reindeer/Caribou Symp. Biol. Pap. Univ. Alaska. Spec. Rep. 1. 551pp.

Skoog, R.O. 1968. Ecology of the caribou (Rangifer tarandus) in Alaska. Ph.D. Dissert., Univ. California, Berkeley. 699pp.

Valkenburg, P., D.A. Anderson, J.L. Davis, and D.J. Reed. 1985. Evaluation of an aerial photocensus technique based on radio-telemetry. Pages 287-300 in T.C. Meredith and A.M. Martell, eds. Proc. Second North Am. Caribou Workshop. McGill Subarctic Research Paper No. 40. McGill Univ. 327pp.

Whitten, K.R., and R.D. Cameron. 1980. Composition and harvest of the Porcupine caribou herd. Alaska Dep. of Fish and Game. Fed. Aid. Wildl. Rest. Prog. Rep. W-17-9, 10, 11 and 21. Job. 3.23R. Juneau, Ak. 22pp.

Whitten, K.R., and R.D. Cameron. 1981. Caribou survey - inventory report. Alaska Dep. Fish and Game. Fed. Aid. Wildl. Rest. Rep. Proj. W-19-1 and W-19-2, Job No. 3.0, 1.0, and 12.0. Juneau, Ak.

Whitten, K.R. and R.D. Cameron. 1984. Size and composition of the Porcupine caribou herd, 1982. Pages 601-605 in G.W. Garner and P.E. Reynolds, eds. 1983 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak. 614pp.

Whitten, K.R., G.W. Garner, and F.J. Mauer. 1984. Calving distribution, initial productivity and neonatal mortality of the Porcupine caribou herd, 1983. Pages 359-420 in G.W. Garner and P.E. Reynolds, eds. 1983 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak. 614pp.

Whitten, K.R., F.J. Mauer, G.W. Garner, and D.E. Russell. 1985a. Fall and winter movements and distributions, and annual mortality patterns of the Porcupine caribou herd, 1983-1984. Pages 515-526 in. G.W. Garner and P.E. Reynolds, eds. 1984 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak. 777pp.

Whitten, K.R., F.J. Mauer, and G.W. Garner. 1985b. Calving distribution, initial productivity and neonatal mortality of the Porcupine caribou herd, 1984. Pages 527-621. in G.W. Garner and P.E. Reynolds, eds. 1984 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak. 777pp.

Whitten, K.R., F.J. Mauer, and G.W. Garner. 1986a. Calving distribution, initial productivity and neonatal calf mortality of the Porcupine caribou herd, 1985. Pages ___-___ in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, Ak. ___ pp.

Whitten, K.R., F.J. Mauer, and G.W. Garner. 1986b. Fall and winter movements and distribution, and annual mortality patterns of the Porcupine caribou herd, 1984-1985. Pages ___-___ in G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitat. U.S. Fish and Wildl. Serv., Anchorage, Ak. ___pp.

DISTRIBUTION, MOVEMENTS AND JUVENILE MORTALITY OF THE PORCUPINE CARIBOU HERD IN NORTHERN YUKON, JUNE 1982 - JANUARY 1986

DON E. RUSSELL
WENDY A. NIXON

Canadian Wildlife Service
Whitehorse, Yukon

January, 1986

INTRODUCTION

This report outlines the results of joint Porcupine Caribou investigations from summer 1982 to winter 1986, between the U. S. Fish and Wildlife Service (funding agency) and the Yukon Department of Renewable Resources (personnel). In December 1983, the senior author joined the Canadian Wildlife Service and all three parties agreed that the project would continue with the same personnel. The project was initially designed to provide information to the funding agency on both the juvenile mortality of the herd and on the possible impact of petroleum development on the range use of the herd. Two mortality projects were initiated. The first, on neonatal mortality, was the prime responsibility of the U. S. Fish and Wildlife Service and the Alaska Department of Fish and Game. In Canada, support for this project was in the form of radio-tracking flights to monitor the mortality collars and to monitor the movement patterns and distribution of animals in Canada. As well, when mortality signals were detected in Canada, the collars were retrieved and the cause of death investigated. Mortality of juvenile caribou, other than neonates, was the focus of the second study and Canadian personnel took the initial lead role in the study. Similar arrangements with monitoring and collar retrieval were negotiated with Alaskan biologists.

Two aspects of caribou range use in relation to petroleum development were investigated. The spring range use of bulls in northern Yukon was studied via radio-monitoring and ground camps (see attached report entitled - Distribution, activity and range use of male caribou in early summer in northern Yukon, Canada). The second project is designed to provide baseline information on the range use of the herd in summer, with particular reference to the use of insect relief areas. This project has one more year of field work until completionand will not be reported here. Both of these projects are the primary concern of the Canadian Wildlife Service.

All of these projects derived partial funding from the U. S. Fish and Wildlife Service, primarily in the form of fixed-wing and helicopter support. The proportion of the contribution varied among projects.

DISTRIBUTION AND MOVEMENTS

Twenty - five surveys were conducted in support of the projects mentioned, varying in length from one day to 7 weeks (Table 1). A brief verbal description of these surveys with accompanying distribution maps is provided. The discussion and maps depict the areas of concentrated use by caribou, as determined by the general location of radio collared individuals and augmented by visual sightings and tracking evidence when possible. Distribution in Alaska is not represented on the maps.

16 June - 26 June, 1982 (Figure 1)

The objective of this survey was to locate and monitor the movements of male caribou prior to their joining females aggregating on the coast during post-calving period. Seven of the ten collars were located in the upper portions of the Colleen and Firth Rivers. The remaining three collars were scattered in northern Yukon; one east of Mt. Sedgwick, one on the lower Firth River, one north of the Porcupine River.

The core group of seven collars moved north and east during the ten day survey period, and five of these were strung out along the Firth River. The others were relocated at the head of Crow and Trail Rivers just west of Mt. Sedgwick.

The distribution of radio collared males may not have realistically reflected the distribution of migrating bulls. Other biologists working in the region reported large numbers of bulls moving north from the northern Old Crow Flats and northern Richardson Mountains.

28 August - 2 October, 1982 (Figure 2)

On 30-31 August, caribou sign was observed which indicated movement east and southeast through the British Mtns. Large numbers of caribou were moving through the mountains, from Bear Mtn. to the head of Black Fox Crk. Approximately 100 caribou were locted east of Old Crow on the Porcupine River.

In early September, scattered bands of caribou were found at the heads of the Firth and Driftwood Rivers, east of the Babbage River, and east and west of the Blow River. Surveys on 21-22 September revealed heavy trailing from the northern Richardson Mtns. to the Driftwood Hills. Many thousands of caribou were observed south of Bonnet Lake and north of treeline. On 25-26 September a few scattered bands were found in the Old Crow Range and a few had crossed the Porcupine River.

The front of migrating caribou was located on the lower Bell River on 1-2 October. Aerial surveys were discontinued at this point, but in mid-October, caribou were observed crossing the Dempster Highway at Eagle Plains.

TABLE 1. Details of radiotracking surveys

PERIOD	DATE	AIRCRAFT	HOURS FLOWN	COLLARS	FIGURE
Summer 1982	16 - 26 June	C206	47	17	1
Fall 1982	28 Aug. - 2 Oct.	C185	45	23	2
Late winter 1983	23 - 27 Feb.	C185	26	55	3
Spring 1983	27 - 29 April	C185	21	50	4
	18 - 19 May	C185	10	36	5
	31 May - 1 June	C185	10	30	6
Calving 1983	10 June	C185	7	8	7
Summer 1983	18 June	C185	7	10	8
	24 June	C185	5	10	9
Fall 1983	24 - 27 October	C206	10	67	10
Early winter 1983	7 - 8 Dec.	Navaho	8	63	11
Late winter 1984	8 - 10 Feb.	C206	21	58	12
Spring 1984	8 April	Seneca	11	49	13
	23 - 28 April	C185	25	35	14
	18 May	Seneca	11	55	15
Summer 1984	1 July - 4 August	C185, B206	115	varied	16
August 1984	22 - 23 August	C185	15	89	17
Fall 1984	20 - 22 September	C185	18	97	18
Early winter 1984	16 - 17 November	Seneca	15	46	19
	6 - 7 December	Seneca	12	52	19
Spring 1985	22 May	Seneca	10	23	20
Summer 1985	16 June - 6 August	C185,C206,B206	150	varied	21
Fall 1985	5 September	Seneca	11	78	22
Fall 1985	15 - 16 October	Seneca	15	96	23
Mid winter 1986	8 - 9 January	Seneca	15	75	24

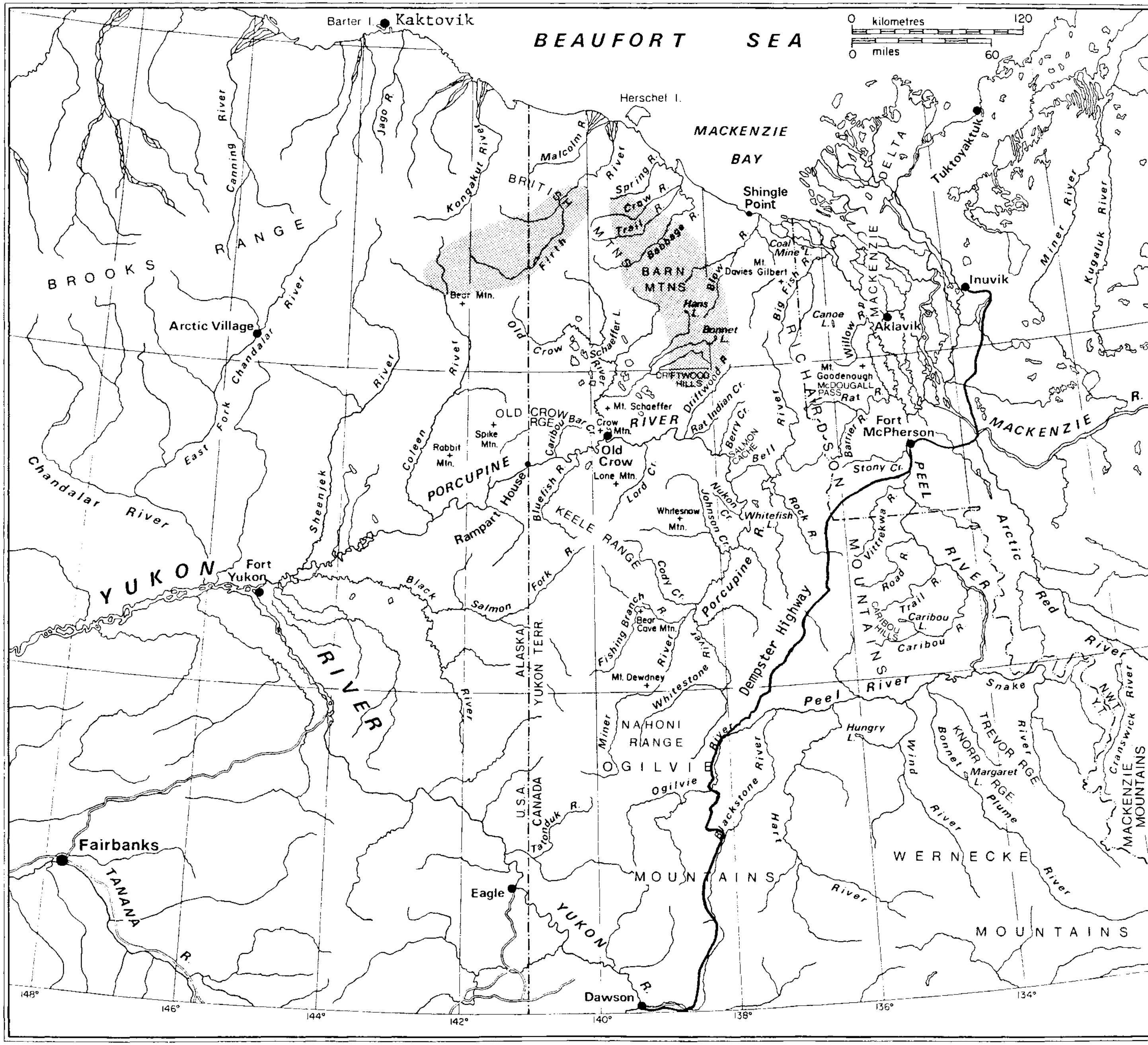


Fig. 1. Porcupine caribou herd distribution 16-26 June, 1982 (primarily bulls).

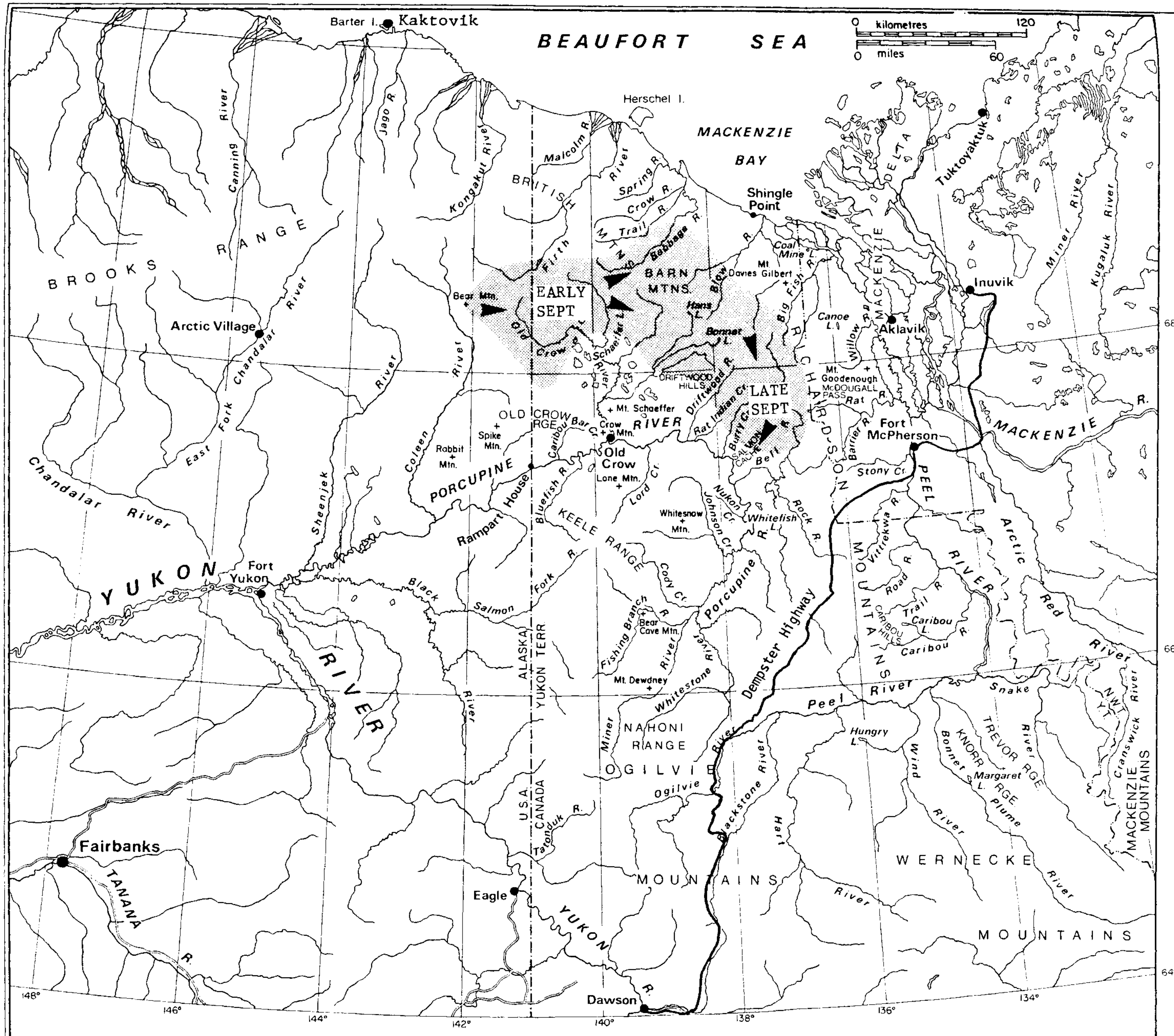


Fig.2. Porcupine caribou herd distribution 28 August - 2 October, 1982.

15 March - 19 March, 1983 (Figure 3)

A dense concentration of caribou occurred in the area of Whitefish Lakes and upper Bell River. Other caribou were scattered south to the Peel River, west to the Fishing Branch, and east to the south Richardson Mtns.

27 April - 29 April, 1983 (Figure 4)

Caribou or their sign were evident in the narrow band extending from Whitefish Lakes to the head of the Babbage River. Animals were concentrated in the low hills at the head of Berry Crk. and the isolated range of hills south of Bonnet Lake and west to the head of the Driftwood River. The North-south extent of this distribution was about 100 miles and generally confined to the Richardson Mountains west of the Bell River. West of the Porcupine River, a much smaller undetermined number of caribou were moving northward through the head of Johnson Creek into the Lord Creek drainage.

18 May - 19 May, 1983 (Figure 5)

Five bulls were located in the area of Johnson Crk., Driftwood River, and Little Flat Creek. Three other bulls were located northeast of Old Crow Flats. Many cows were located in the region of Timber Crk., Muskeg Crk., Joe Crk. and the Firth River. The remaining collared cows were located in the upper Bell and upper Blow Rivers, and between the Babbage and Trail Rivers. Movement was generally north and west.

31 May - 1 June, 1983 (Figure 6)

A large number of caribou were found on the Coastal Plain south of Clarence Lagoon and Komakuk. Others were located on the Malcolm and Firth River deltas, and on the upper Firth River among the Aspen, Joe, and Muskeg Crk. tributaries.

10 June, 1983 (Figure 7)

Caribou (bulls primarily) were concentrated in an arc along the north edge of the Old Crow Flats and in the headwaters of the Firth River. Scattered groups were also noted on the south edge of the British Mountains and along the coastal plain near the mouth of the Babbage River.

18 June, 1983 (Figure 8)

Surveys continued to concentrate on the bull segment of the herd. The majority of radiocollared bulls were relocated within the headwaters and tributaries of the Firth River. Animals were noted also scattered north of Old Crow Flats, in the Crow

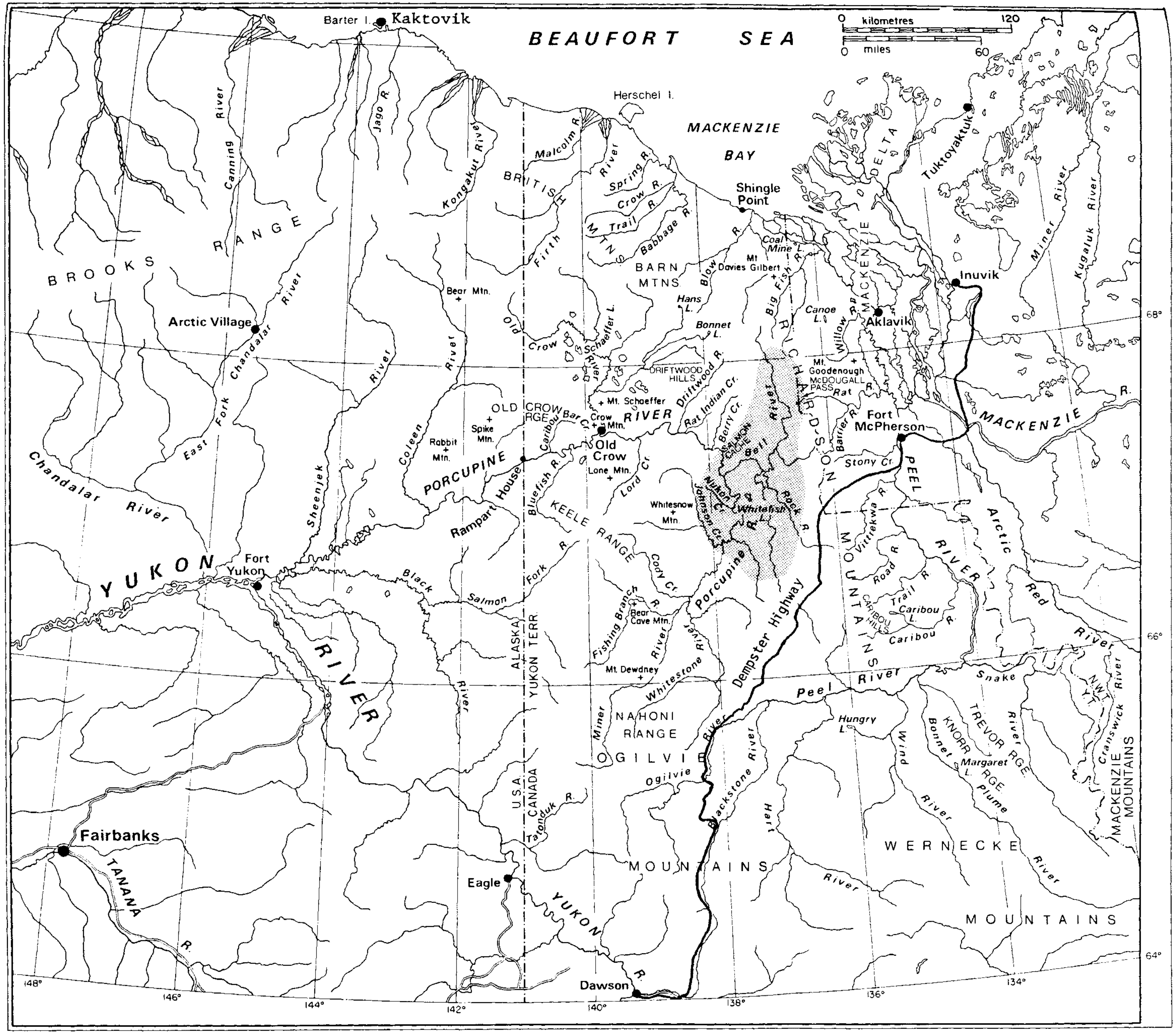


Fig. 3. Porcupine caribou herd distribution 15-19 March, 1983.

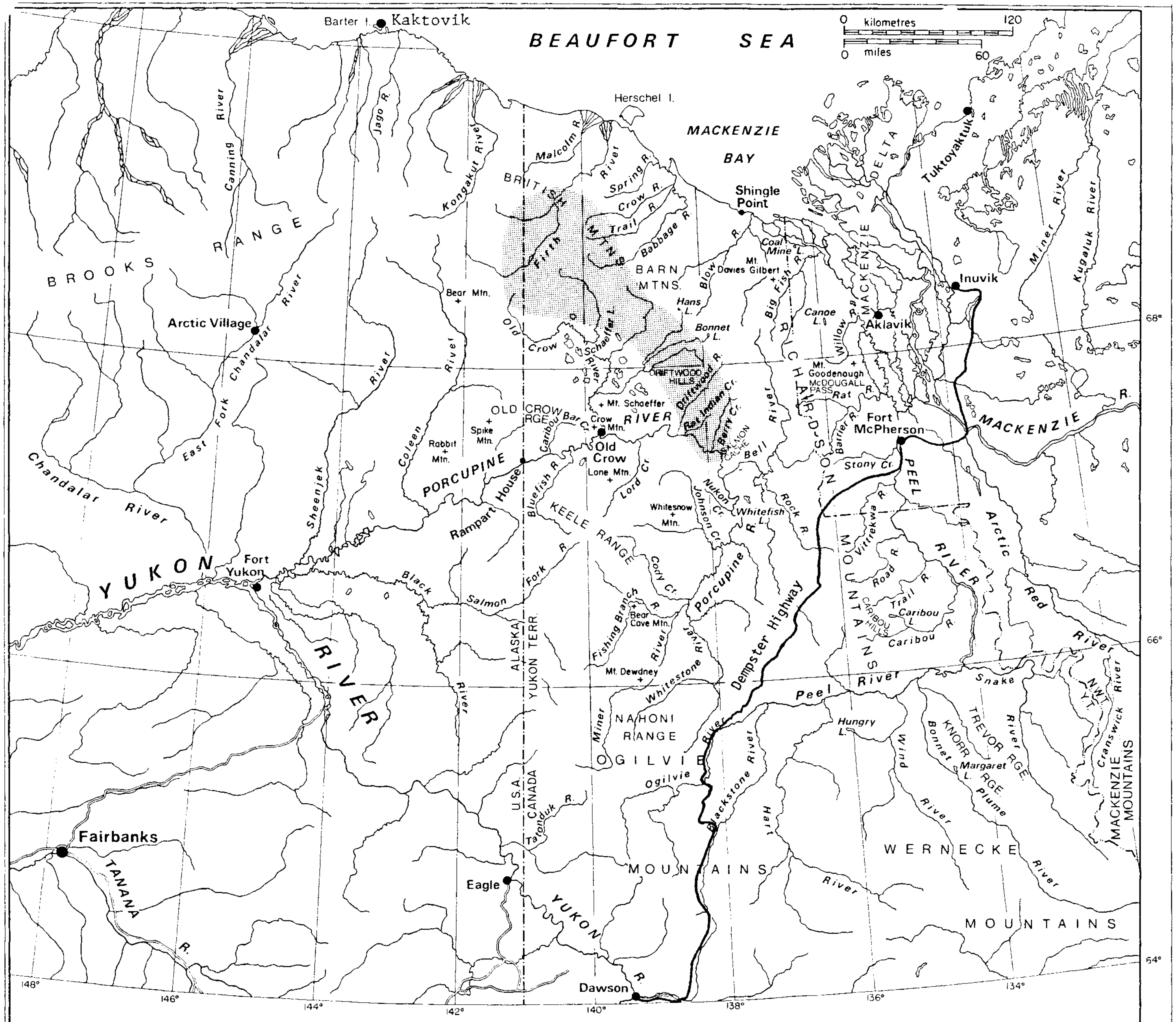


Fig. 4. Porcupine caribou herd distribution 27-29 March, 1983.

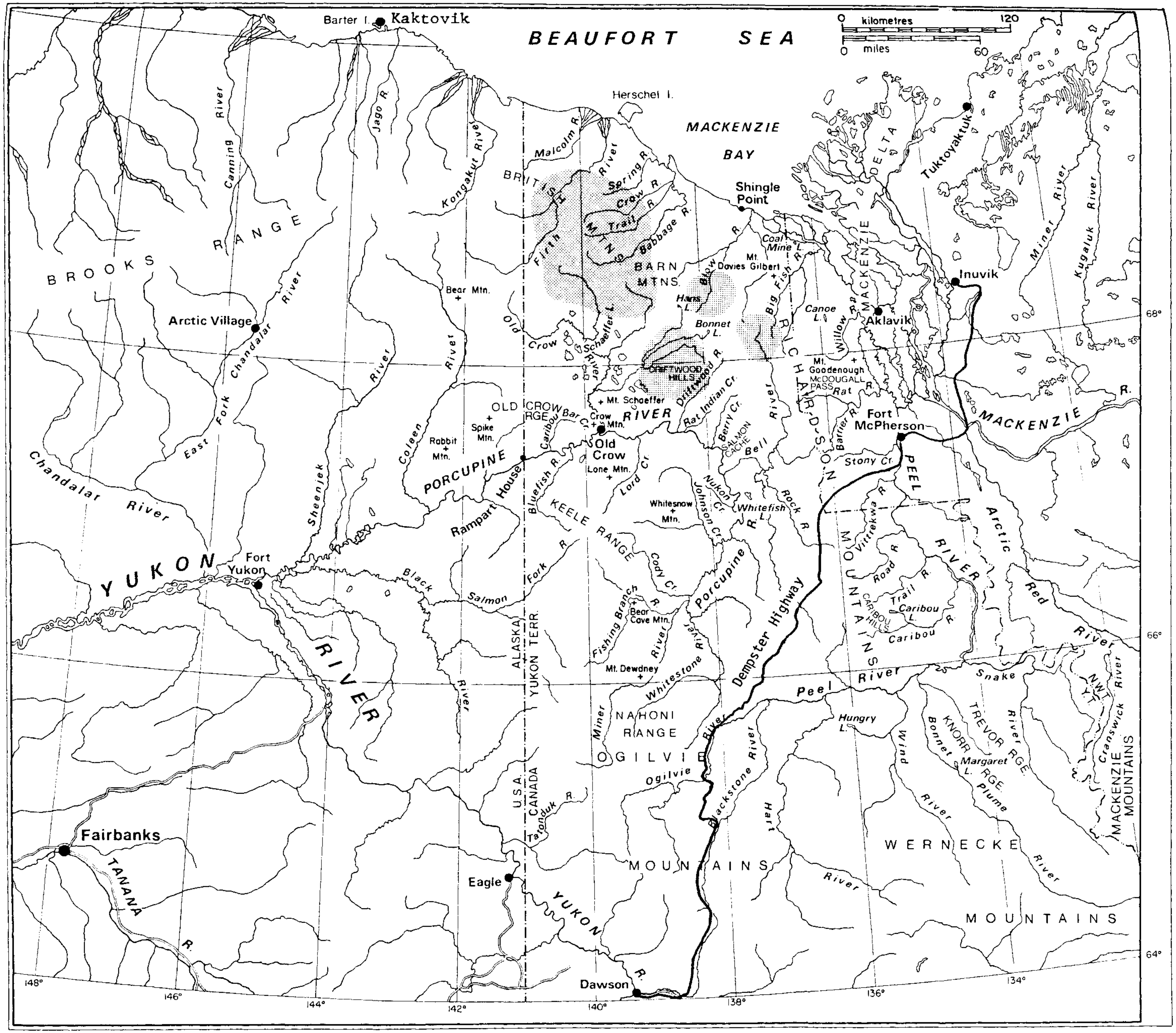


Fig. 5. Porcupine caribou herd distribution 18-19 May, 1983.

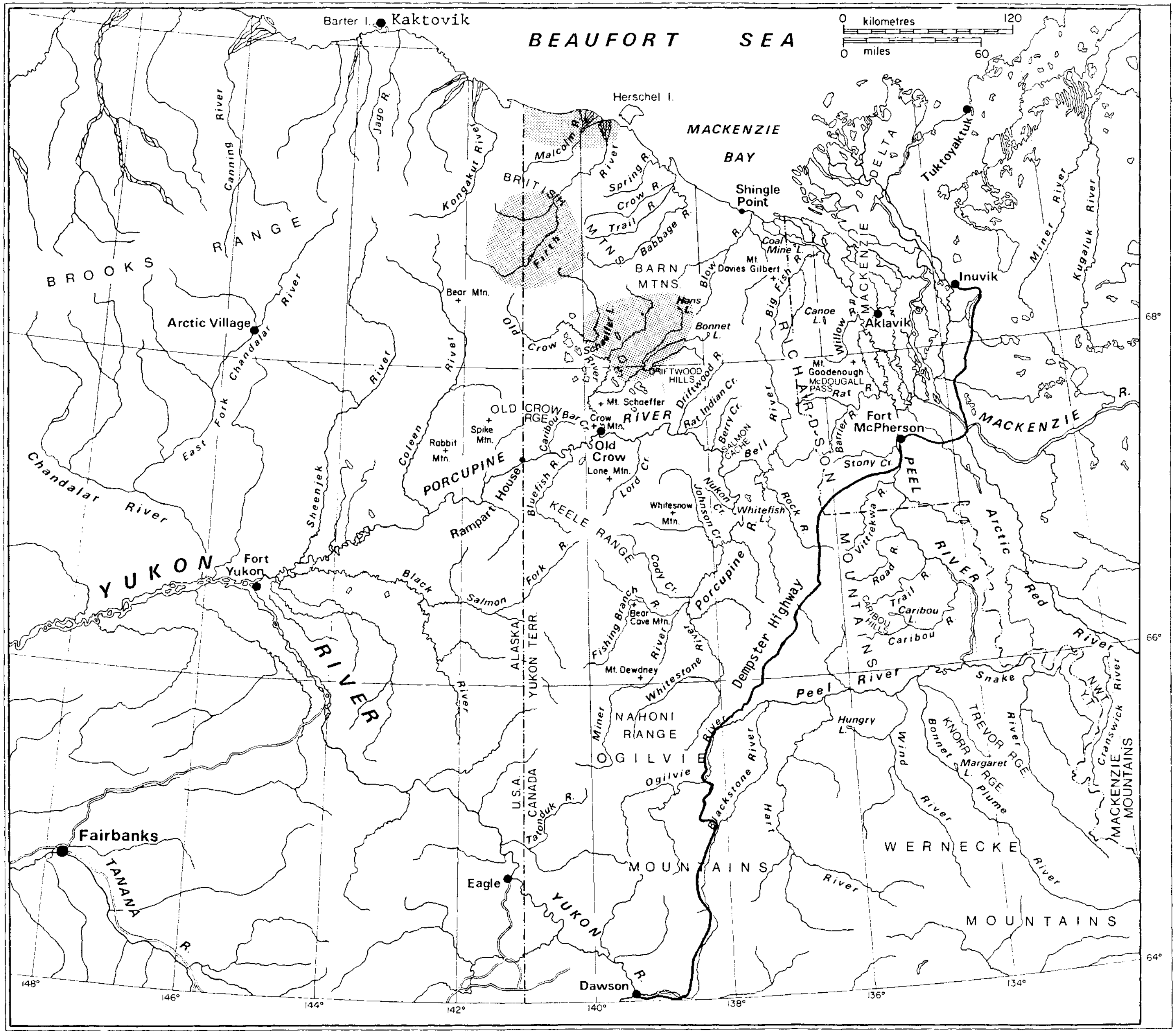


Fig. 6. Porcupine caribou herd distribution 31 May - 1 June, 1983.

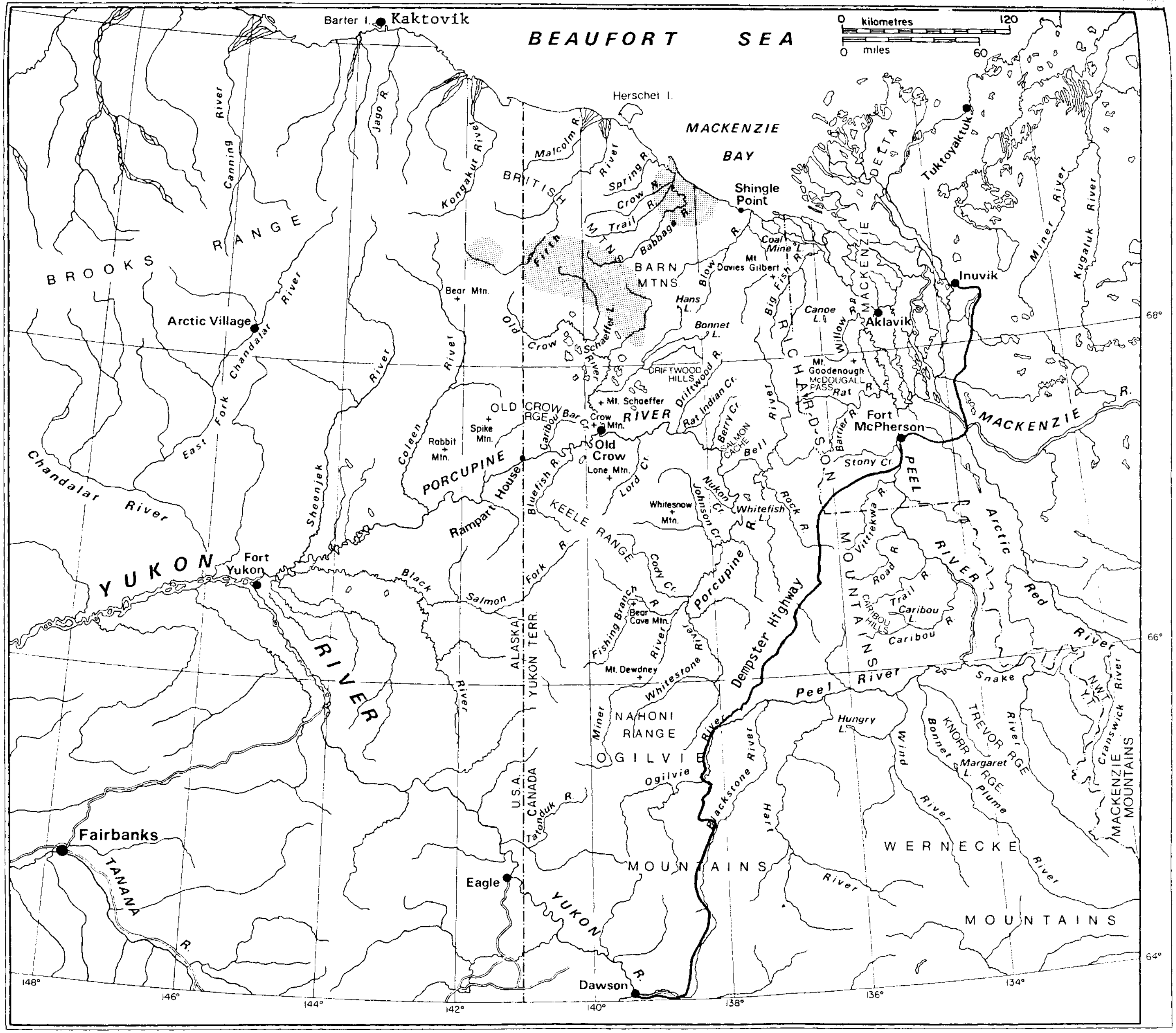


Fig. 7. Porcupine caribou herd distribution 10 June, 1983.

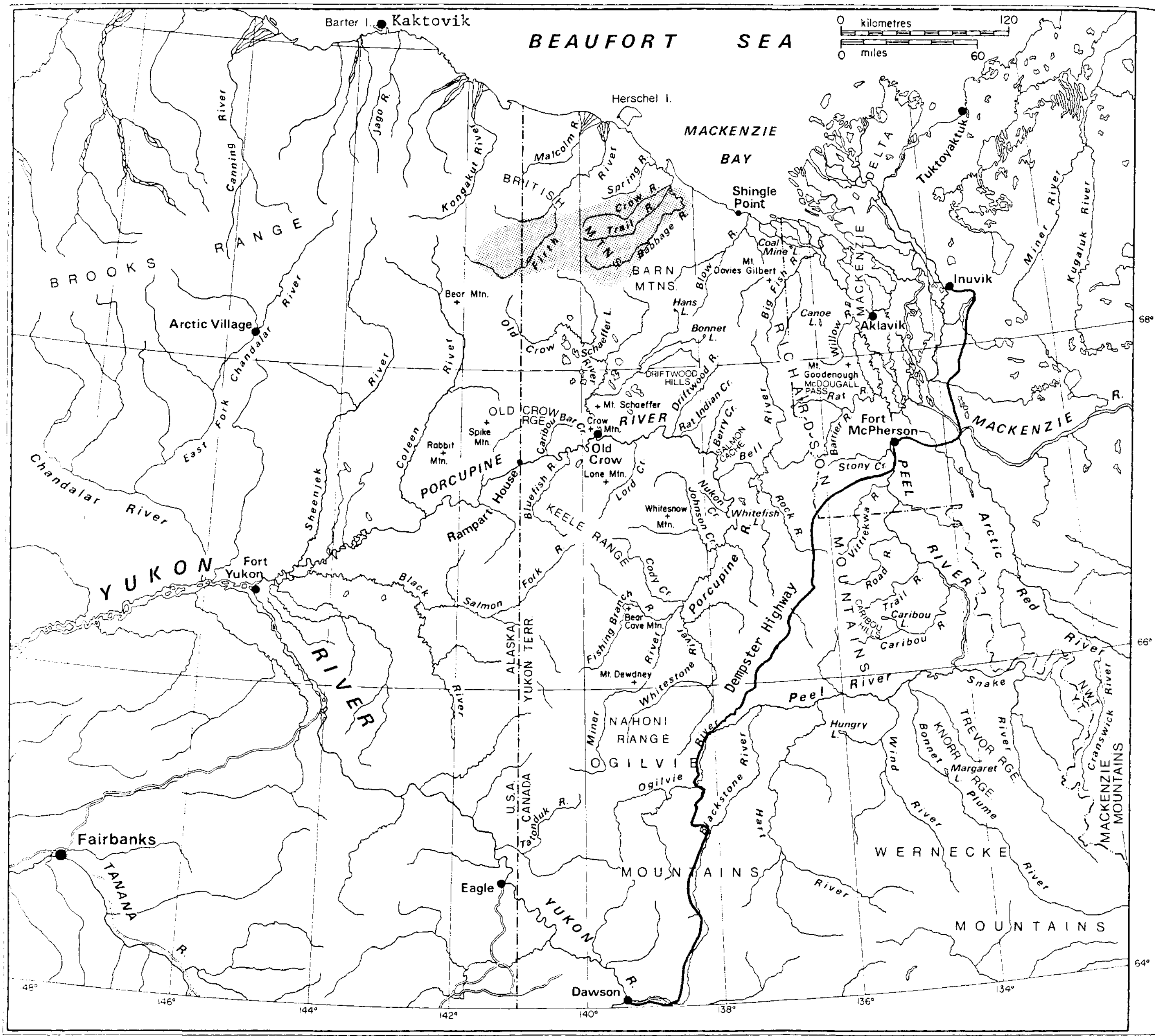


Fig. 8. Porcupine caribou herd distribution 18 June, 1983 (primarily bulls).

drainage and on the coastal plain.

24 June, 1983 (Figure 9)

The majority of bulls still remained in the Firth drainage, scattered from Joe Creek to the mouth of the Firth. More of a concentration appeared in the Crow River drainage compared to the 18 June survey.

24 October - 27 October, 1983 (Figure 10)

An extensive survey over the winter range revealed that the majority of Yukon wintering animals were concentrated in the Ogilvie and Hart basins (67 of 70 collars relocated). Trailing in the area was extensive and snow cover was 100%. The remaining collars were scattered north to Old Crow generally evenly spaced along the Old Crow migration route.

7 December - 8 December, 1983 (Figure 11)

By early winter the distribution had shifted detectably to the north with increased number of collars located in the Peel plateau and Eagle plains region. However, the Ogilvie and Hart drainages still contained the majority of collars.

8 February - 10 February, 1984 (Figure 12)

A northward shift in distribution continued by late winter with 35 of 60 collars relocated in the upper Whitestone drainage and Eagle plains. A large number of collars still remained in the Ogilvie basin.

8 April, 1984 (Figure 13)

The main concentration of radio-collared caribou was in the Fishing Branch River basin and lower Miner River (25 collars). The remainder were found in the upper Whitestone River basin (10 collars), the Ogilvie River basin (11 collars) and the Hart River basin (8 collars). The six remaining collars were relocated scattered between the areas of concentration.

23 April - 28 April, 1984 (Figure 14)

Spring migration proceeded slowly since the previous relocation flight, with the majority of animals still in the Fishing Branch drainage and lower Miner River. Animals in groups of 50 to several hundred were beginning to concentrate in the mountains south of Old Crow but did not appear to be progressing further north onto the Little Flats south of Old Crow. A few animals were scattered as far south as the Hart basin.

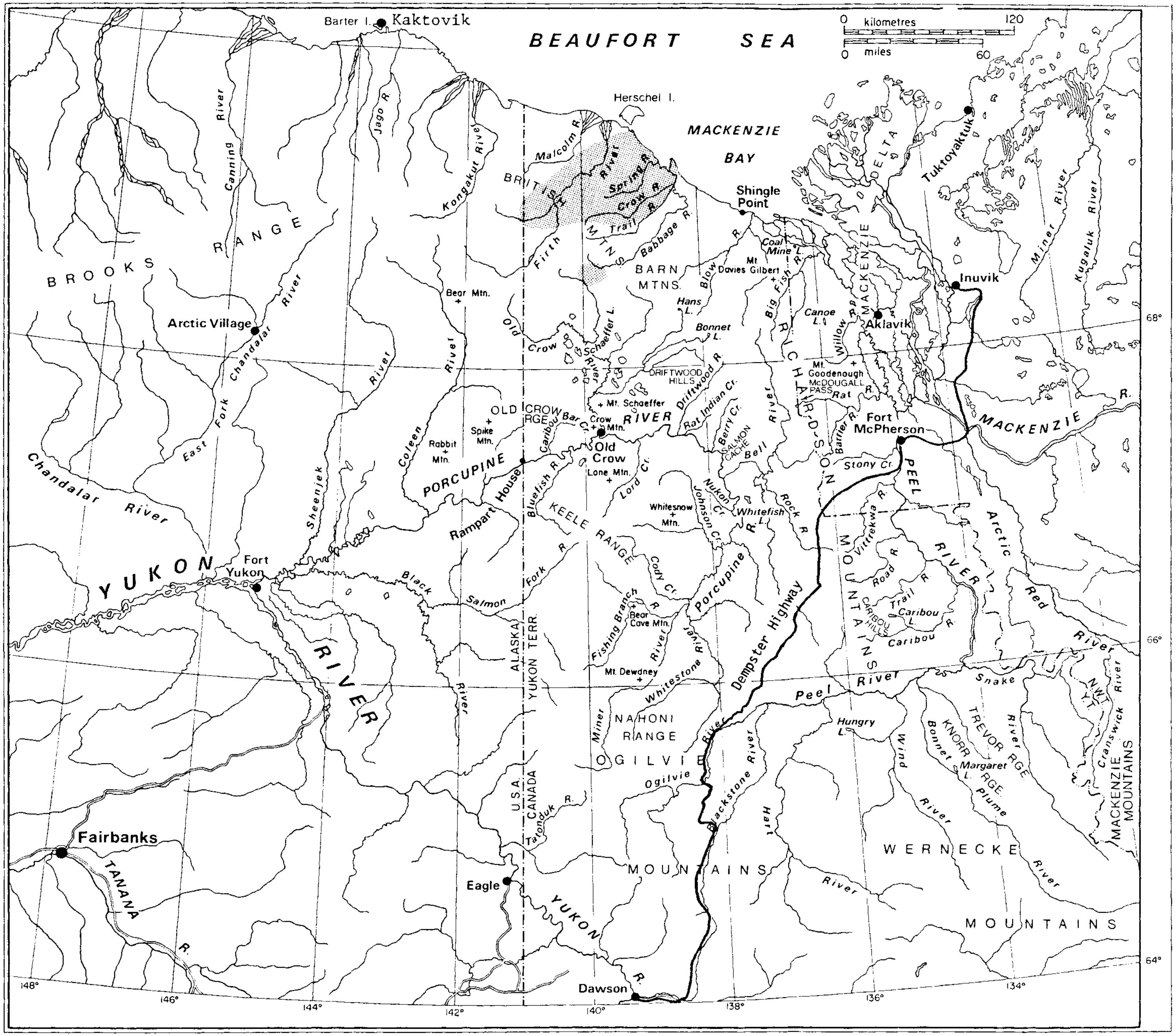


Fig. 9. Porcupine caribou herd distribution 24 June, 1983 (primarily bulls).

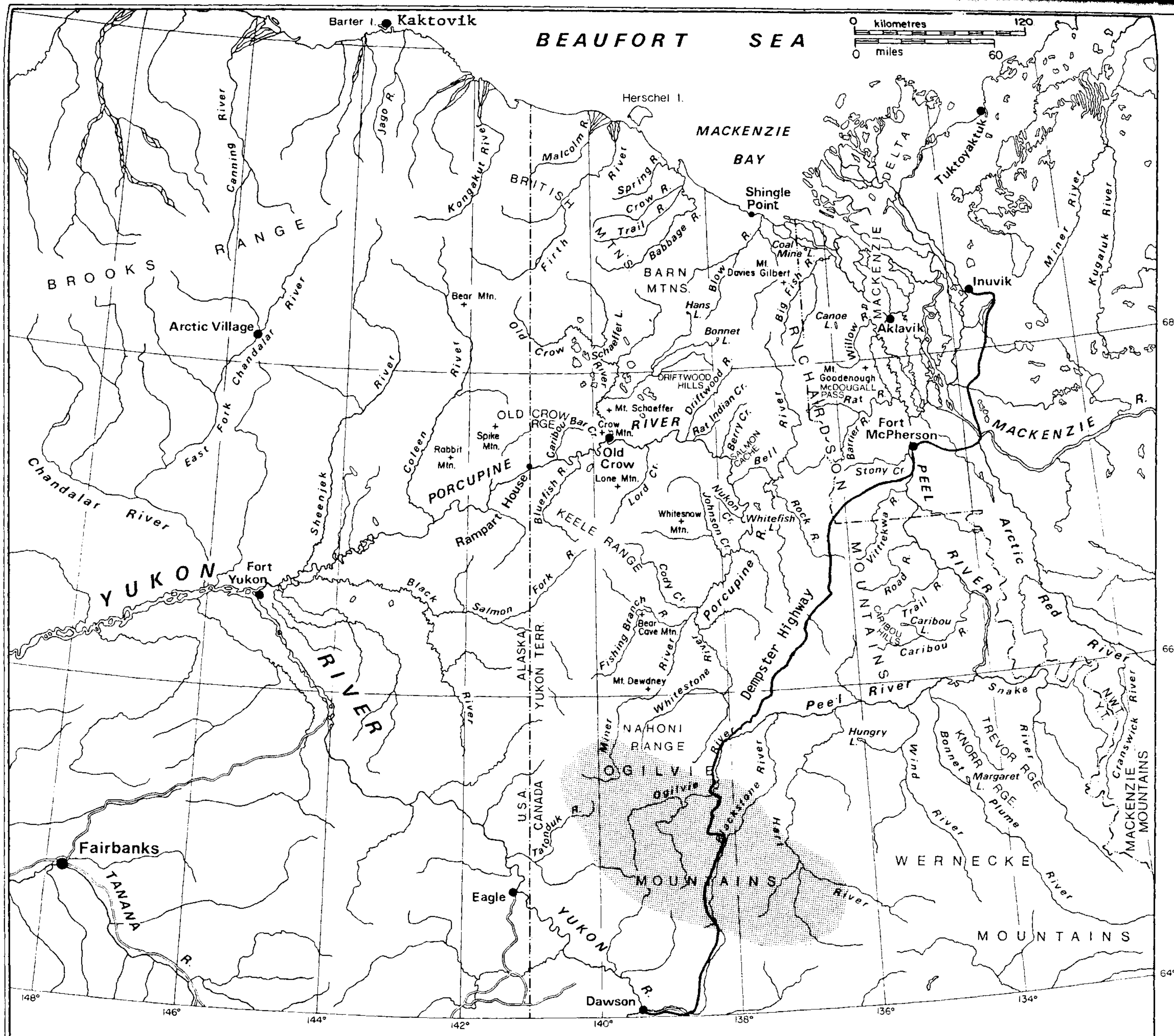


Fig. 10. Porcupine caribou herd distribution 24-27 October, 1983.

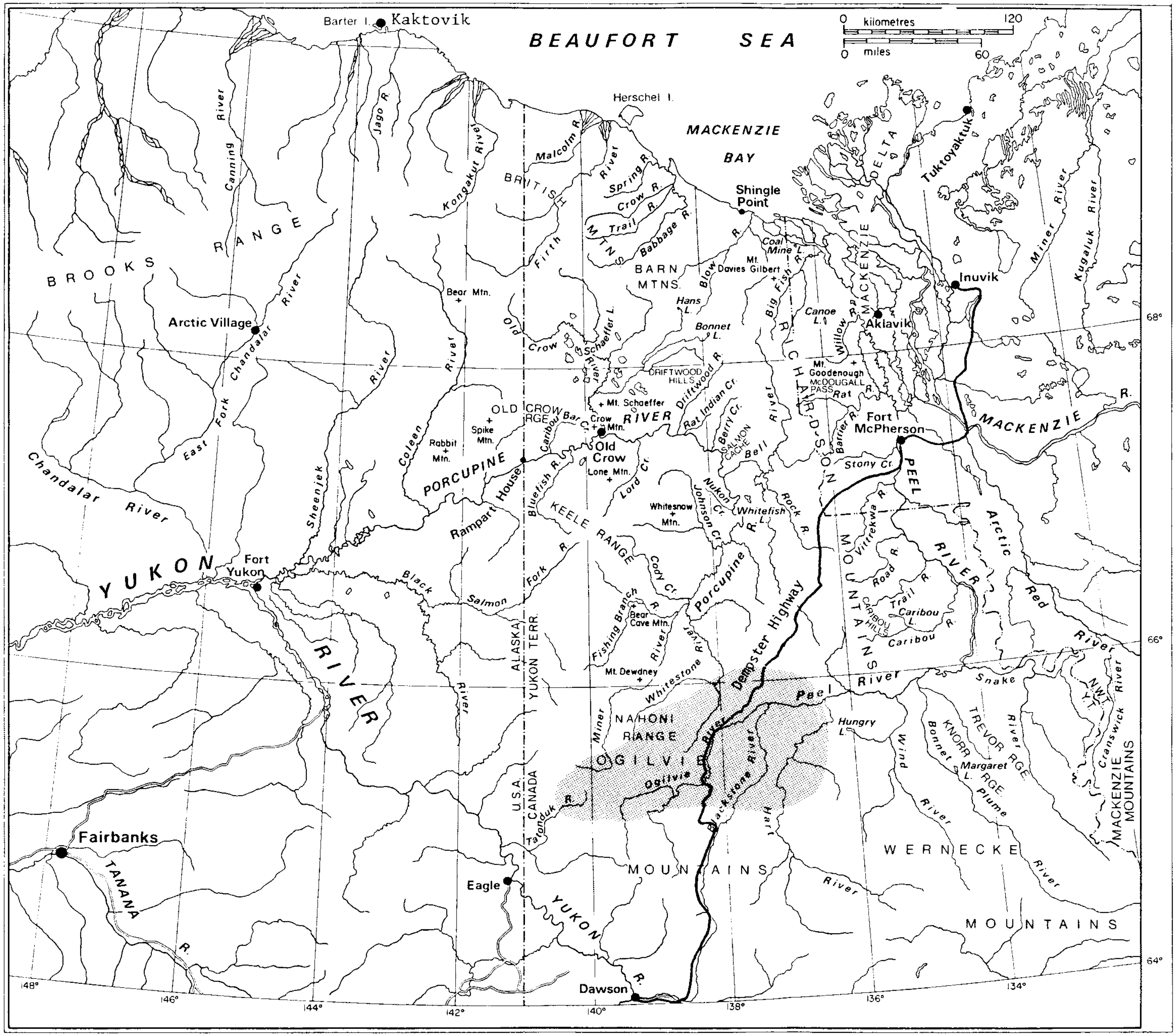


Fig. 11. Porcupine caribou herd distribution 7-8 December, 1983.

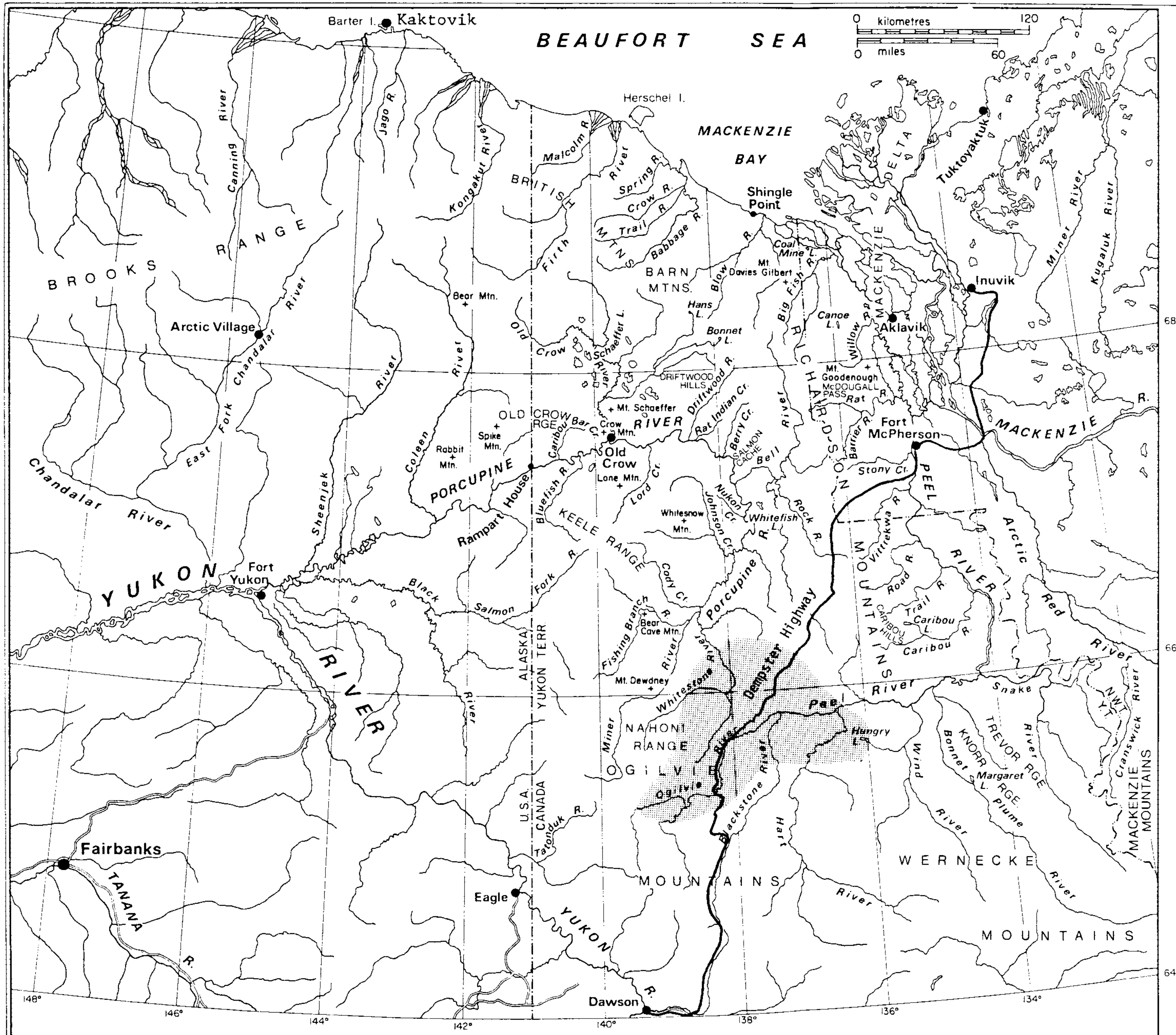


Fig. 12. Porcupine caribou herd distribution 8-10 February, 1984.

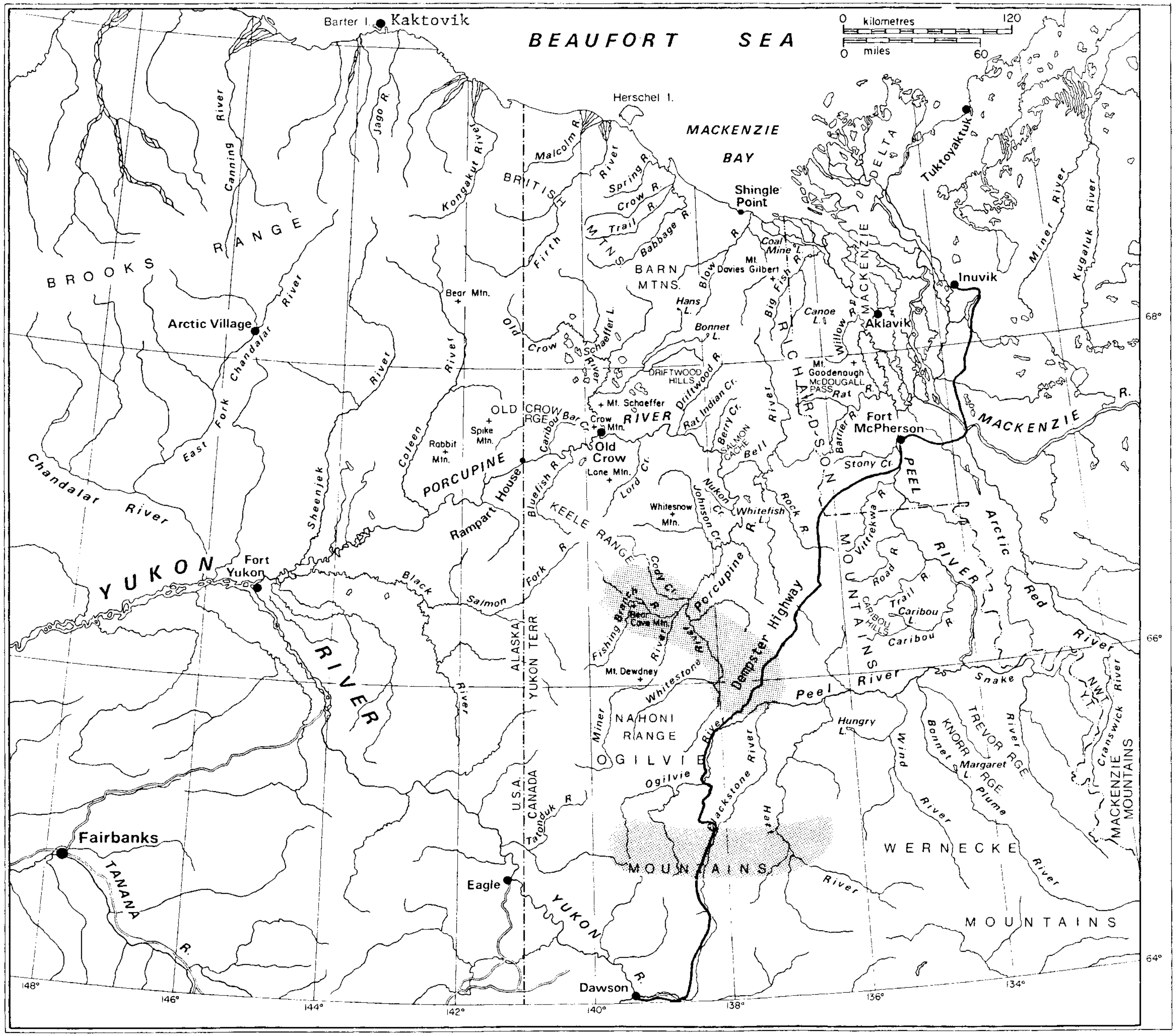


Fig. 13. Porcupine caribou herd distribution 8 April, 1984.

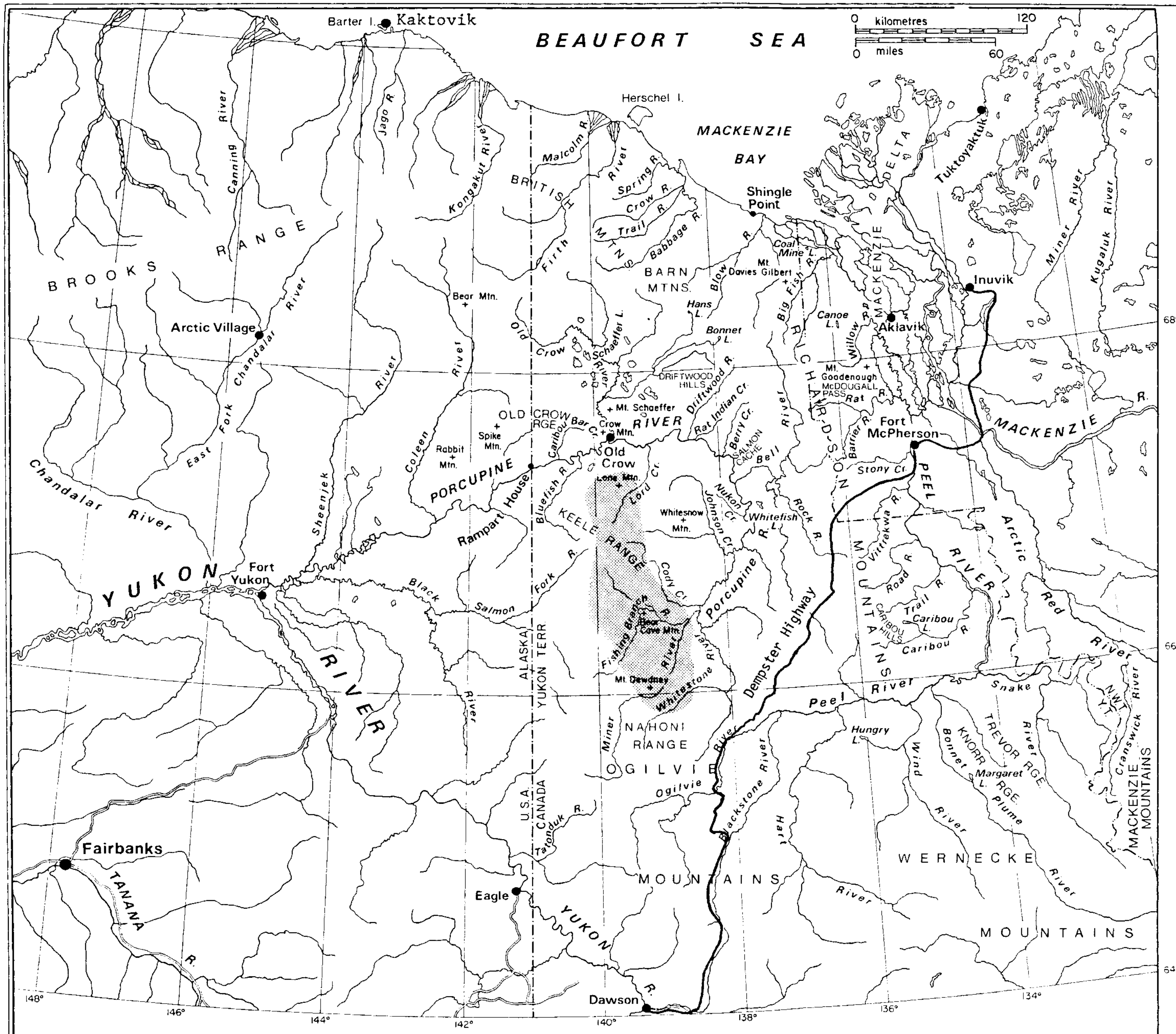


Fig. 14. Porcupine caribou herd distribution 23-28 April, 1984.

18 May, 1984 (Figure 15)

During this relocation flight the majority of animals were located northwest, west and southwest of the Old Crow Flats. Another concentration still remained in the Bluefish River area while a few animals had proceeded into the Babbage River, Trail River and Barn Mountain region.

4 July - 3 August, 1984 (Figure 16)

Intensive radio tracking of selected collars was conducted during the period of insect harassment as part of ongoing Canadian Wildlife Service research into the range use patterns of the Porcupine herd. By 5 July, large groups of post-calving cows and trailing bulls had joined up by the Yukon/Alaska border and were forming discrete groups. Our radio-tracking flights indicated that about 100,000 animals were in the Yukon in 13 groups. We focused on the largest of these groups to follow through the season. This group, located on the Spring River contained close to 40,000 animals with 32 radio-collars. On 6 July and for two days strong winds blew from the southwest preventing us from monitoring the group. On 8 July winds had subsided enough to relocate our group, greatly fragmented, approximately 30 miles to the southwest at the head of the Trail River. For the next five days the animals moved little. Mosquitoes were bothersome during this time, and the typical diurnal pattern was foraging at night, moving to relief areas by 0800, remaining in these areas until 1930, and then moving out into the basins of Muskeg Creek for another period of feeding. On 12 July another storm began and continued until 15 July. The large group split into at least 6 smaller groups, all but two of which moved wéstward into Alaska along the northern edge of Old Crow Flats.

By 19 July only about 8,000 caribou remained in the Yukon. These animals, in various size groups, moved quickly eastward, through the Barn Range, across the Blow valley, and remained in the northern Richardson Mnts. until 1 August. By that time the frequent storms and cool weather served to disperse the larger groups, and bands rarely exceeded 100 caribou in August.

22 August - 23 August, 1984 (Figure 17)

Reports from Alaska that caribou had returned to the Yukon from the southern Brooks Range promted another relocation flight in late August. Radio-collared caribou were located throughout the northern Yukon, with the majority southwest of the Old Crow Flats.

20 September - 22 September, 1984 (Figure 18)

Ninty-three collared caribou were relocated during this pre-rut survey. Three areas of concentration were noted - the headwaters of the Blow River/northern Richardson Mnts. (27

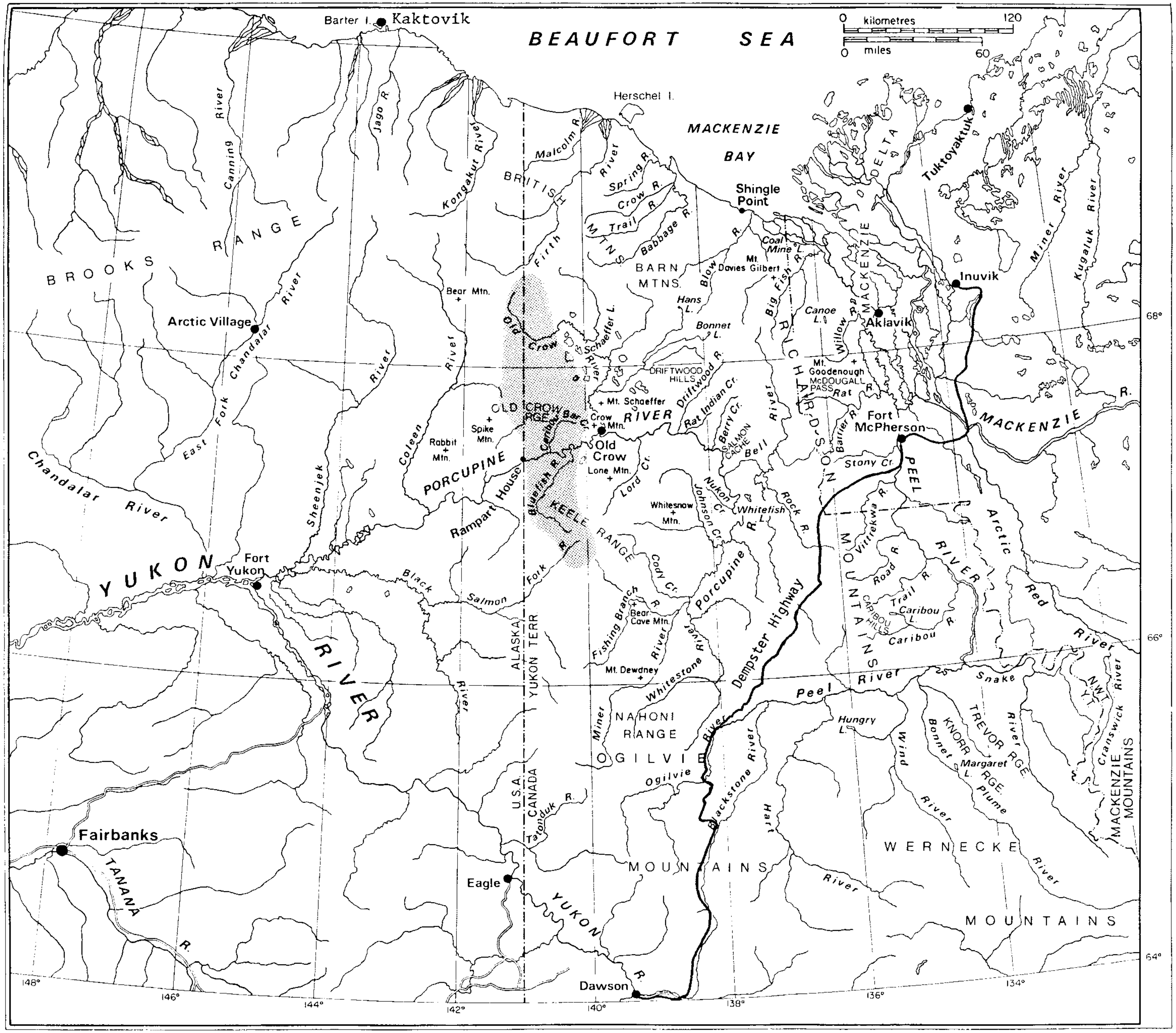


Fig. 15. Porcupine caribou herd distribution 18 May, 1984.

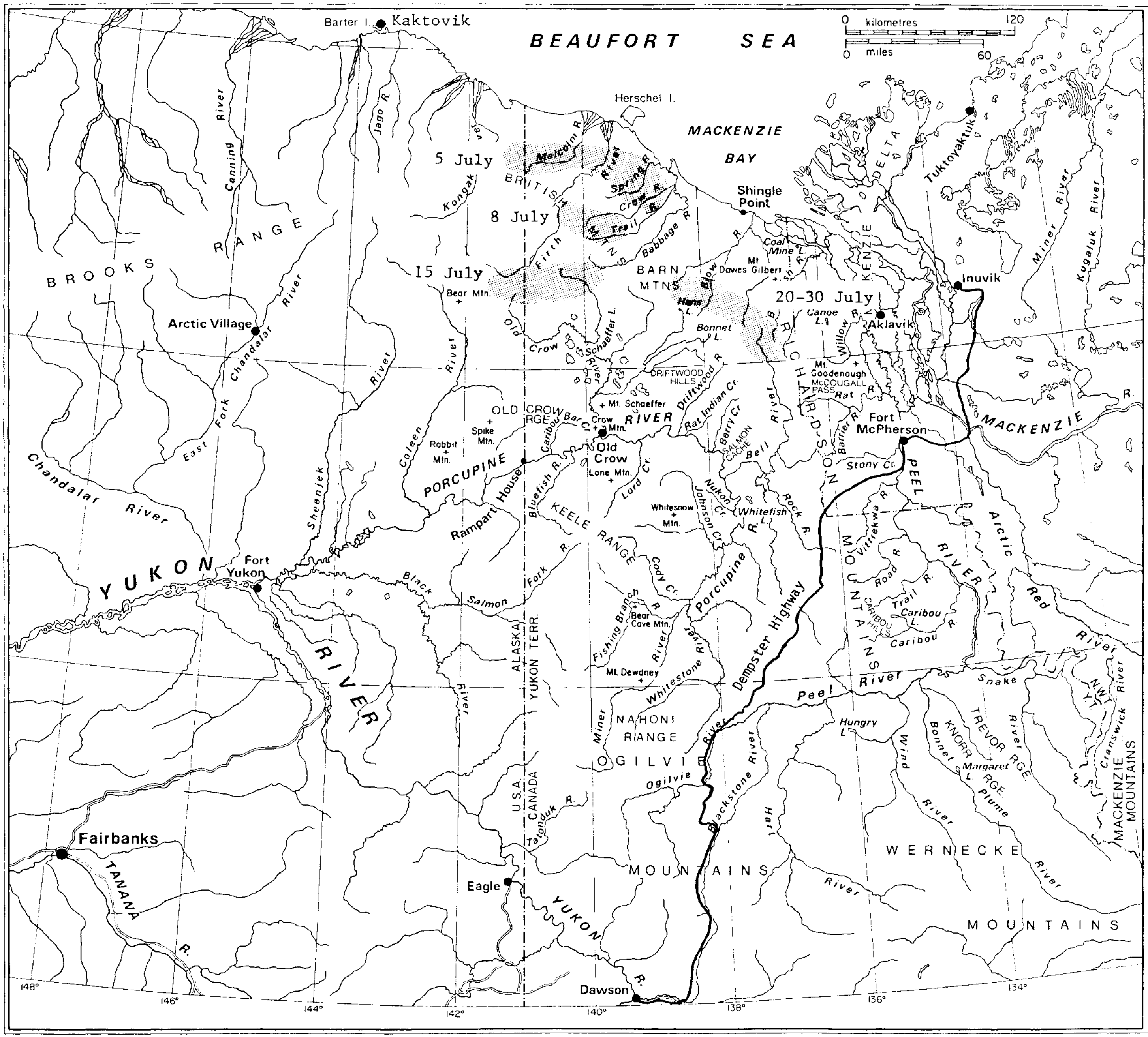


Fig. 16. Porcupine caribou herd distribution 4 July - 3 August, 1984.

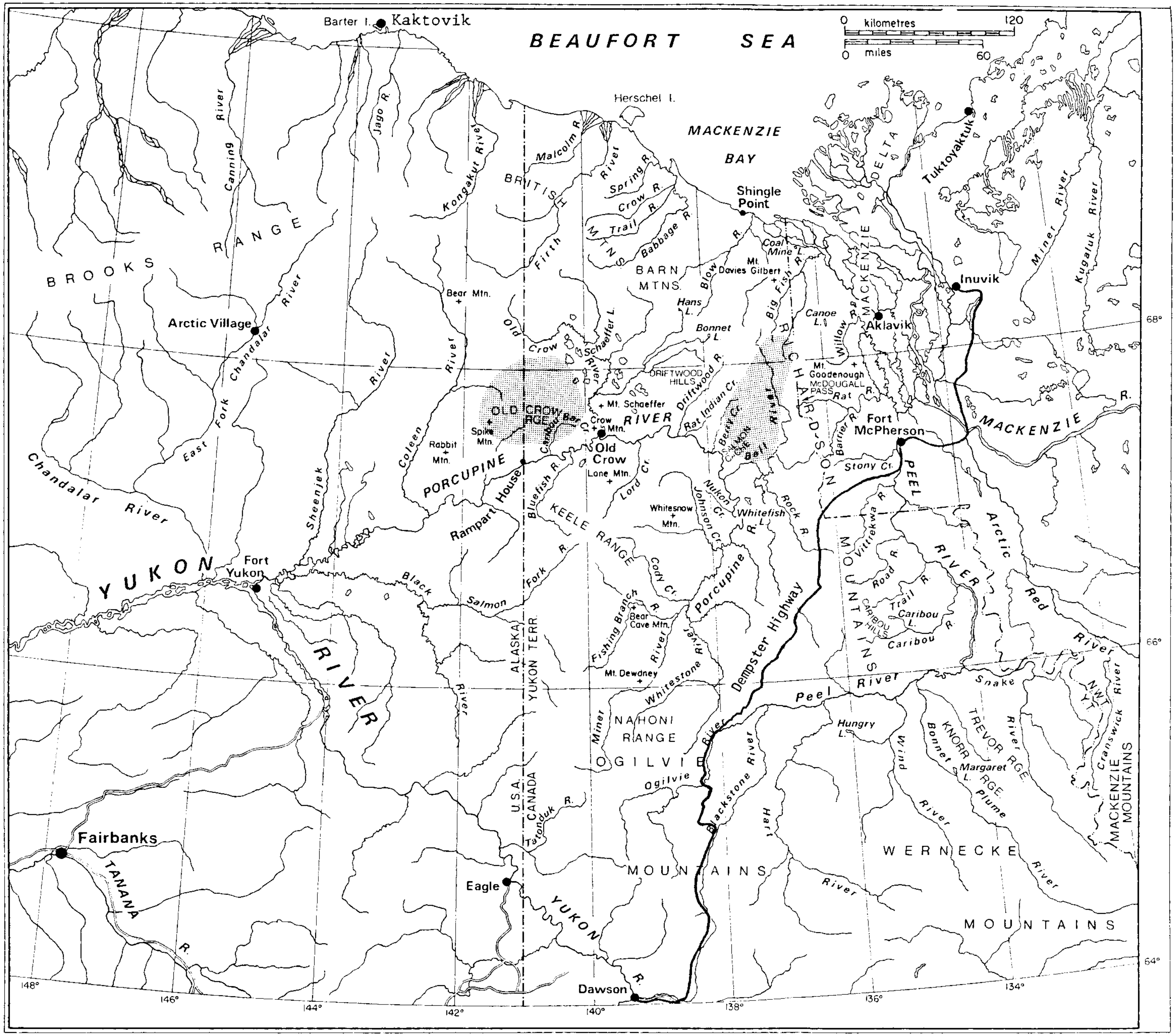


Fig. 17. Porcupine caribou herd distribution 22-23 August, 1984.

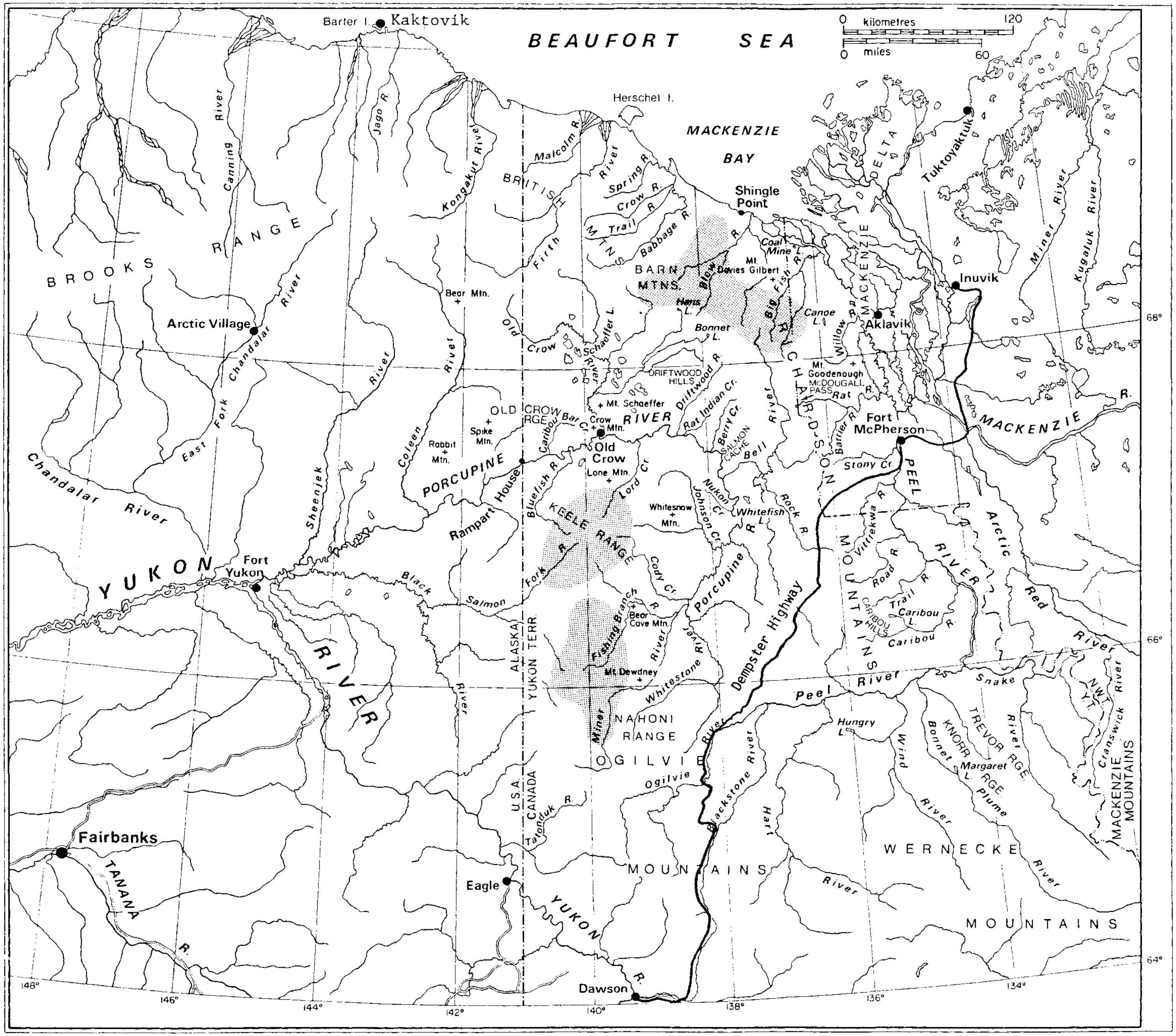


Fig. 18. Porcupine caribou herd distribution 20-22 September, 1984.

collars), south of Old Crow/head of Lord Creek (19 collars), and the head of the Fishing Branch River (12 collars). The furthest south collars were located was in the head of the Miner River (65°40' lat. 140°0' long.).

16 - 17 November, 6 - 7 December, 1984 (Figure 19)

These two surveys revealed essentially similar distributions and represent the early winter distribution of the herd. The vast majority of the herd were located in the northern Richardson Mnts., from the North Slope to the latitude of Fort Macpherson (35 and 44 collars respectively for the two surveys). Other areas of occupation included the north eastern portion of the Eagle Plains (6 and 3 collars, respectively), west of Old Crow Flats (3 and 4 collars) and the Ogilvie basin (2 and 1 collar). If any shift in distribution occurred between the surveys it was animals in the far north moving south and east (on to the MacKenzie Delta near Aklavik), and animals on the Eagle Plains moving north into the Whitefish Lakes region.

22 May, 1985 (Figure 20)

Only 23 collars were relocated in this survey as most animals (primarily cows and juveniles) had already moved into Alaska along the north end of the Old Crow Flats and along the North Slope. Of those found the majority (17), were located west of the Babbage river, primarily in the head of the Crow and Firth Rivers. Only 2 collars (both bulls) remained in the northern Richardson Mnts.

22 June - 6 August, 1985 (Figure 21)

Fifty collars were located while surveying the north slope of northern Yukon June 22, 1985. These were primarily cows distributed in small bands (<200 caribou) from west of the Babbage River to the Alaska border. Most of these were in foothills and on the coastal plain between the Babbage and Malcolm Rivers. A brief survey flown June 23 along the coastal plain and feethills indicated a steady westward movement of caribou. By June 27, most of these caribou were west of the Malcolm River and moving into Alaska.

Poor weather interfered with flying early in July. Relocation surveys July 5 and 6 indicated an eastward movement of caribou from Alaska through the British Mnts. in groups ranging from approx. 3,000 to approx.+20,000 caribou. These groups made extensive use of the upland areas east of the Firth River at the headwaters of the Crow and Trail Rivers. These groups periodically split up and reformed during the second week of July with group size varying from approx. +1,000 to +25,000. During this time the caribou started moving south and east making extensive use of the Muskeg Creek drainage.

By July 11 several thousand caribou were moving through the

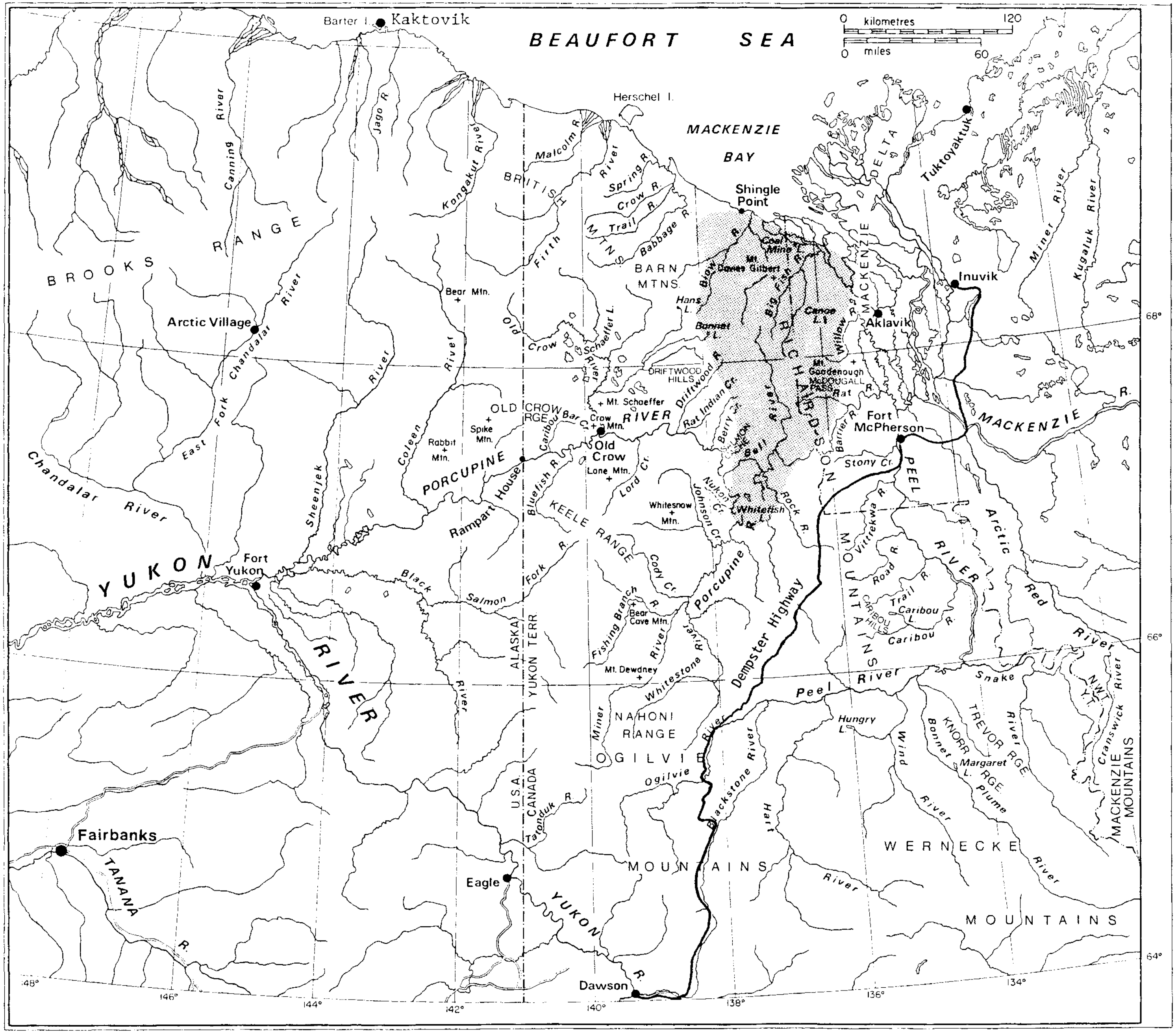


Fig. 19. Porcupine caribou herd distribution 16-17 November, and 6-7 December.

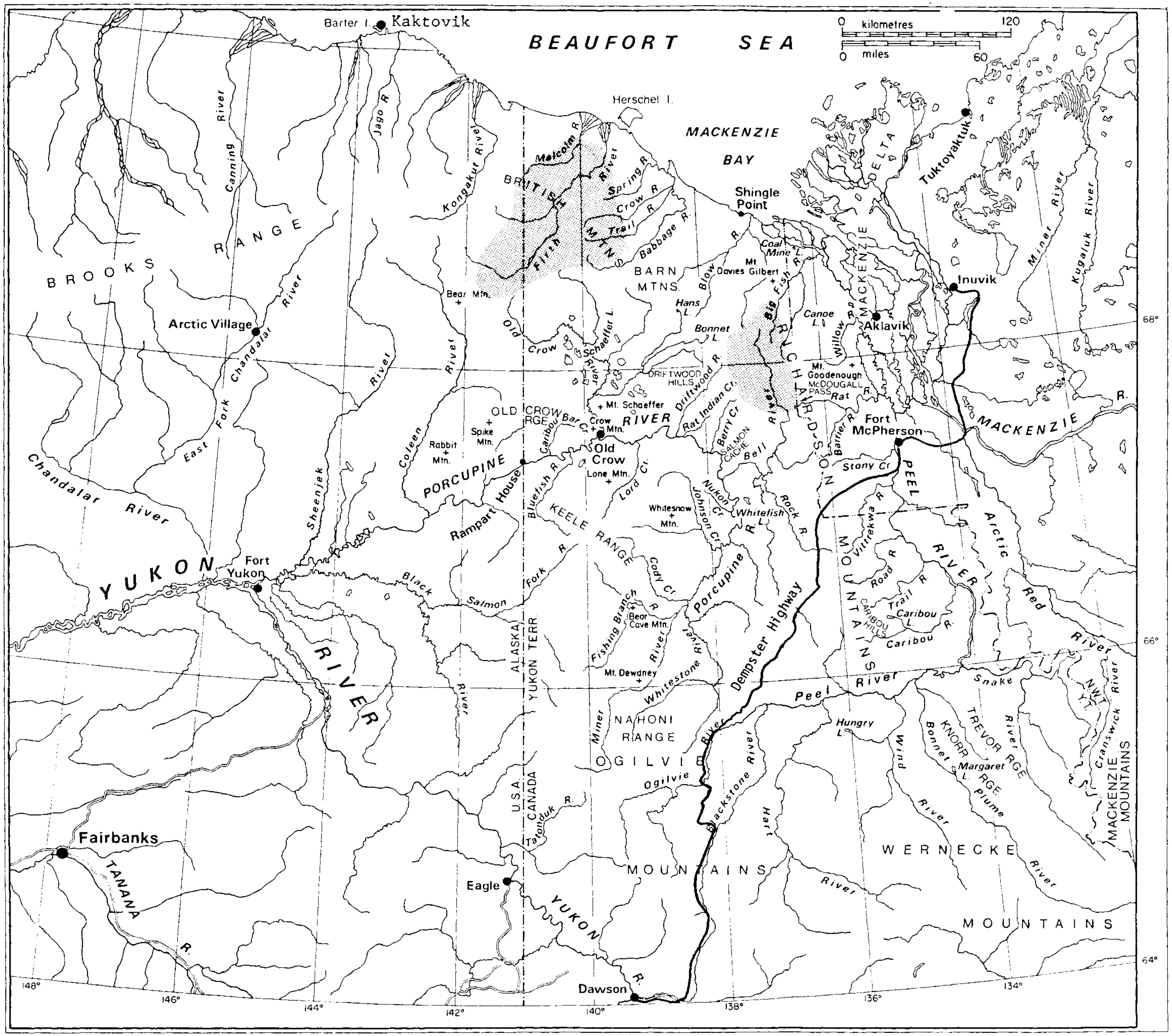


Fig. 20. Porcupine caribou herd distribution 22 May, 1985 (primarily bulls).

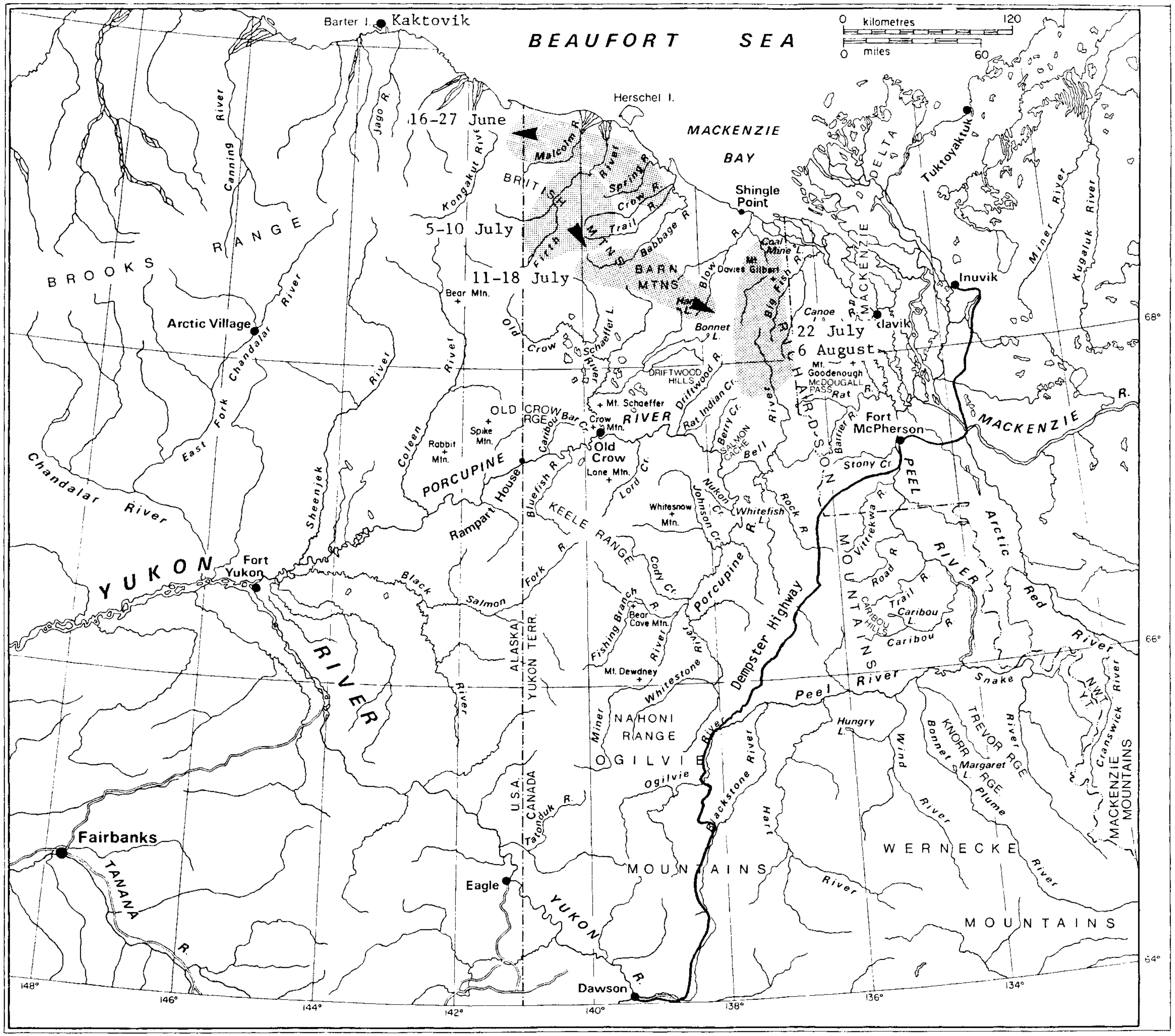


Fig. 21. Porcupine caribou herd distribution 22 June - 6 August, 1985.

headwaters of the Babbage River. By mid-July, approx. 20,000 caribou were found in the middle of the Barn Range. This group continued moving east and were found east of the Blow River July 18 in groups of approx. 4,000 to 12,000.

Approximately +25,000 caribou used the Richardson Mtns. the last week of July and first week of August. Group size averaged <10,000 and varied from 1,000 to 9,000 depending on weather conditions and hence, insect activity. Movement was generally southward the last week of July (as far as 68° 00'lat.) and then northward by August 2 to the Rapid Creek and Purkis Creek drainages. When the final survey was done 6 August most caribou in northern Yukon were found in the extreme north Richardson Mtns. on the edge of the coastal plain.

5 September, 1985 (Figure 22)

A total of 78 adult and 22 calf collar frequencies were located on this survey. A couple of caribou were located on the north slope, but the majority were located in two general areas; one east of the Old Crow flats in the Driftwood River drainage and the second south of the Porcupine River and north of the Fishing Branch River. Six were located in the area of Whitefish Lakes, and ten were located between Old Crow and the Alaska border.

15-16 October, 1985 (Figure 23)

A total of 96 collar frequencies were located on this survey. The majority of caribou were found in the Ogilvie River basin west of the Dempster Highway and in the headwaters of the Tatonduk River. A second small concentration of caribou was found in the southern Richardson Mnts. Others were scattered from the northern Yukon south to the Blackstone and Hart River drainages, and from the Alaska border to the Richardson Mtns.

8-9 January, 1986 (Figure 24)

Most of the 75 collar frequencies located on this survey were in the southern Richardson Mtns. between the Peel River drainage and the Whitefish Lakes/Bell River region. Others were scattered throughout northern Yukon.

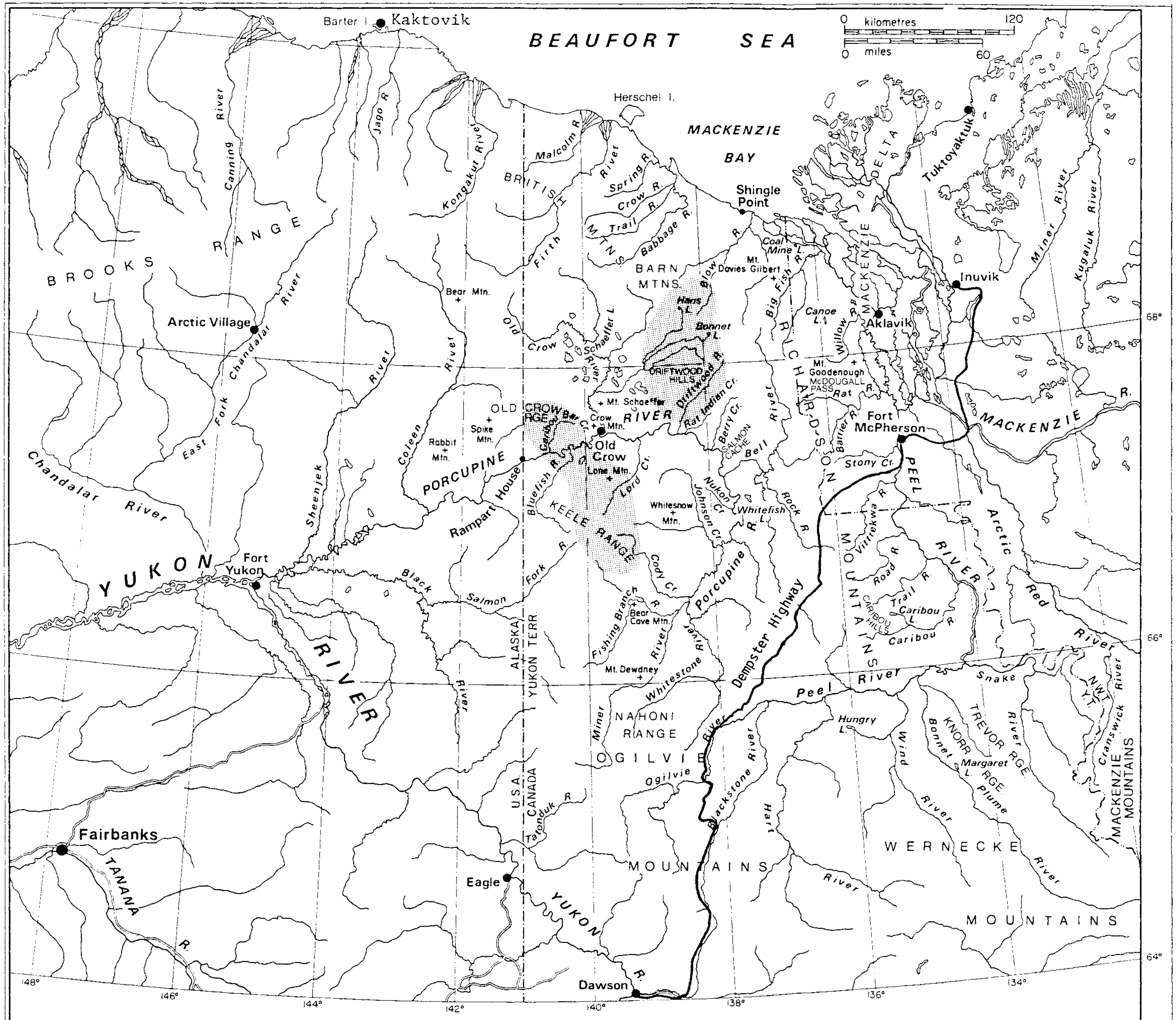


Fig. 22. Porcupine caribou herd distribution 5 September, 1985.

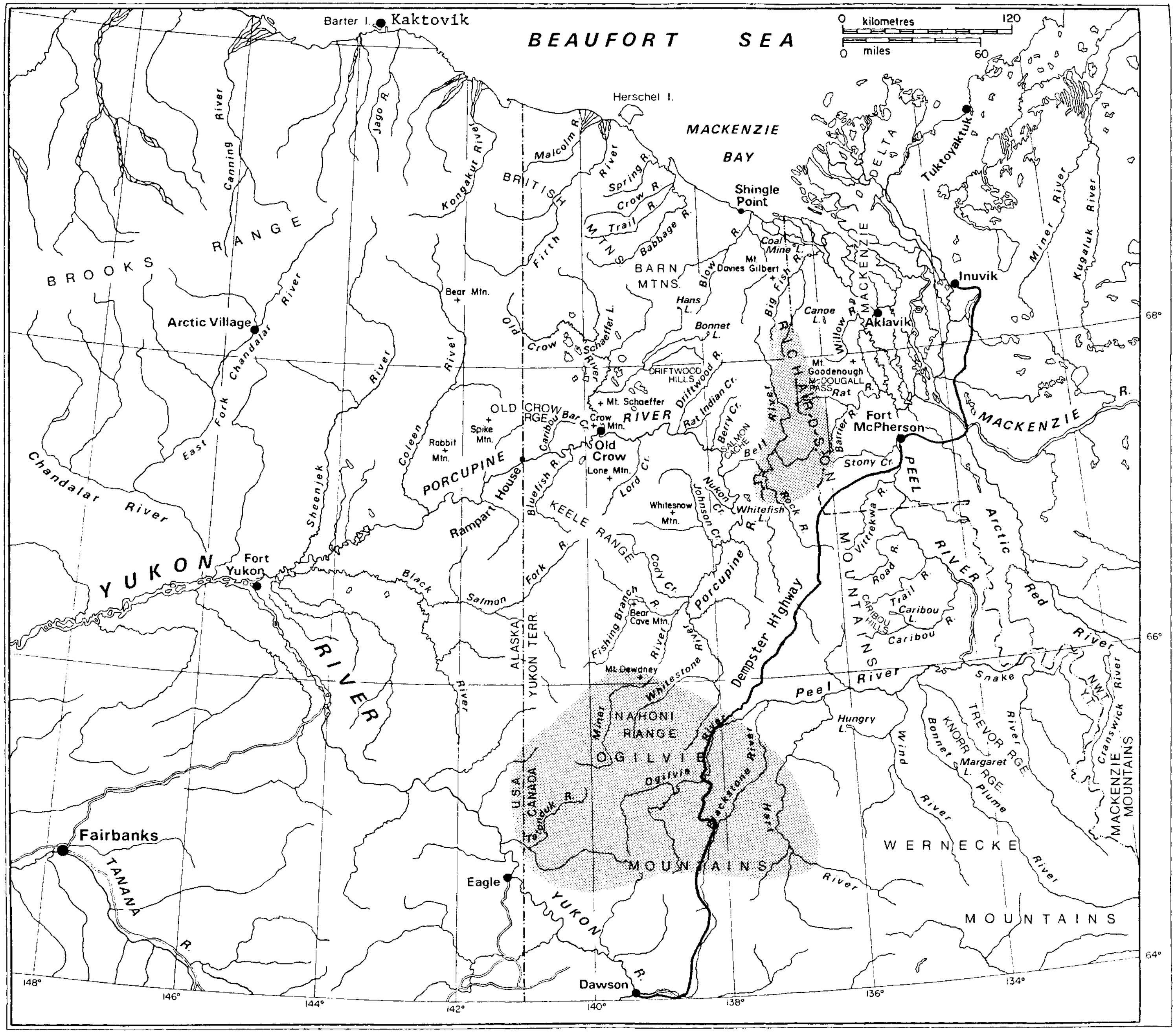


Fig. 23. Porcupine caribou herd distribution 15-16 October, 1985.

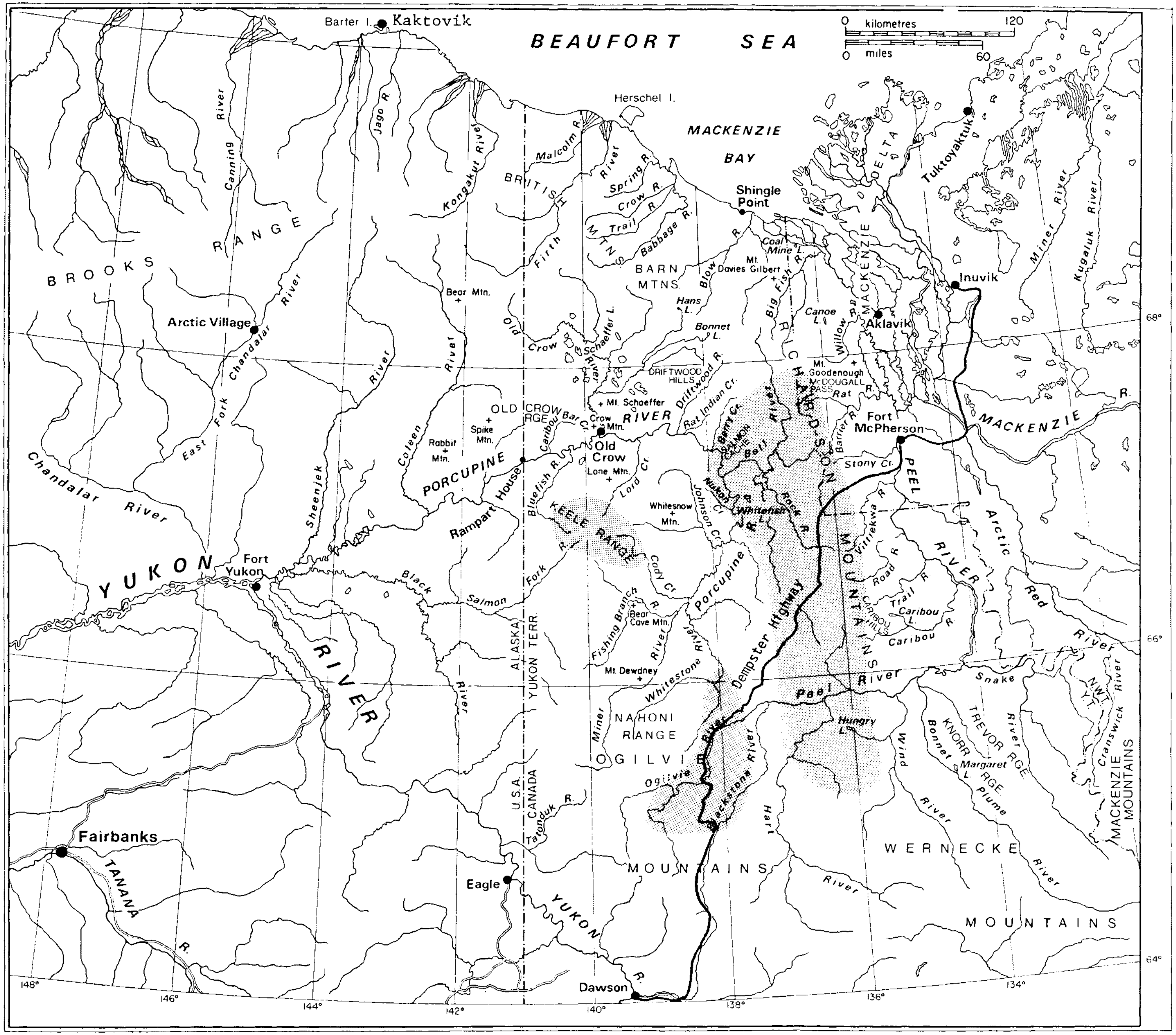


Fig. 24. Porcupine caribou herd distribution 8-9 Jnauary, 1986.

JUVENILE MORTALITY

This report deals strictly with a cohort of short yearlings affixed with radio-collars in March, 1983 and monitored for 28 months. Since that time a large number of short yearlings were recollared having originally been collared as neonates and having survived to 10 months. These additional animals should be used to augment our sample, however the data were not available to the authors.

From 24 - 29 March, 1983, 43 radio-collars were affixed to juvenile caribou in the Whitefish Lakes region in northern Yukon (from distribution depicted in Figure 4). Of those collared 6 were 22 month old females, 35 were 10 month old females, and 2 were 10 month old males. The rationale for collaring primarily females was to be able to collect data on age specific reproductive rates.

Among the 10 month old cohort, six mortalities and five collar failures occurred during the 28 month period (Table 2). Using the formula presented by Gasaway et al (1983), we calculate an overall mortality of 17.2% over the 28 months. Annual mortality rates are 8.2% for animals 10 months to 21 months (i.e. essentially yearlings), and 9.5% for animals 22 - 34 months (2 year olds). No mortality occurred in the final 4 months.

Only one collar failed and no mortalities occurred for the six caribou in the 22 month cohort.

TABLE 2. Status of 43 juveniles collared March, 1983 and monitored for 28 months.

Collar	Age[1]	Sex	Status	Collar	Age	Sex	Status
PY45	10	F	ACTIVE	PB70	10	F	MORT. 10/84
PY47	10	F	ACTIVE	PB71	10	F	ACTIVE
PY48	10	F	ACTIVE	PB72	10	F	ACTIVE
PY49	22	F	ACTIVE	PB74	10	F	ACTIVE
PY50	10	F	MORT. 01/85	PB75	10	F	MORT. 04/83
PY51	10	F	ACTIVE	PB76	10	F	ACTIVE
PY52	10	F	ACTIVE	PB77	10	F	ACTIVE
PY53	10	F	ACTIVE	PB78	10	F	ACTIVE
PY55	10	F	MORT. 12/83	PB79	10	F	FAIL. 12/84
PY56	10	F	ACTIVE	PB80	10	M	ACTIVE
PY57	10	F	ACTIVE	PB81	10	F	ACTIVE
PY59	10	F	ACTIVE	PB82	10	F	ACTIVE
PY60	10	F	FAIL. 09/84	PB83	10	F	ACTIVE
PY61	10	F	FAIL. 10/83	PB84	10	F	ACTIVE
PY62	10	F	ACTIVE	PB86	22	F	ACTIVE
PY63	10	F	MORT. 10/83	PB87	22	F	ACTIVE
PY64	10	F	ACTIVE	PB89	10	F	ACTIVE
PY65	10	M	FAIL. 12/84	PB90	10	F	ACTIVE
PY66	10	F	FAIL. 12/84	PB91	10	F	ACTIVE
PY67	22	F	ACTIVE	PB92	10	F	MORT. 10/84
PY68	10	F	ACTIVE	PB94	22	F	FAIL. 05/84
PY69	22	F	ACTIVE				

1 - age in months as of March, 1983

ACKNOWLEDGEMENTS

These projects benefitted from many individuals since 1982. The excellent flying service we received from Alkan Air, Aklak Air, Trans North Turbo Air, and Midwest helicopters was greatly appreciated. We would like to thank especially Hugh Kitchen, Ed Pryor and Dean Cameron. Many people helped with the radio-tracking surveys, notably Art Martell, Lisa Hartman, Norm Barichello and Jean Carey.

The cooperative nature of these projects was particularily rewarding for us and we extend our thanks to Gerald Garner, Fran Mauer of the U. S. Fish and Wildlife Service and Ken Whitten from the Alaska Department of Fish and Game. Gerald Garner oversaw the, at times, complicated financial arrangements. We wish to also thank the Yukon Department of Renewable Resources and the Canadian Wildlife Service for their support throughout the project.

REFERENCES

Gasaway, W. C., R.O. Stephenson, J. L. Davis, P. E. K. Shepherd, and O. E. Burris. 1983. Interrelationships of wolves, prey, and man in winter for Alaska. Wildl. Monogr. 93, pp. 1 - 42.

APPENDIX 1.

Distribution, activity and range use of male caribou in early summer in northern Yukon, Canada

- A. M. Martell, W. A. Nixon and D. Russell

Paper presented at the Fourth International Reindeer/Caribou Symposium, Whitehorse, Yukon, August, 1985

Distribution, Activity and Range Use of Male Caribou in Early Summer in Northern Yukon, Canada

A.M. MARTELL[1], W.A. NIXON[2], and D.E. RUSSELL[2]

ABSTRACT. Males of the Porcupine Caribou Herd separated from females from the onset of spring migration until they joined them on the calving grounds in late June or early July, 4-6 weeks later. From late May to late June males spent an average of 50% of their time feeding and less than 2% standing and trotting/running. Males spent an average of 29% of their time lying and 19% walking, except in mid-June (40% lying, 6% walking). The average lengths of active and resting periods were 112 minutes and 104 minutes, respectively, from late May to mid-June, but decreased sharply in late June to 78 minutes and 69 minutes, respectively. Tussock meadows were selected in late May and early June, wet sedge meadows were avoided until late June, dwarf shrub heaths were avoided after late May, and alluvial willow thickets were avoided in late May and early June but were selected in mid-June and late June. Caribou fed primarily on lichens and *Vaccinium* in late May, lichens and *Eriophorum* in early June, *Eriophorum* in mid-June and *Salix* in late June.

Key words: *Rangifer*, caribou, activity budget, habitat selection, food habits, Yukon.

[1] Canadian Wildlife Service, P.O. Box 340, Delta, British Columbia, Canada V4K 3Y3

[2] Canadian Wildlife Service, 202-204 Range Road, Whitehorse, Yukon, Canada Y1A 3V1

INTRODUCTION

The Porcupine Caribou Herd (*Rangifer tarandus granti*) calves on the Arctic Coastal Plain of northeastern Alaska and northwestern Yukon, and winters primarily in north-central Yukon and adjacent Alaska. Calving occurs from late May to mid-June with a peak in the first week of June. During calving, and for a variable period before and after calving, males are segregated from females. It has been suggested that this segregation occurs because males follow the northward initiation of growth of forage while pregnant females move quickly to the calving grounds for other reasons, such as predator avoidance (Whitten and Cameron 1979). Recent proposals for a seaport, quarries and roads in northern Yukon in the area used intensively by males in early summer have focused attention on the need for information on that component of the herd.

STUDY AREA

Investigations were conducted in northern Yukon, north of the Porcupine River (Fig. 1). The area can be divided from south to north into three broad ecoregion bands: Old Crow Basin, Northern Mountains and Northern Coastal Plain (Wiken et al. 1981). The Old Crow Basin, which includes the Old Crow Flats and the surrounding pediments, is generally flat or gently undulating terrain covered by boreal forest - tundra transition zone vegetation. The Northern Mountains include the British, Barn and Richardson Mountains with broken, ridged terrain interspersed by river valleys and intermountain basins. Vegetation consists of arctic and alpine tundra communities except for some intrusion of boreal forest along river valleys. The Northern Coastal Plain slopes gently from the mountains to the Beaufort Sea and is covered by arctic tundra vegetation.

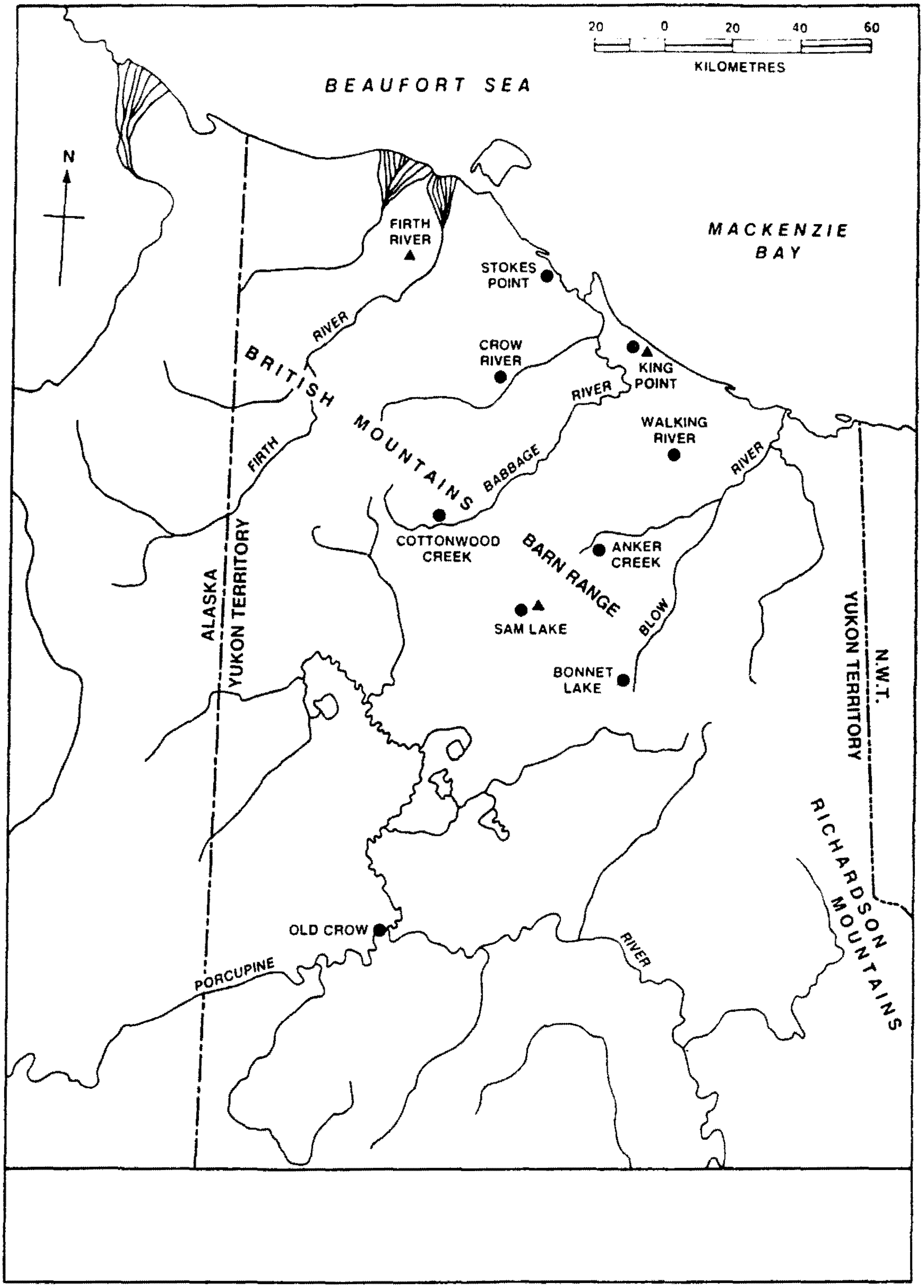


Fig. 1. Map of northern Yukon showing locations of field camps (triangles) and sites for documenting plant phenology (circles).

Three campsites were used for observing caribou in 1983: Sam Lake, 21 May - 12 June; King Point, 13-21 June; Firth River, 22-30 June (Fig. 1). The Sam Lake camp was at the southern edge of the Barn Mountains and overlooked rolling, tundra-covered pediments. The King Point and Firth River camps both lay on the coastal plain in rolling arctic tundra. Sites for documenting plant phenology (Fig. 1) were established on the Old Crow pediments (Sam Lake, Bonnet Lake), in the intermountain basins (Cottonwood Creek, Anker Creek), on the inner coastal plain (Crow River, Walking River) and at the coast (Stokes Point, King Point).

METHODS

Distribution

To follow the movements of caribou, radio transmitters on collars were placed on animals on the winter range. Between 5 and 15 caribou were available for relocation each year (1981 - 5; 1982 - 5; 1983 - 15). In 1981 and 1982, four relocation surveys were flown between 3 and 28 June and in 1983 six surveys were flown between 8 May and 1 July. In addition to the locations of radio-collared animals, the locations of all male caribou observed on aerial surveys and reported by other researchers were plotted on maps.

Activity

We observed caribou with 15x-60x zoom spotting scopes from the three field camps. A band of caribou was defined as a socially interacting group of animals spatially distinct from other bands in the area. Activity data were collected using the instantaneous scan method (Altmann 1974). We scanned each band at 15-minute intervals and tallied the number of caribou engaged in each of five general activities. The proportion of caribou observed in each activity and the estimated 95% confidence limits were calculated by the ratio estimator method (Cochran 1977). Because of serial correlations among 15-minute observations of a given band of caribou, but not among different bands, estimated 95% confidence limits were based on a single ratio for each band observed. Differences were considered to be significant if the estimated 95% confidence limits did not overlap.

Phenology

We observed snowmelt and the development of vegetation in eight relatively flat cottongrass (*Eriophorum vaginatum*) tussock meadows (Fig. 1). We estimated the relative stage of development of the flowers of *Eriophorum vaginatum* (flower bud, early flower, full flower, past flower, seed) for 24 tussocks at approximately 5-m intervals along a transect at each site. Along the same transect we also documented the relative stage of development of the leaves of 24 plants of *Salix pulchra*, *Betula glandulosa* and *Ledum palustre* (leaf bud, leaf unfolding, full leaf).

Habitat Selection

We divided the area of observation at each campsite into six distinct habitat types and determined their availability by mapping them on aerial photographs. The habitat types and their approximate classification according to Viereck and Dyrness (1980) were: Tussock Meadow, 2C2c; Wet Sedge Meadow, 2A3a; Dwarf Shrub Heath, 2D2a and 2A4a; Alpine Barren, 2E1b; Alluvial Willow, 3A1a; and Open White Spruce, 1A3d. We also documented the use of late snow patches and sandy beaches at some camps. The areas observed at campsites appeared to be representative of much wider areas based on examination of aerial photographs and observations from aircraft.

Food Habits

We collected composite fecal samples at Sam Lake (22 May, 4-5 June, 12 June), King Point (15-17 June), Firth River (26-27 June) and Stokes Point (15 June, 27 June). Each composite sample contained 20 fecal pellets, one from each of 20 different fresh pellet groups. Fecal samples were analyzed (Sparks and Malecheck 1968) at the Composition Analysis Laboratory at Colorado State University, Fort Collins. The relative density of plant fragments was based on 100 fields per sample. All samples were analyzed at the same time by the same technician. The accuracy of fecal analysis is influenced by differential digestion among plant species (Holechek et al. 1982). Therefore, the results represent proportions of discerned fragments in fecal samples rather than actual proportions of the ingested diet.

Data Analysis

For the purpose of comparison among data sets, the field season was divided into four periods: late (20-31) May, early (1-11) June, mid (12-20) June and late (21-30) June. Statistical procedures follow Siegel (1956) and Sokol and Rohlf (1969).

RESULTS AND DISCUSSION

Distribution

Male caribou follow the females on spring migration along essentially the same routes leading from the two principal wintering areas, the Ogilvie Mountains of north-central Yukon and the Arctic Village region of northeastern Alaska. Females reach the calving grounds in mid to late May while males fan out into the rolling pediments north and east of the Old Crow Flats and into the wide basins near the headwaters of the Firth River (Fig. 2a). In early

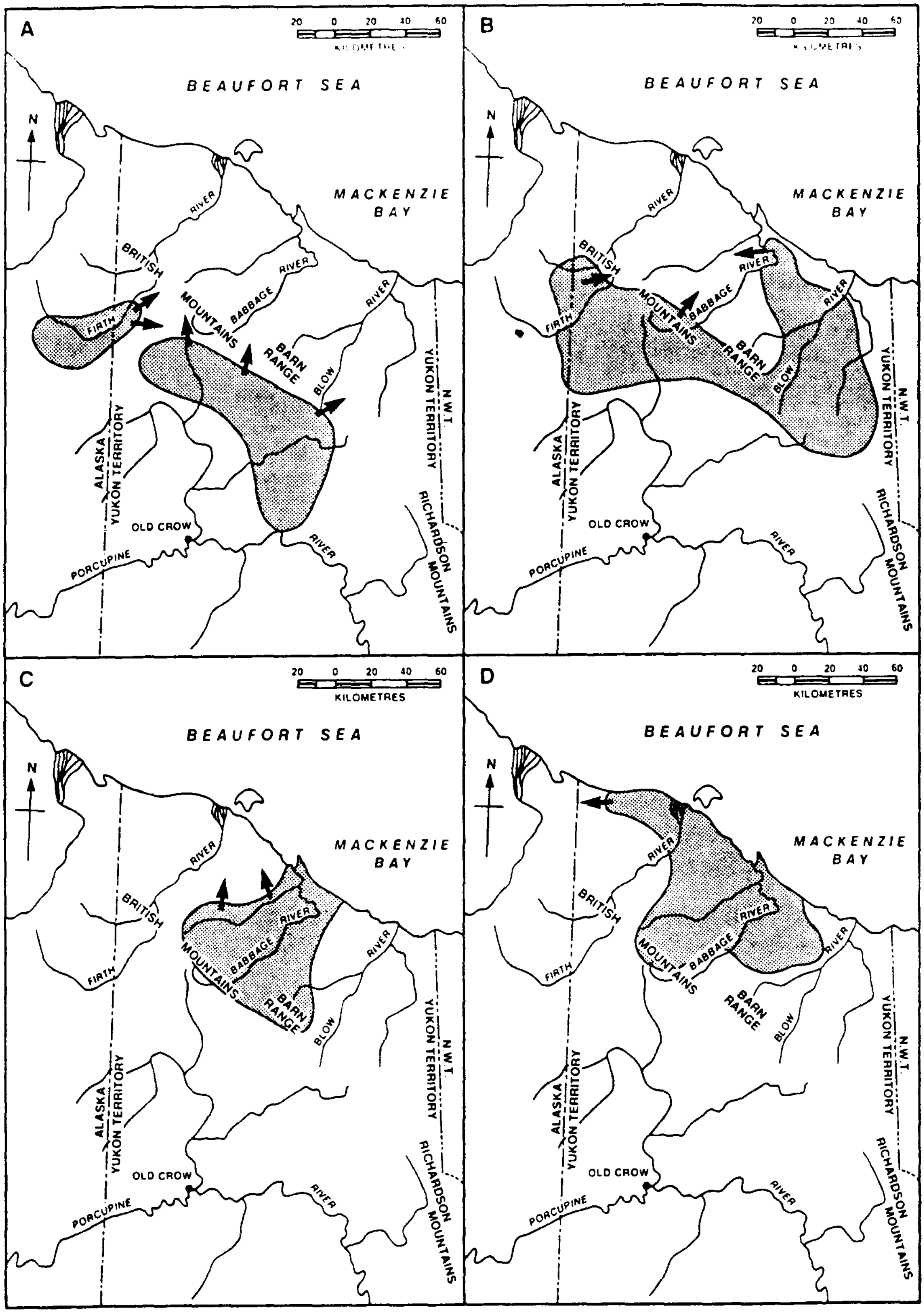


Fig. 2. General distribution (shaded) and direction of movement (arrows) of male caribou in northern Yukon in late May (A), early June (B), mid-June (C), and late June (D).

June, at the time of calving, males are distributed in a broad crescent south and east of the calving grounds (Fig. 2b). By this time, if not earlier, males from both the Alaskan and Yukon wintering areas are well mixed. Males then move eastward south of the British Mountains and northwestward from the Richardson Mountains and by mid-June large aggregations begin to form in the intermountain basins near the headwaters of the Spring, Trail, Babbage and Running Rivers as well as, in some years, on the Firth River (Fig. 2c). By late June males are found moving westward and northwestward towards the coast of the Beaufort Sea near the Alaska-Yukon border (Fig. 2d). At this time, band sizes frequently number in the thousands and smaller bands which have lingered behind move quickly to join the larger concentrations. Most males meet and mix with females and young on the Alaska-Yukon coastal plain by early to mid-July before returning eastward to the Richardson Mountains.

Males, therefore, are essentially segregated from females during May and June. The consistent pattern of distribution and movements among years and the formation of aggregations in mid-June prior to joining females and prior to the insect season suggests a response to food resources combined with a form of social facilitation.

Activity

In late May, at Sam Lake, many females were moving through the area and males occurred in both male-dominated and female-dominated bands. Therefore, observations included both types of bands. After that time, only male-dominated bands were observed. The average size of bands was relatively constant from late May to mid-June but increased significantly in late June (Table 1).

TABLE 1. Size and rate of movement (km/hr) of bands of male caribou in northern Yukon in 1983[1].

Period	Size				Rate[2]			
	(n)	$\bar{x}$	±	SE	(n)	$\bar{x}$	±	SE
late May	(45)	17.5	±	1.78[a]	(574)	0.35	±	0.026[a]
early June	(55)	24.2	±	2.90[a]	(730)	0.54	±	0.025[b]
mid-June	(65)	19.9	±	4.47[a]	(1088)	0.15	±	0.007[c]
late June	(29)	103.8	±	21.62[b]	(301)	0.74	±	0.042[d]

[1] Band sizes or rates of movement with the same superscript are not significantly different from each other at the p = 0.05 level.

[2] Rate was measured from the estimated distance moved by bands between 15-minute scans.

There was no significant difference in the proportion of time spent feeding or trotting/running among observation periods (Table 2). In mid-June the proportion of time spent lying was significantly higher than during other periods and the proportion of time spent walking was significantly lower than during other periods. The proportion of time spent standing was significantly lower in late June than during other periods. The rate of movement (Table 1) mirrored the proportion of time spent walking (Table 2) and was conspicously low during mid-June.

It is not possible to make precise comparisons of activity budgets among studies because of differences in methods of calculation. In general, for the same season, Roby (1978) found that male caribou in north-central Alaska spent less time feeding (39%) and more time lying (47%) than males we observed.

The mean length of both active and resting periods declined significantly from late May to late June (Table 3). The decrease from mid- June to late June was particularly conspicuous. The mean late May to mid- June active period we observed (112 minutes) was shorter than reported for summer for male reindeer (135 minutes) (Segal 1962), while the mean late May to mid-June resting period (104 minutes) was not significantly different (105 minutes).

Phenology

On 18-19 May 1983, the Old Crow pediments were about 80% snow covered while farther north all sites were about 95% snow covered. By 3 June the snow cover had declined to less than 5% on the Old Crow pediments and the coast but was about 50% (30-70%) between those sites. By 10 June the intermountain and inner coastal plain sites were about 10% (5-20%) snow covered and by 17 June all sites were essentially snow-free.

TABLE 2. Daily activity budgets (% time ± estimated 95% confidence intervals) for male caribou in northern Yukon in 1983.

Date	Late May	Early June	Mid-June	Late June
Number of observations	619	787	1,153	330
Number of bands	45	55	65	29
Number of individuals	8,443	14,498	19,554	25,592
Feeding	51.0 ± 4.0	47.6 ± 3.4	52.0 ± 3.0	49.0 ± 2.8
Lying	31.1 ± 6.4	31.9 ± 5.0	40.4 ± 3.3	25.4 ± 4.3
Standing	1.8 ± 1.1	0.9 ± 0.3	0.9 ± 0.2	0.4 ± 0.1
Walking	14.8 ± 4.9	19.1 ± 2.4	6.3 ± 0.9	24.1 ± 5.6
Trotting/running	1.2 ± 1.1	0.5 ± 0.3	0.3 ± 0.3	1.0 ± 0.4

TABLE 3. Length (minutes) of active and resting periods[1] ($\bar{x} \pm$ SE) for male caribou in northern Yukon in 1983[2]. Sample sizes in parentheses.

	Late May	Early June	Mid-June	Late June
Active period	(7) 118 ± 18.4^{a}	(10) 111 ± 12.9^{ab}	(29) 110 ± 6.4^{ab}	(5) 78 ± 11.0^{b}
Bedded period	(23) 103 ± 6.9^{a}	(34) 98 ± 5.2^{a}	(46) 109 ± 4.7^{a}	(12) 69 ± 6.5^{b}

[1] The length of an active period was calculated as the time between the point when the majority of a group ceased lying until the majority of the same group was again lying. The length of a resting period was calculated in an analogous manner.

[2] Active periods (or bedded periods) with the same superscript are not significantly different from each other at the p = 0.05 level.

In general, the development of vegetation was most rapid on the Old Crow pediments (Table 4). In early June, the development of *Eriophorum vaginatum* was more advanced on the coastal plain than at inland sites but by mid-June plant development on the coast was behind that at other sites and remained so. This was probably due to the temperature gradient which develops between the coast, which is strongly influenced by the ice-covered Beaufort Sea, and the thermal basin surrounding the Old Crow Flats (Pearson and Nagy 1976). In general, plant development on the Old Crow pediments was at least a week in advance of that on the coast.

Habitat Selection

Tussock Tundra was weakly selected in late May and early June while Wet Sedge Meadow was strongly avoided until late June (Table 5). Dwarf Shrub Heath began to be avoided weakly after late May and Alluvial Willow shifted from being avoided in late May and early June to being selected in mid-June and late June. Other habitat types were too poorly represented to compare.

Food Habits

In late May *Cladonia*-type lichens and *Vaccinium* (likely *V. vitis-idaea*) were the most important components of the fecal sample (Table 6). Those species continued to be important in early June, although *Eriophorum* (likely *E. vaginatum*) was the most important item. *Eriophorum* predominated in the samples in mid-June but declined sharply in late June. *Salix* increased markedly from early June to mid-June and dominated the samples in late June.

There were no marked differences in diet, as reflected in fecal samples, at the two sample sites in late June, but there was a noticeable variation among sites in mid-June. In mid-June the proportion of *Eriophorum* increased from

TABLE 4. Phenology of vegetation in northern Yukon in 1983. The percent of plants in each stage of development is presented in sequence. Blank spaces indicate that the plant had not yet begun to develop.

	DATE				
	June 3	June 10	June 17	June 24	July 1
<u>Eriophorum vaginatum</u>	B/E/F/P/S[1]	B/E/F/P/S[1]	B/E/F/P/S[1]	B/E/F/P/S[1]	B/E/F/P/S[1]
coast	0/33/67/0/0	0/6/92/2/0	0/0/0/100/0	0/0/0/0/100	0/0/0/0/100
coastal plain	0/48/52/0/0	0/0/88/12/0	0/0/0/100/0	0/0/0/0/100	0/0/0/0/100
mountain basins	0/88/12/0/0	0/2/67/31/0	0/0/0/90/10	0/0/0/0/100	0/0/0/0/100
pediments	0/60/40/0/0	0/4/46/50/0	0/0/0/0/100	0/0/0/0/100	0/0/0/0/100
<u>Salix pulchra</u>[3]	B/U/L[2]	B/U/L[2]	B/U/L[2]	B/U/L[2]	B/U/L[2]
coast		100/0/0	0/100/0	0/96/4	0/0/100
pediments	58/42/0	38/62/0	0/10/90	0/0/100	0/0/100
<u>Betula glandulosa</u>			B/U/L[2]	B/U/L[2]	B/U/L[2]
coast			56/27/17	2/54/44	0/0/100
coastal plain			46/50/4	0/0/100	0/0/100
mountain basins			48/38/14	0/0/100	0/0/100
pediments			2/29/69	0/0/100	0/0/100
<u>Ledum palustre</u>					B/E/F/P/S[1]
coast					86/14/0/0/0
coastal plain					80/20/0/0/0
mountain basins					66/34/0/0/0
pediments					0/0/100/0/0

[1] flower bud/early flower/full flower/past flower/seed

[2] leaf bud/leaf unfolding/full leaf

[3] <u>Salix pulchra</u> was not sufficiently abundant to tally on the inner coastal plain and intermountain basin sites

TABLE 5. Availability (A, % area), utilization (U, % caribou) and selection (S)[1] of habitat types by male caribou in northern Yukon in 1983. Approximate area observed at each campsite in parentheses.

	Sam Lake (29 km^2)					King Point (26 km^2)			Firth River (23 km^2)		
	Late May			Early June		Mid-June			Late June		
Habitat Type	A	U	S	U	S	A	U	S	A	U	S
Tussock Meadow	51	60	+0.16	82	+0.24	88	97	+0.05	76	80	+0.02
Wet Sedge Meadow	18	3	-0.69	1	-0.88	10	1	-0.87	19	17	-0.05
Dwarf Shrub Heath	21	18	+0.02	14	-0.20	-	-	-	4	2	-0.20
Alpine Barren	1	1	0.00	1	-0.05	-	-	-	1	<1	-0.83
Alluvial Willow	8	3	-0.36	1	-0.73	<1	1	+0.54	<1	1	+0.90
Open White Spruce	1	-	-1.00	<1	-0.87	-	-	-	-	-	-
Beach	-	-	-	-	-	1	<1	-0.75	-	-	-
Late Snowpatch[1]	-	15	-	-	-	-	<1	-	-	<1	-

[1] Selectivity measured as (U-A)/(U+A). Utilization values were adjusted by removing late snowpatches because their availability could not be measured.

TABLE 6. Average percentages of discerned plant fragments in fecal samples collected from male caribou in northern Yukon in 1983. Sample sizes in parentheses.

Food Items[1]	Late May (1)	Early June (1)	Mid-June (3)	Late June (2)
Moss	8.6	4.3	2.6	0.1
Lichens	33.9	34.9	3.0	0.3
Cetraria-type	4.5	3.0	0.6	0.2
Cladonia-type	23.4	28.7	1.6	0.2
Stereocaulon	5.2	3.2	0.8	-
Horsetails (*Equisetum*)	-	1.5	0.3	0.1
Graminoids	10.0	36.7	67.3	2.3
Carex	6.8	3.1	1.0	0.7
Eriophorum	3.2	33.6	65.8	1.5
Deciduous Shrubs (*Salix*)	-	2.0	16.5	95.8
Evergreen Shrubs	47.5	19.9	9.6	0.6
Dryas	1.5	0.7	5.0	0.3
Ledum	5.3	3.7	1.1	-
Vaccinium	40.8	14.7	3.6	0.1
Forbs	-	0.6	-	0.7

[1] *Astragalus*, *Festuca*, fungi, *Lupinus*, *Peltigera*, *Picea*, *Poa*, *Saxifraga* and unidentified Ericaceae occurred at average frequencies of less than 1% in some sampling periods.

Sam Lake (50%) to King Point (61%) to Stokes Point (91%) while evergreen shrubs declined over the three sites (25%, 3%, 1%, respectively). Also, Salix was highest at King Point (32%), lower at Sam Lake (16%) and lowest at Stokes Point (1%). Those variations did not appear to be precisely related to either availability or phenological stage. The phenological stages of Eriophorum and Salix were more similar between Stokes Point and King Point than to Sam Lake.

Thompson and McCourt (1981) have previously reported on the diet of the Porcupine Caribou Herd based on fecal analysis. They reported that Eriophorum (56%) and lichens (37%) were the most important components in fecal samples in late May and that samples were dominated by Eriophorum (77%) in early June and by Salix (99%) in late June. Although the proportions of lichen in late May and Salix in late June are consistent with our findings, the proportions of Eriophorum are not; they appear high in relation to expected phenological stage, especially in late May. Duquette (1984) reported on diet of females of the Porcupine Caribou Herd based on fecal samples and found that in late (16-26) May samples were dominated by lichens (41%), Salix (22%) and evergreen shrubs (16%), with Eriophorum making up less than 1%. The high proportion of Salix is noticeably different either from that we observed (0%) or from that reported by Thompson and McCourt (1981) (0.1%). In late May, therefore, caribou of the Porcupine Herd apparently feed primarily on lichens but supplement the diet with whatever palatable green matter is available.

SUMMARY AND CONCLUSIONS

In late May male caribou were distributed south of the mountains where snowmelt was more advanced than farther north. Caribou used tussock meadows, dwarf shrub heaths and alpine barrens but avoided low-lying wet sedge meadows and alluvial willow thickets where snowmelt was slower. Diet consisted primarily of lichens and evergreen shrubs which were widely distributed in the habitat types utilized. By early June, as snowmelt progressed south of the mountains and on the eastern coastal plain, males moved northward to those areas. Intermountain basins, where snowmelt was retarded, were avoided. As the season progressed males continued to use, and avoid, essentially the same habitat types but there was less use of dwarf shrub heaths. They continued to feed on lichens but began to use Eriophorum as it came into flower. In mid-June, males moved into intermountain basins as snowmelt there progressed. Caribou used tussock meadows and alluvial willow thickets as the diet shifted to Eriophorum and Salix. At that time, large aggregations of caribou formed in intermountain basins and they spent more time lying, less time walking, and had a lower rate of movement than in other periods. By late June, males began to use the western coastal plain where they used tussock meadows, wet sedge meadows and alluvial willow thickets. Salix, which was common in all three habitat types, predominated in the diet. At that time, Salix on the coast was at a similar phenological stage to that at inland sites two weeks earlier when it was not used as heavily as Eriophorum. However, by late June Eriophorum was in seed and therefore not as desirable as a food for caribou. In late June average band size increased significantly and rate of movement was greatest as males moved westward towards Alaska. As well, the mean length of active and resting periods decreased by about one-third. This sharp decrease may reflect both the high availability and high digestibility of young willow leaves.

In general, the distribution of male caribou followed the pattern of snowmelt and plant phenology and diet reflected both preference and phenological stage. Activity and movements, however, were not related to snowmelt, plant phenology or diet. Rather, they appeared to follow a temporal pattern.

ACKNOWLEDGEMENTS

We would like to thank the many people who helped with various aspects of the study, in particular L. Hartman and F. Jensen for their assistance with the field work. We are grateful to G. Hobson of the Polar Continental Shelf Project, Canada Department of Energy, Mines and Resources, and to P. Lewis and J. Ostrick of the Western Arctic Scientific Resources Centre, Canada Department of Indian Affairs and Northern Development, for their continued logistic support. The study was conducted while the first two authors were with the Canadian Wildlife Service, Whitehorse, and the third author was with the Department of Renewable Resources, Government of Yükon, Whitehorse.

REFERENCES

ALTMANN, J. 1974. Observational study of behaviour: sampling methods. Behaviour 49:227-265.

COCHRAN, W.G. 1977. Sampling techniques. Third edition. John Wiley and Sons, New York. 444 p.

DUQUETTE, L.S. 1984. Patterns of activity and their implications to the energy budget of migrating caribou. M.Sc. Thesis, University of Alaska, Fairbanks. 95 p.

HOLECHEK, J.L., VAVRA, M., and PIEPER, R.D. 1982. Botanical composition determination of range herbivore diets: a review. Journal of Range Management 35:309-315.

PEARSON, A.M., and NAGY, J. 1976. The summer climate at Sam Lake, Yukon Territory. Arctic 29:159-164.

ROBY, D.D. 1978. Behavioral patterns of barren-ground caribou of the Central Arctic Herd adjacent to the Trans-Alaska Oil Pipeline. M.Sc. Thesis, University of Alaska, Fairbanks. 200 p.

SEGAL, A.M. 1962. Reindeer in the Karelian A.S.S.R. Soviet Academy of Sciences, Moscow. [Translated from Russian, Canadian Wildlife Service, Ottawa.]

SIEGEL, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Company, New York. 312 p.

SOKAL, R.R., and RHOLF, F.J. 1969. Biometry. W.H. Freeman and Company, San Francisco. 776 p.

SPARKS, D.R., and MALECHEK, J.C. 1968. Estimating percentage dry weight in diets using a microscope technique. Journal of Range Management 21:264-265.

THOMPSON, D.C., and McCOURT, K.H. 1981. Seasonal diets of the Porcupine Caribou Herd. American Midland Naturalist 105:70-76.

VIERECK, L.A., and DYRNESS, C.T. 1980. A preliminary classification system for vegetation of Alaska. United States Department of Agriculture, Forest Service, General Technical Report PNW-106. 38 p.

WHITTEN, K.R., and CAMERON, R.D. 1979. Nutrient dynamics of caribou forage on Alaska's arctic slope. <u>In</u>: Reimers, E., Gaare, E., and Skenneberg, S. (eds.). Proceedings of the Second Reindeer/Caribou Symposium, Roros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim: 159-166.

WIKEN, E.B., WELCH, D.M., IRONSIDE, G.R., and TAYLOR, D.G. 1981. The Northern Yukon: an ecological land survey. Environment Canada, Lands Directorate, Ecological Land Classification Series No. 6. 197 p.

AFWRC Progress Report: Subwork Unit 4

CARIBOU USE OF POTENTIAL OIL AND GAS DEVELOPMENT AREAS IN THE 1002 REGION OF THE ARCTIC NATIONAL WILDLIFE REFUGE

Larry F. Pank
Wayne L. Regelin
Catherine H. Curby
Steven G. Fancy

Key words: Porcupine caribou herd, satellite telemetry, movements, Arctic National Wildlife Refuge

Alaska Office of Fish and Wildlife Research
U.S. Fish and Wildlife Service
101 12th Ave., Box 20
Fairbanks, Alaska 99701

AFWRC Progress Report: Subwork Unit 4

Caribou use of potential oil and gas development areas in the 1002 region of the Arctic National Wildlife Refuge.

L.F. Pank, W.L. Regelin, C.H. Curby, and S.G. Fancy.

The use of conventional radio-telemetry techniques to track animals has resulted in major advances in our understanding of the movements and behavior of individuals and populations. Much of the detailed information in this and earlier volumes regarding habitat use, daily and seasonal movements, mortality rates, den locations and other aspects of the life histories of the species studied could not have been obtained without the use of radio-telemetry. Nevertheless, conventional radio-tracking techniques have a number of drawbacks and limitations, many of which become more pronounced in remote, high-latitude areas. Systematic collection of data by conventional methods is not possible in the arctic because of unpredictable weather conditions which restrict tracking flights, and the remoteness of most areas. Long periods of darkness in winter, high costs for aircraft time, and safety considerations further restrict the use of conventional methods.

This report presents preliminary findings of a study using satellite telemetry in an attempt to overcome many of the problems listed above and to provide additional data not available using conventional radio transmitters. The satellite telemetry system described here systematically collected accurate locational and behavioral data on barren-ground caribou (Rangifer tarandus granti) within the Arctic National Wildlife Refuge (ANWR) and Yukon Territory. This report presents preliminary analyses of the potential interaction between (1) caribou of the Porcupine Caribou Herd (PCH) and the Central Arctic Herd (CAH), and (2) potential developments within the 1002 area of the ANWR. In addition to the analyses described here, the detailed movement and behavioral data collected by satellite telemetry are being used to (1) identify critical habitats, including areas used for insect relief, (2) monitor the fidelity of individual caribou to specific calving areas, migration routes, and seasonal ranges, (3) provide detailed data on rates of movement and seasonal movement patterns, and (4) monitor activity patterns throughout the year. The results of these additional analyses will be presented in future reports.

Methods

The major components of the satellite telemetry system are ten transmitters attached to adult female caribou, the ARGOS data collection system (Center National d'Etudes Spatiales, France) aboard TIROS-N series satellites, and a series of ground tracking and command stations. Two functional satellites (currently NOAA-6 and NOAA-9) are maintained in near-polar orbits by the National Oceanic and Atmospheric Administration (NOAA). The satellites orbit at an altitude of 830-850 km and complete one orbit every 102 min. The ten transmitters were built by Telonics, Inc. (Mesa, AZ) and operate at a frequency of 401.650 MHz. Each complete transmitter package, including the attachment collar and a conventional transmitter, weighs approximately 1.6 kg. The difference between the transmitted frequency and that received by the satellite (the doppler frequency shift) provides the basis for determining each caribou's location. An internal timing circuit activated each transmitter for 6 h each day (0600 - 1200 Alaska Standard Time or 1200 - 1800 AST) during which data were transmitted once each minute. As many as 16 transmissions could be received during one overpass by a satellite within "view" of a transmitter. Data received during an overpass were downlinked to earth stations once each orbit and relayed to the ARGOS processing center in Toulouse, France for additional analyses. The data could be accessed within 8 h of an overpass via telephone (using the Alaskanet and Tymnet computer networks) and were also received monthly on 9-track tape from ARGOS.

In addition to providing data needed to determine the caribou's location, the transmitters remotely monitored the temperature of the internal transmitter package, the short-term activity of the caribou, and the activity of the caribou during the previous 24 h. The internal transmitter temperature is highly correlated with ambient temperature whereas the short-term (previous 60 sec) activity sensor can be related to specific activities such as lying, walking, and running (Pank et al. 1985a). The long-term or 24 h sensor is used primarily as a mortality sensor. The transmitted values represent the number of seconds during a 60 sec or 24 h period in which movements by the caribou triggered the closing of a mercury switch within the transmitter.

Most of the analyses described here were conducted using the Map Overlay and Statistical System (MOSS). This computer graphics package provides a means of overlaying and processing various types of two or three dimensional data, and was used to determine the distribution of caribou locations each month and their proximity to potential developments. Based on previous experiments (Pank et al. 1985a), the mean error in determining the locations of caribou used in the analyses (i.e., point locations) was approximately 530 m. For the purpose of these analyses, an interaction between a caribou and the development scenarios occurred whenever a point location, or any segment of a line connecting two point locations calculated for the same caribou on adjacent days, was within 3 km of a road, pipeline, drill pad, airfield, or other development infrastructure (Dau and Cameron 1986).

The two development scenarios used in these analyses typify arctic oil development elsewhere, and were similar to the development scenarios which were used for the analysis of the Arctic National Wildlife Refuge, Alaska Coastal Plain Resource Assessment. The smaller development scenario, referred to in this report as the "limited scenario", excluded development in the southeastern portion of the 1002 area.

A map of insect relief habitat within ANWR was developed from LANDSAT land classification maps and field studies of insect distribution and abundance (Pank et al. 1985b). The value of various habitats for insect relief was determined from insect sweep counts, sticky traps, and caribou pellet group densities (Pank et al. 1985b). The resulting map, consisting of 200 m x 200 m pixels covering the entire refuge, was transformed to a format compatible with the MOSS graphics package for future analyses of caribou use of insect relief habitats.

Results

The movements of two of the ten satellite-collared caribou (nos. 5890 and 5894) during 1985 and early 1986 suggest that these two caribou are not members of the Porcupine Caribou Herd. Caribou 5890 did not have a calf in 1985, but caribou 5894 calved near the delta of the Canning River in an area considered to be part of the calving grounds of the CAH. Consequently, since herd membership is currently defined on the basis of a caribou's calving location, caribou 5894 must be considered as a member of the CAH. The movements of these two caribou are currently thought to be representative of up to 1,000 CAH caribou which winter north of the Brooks Range and reside within the ANWR for most of the year (K. Whitten, pers. comm.). Because of the many differences between the movements of these two CAH caribou and the eight PCH caribou, the two herds were treated separately in all analyses.

Table 1 summarizes the calving success and seasonal range use patterns for each of the ten caribou. Five of the caribou calved within the 1002 area; three of the other five calved in Canada, and two did not have calves. The eight PCH caribou were all originally collared on the winter range south of the Brooks Range in the ANWR. Only half of these caribou wintered in the ANWR during the subsequent winter (Table 1).

Only five of the eight PCH caribou entered the 1002 area in 1985, all between 29 May and 26 July. The five caribou spent an average of 15.2 (± 8.9 SD) days within the eastern half of the 1002 area (Figs. 1-2). Of the 232 point locations for PCH caribou within the 1002 area, 51 (22%) occurred within 3 km potential of infrastructure under the full leasing scenario.

The analysis of caribou routes between locations on adjacent days was conducted in an attempt to estimate the expected number of daily interactions between caribou and development infrastructures. Under the full leasing scenario, 34% of the 67 routes within the 1002 area came within 3 km of potential infrastructures, and 10% were within this distance under the limited scenario (Table 2). If the movements of all eight PCH caribou are considered, the percentages are 6.2% and 1.9% of the daily routes, respectively.

The two CAH caribou occurred within the 1002 area during every month except January and February 1986, when they wintered just south of the 1002 border in the Sadlerochit Mountains. The CAH caribou encountered the potential development scenario to a much greater extent than did the PCH caribou; 413 (32.7%) of 1264 point locations within the 1002 area were within 3 km of potential infrastructure under the full leasing scenario. Only one location occurred within the area distinguishing the full from the limited scenario, such that 412 of 1264 locations were within 3 km of limited scenario infrastructures.

Between April and October (route analyses were not conducted for later months because of time constraints), 302 (83%) of the 364 daily routes of the CAH caribou were within the 1002 area. Of these, 118 (39%) were within 3 km of infrastructure under the full scenario, and 117 (39%) were within that distance under the limited scenario.

The availability of habitats used by caribou for insect relief, and the proportions of these habitats which occur within 3 km of the two development scenarios, are shown in Table 3. The insect relief map is presented in Figure 3. For each of the scenarios, the proportion of each insect relief habitat within 3 km of an infrastructure is similar to that found in the 1002 area. If the movement patterns of caribou within the 1002 area are altered because of high levels of activity in the development area or for other reasons, additional insect relief areas may become inaccessible. However, gravel structures such

Table 1. Calving success and range use patterns for satellite-collared caribou between April 1985 and February 1986. The mean number of satellite overpasses during which sensor data was received, and the mean number of locations calculated per day, is shown for each caribou. Transmitters were activated for only 6 h during each 24 h period.

Caribou	Mean (± SD) Overpasses/d	Mean (± SD) Locations/d	April 85 Capture Area	June 85 Calving Area	1985-1986 Winter Area
PCH					
5870	4.9 (3.7)	2.4 (2.0)	ANWR, South	No calf	ANWR, S. Brooks Range
5871	6.1 (4.3)	2.5 (1.8)	" "	Upper Angen R. 1002 area	Yukon Terr.
5872	5.0 (3.4)	2.7 (2.1)	" "	Egaksrak/ Aichilik R. 1002 area	Yukon Terr.
5873	6.4 (3.5)	3.5 (2.2)	" "	Yukon Terr., Lower Spring River	Yukon Terr.
5874	5.5 (3.2)	3.1 (2.1)	" "	Yukon Terr., S. Herschel Island	Yukon Terr.
5875	5.6 (3.8)	3.1 (2.3)	" "	Yukon Terr., S. Herschel Island	ANWR, S. Brooks Range
5876	5.1 (3.2)	2.9 (2.0)	" "	Upper Jago, 1002 area	ANWR, S. Brooks Range
5877	6.6 (3.9)	3.6 (2.5)	" "	Upper Jago, 1002 area	ANWR, S. Brooks Range
CAH					
5890	6.6 (3.3)	3.8 (2.2)	Sadlerochit Mountains	No calf	1002 area/ Sadlerochit Mountains
5894	5.8 (2.8)	3.6 (2.1)	" "	Canning Delta	1002 area/ Sadlerochit Mountains

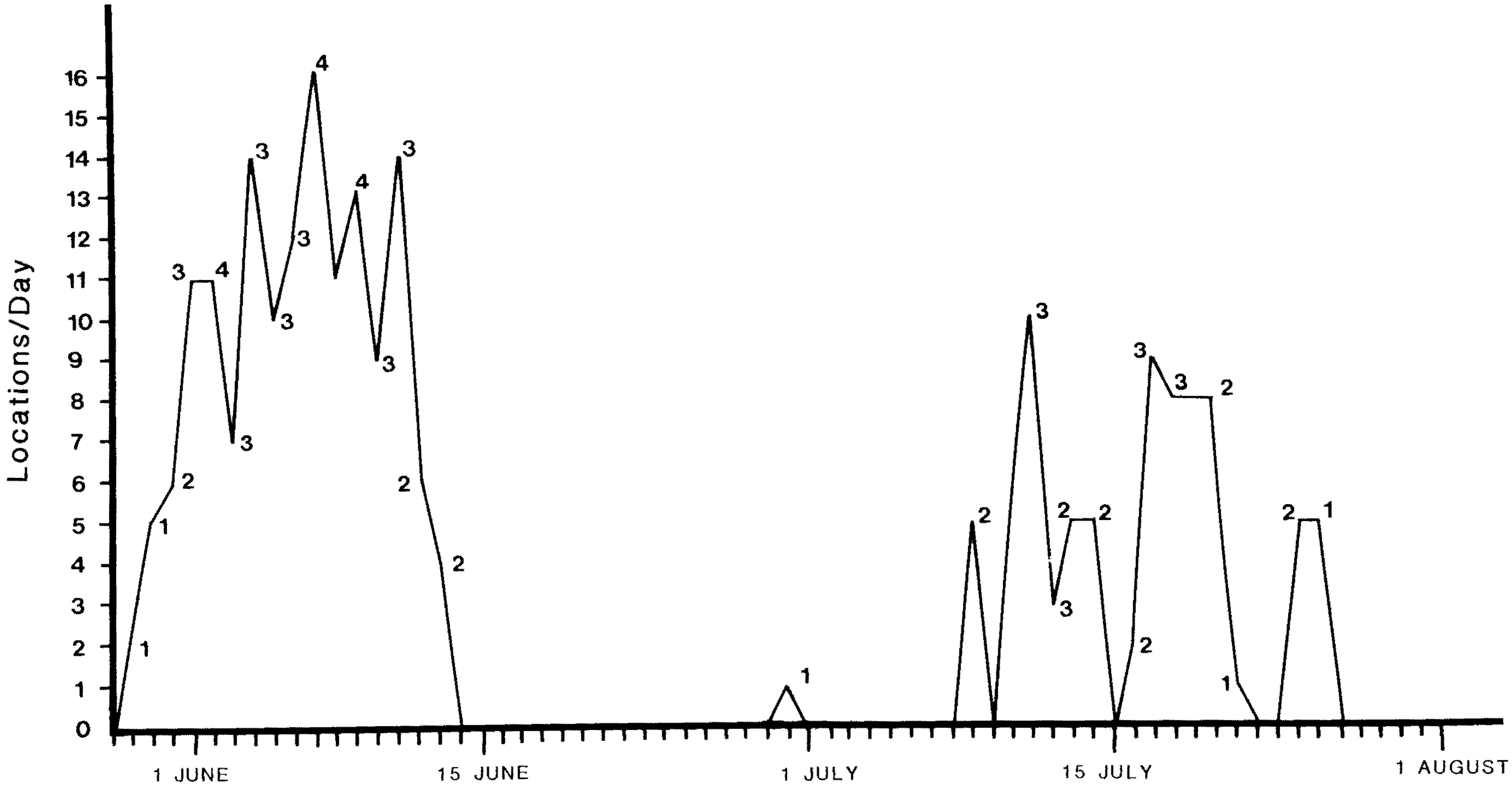


Fig. 1. Number of locations per day and number of satellite-collared caribou of the Porcupine Herd within the 1002 area during summer, 1985.

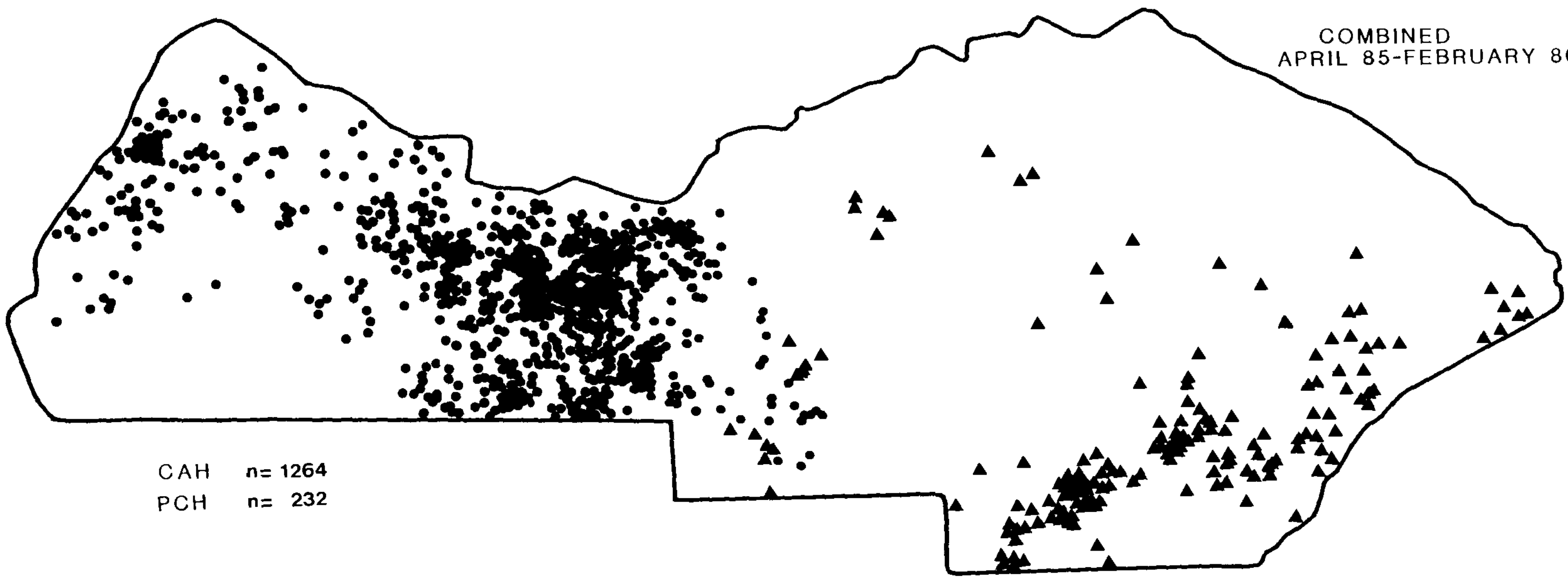


Fig. 2. Locations of adult female satellite-collared caribou of the Porcupine and Central Arctic herds within the 1002 area between April 1985 and February 1986.

Table 2. Proportion of caribou routes between locations on adjacent days which came within the 1002 area and within 3 km of development infrastructures for the full or limited leasing scenarios.

	Month							Combined
	April	May	June	July	August	September	October	April-October
Porcupine Herd								
Sample size	254	191	205	168	235	203	222	1478
% in 1002	0	1.0	18.0	16.7	0	0	0	4.5
% in Full	0	0	6.3	6.0	0	0	0	1.6
% in Limited	0	0	0	4.2	0	0	0	0.5
Central Arctic Herd								
Sample size	29	59	55	45	61	56	59	364
% in 1002	37.9	100.0	76.4	73.3	96.7	100.0	71.2	83.0
% in Full	0	47.5	16.4	37.8	49.2	30.4	28.8	32.4
% in Limited	0	47.5	14.5	37.8	49.2	30.4	28.8	32.1

Table 3. Availability of insect relief habitat within the 1002 area and within 3 km of potential development areas.

Habitat	Area within 1002 (km^2)	Proportion of Area (%) 1002	Full Scenario	Limited Scenario
Dry Prostrate Dwarf Scrub	42.6	0.64	0.66	0.80
Barren Floodplain	160.9	2.42	2.27	2.31
Barren Scree	0.9	0.01	0	0
Scarcely Vegetated Floodplain	87.7	1.32	0.59	0.57
Scarcely Vegetated Scree	1.8	0.03	0	0
Shallow Water	1.8	0.03	0.01	0.01
Coastal Zone (3 km)	708.2	10.66	8.87	11.25
Total insect relief	1003.9	15.11	12.39	14.95
Total 1002 area	6645.8			

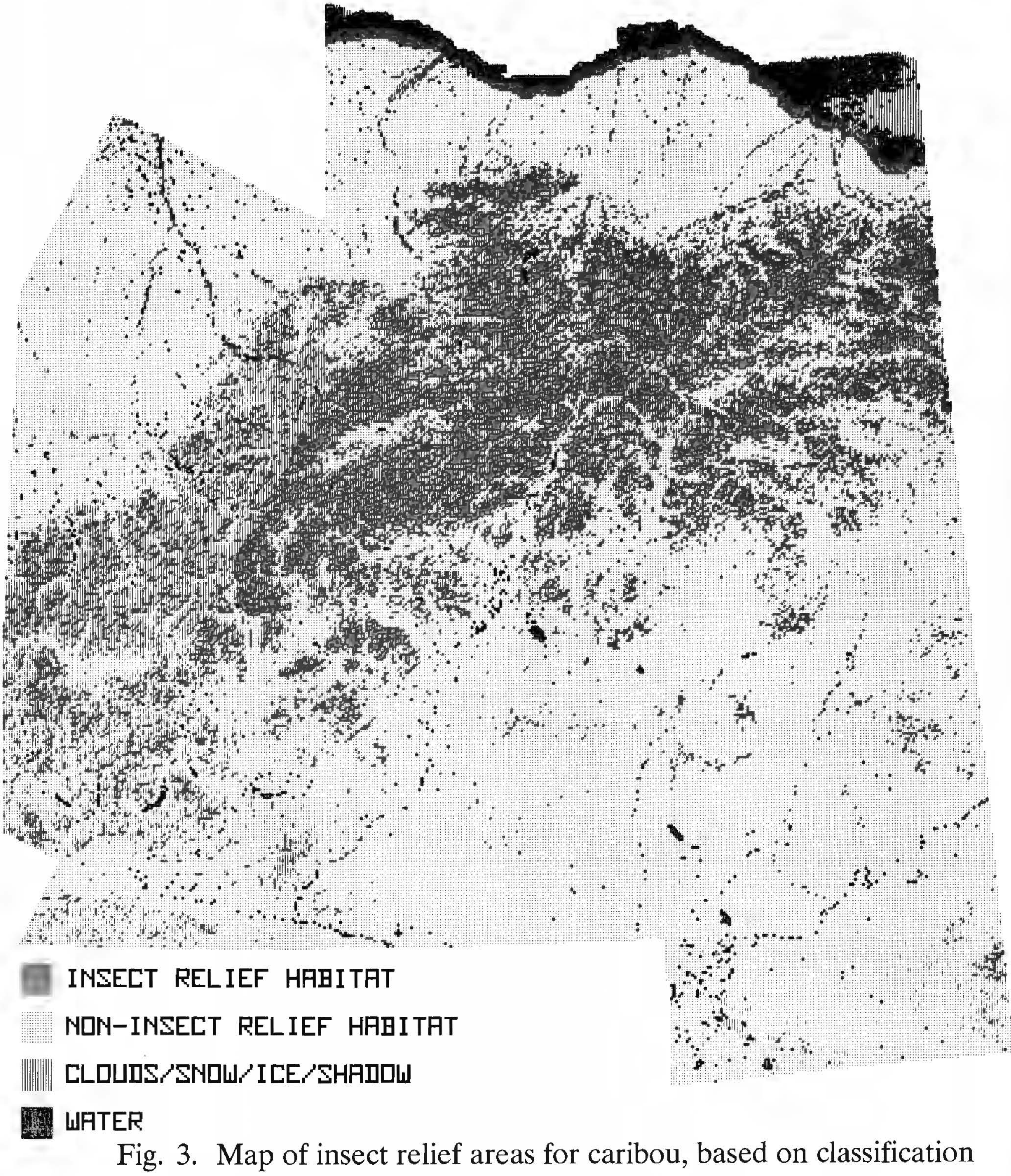


Fig. 3. Map of insect relief areas for caribou, based on classification of LANDSAT multi-spectral scanner data.

as roads and drill pads may provide caribou with relief from insects if levels of vehicle and human activity are low (Fancy 1983).

The mean daily distance traveled, based on the straight-line distance between locations on adjacent days for each caribou, reached a maximum in July for both herds (Fig. 4). The greater distances traveled during July are probably a reflection of insect avoidance movements. The lowest daily movements for both herds occurred in winter (Fig. 4).

Discussion

The results of the satellite telemetry studies to date indicate that this technology is an accurate, reliable and cost-effective means of systematically collecting detailed movement and activity data on caribou and other large mammals. The results presented in this report exemplify some of the uses of data obtained from satellite-collared animals.

Extrapolation of these results to the herds in general must be very tentative because of the small sample sizes and short time frame involved with these analyses. The calculations which follow are presented as an example of how the satellite telemetry results can be used to estimate interactions between the herd and the development scenarios once an adequate sample size representing several years of movements and additional caribou has been attained. Several assumptions are involved in making these extrapolations:

Assumption 1: The movements and behavior of the satellite-collared caribou are representative of uncollared caribou in each herd. Since the adult cow segment of the PCH is known to exhibit different range use and movement patterns from the bull and yearling female segments, data for satellite-collared adult cows must not be extrapolated to these other sex/age classes. Furthermore, the movements of the two CAH caribou are not representative of the movements of most of the caribou in that herd. The size of the CAH segment utilizing the ANWR is thought to be on the order of 1000 caribou, but additional study is needed to determine the actual size and seasonal movements of this segment. The assumption that the eight satellite-collared caribou are representative of uncollared adult PCH cows appears to be reasonable.

Assumption 2: The satellite telemetry system provides an accurate and unbiased sample of the movements and behavior of collared caribou. We are continuing to evaluate this assumption, but at this time it appears to be reasonable.

Assumption 3: Movement and behavioral data obtained in 1985 are representative of other years. We cannot compare the satellite telemetry data obtained in 1985 with those in previous years since these transmitters were first deployed in April 1985. The movements of the eight PCH caribou in 1985 fit the general movement patterns determined in previous years using conventional methods. However, several years of detailed satellite telemetry data are needed before this assumption can be evaluated.

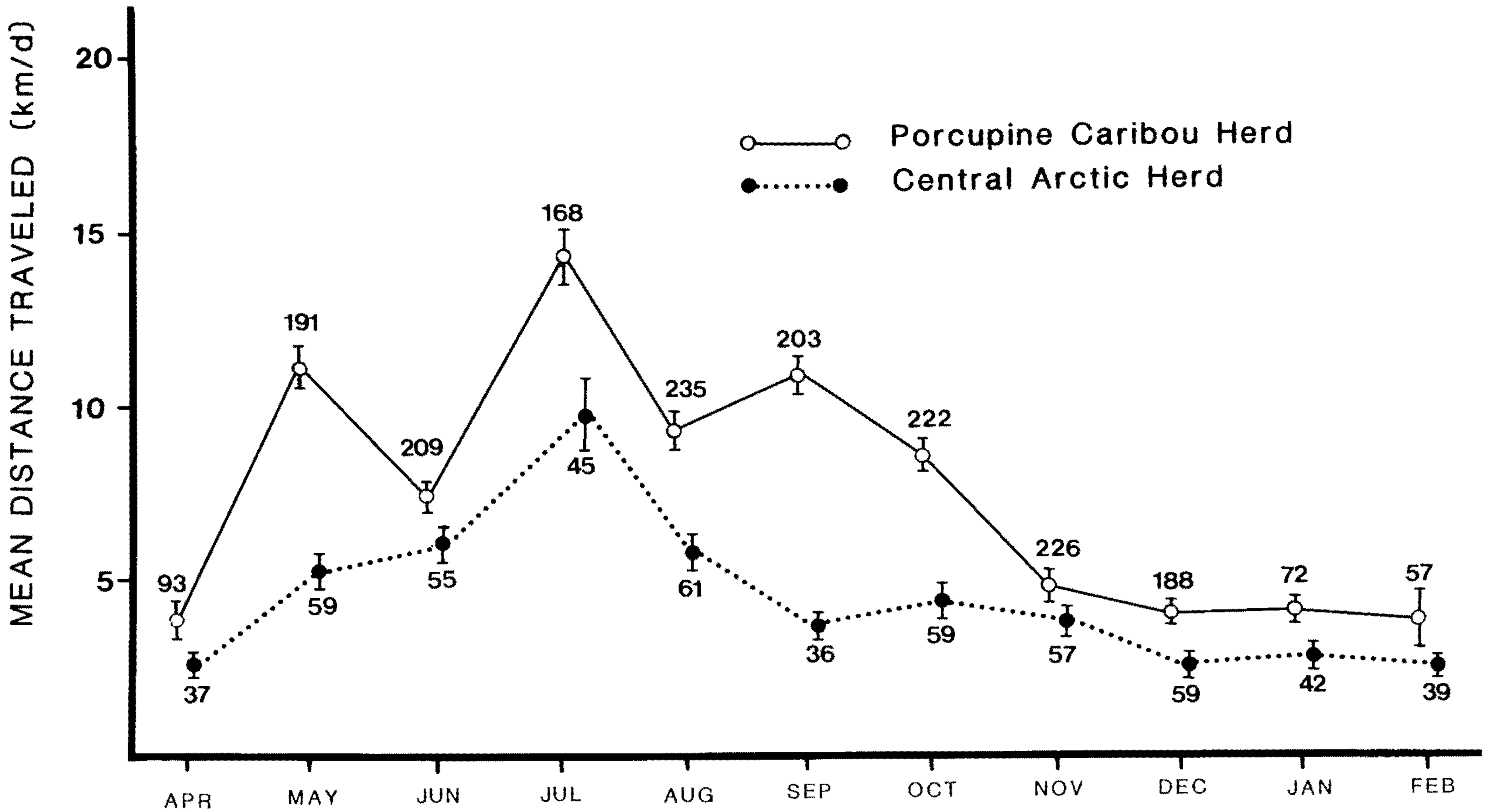


Fig. 4. Mean daily distance travelled by satellite-collared caribou of the Porcupine and Central Arctic herds. Means are based on straight-line distances between locations determined approximately 24 h apart.

Whitten (1987) provided the most recent estimate of herd size and population trends for the PCH based on the 1982 photo census and surveys conducted in recent years. Based on the "best guess" estimate of 165,000 caribou in 1985, and the sex/age ratios of 60 bulls per 100 adult cows, 35 yearlings per 100 adult cows, and 50 calves in July per 195 adults and yearlings, an estimate of 67,350 adult cows is attained. Based on the ratio of 5 of 8 satellite-collared PCH cows which entered the 1002 area in 1985, approximately 42,000 cows entered the 1002 area. Thirty-four percent of the daily routes of PCH caribou within the 1002 area came within 3 km of the full development scenario; if extrapolated to the estimated 42,000 cows, approximately 14,250 daily encounters between caribou and the development scenario are expected. For the limited development scenario, 4200 daily encounters are expected.

The number of CAH caribou using the 1002 area has not been accurately determined, but for every 100 caribou present, similar calculations as above yield an estimate of 32 daily encounters between CAH caribou and the full or limited scenarios between April and October.

We again caution that these calculations are based on preliminary data for a small number of caribou and for only one year. Furthermore, only adult cows are included in these estimations. With additional data, we will eventually be able to assess the variability between individuals and between years, and give a better estimate of the degree of interaction between caribou and the development scenarios. However, they represent the best available estimate of the degree of interaction between caribou and the potential developments at this time.

Literature Cited

Dau, J.R., and R.D. Cameron. 1986. Effects of a road system on caribou distribution during calving. Rangifer, Special Issue No. 1:95-101.

Fancy, S.G. 1983. Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. Arctic 36:193-197.

Pank, L.F., W.L. Regelin, D. Beaty, and J.A. Curatolo. 1985a. Performance of a prototype satellite tracking system for caribou. In: R.W. Weeks and F.M. Long (eds.), Proc. Fifth Intern. Conf. Wildlife Biotelemetry, Chicago, Ill.

Pank, L.F., C.H. Curby, B. Nankivell, C. Simon, and R. Wright. 1985b. Probe: Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the ANWR. p. 695-724 In G.W. Garner and P.E. Reynolds (eds.), 1984 update report, baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, Ak. 777pp.

Whitten, K.R. 1987. Population status and trends of the Porcupine caribou herd, 1982-1985. In: G.W. Garner and P.E. Reynolds, eds. 1985 update report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildl. Serv., Anchorage, AK.

AFWRC Progress Report: Subwork Unit 3

A sampling method to determine caribou use of coastal tundra on the Arctic National Wildlife Refuge: caribou use of the area surrounding the Kaktovik Inupiat Corporation (KIC) exploratory well No. 1 Site.

Larry Pank
Peggy Kuropat

Key Words: Porcupine caribou herd, sampling, fecal pellet densities, exploratory well, Arctic National Wildlife Refuge.

Alaska Office of Fish and Wildlife Research
U.S. Fish and Wildlife Service
101 12th Ave., Box 20
Fairbanks, Alaska 99701

AFWRC Progress Report Subunit 3

A sampling method to determine caribou use of coastal tundra on the Arctic National Wildlife Refuge: caribou use of the area surrounding the Kaktovik Inupiat Corporation (KIC) exploratory well No. 1 site.

Peggy Kuropat and Larry Pank, U.S. Fish and Wildlife Service, Alaska Office of Fish and Wildlife Research, Anchorage, Alaska.

Abstract: The line transect sampling method was field tested to determine its suitability for estimating the densities of caribou fecal pellet groups. Pellet count densities were estimated in the drier landcover classes derived from LANDSAT imagery on the arctic coastal plain. The study area was within the Arctic National Wildlife Refuge in northeastern Alaska. Pellet densities were estimated for a study area which contained two sites; one site centered on an exploratory well while the second site served as a control site of similar landcover composition. The initial surveys of pellet densities provide a pre-disturbance baseline of relative use and can serve as an index of area use over time.

A sampling method to determine caribou use of coastal tundra on the Arctic National Wildlife Refuge: caribou use of the area surrounding the Kaktovik Inupiat Corporation (KIC) exploratory well No. 1 site.

Barren-ground caribou (Rangifer tarandus granti) of the Porcupine Caribou Herd (PCH) range over the coastal tundra of Alaska's arctic slope within the Arctic National Wildlife Refuge (ANWR) and Northwest and Yukon Territories of Canada. The majority of use by the PCH on the coastal plain in ANWR occurs between late May to mid-July. Large groups of cows move to calving grounds on the coastal plain in late spring. Range use in the summer can include movements of large numbers of adult bulls and cows with calves moving along the coastal plain and foothills of the Alaska/Yukon Territory border to relief habitat from insect harassment (U.S. Fish and Wildlife Service 1982, Whitten et al. 1984, 1985).

Public and agency concern over the possible impacts of petroleum development include potential displacement of caribou in their seasonal movements to and use of calving and insect relief areas on the coastal plain in Alaska (Cameron 1983). Baseline studies are being conducted on the coastal plain to inventory the biological and geological resources of the ANWR and to assess the potential impact on the wildlife resources of gas and petroleum related exploration and oil field development (Garner and Reynolds 1984, 1985). Studies conducted to date have documented caribou responses to development (Carruthers et al. 1984, Cameron et al. 1985) but, with the exception of the Milne Point area (Dau and Cameron, in press), lack quantified baseline information on the habitat selection, timing of use and seasonal movements of bull and cow/calf bands in areas prior to exploration drilling or commencing field development.

Predevelopment studies may be hampered by limited access if road systems, helicopter, or support facilities for long term field studies are not available. Exploratory drilling activity on the Kaktovik Inupiat Corporation (KIC) land surrounded by the ANWR and within the range area of the Porcupine herd provided an opportunity to develop cost efficient field methods to determine baseline use of an area by caribou prior to site exploration or development even if caribou are not present on site at the time of the field work or if refuge management or field budgets limit access during a critical season of use.

A commonly applied wildlife management technique is the use of fecal pellet group counts to estimate relative animal use of a specific area by ungulates (Neff 1968, Collins 1981). The pellet group method can be used to estimate the relative intensity of use and trends in use of an area over time (Julander et al. 1963). For example, pellet group densities have been used to determine habitat availability and use by northern ungulates (Cairns and Telfer 1980) and to estimate wildlife response and habitat loss in relation to the development and densities of roads (Rost and Bailey 1979, Lyons 1983). This report summarizes results of a field study to develop a repeatable sampling method to monitor changes in caribou use patterns on the coastal plain in ANWR.

The objectives of this study were:

1. To develop and evaluate a cost-effective and repeatable sampling method to assess relative pre- and post treatment use of an area by caribou following site development.

2. To acquire site specific baseline information on relative use by caribou on the KIC #1 exploratory well and adjacent control sites.

The study area was located on the arctic coastal plain 12 miles east of Kaktovik, Barter Island, Alaska near the delta of the Niguanak River and along the Tapkaurak and Oruktalik Lagoons of the Beaufort Sea Coast (Figure 1). The study area included the well site and a control site. The sites are in an area of level and poorly drained tundra soils characterized by permafrost, shallow seasonal ground thaw, flat- and low-centered polygons, strangmors, frost boils, thaw lakes, dried lake basins, and shallow streams. The diversity of vegetation in the area reflects the variation in moisture gradients found on a continuum from dry frost boils and moist shrub meadows interspersed with strangmors, to low-centered polygons and extensive areas of flat terrain covered by wet sedge (Walker et al. 1982).

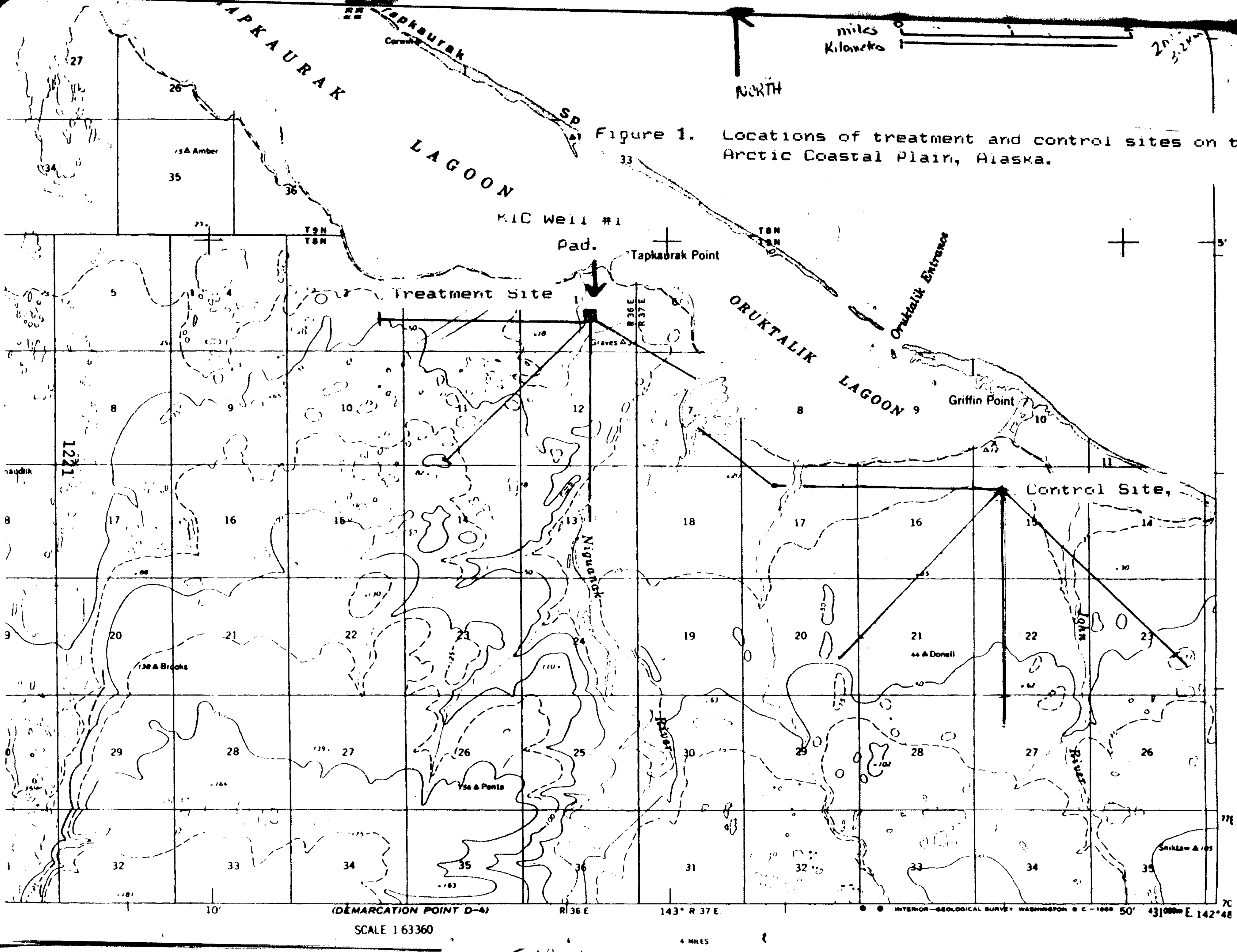
The well site was centered on the KIC exploratory well #1 pad which consisted of a 50 m x 100 m gravel pad base on mineral soil covered by a layer of closed cellfoam insulation and an upper deck of wooden planks. Structures on the drill pad included the drill rig, support trailers, a maintenance shop, storage tanks, water and diesel supply systems, housing facilities for a 70 man camp, a helicopter landing pad, weather tower, storage cargo vans, a diesel generator system, and stores of timber, drill casing, and drilling mud. The drill rig was not operational during the 1985 summer field season; the drilling boom had been lowered down in May 1985 and was horizontal to the pad deck. A communications van, which housed the telecommunications equipment and the communications and power cords for the winter air strip, was located a few yards off the southeast corner of the drill pad. The tundra overburden had been scraped off the pad site and stockpiled along the southern perimeter of the pad. Waste water, drilling mud, and debris from the drilling operation were stored in a fenced, gravel-bermed waste pit located on the west end of the drill pad. A diesel generator housed in a metal trailer was in continuous operation to supply power to the camp facilities and telecommunications system. The sound of the generator was continuous but not detectable by sound meter (<35 dB) at distances greater than 50m from the drill pad depending on wind direction and velocity. The well site was not operational during the summer and was maintained by a 2 man crew.

Methods

Field Methods

Field work was conducted from 4 to 23 June 1985 from a base camp established near a small creek midway between the two study sites. Between 4 and 11 June, the well site and a control site were located and radiating transect lines (radii) were set out from center points of the two sites (Figures 2-3). The center point of the well site was on the southwest corner of the perimeter of the Arctic Slope/Chevron KIC No. 1 well pad (70°5'N, 143°1'W) away from the stockpiled overburden and disturbed vegetation. The center point of control site (70°3'N, 142°1'W) was 6.5 km to the east, and 0.7 km south of Griffin Point.

The control site selected was similar to the treatment site in the following attributes:



TAPKAURAK LAGOON
Tapkaurak Sp
Corwin
NORTH
miles
Kilometers
Figure 1. Locations of treatment and control sites on the Arctic Coastal Plain, Alaska.
KIC Well #1 Pad.
Treatment Site
Tapkaurak Point
ORUKTALIK LAGOON
Oruktalik Entrance
Griffin Point
Control Site,
Amber
Graves
Brooks
Donell
Penta
Sniktaw
Niguanak River
T9N
T8N
R 36 E
R 37 E
(DEMARCATION POINT D-4)
143° R 37 E
142°48'
10'
50'
SCALE 1:63360
4 MILES
INTERIOR—GEOLOGICAL SURVEY WASHINGTON D C—1955

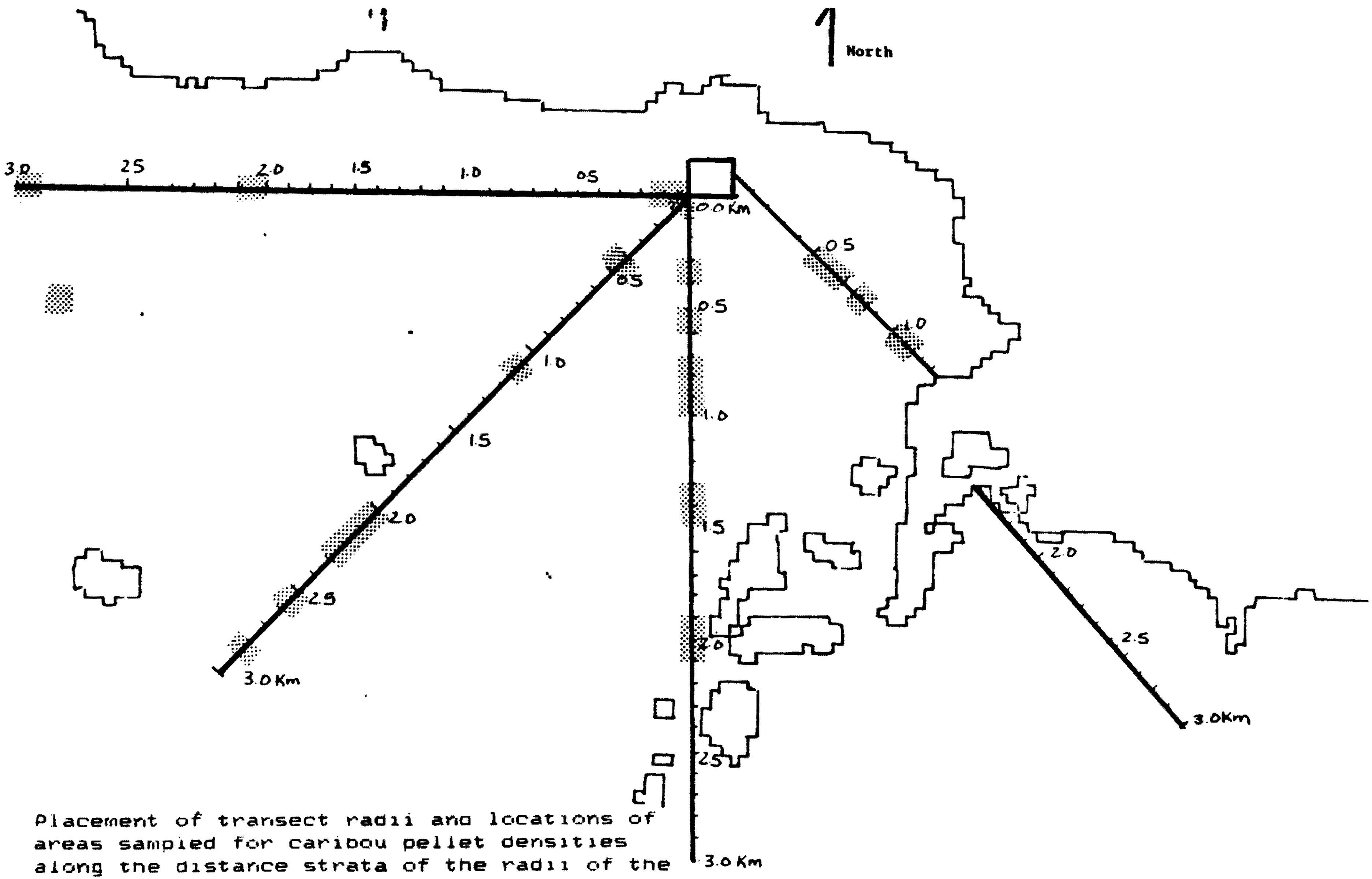


Figure 2 Placement of transect radii and locations of areas sampled for caribou pellet densities along the distance strata of the radii of the Treatment Site, KIC Well #1 Drill Pad. Tapkaurak Point, Alaska.

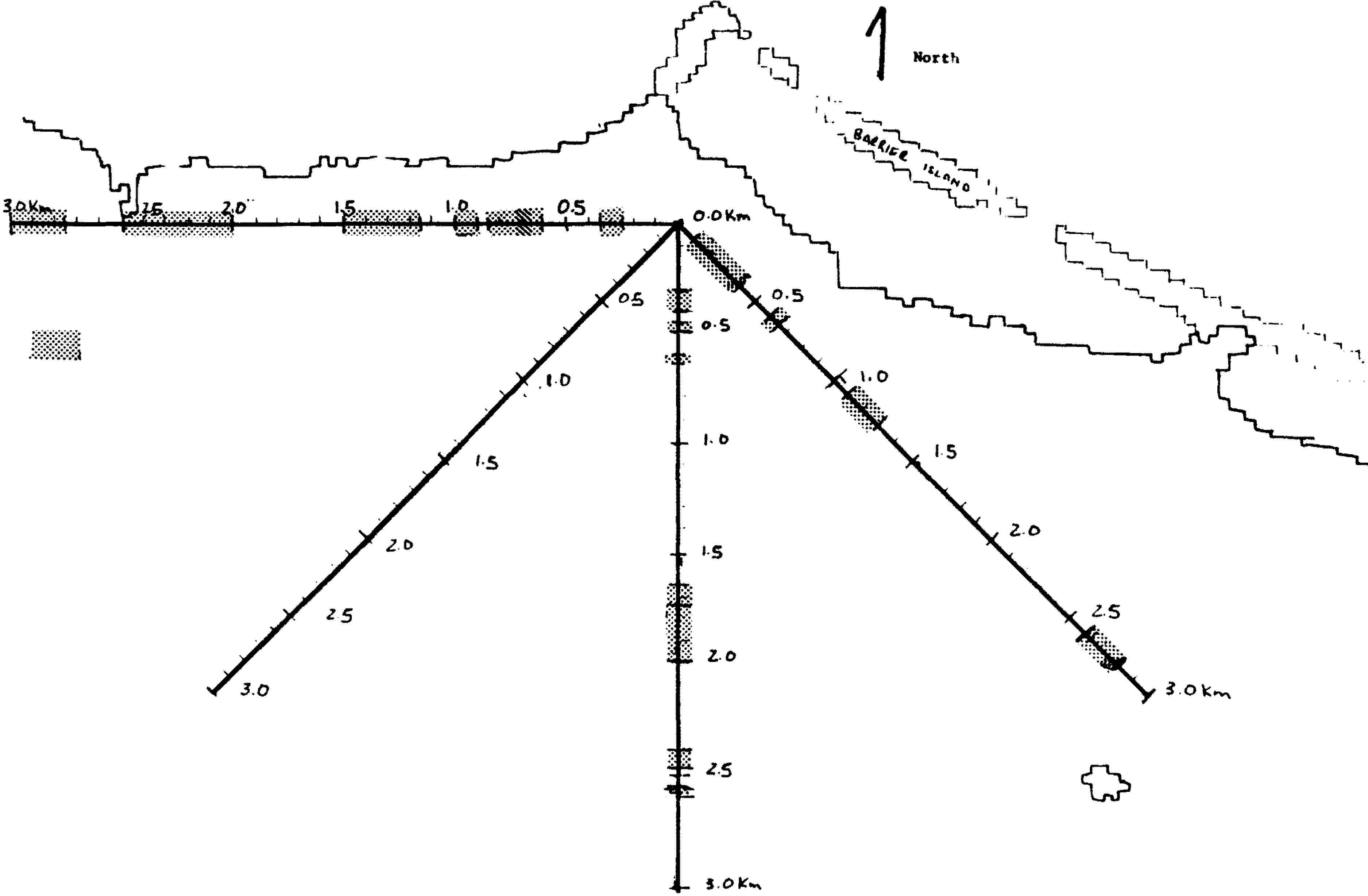


Figure 3 Placement of transect radii and locations of areas sampled for caribou pellets densities along the distance strata of the radii of the Control Site. Griffin Point, Alaska.

1. Frequency and spatial distribution of land cover classes as determined by LANDSAT imagery,

2. Similar coastline along each side, and

3. Placement of radii on compass bearings within sites relative to the coastline.

Vegetation was classified by landcover types derived from LANDSAT imagery of landforms, growth forms, and percent cover of vegetation as described by U.S. Geological Survey and U.S. Fish and Wildlife Service (1985) based on Walker et al. (1982). Classifications of the LANDSAT landcover types in the study area described as follows were identified on landcover maps.

1. Dry prostrate dwarf shrub dominated by *Dryas* spp., prostrate *Salix* spp., and *Saxifraga oppositifolia*. This landcover type was common along the river terrace above the Niguanak River, on raised microsite ridges along polygonal troughs, and in pockets of heath-snowed vegetation below late melting snow-beds.

2. Moist prostrate dwarf shrub typified by large areas of moist meadows of *Salix planifolia pulchra* and non-tussock forming species of *Carex* and *Eriophorum* sedges.

3. Moist graminoid tussock of *Eriophorum* spp. and *Carex bigelowii* found in scattered patches in areas of slight microsite relief.

4. Moist/wet tundra complex occurred as a mixture of low shrubs on raised areas such as strangmors and polygonal rims, and of wet graminoids on flat and low-center polygons. This landcover also included high-center polygons with thermokarst pit rims.

5. Wet graminoid meadows were associated with wet habitats of low- or flat-centered polygons. The meadows contained saturated soils or standing water throughout the summer with a continuous cover of sedge vegetation. Shrub cover was limited to elevated polygon rims and formed a minor component.

6. Very wet graminoid areas included marshy areas around deltas and ponds, along rivers, low areas with standing water, and ponds with *Arctophila fulva*.

7. Lakes.

8. Barren floodplain and sand/gravel bars.

9. Off shore shallow water.

Four transects (radii) were staked out in the two circular study sites; the direction of the radii and proximity to the coastal shoreline were the same for both sites (Figure 1). The four radii, each three kilometers in length, were staked out from a common, flagged center point on compass bearings from true north to the southeast (135°), south (180°), southwest (225°) and west (270°). The radii were divided into three 1 km distance strata starting with the center point as 0.0 km. Distance strata along each radii were marked at 100 m intervals with plastic flags on 1 m tall wire stakes. The flags were color-coded and set with one color denoting a 0.5 km section of the radii. For example, the 0.5 to 0.9 km markers were blue flags, the 1.0 to 1.4 km markers were yellow flags, and the 1.5 to 1.9 km markers were red flags. The color coded segments enabled the observers to relocate the radii on the tundra, to accurately locate the distance within the strata sampled for artifacts and pellet groups, and to ground-truth the vegetation sampled in a distinct landcover type with the landcover map.

Sampling of Caribou Artifacts

Between June 12 and June 22, the four radii in each of the two sites were surveyed along their entire 3 km lengths for caribou artifacts including hair, bone, and antler before substantial numbers of caribou moved into the area for the current season. Tracks were aged as to fresh or old and the width of trails was recorded. The line transect sampling method (Burnham et al. 1980) was used to estimate the densities of caribou artifacts along the radii in the different distance strata. A 100 m thin rope line was stretched between the 100 m flags to provide a sight reference line for the observers to follow. An observer walked down the rope line with one foot on each side of the line and scanned from the center line out over both sides of the line for caribou artifacts. As the observer walked down the line, all artifacts sighted from the line were recorded by the other team member on field from as to : 1) type of artifact, 2) location along the line, and 3) the perpendicular distance in meters to the line.

Sampling of Pellet Group Densities

To estimate intensity of use of the study sites by caribou, pellet groups and patties were counted along the radii in the drier lancover types where pellets were visible. The landcover types sampled were restricted to: 1) dry prostrate dwarf shrub, 2) segments of moist/wet tundra complex such as the tops of frost boils, and raised ridges of polygons, 3) moist graminoid tussock, and 4) moist prostrate dwarf shrub meadows where dense overgrowth of dead graminoid leaves did not limit pellet visibility to the observer. Transect lengths were calculated from surveyed segments.

Application of existing estimators for pellet group densities contain inherent biases when applied to caribou as animal herding and mobility of bands contribute to the difficulty in defining a pellet group. The spatial distribution of pellets was placed into two classes to resolve this problem. These two classes included:

1. Individual pellet groups, which made pellet counts feasible, of
   a. Single isolated pellets (1 pellet/ft^2),
   b. Clumped pellets (1 pellet/ft^2 and,

2. Patties of consolidated pellets, which made pellet counts impractical but measurement of pattie length feasible.

Sample size for a pellet group included single pellet observations within the one ft^2 criteria. Since pellet groups can be scattered when deposited, or weathered differently due to substrate base, moisture, frost action, or wind scouring, the presence of one pellet was designated as sufficient to quantify one observation. Though this is a possible source of error in estimating density (Neff 1968:607), the sole pellet criteria may have increased observer attention when scanning down the line. While minimum group size was smaller than that used in other studies (Neff 1968, Cairns and Telfer 1980) the one ft^2 area encircling pellets was similar to the 30 cm diameter used by Rollins et al. (1984).

Observers scanned under the line and peripheral area extending out to at least one meter from the line for pellet groups. Each observation was measured as to perpendicular distance from centerline to the center of a pellet groups encompassing a one $foot^2$ area. At each initial pellet observation, all the pellets within a one $foot^2$ area were counted and recorded as one pellet group observation. One or more patties within the one $foot^2$ area were counted as separate observations, and measured for lengths. Group placement along the distance strata of the radii was also recorded. To insure compliance with the assumptions of the sampling technique (Burnham et al. 1980), the length of the transect distance sampled was noted to the 0.01 km, no pellets/patties directly on the line were missed, and the perpendicular distance from a pellet group/pattie to the rope line was measured to the nearest cm. Pellet groups were classified as to number and type: a single pellet, groups of pellets, or moist summer patties. In addition to the location, each pellet group was classified as to type (pellets or summer pattie), age (fresh, less than 6 months, older than 6 months) condition (smooth, moss or lichen covered) and landcover where located.

Sample sets included a minimum of 40 individual measurements of old (not fresh) pellets in each of 3 directional strata (0-1 km, 1-2 km, 2-3 km) along 3 radii in the control site and 4 radii in the treatment site. The southwest radii on the control site was predominately moist graminoid landcover and did not meet the sampling criteria; the transect was sampled for the other caribou artifacts of interest.

Field sampling of pellet counts was completed before significant numbers of caribou were observed in the area. While data on fresh pellet groups were included in measurements, only old pellet groups were included in analysis to estimate the pellet group densities in the pre-treatment assessment of use of the well site and control site.

Data Analysis

Density estimates of pellet groups were based on the estimator for line transect data suggested by Burnham et al. (1980):

$$D=nf(0)/2L,$$

where $\underline{D}$ is a density estimate, $\underline{n}$ is the number of objects counted during a census, $\underline{f}(0)2$ is an estimate of the probability distance function of perpendicular distance sightings evaluated at zero distance, and $\underline{L}$ is the length of the line transect. The TRANSECT program, (Burnham et al. 1980) was used to 1) calculate the mean perpendicular distances and 2) produce a Fourier series estimator then used to estimate $\underline{f}(0)$ The Fourier series is a non-parametric estimator with properties of model robustness, pooling robustness, shape criterion, and high estimator efficiency for line transect data for as long as

$\underline{f}$ (0) is a monotonically decreasing function (Burnham et al. 1980). Histograms of the perpendicular distance measurements were arranged, plotted, and checked by distance strata and radii in the well and control sites to affirm monotonically decreasing distributions. The variance for each density estimate was empirically calculated from replicate transects within each strata and radii by the DEFT option on the TRANSECT program (Laake et al. 1979).

Outline measurements of extreme perpendicular distances were dropped from the data set to reduce the number of terms in the Fourier sites estimator and to increase estimator accuracy (Burnham et al. 1980:108-110). Less than 1% of the initial measurements from each strata group were excluded.

Results

Objective 1.

Use of a Landcover map derived from LANDSAT Imagery. LANDSAT landcover maps were used to correlate the location and direction of radii on the control and well sites. The diversity of microsite relief and moisture gradients resulted in a variety of landcover types presented in 50 m by 50 m pixel blocks. Coastline, lakes, and river courses were distinguishable on the maps. Map detail was sufficient for observers to navigate and locate their position based on the landcover map rather than relying solely on the USGS topographic maps. Tests of the landcover map were based on: 1) the setting and relocating of the radii flags and 2) by survey crews walking across the tundra to camp or to center points.

Development of a sampling method to assess the relative habitat use of an area by caribou. The sampling design had designated a sample size of 40 artifacts for each site as necessary for an adequate sample size to estimate densities with the line transect methods (Burnham et al. 1980). The artifact densities were insufficient to estimate densities within strata with line transect. There were 85 artifacts on the control site and 25 artifacts on the well site; both sites received equal search effort of 12 km each. An estimated line length of 20 km would be required to acquire 40 observations on the well site area.

The sampling density to estimate pellet group densities also required a minimum of 40 observations per distance segment of each radii. Sampling was limited to the landcover types which did not prevent observers from locating every group directly along the line. In order to apply the density estimates based on line transect to the entire area, we assumed that the defecation rate of caribou was constant and the location was random with respect to foraging and post-calving aggregation movements. With this assumption there is an equal probability of pellets being deposited in all land cover types; sampling some but not all of the lancover types will give a distribution representative of overall densities.

Standardization of field methods and data recording to insure repeatability of measurements between observation teams was done during a one day training session. A group of four observers worked together staking out and measuring one segment of the line. Team members rotated duties of locating and measuring pellet groups, locating and measuring artifacts, and of recording observations of field forms. As a followup, short segments (usually less than 100m in length) of four radii were resampled to determine the repeatability of the recording technique. It was possible for one team to sample one segment of the line, switch positions of recorder and observer, and then rewalk the line to recount and locate the same pellet groups.

The cost efficiency of this technique is difficult to compare as only one sampling scheme was completed. The time estimate for each radii required usually three trips along the line and up to one and 1/2 days of field work depending on the walking distance from base camp. The line was initially walked and staked, then rewalked to sample for artifacts and pellet groups. The line was walked a third time to pull all but the initial centerpoint and terminal 3.0 km flags. The end points were marked on site and on maps to facilitate resampling in the future. The plastic flags were visible up to 2 km on the tundra when observers scanned the approximate area.

Objective 2

Density of caribou artifacts on the well and control sites. Artifact sample sizes were insufficient for quantitative density estimation by line transect and were limited to qualitative analysis. A total of 110 artifacts were found on the well and control sites which received equal search effort (Table 1). There were 85 artifacts on the control radii and 25 artifacts on the well radii. Seventy-five percent of observed artifacts were within 10 m of radii lines. Hair was the most common artifact on both sites and comprised 82% of the control site artifacts and 52% of the well site artifacts. Antlers were more common on the control site (6 antlers) than on the well site (1 antler); antlers were usually well embedded in moss and had not been dropped during the past year. Scattered bones were more common on the well site radii (11 bones) than on the control radii (7 bones). On the southeast well radii less than 1 km from the well site there was a complete skeleton with the skull and antlers entangled in wire. The source of the wire was probably a nearby fence originally erected around 2 grave markers but now strewn over the tundra. All unusual or white objects observed from the transects were inspected as potential caribou artifacts; objects inspected included bird feathers and bones, NOAA weather balloon debris, paper litter, 3 rusted animal traps, and two dead arctic foxes (*Alopex lagopus*).

Tracks were excluded from artifact sampling after initial attempts because it was not always possible to distinguish between old and new tracks. An estimate of recent or old caribou artifiacts was based on the presence or absence of lichen or moss growth.

Density of pellet groups on the well and control sites. Density of pellet groups were analysed by radii and distance strata for the control and well site (Table 2). There was no significant difference between the overall well and control sites (Table 3). When densities were compared within a site the control southeast radii had a higher pellet densities than the south radii ($P<0.05$) and the west radii ($P<0.025$). There were no significant differences between the pellet densities on the well site radii. When corresponding radii between sites were compared, there was a higher density of pellet groups on the control southeast radii than on the well site southeast radii ($P<0.025$). Pellet group densities were also higher on the 2-3 km distance strata on the control site than on the corresponding well 2-3 km strata ($P<0.05$).

Table 1. Summary of caribou artifacts found along radii on control and well sites near the KIC exploratory well #1, June 1985.

Distance Strata		Well Site						Control Site					
0.0 to 1.0 km	a	0	0	0	1	0	0	0	1	0	0	0	0
	b	4	1	1	2	0	0	7	0	0	0	0	0
	h	2	0	1	1	0	0	16	0	0	1	1	0
1.0 to 2.0 km	a	0	0	0	0	0	0	1	0	0	0	0	0
	b	2	0	0	0	0	0	0	0	0	0	0	2
	h	2	0	1	0	0	0	11	1	0	0	1	0
2.0 to 3.0 km	a	0	0	0	0	0	0	2	1	1	0	0	0
	b	1	0	0	0	0	0	0	0	0	0	0	0
	h	3	0	0	1	1	1	32	4	0	0	1	2
Artifact total 0.0 to 3.0 km	a	0	0	0	1	0	0	3	2	1	0	0	0
	b	7	1	1	2	0	0	7	0	0	0	0	1
	h	7	0	2	2	1	1	59	5	0	1	3	2
		10	20	30	40	50	105	10	20	30	40	50	105 **

* Number and type of artifact: a = antler, b = bone, h = hair

** Perpendicular distance in meters from radii line.

Table 2. Density (groups per m^2) of caribou pellet groups by directional radii and distance stratas on the control and well sites.

	Control Site	Well Site
Directional radii:	Mean ± S.E.	Mean ± S.E.
Southeast	0.03018 ± 0.0635 n=204, 1=653 m	0.1028 ± 0.0156 n=104, 1=562 m
South	0.0977 ± 0.0985 n=165, 1=807 m	0.1251 ± 0.0350 n=229, 1=856 m
Southwest	Not Sampled	0.0970 ± 0.0379 n=202, 1=753 m
West	0.1479 ± 0.0430 n=304, 1=1188 m	0.1859 ± 0.0676 n=193, 1=631 m
Distance Strata:		
0-1 Km	0.2095 ± 0.0678 n=196, 1=794	0.1348 ± 0.0388 n=303, 1=1145
1-2 Km	0.1121 ± 0.0511 n=153, 1=1129	0.1276 ± 0.0283 n=265, 1=864
2-3 Km	0.2479 ± 0.0936 n=324, 1=725	0.0799 ± 0.0325 n=160, 1=793
Overall mean ± se	0.1774 ± 0.0424 n=673, 1=2648	0.1206 ± 0.0202 n=728, 1=2802

n = number of pooled perpendicular measurements of pellet groups.
1 = length of line in meters sampled for pellet groups.

Table 3. Calculated *t*′ values and significance levels (Snedecor and Cochran 1974:115).

Location	Radii	*t*′ value	P level
Control Site			
	southeast vs south	1.74	<0.05
	southeast vs west	2.02	<0.025
	south vs west	0.46	n.s.
Well Site			
	southeast vs south	0.59	n.s.
	southeast vs southwest	0.10	n.s.
	southeast vs west	1.22	n.s.
	south vs southwest	0.68	n.s.
	south vs west	0.81	n.s.
	southwest vs west	1.15	n.s.
Control Site (C) vs Well Site (WS)			
	southeast (CS vs WS)	3.07	<0.025
	south (CS vs WS)	0.26	n.s.
	west (CS vs WS)	0.48	n.s.
	0 to 1 km (CS vs WS)	0.97	n.s.
	1 to 2 km (CS vs WS)	0.26	n.s.
	2 to 3 km (CS vs WS)	1.71	<0.05
Overall Control Site vs Well Site		1.21	n.s.

Discussion

The purpose of this study was to develop methods of assessing the use of areas of the coastal palin by caribou. The landcover maps derived from LANDSAT imagery pictorally presented areas based on variation due to topography vegetation and moisture regimes. The fine scale of these large scale maps provided the resolution necessary to locate comparable treatment and control site within an overall study area. Ground truthing of these land cover maps provided an assessment that it was possible to set up a sampling design to collect baseline information on use of the area. Adequate sample sizes for pellet groups were collected in all but one of the radii, which by both landcover maps and ground truthing was not suitable for sampling. Caribou artifacts were too sparsely distributed to be useful as indicators of area use.

The use of pellet group densities to assess area use requires a repeatable sampling procedure to detect variations in density within and between study sites. Line transect sampling was a relatively quick field sampling method and the distributions of pellet groups fit the assumptions of the Fourier series density estimator f(0) (Burnham et al. 1980).

The use of pellet group densities to assess pre- and post disturbance use of a site by caribou requires an understanding of the problems in detecting a change in animal use. A study (L. Pank, in prep.) is under way to determine weathering, degradation, and disappearance rates of pellets in the different lancover types of the coastal plain. Weathering and degradation rates of pellet groups are necessary to estimate an adequate sampling period between initial survey and post-disturbance to reduce errors in estimating use due to the resampling of previously noted groups.

When sampling between two sites, it is also necessary to consider within-site variation due to topographic relief or landcover diversity; within site variation may be greater than between site variation. The number of transects adequate to assess within site diversity and to detect between site variation may have to be increased. Consideration must also include how to scale change due to disturbance resulting from natural changes in herd movements and population dynamics.

Use of pellet group densities of caribou have the following strong points as a survey technique of animal use. The majority of use of the coastal plain by the Porcupine herd occurs from late spring through early summer. Calving caribou are in small groups in localized areas which have received repeated annual use (Whitten et al. 1985). Trends in use over time may be quantifiable in these localized areas. Caribou form into larger groups beginning with the post-calving aggregations in mid-June. Caribou increase the time spent in walking and feeding on new growth forage available with shorter periods of lying (Art Martell, pers. comm.). The defecation rate of caribou is presumably high given the movement and foraging activity (Collins 1981) and the higher rumen turnover time (8 hr) of animals feeding on summer forage (White and Trudell 1980). Therefore pellet groups should be deposited over localized area as caribou groups move through these areas to preferred foraging habitats and relief areas from insect harassment.

The responses of caribou to petroleum-related development on the coastal plain in Alaska include displacement from localized areas such as calving, summer range and insects relief area near transportation corridors and production facilities. For example, pipeline and other construction has displaced maternal bands from calving areas at Prudhoe Bay (Cameron et al. 1985) and Milne Point (Dau and Cameron, in press) and from summer range along the Dalton Highway-pipeline corridor. Baseline data of relative use based on pellet group densities may provide long term monitoring to assess the relative responses of caribou to site developments on the coastal plain.

Acknowledgements

The Alaska Office of Fish and Wildlife Research (USFWS) conducted this study. Partial funding for the project was provided by Chevron U.S.A. Inc. through the Arctic National Wildlife Refuge. Field assistants included l. Jozwiak, C. Benson, and B. Zimot, volunteers from the Student Conservation Corps. K. Butters of Trans Alaska Helicopters transported crews in the field. D. Reed, biometrician with the Alaska Department of Fish and Game in Fairbanks, provided technical assistance in running the TRANSECT computer program. Field logistics and clerical support was provided by the staff of the Arctic National Wildlife Refuge, U.S. Fish and Wildlife Service.

Literature Cited

Burnham, K. D., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. J. Wild. Monograph No. 72:1-202.

Cairns, A. L. and E. S. Telfer. 1980. Habitat use by 4 sympatric ungulates in boreal mixed wood forest. J. Wildl. Manage. 44(4)849-857.

Cameron, R. D., 1983. Issue: Caribou and petroleum development in Arctic Alaska. Arctic 36:227-231.

Cameron, R. D., K. R. Whitten, and W. T. Smith. 1985. Effects of the Trans-Alaska Pipeline on the distribution and movements of caribou. Final Report. Alaska Dept. Fish and Game. Fed. Aid Wild. Restoration Proj. Rept. Proj. W-17-7, W-17-8, W-17-9, W-17-10, W-17-11, W-17-12, W-21-1, W-21-2, W-22-1, W-22-2, W-22-3, W-22-4 Job 3.18R. Juneau, AK 24p.

Carruthers, D. R., R. D. Jakimchuk, and S. H. Ferguson. 1984. The relationship between the Central Arctic Caribou herd and the Trans-Alaska pipeline. Prepared for Alyeska Pipeline Service company by Renewable Resources Consulting Services, LTD. 153 pp.

Collins, W. B. 1981. Habitat preferences of mule deer as rated by pellet-group distribution. J. Wildl. Mgmt. 45:969-972.

Dau, J. r. and R. D. Cameron. In press. Effects of a road system on caribou distribution during calving. Pages - in W. D. fuller, M. T. Neitfield, M. A. Harris eds. Proc. Fourth Int. Reindeer/Caribou Sump. Whitehorse, Yukon Terr. 22-25 Aug. 1985.

Garner, G. W. and P. E. Reynolds. 1984. eds. 1983 update report baseline study of fish, wildlife and their habitats. U.S. Fish and Wildl. Serv. Anchorage, AK 614pp.

Garner, G. W. and P. E. Reynolds. 1985. eds. 1984 update report baseline study of fish, wildlife and their habitats. U.S. Fish and Wildl. Serv. Anchorage, AK 777pp.

Julander, (., R. B. Ferguson, and J. E. Dealy. 1963. Measure of animal range use by signs. Pages 102-108 in Range research methods. U.S. Dep. Agri., For. Serv., Misc. Publ. 940.

Laake, J. L., K. P. Burnham, and D. R. Anderson. 1979. User's Manual for Program TRANSECT. Utah State Univ. Press Logan, Utah. 26 pp.

Lyon, J. J. 1983. Road density models describing habitat effectiveness for elk. J. For. 81(9):592-595.

Neff, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: A review. J. Wildl. Mgmt. 32:597-614.

Rollins, D. F., C. Bryant, and R. Montandon. 1984. Fecal pH and defecation rate of eight ruminants fed known diets. J. Wildl. Manage. 48(3)807-813.

Rost, G. R. and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. J. Wildl. Manage. 43(3)634-641.

Snedecor, G. W. and W. G. Cochran. 1974. Statistical methods. Iowa State Univ. Press. Ames, Iowa. Sixth edition. 593 pp.

U. S. Geological Survey and U. S. Fish and Wildlife Service. 1985. Preliminary classification from a Landsat-derived vegetation map of the Arctic National Wildlife Refuge, Alaska. Draft report. Anchorage, Alaska.

U. S. Fish and Wildlife Service. 1982. Arctic National Wildlife Refuge coastal plain resource assessment -- initial report baseline study of the fish, wildlife and their habitats. Anchorage, AK 507pp.

Walker, D. A., K. R Everett, W. Acevedo, L. Gaydos, J. Brown and P. J. Webber. 1982 LANDSAT-assisted environmental mapping in the Arctic National Wildlife Refuge. U. S. Army Cold Regions Research and Engineering Laboratory, Hanover NH. CRREL Rep. 82-87. 59 pp.

White, R. G. and J. M. Trudell. 1980. Habitat preference and forage consumption by reindeer and caribou near Atkasook, Alaska. Arctic and Alpine Res. 12(4)511-529.

Whitten, K. R., F. J. Mauer, and G. W. Garner. 1984. Calving distribution, initial productivity and neonatal mortality of the Porcupine caribou herd, 1983. Pages 359-420 in G. W. Garner and P. E. Reynolds, eds. 1983 update report baseline study of fish, wildlife and their habitats. U. S. Fish and Wildl. Serv., Anchorage, AK. 617 pp.

Whitten, K. R., F. J. Mauer, and G. W. Garner. 1985. Calving distribution, initial productivity, neonatal mortality of the Porcupine caribou herd, 1984. Pages 527-561 in G. W. Garner and P. E. Reynolds, eds. 1984 update report baseline studies of the fish, wildlife and their habitats. U. S. Fish and Wildl. Serv., Anchorage, AK. 777pp.

SPATIAL AND TEMPORAL DISTRIBUTION OF BITING AND PARASITIC INSECTS ON THE COASTAL PLAIN AND ADJOINING FOOTHILLS OF THE ARCTIC NATIONAL WILDLIFE REFUGE

C. Benson
C. Curby
B. Zimont
E. Jozwiak

Key words: Porcupine caribou her, summer range, insects, insect relief habitat, traps, model

Caribou Project
Arctic National Wildlife Refuge
101 12th Avenue
Fairbanks, Alaska 99701

AFWRC Progress Report Sub-work Unit 5:

Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the Arctic National Wildlife Refuge, 1985.

Carl A. Benson, Cathy Curby, Benjamin Zimont, and Elizabeth Jozwiak
U.S. Fish and Wildlife Service
Alaska Fish and Wildlife Research Center, Anchorage, Alaska

Abstract: Results of the for third-year studies of the spatial and temporal distributions of mosquitos on the coastal plain and the adjoining foothills of the Arctic National Wildlife Refuge (ANWR) are reported. Objectives were to increase the data base from 1984 concerning levels of mosquito activity and harassment on the coast, plains, and foothills; to test the associations between mosquito activity and landcover, terrain, aspect, and moisture regime as well as the relationship between activity and distance from riparian or coastal habitats; to discern relationships between diel patterns of mosquito activity and weather at the coast, plains, and foothills sites; to develop a method and sampling protocol to indirectly assess and predict the level of mosquito harassment to caribou; to assess the accuracy and limitations of White's 1975 model for predicting insect harassment of caribou. A total of 37 sticky trap locations were established in three geographic areas: 13 at the coast and 12 each at the plain's and foothill's cells. Weather and insect data were collected from mid and late June to mid July on a daily basis. Mosquito activity was measured by sticky paper trap and sweep net catch, and by assigned levels of mosquito harassment to humans and caribou. Mosquitoes were generally most abundant in the plains but weather parameters may have allowed higher levels of activity at the coast. A zone of insect relief habitat exists along the coast, the width of which varied with weather conditions. Mosquito activity appeared to be associated with landcover in the plains and to a lesser degree in the foothills and along the coast. Some large braided rivers in the plains provide corridors of insect relief. In the foothills, exposed ridges were confirmed as insect relief habitat, and valley as insect habitat. Weather variable alone did not correlate well with mosquito activity and harassment. Sweep nets proved to be the best technique for assessment of insect activity and produced the highest level of agreement when contrasted with White's (1975) predicted caribou harassment model.

Alaska Fish and Wildlife Research Center Progress Report Sub-work Unit 5.

Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the Arctic National Wildlife Refuge, 1985.

The spatial and temporal distributions of biting and parasitic Dipterans are major factors influencing the ecology of the Porcupine caribou herd (PCH). Insect harassment and infestation have been implicated as primary modifiers of caribou behavior, energetics, and habitat use. Wright (1980) concluded that the midsummer spatial distribution of semi-domestic reindeer was more closely allied with insect relief than with forage availability during periods of critical energy balance. The insect-caribou literature and the justification for insect research on the summer range of the PCH were addressed in the first progress report (Pank et al. 1984). The adverse effects of insects on caribou, the importance and potential loss of insect relief habitat with development, and the potential for development and increased human activity on the summer range of the PCH emphasize the need to: 1) identify and locate the insect relief habitats on the arctic coastal plain, 2) confirm the importance of insect/PCH interactions, and 3) develop guidelines that prevent or mitigate the loss of insect relief habitat if development occurs. This study is the third year of ongoing work to address the following long range objectives.

1. Define the spatial and temporal distribution of biting and parasitic Dipterans on the summer range of the PCH.

2. Correlate the spatial and temporal distributions of insects and caribou at multiple scales of measure (i.e., site specific to summer range).

3. Define and map the relief habitat on the summer range of the PCH.

4. Define the correlations between weather variables, insect activity and harassment levels (caribou, human).

5. Develop a predictive model for the potential spatial and temporal distribution of the PCH on the summer range based on insect and weather variables.

6. Determine if the caribou models that define behavioral responses of caribou to insect harassment are applicable to the PCH.

Extensive sampling in 1983 produced an overview of the temporal and spatial distribution of five families of biting and parasitic Dipterans over the entire coastal plain and adjoining foothills of the Arctic National Wildlife Refuge (ANWR) (Pank et al. 1984). Based on the results, mosquitos (Culicidae) were the principal insect modifier of the PCH behavior within the study area. The research in 1984 shifted from the 1983 extensive sampling to intensive sampling of insect activity and weather in three areas during the peak of caribou-mosquito interaction. In 1985, both intensive and extensive sampling methods were utilized to increase the existing data set. Extensive sampling was used to provide an overview of correlations between major landcovers of ANWR and associated mosquito activity, thus allowing a more complete comparison between site specific data, temporal distribution of mosquitos at coastal, plains and foothills cells, and diel patterns of weather and insect activity.

1985 General Objectives:

1. Contrast spatial and temporal distributions of mosquitos during the 1985 sampling period with the previous two years' data sets.

2. Contrast the data on spatial and temporal distribution of insects which was gathered extensively, with data collected from intensively monitored trap locations.

Site Specific Objectives:

1. <u>Coastal Cell</u>: Determine the influence of distance from coastal and riparian habitats on insect activity.

2. <u>Plains Cell</u>: Determine the influence of distance from riparian habitat and associated landcovers on insect activity.

3. <u>Foothills Cell</u>: Determine the relationships between topography, aspect and associated landcovers with insect activity.

Materials and Methods

The coastal plain and adjoining foothills of ANWR were partitioned into three cells - coast, plains, and foothills - duplicating the areas sampled in 1984. Operations were based out of camps within each cell. Totals of 13, 12, and 12 trap locations were established in the coast, plains and foothills cells, respectively (Figure 1).

Specific objectives within each cell dictated site placement. The coastal region on the Jago River Delta was represented by a grid of four rows with three trap locations per row placed at increasing distances from the Arctic coast and the adjacent Jago River. Three replicate trap locations at increasing distances from the coast and four at increasing distances from the Jago River were sampled to determine the effect of distances from coastal and riparian habitat on insect activity. The Aichilik River trap locations were established based on distance from riparian habitat and on landcover type. Traps were placed in the same locations as the 1984 traps. Distances between trap locations varied with distance between landcover categories. The Lake Peters study area was located in the foothills cell of the ANWR. Trap locations were established on valley, slope, and summit/ridge areas to determine the effect of topography and aspect on insect activity. Distances to the coast and to riparian habitat, as well as elevation, slope, aspect, and landcover class (Walker et al. 1983) were recorded for each trap location. Characteristics of all 1985 trap locations are listed in Table 1.

1985		1984		1983	
coast	= XIII	coast	= I, IV, X	I	= east coast site
plain	= XI	plain	= XI	II	= east plain site
foothills	= XIV	foothills	= XII	III	= east foothills site
				IV	= center coast site
				V	= center plain site
				VI	= center foothills site
				VII	= west coast site
				VIII	= west plain site
				IX	= west foothills site
				A	= aufeis
				B	= coastal bluff
				C	= ridge

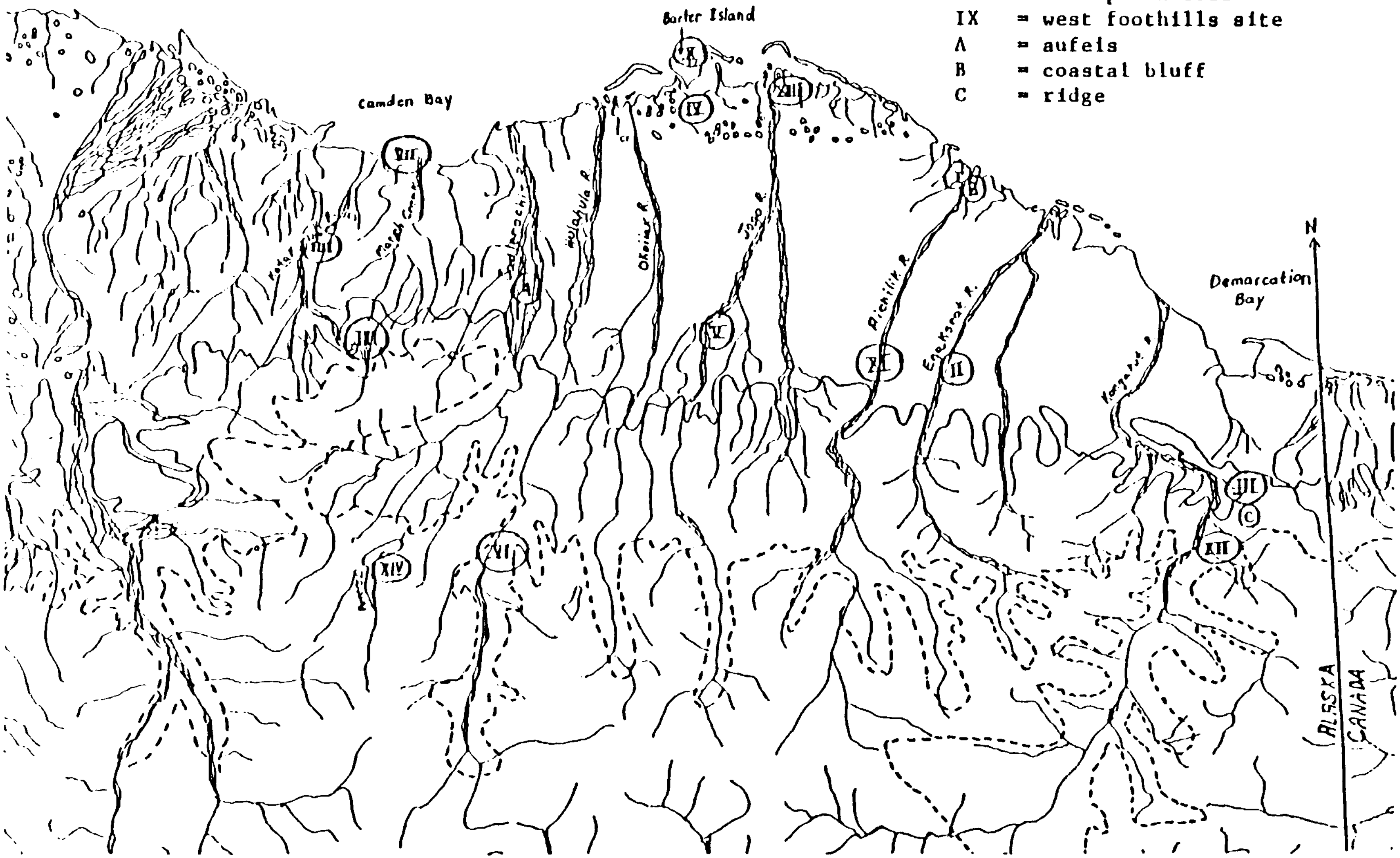


Figure 1. General locations of insect and weather collection sites in the Arctic National Wildlife Refuge in 1983, 1984, and 1985.

Table 1. Characteristics of landcover, location and topography for individual insect trapsites in the Arctic National Wildlife Refuge, Alaska, 1985.

Location	Trapsite Number	Insect Hab.[1]	Land Cover[2] (A)	Land Cover[2] (B)	Land Cover[2] (C)	Dist. North To Coast (Km)	Dist. To Riparian Habitat (Km)	Moisture Regime	Topography: Elev. (m)	Topography: Slope (degrees)	Topography: Aspect (degrees)	Topography: (Terrain)
Coast	101	IR	E	X	a	3.30	0.00	Dry	0	0	0	Coast Plain
Jago Delta	102	IH	C	IV	a	2.60	1.00	Wet	0	0	0	Coast Plain
	103	IH	C	IV	a	2.50	2.00	Wet	0	0	0	Coast Plain
	104	IR	E	IX	h	2.90	0.00	Moist	0	0	0	Coast Plain
	105	IH	B	III	b	2.00	1.00	Very Wet	0	0	0	Coast Plain
	106	IH	B	III	b	1.80	2.00	Very Wet	0	0	0	Coast Plain
	107	IR	E	IX	h	2.50	0.00	Moist, Well Drained	0	0	0	Coast Plain
	108	IH	B	III	b	1.50	1.00	Very Wet	0	0	0	Coast Plain
	109	IR	C	V	c	1.20	2.00	Dry	0	0	0	Coast Plain
	110	IR	E	IX	h	1.50	0.00	Moist	0	0	0	Coast Plain
	111	IH	B	III	a	0.70	0.80	Very Wet	0	0	0	Coast Plain
	112	IR	C	V	c	0.00	1.50	Dry	0	0	0	Coast Plain
	113	IR	C	V	c	4.20	0.00	Dry	0	0	0	Coast Plain
Plain	201	IR	E	X	a	25.2	0.10	Dry	200	0	0	Plain
Aichilik	202	IR	C	V	c	25.2	0.30	Dry	200	0	0	Plain
	203	IH	B	III	a	24.0	1.60	Wet	200	0	0	Plain
	204	IH	C	V	b	24.0	2.20	Moist, Well Drained	200	5	22.5	Plain
	205	IR	E	X	a	25.6	0.10	Dry	200	0	0	Plain
	206	IR	C	V	c	25.6	0.30	Dry	200	0	0	Plain
	207	IH	B	III	a	24.8	0.75	Wet	200	0	0	Plain
	208	IH	C	V	b	24.0	1.80	Moist, Well Drained	210	5	135.0	Plain
	209	IR	E	X	a	26.8	0.50	Dry	200	0	0	Plain
	210	IR	C	V	c	25.6	0.20	Dry	200	0	0	Plain
	211	IH	B	III	a	25.2	1.00	Wet	200	0	0	Plain
	212	IH	C	V	b	24.8	1.70	Moist, Well Drained	220	5	90.0	Plain
Foothills	311	IH	C	VII	a	71.2	25.60	Moist	960	10	225.0	Valley
Peters Lake	321	IH	C	V	b	70.4	24.80	Moist, Well Drained	840	5	270.0	Valley
	331	IH	C	V	b	68.0	22.40	Moist, Well Drained	870	15	180.0	Valley
	341	IH	E	IX	a	69.2	23.60	Dry	975	0	0	Valley
	312	IR	C	V	d	71.2	25.60	Dry	1110	25	270.0	Slope
	322	IH	C	V	d	70.4	24.80	Dry	1050	30	270.0	Slope
	332	IR	E	IX	j	69.6	24.00	Dry	1170	10	180.0	Slope
	342	IH	C	VII	b	69.2	23.60	Moist	1080	5	315.0	Slope
	313	IR	E	IX	j	71.2	25.60	Dry	1260	0	270.0	Ridge
	323	IR	E	X	d	70.4	24.80	Dry	1305	0	0	Ridge
	333	IR	E	X	d	70.0	24.40	Dry	1275	0	0	Ridge
	343	IR	E	X	d	70.0	24.40	Dry	1305	0	0	Ridge

[1] Insect Codes: IH = Insect habitat; IR = Insect relief.

[2] Walker et al. 1983.

Levels of mosquito harassment to humans were determined during each trap location visit. The levels were: 0 = mosquitos not present, 1 = mosquitos present not biting, 2 = mosquitos present and biting, 3 = mosquitos so numerous they are easily inhaled. Insect harassment of caribou was recorded at the trap locations when caribou were present and during continuous and instantaneous caribou observations at each of the three study locations. The level of harassment was based on the behavioral responses defined by Thompson (1973).

Objective measurements of mosquito harassment were collected with the use of sweep nets and sticky traps. The sweep net consisted of a 1.0-m handle, a 0.4-m diameter hoop, and a muslin bag (0.6 m without tip) which was equipped with a 0.25-m net tip attached with velcro. Captured insects were counted on site or, if time did not permit, the tip was removed and tied for later investigation. Sweeps were performed by facing downwind, positioning the left hand at the pivot point marked 0.7 m from the bottom of the hoop, and swinging the net in a 180 degree arc in a vertical plane starting and ending at the height of the pivot point (approximately 0.8 m above the ground) at a rate of one swing per second, for 100 swings. The volume of air processed by one 180 degree sweep was 0.32 cubic meters. Sweeps were conducted at Jago Delta from June 30 to July 11, at Aichilik from June 20 to July 11 and at Lake Peters from June 16 to July 11 (Appendix A).

A non-attractant sticky trap was placed at all trap locations within each of the three study sites. The trap consisted of a "stovepipe" cylinder (12.7 cm in diameter) which was attached to a 1.0-m long steel stake. The stake was supported by a concrete reinforcement bar which was driven into the ground. An octagonal rain shield (30.0 cm in diameter) was attached to the top of the trap by a wing nut. White plastic shelf liner (30.5 x 40.0 cm), coated with "Tanglefoot" adhesive, was selected for its passivity to mosquitos (Taylor 1962). The sticky papers were attached to the cylinders with four Lion clips. Mosquitos captured on the paper were counted daily. At the Aichilik, Lake Peters, and Jago Delta sites, traps were deployed on June 19, June 29, and July 2, respectively. The order of trap location visits was varied to avoid influence by temporal patterns of mosquito activity and weather.

Weather and mosquito harassment data were collected from all trap locations. Weather data recorded during each trap visit included relative humidity, current ambient air temperature, insolation air temperature (not shaded), mean and gust wind speed, wind direction, soil temperature, fog cover, cloud cover, ceiling height, and visibility. Weather measurements were taken at approximately 0.9 m above ground level. Soil temperature was recorded at a depth of 5 cm. Mean windspeed and gust windspeed were taken using hand held anemometers. One wind spectrum analyzer and one totalizing anemometer were placed at Lake Peters. Prevailing wind direction was determined by compass bearing. Ambient air temperature was taken facing away from the sun using the dry bulb of a sling psychrometer. The presence or absence of sun was noted when taking insolation air temperature. Thaw depth was noted until permafrost receded beyond the length of the soil thermometer (10 cm). The minimum and maximum air temperatures occurring between trap visitations were measured using bimetal MIN/MAX thermometers. The MIN/MAX thermometers were placed inside the open ended trap cylinders to avoid direct sunlight. Lake Peters experienced excessive wind velocities that resulted in trap and thermometer vibrations, and thus demanded that the recording thermometers be placed in stone shelters. Relative humidity was calculated from sling psychrometer measurements. Percent cloud cover from 10° off the horizon, precipitation type, and fog presence were recorded.

Caribou observations were recorded during instantaneous and continuous scans. Weather data (relative humidity, current ambient air temperature, insolation air temperature, mean and gust windspeed, wind direction, soil temperature, fog cover, cloud cover, ceiling height, and visibility), sweep counts, caribou harassment level, number of caribou in group, direction of movement, major activity, and landcover class occupied were recorded during instantaneous scans. During continuous scans, major caribou activity and the length of time spent in a defined behavior bout were measured. Landcover type, weather data and human and caribou harassment levels were recorded during each scan. At Jago Delta, head position and direction of movement were also recorded.

An insect weather survey was conducted on July 9 in thirteen landcover types in the coastal, plains, and foothills cells of ANWR. Time, weather data, human harassment and sweep net mosquito counts were recorded in each landcover type. Three individuals each took three sweep samples and determined levels of insect harassment at each landcover class. A helicopter was used for transport to predetermined sites.

Twenty-four hour weather and sweep net counts were conducted at each study site to quantify diel patterns of mosquito activity. This data was taken twice at Jago Delta and three times at the Aichilik and Lake Peters locations (Appendix A). Observers at the foothill and coastal sites conducted 24-hour counts from 2100 hours to 2100 hours the following day. Observations at the plains site began at 0900 hours and terminated at the same time 24 hours later for the first two collection periods. Observers at all sites conducted 24-hour collection periods during coinciding hours on the last count on July 10. Mosquito counts and weather data were collected hourly. Weather information was collected according to the method followed for trap site weather. Twenty-four hour data collected during one concurrent period in all sites was graphed. All references to hour of day in this report are Alaska Standard Time (AST).

Preliminary Results

Weather

National Oceanic and Atmospheric Administration data from the Barter Island weather station reported that 1985 average temperatures for June were warmer than June of 1984, with more precipitation, higher wind speeds, and more fog but with the same amount of cloud cover. July 1985 was also warmer, but with less precipitation, approximately the same average windspeed, and cloudier with more days of fog than during July 1984. August 1985 temperatures were higher, precipitation lower, with less wind and cloud cover but the same number of days of fog as August 1984 (Table 2). From data collected at trap locations (insect relief and insect habitat site data combined) in 1983 through 1985, it appears that weather trends from the coast to the foothills are variable from summer to summer (Table 3). In 1985, ambient air and soil

Table 2. Weather data from Barter Island, Arctic National Wildlife Refuge, Alaska. Data obtained from National Oceanic and Atmospheric Administration.

Date	Temperature (°C)			Mean Wind-speed (kph)	Fog (No. of (Days)		Cloudcover (No. of Days)		Precipitation (cm)
	Mean	Minimum	Maximum		Heavy	Light	Clear	Cloudy	
June									
1984	1.2	-0.4	2.9	15.1	12	6	4	26	0.18
1985	2.6	-0.4	5.5	19.3	6	15	4	26	0.30
July									
1984	4.0	1.3	6.7	18.0	12	8	3	28	4.3
1985	4.9	1.3	8.4	17.9	8	16	1	30	1.9
August									
1984	2.9	0.7	5.1	20.0	6	16	2	29	5.1
1985	4.1	1.1	7.0	18.8	15	6	3	28	0.5

temperatures were low on the coast, highest at the plains study site, and intermediate in the foothills (Appendix E, F). In both 1983 and 1984, however, soil and ambient air temperatures increased from the coast to the foothills (Table 3). Mean soil temperatures in all cells were higher in 1985 than those recorded the previous year. Soil temperatures in 1983 were warmer than those recorded during 1984. The coast exhibited higher ambient air temperatures in 1985 than in the two previous field seasons. The plains experienced lower ambient air temperatures in 1985 than in 1984, but 1985 temperatures were higher than in 1983. In 1985, foothills ambient air temperatures were lower than those in 1983 and 1984 (Table 3). Mean windspeed, averaged over the three field seasons, decreased from the coast to the foothills. In 1984, however, the coast reported the lowest average windspeeds of the three cells, the plains recorded the highest average windspeed, while the foothills' average windspeed was only slightly higher than that of the coast (Table 3). Mean sweepnet catch and human harassment values were found to be lower at all trap locations designated as insect relief habitat than at insect habitat locations in all cells in 1985.

Appearance of Mosquitos

Mosquitos appeared later in 1985 than in 1984, and at approximately the same

Table 3. Mosquito catches, mosquito harassment and weather data collected during each trap visit in the Arctic National Wildlife Refuge, Alaska, in 1985 compared with 1984 and 1983 data. Expressed as median, where appropriate, mean, standard deviation, and sample size. Data from 1985 can be found in Appendicies B to J.

	Coast			Plains			Foothills		
Date	Insect Relief	Insect	Combined	Insect Relief	Insect	Combined	Insect Relief	Insect	Combined
Sticky Traps[a] (catch/day)									
1983	0.0,0.0(6)	0.1,0.2(6)	0.1,0.2(12)	0.0,0.0(3)	0.1,0.2,(3)	0.1,0.1(6)	0.1,0.2(3)	0.6,0.0(2)	0.3,0.3(5)
1984	2.1(359.6)	2.2(41.0)	2.1(400.6)	6.2(109.7)	18.4(107.9)	12.3(217.6)	1.7(187.3)	1.2(152.8)	1.4(340.1)
1985	0.3,0.8(49)	1.1,2.4(47)	0.7,1.8(96)	1.6,3.7(114)	2.8,7.8(111)	2.2,6.1(225)	1.2,1.6(54)	1.1,1.8(54)	0.5,1.3(235)
Human Harassment[b] (levels 0-3)									
1983	0.2,0.4,(6)	0.2,0.4(6)	0.2,0.4(12)	0.3,0.6(3)	0.3,0.6(3)	0.3,0.5(6)	1.2,0.3(3)	1.5,0.5(3)	1.3,0.4,(6)
1984	0,0.3,0.6(214)	0,0.0,0.0(6)	0,0.2,0.6(220)	1,0.8,0.8(99)	1,1.2,0.8(91)	1,1.0,0.8(190)	1,1.0,0.8(149)	1,1.1,0.8(121)	1,1.1,0.8(270)
1985	0,0.1,0.4(49)	0,0.4,0.6(47)	0,0.2,0.5(96)	0,0.3,0.5(114)	0,0.4,0.7(111)	0,0.4,0.6(225)	0,0.1,0.3(119)	0,0.4,0.6(116)	0,0.5,1.3(235)
Sweep Net Catches (catch/100 sweeps)									
1984	0.7,4.0(207)	0.0,0.0(7)	0.7,3.9(214)	5.8,12.2(99)	33.3,63.5(90)	18.9,46.6(189)	19.5,52.9(149)	27.0,93.0(122)	22.4,73.3(270)
1985	0.1,0.2,(49)	2.7,7.7(47)	1.4,5.5(96)	1.1,5.4(114)	4.3,15.3(111)	2.7,11.5(225)	0.2,0.7(119)	0.7,2.1(116)	0.4,1.6(235)
Soil Temperature (°C)									
1983	8.3,5.3(6)	4.4,1.5(6)	6.3,4.3(12)	12.4,3.6(3)	3.5,3.7(3)	8.0,5.8(3)	19.6,7.5(3)	6.4,1.2(3)	13.6,8.3(6)
1984	2.9,2.4(214)	4.6,1.8(7)	2.9,2.4(221)	8.2,4.7(98)	1.4,1.4(90)	5.0,4.9(188)	9.2,3.1(144)	6.5,3.4(119)	8.0,3.5(263)
1985	5.6,2.5(49)	2.6,1.5(47)	4.1,2.6(96)	11.6,4.7(114)	7.1,3.1(111)	9.4,4.6(225)	9.6,2.6(119)	8.4,2.7(116)	9.0,2.7(235)
Relative Humidity (%)									
1983			79.3,10.0(6)			75.0,20.2(3)			57.7,21.0(3)
1984	95.4,11.7(44)	91.7,15.3(3)	95.2,11.8(47)	55.1,13.4(85)	55.1,13.9(78)	55.1,13.6(163)	62.5,17.9(149)	64.4,18.1(122)	63.4,18.0(271)
1985	97.6,5.2(49)	95.1,6.8(47)	96.6,6.0(96)	69.7,15.7(114)	71.5,15.2(111)	70.6,15.5(225)	59.4,19.9(119)	60.7,18.7(116)	60.1,19.3(235)
Ambient Air Temperature (°C)									
1983			6.1,2.1(6)			10.5,7.0(3)			13.9,7.6(3)
1984	4.9,2.5(58)	6.4,3.1(7)	5.1,2.6(65)	12.0,3.8(100)	12.6,3.3(91)	12.3,3.6(191)	13.5,4.4(149)	13.5,4.3(122)	13.5,4.4(271)
1985	5.5,1.5(49)	7.1,3.0(47)	6.3,2.5(96)	11.7,4.2(114)	11.6,4.4(111)	11.7,4.3(225)	9.5,3.2(119)	10.7,3.5(116)	10.1,3.4(235)
Maximum Air Temperature (°C)									
1983 max	20.1	19.1		28.9	28.1		36.7	32.3	
1984 max	16.1	13.0		25.5	35.1		34.2	37.6	
Mimimum Air Temperature (°C)									
1983 min	-1.3	-9.8		-0.5	-0.7		1.1	-4.6	
1984 min	-11.4	-4.8		-5.5	-3.2		-5.9	-3.6	
Windspeed (KPH)									
1983			12.2,4.1(6)			7.0,2.6(3)			4.3,5.1(3)
1984	6.3,4.2(215)	5.3,3.0(7)	6.2,4.2(222)	11.4,6.6(100)	12.0,6.4(91)	11.7,6.4(191)	8.3,6.6(150)	4.4,3.4(122)	6.5,5.7(272)
1985	17.4,8.0(49)	14.0,7.2(49)	15.5,7.7(96)	9.0,4.5(114)	9.3,3.9(111)	9.2,4.2(225)	15.4,14.9(119)	6.9,7.0(115)	11.2,12.4(235)
Cloud Cover (levels 0-5)									
1984	5,3.9,1.7(215)	5,4.0,1.7(7)	5,3.9,1.7(222)	5,4.1,1.2(100)	5,3.8,1.4(91)	5,4.0,1.3(191)	4,4.0,1.2(148)	4,3.8,1.3(121)	4,3.9,1.2(269)
1985	4,3.3,1.4(49)	4,3.1,1.5(47)	4,3.2,1.4(96)	2,2.5,1.5(114)	3,2.6,1.5(111)	3,2.5,1.5(225)	3,2.5,1.5(119)	3,2.5,1.4(115)	3,2.5,1.4(235)

[a] 1983 sticky trap catches expressed as mean catch per day, standard deviation, and (number of sticky paper sheets). 1984 sticky trap catches expressed as mean catch per day and (number of trap days). 1985 sticky trap catches expressed as mean catch per day, standard deviation, and (number of trap days).

[b] 1983 human harassment data expressed as mean, standard deviation, and sample size. 1984 and 1985 medians are included.

time as in 1983. The peak mean sweep net capture in 1985 occurred earlier in all cells than in 1984 but fewer were caught. From available data, abundance appears to be much lower in 1985 than in the two previous years.

In 1985, the first hatch of mosquitos in the coastal cell occurred before data was first taken on June 30. At the plains site, the first mosquitos were noted on June 24 and were considered numerous two days later on June 26. By the 27th of June most caribou were observed exhibiting insect harassment behavior. At the foothills site, the first mosquitos appeared on June 24th and were numerous enough to be considered bothersome. In 1984 the first appearance of more than a few mosquitos occurred earlier than in 1985, on June 12, June 16, and June 18 at the foothills, plains, and coast study sites, respectively. The first sticky trap catches in 1984 occurred during the first trapping period beginning the 22 to the 24th of June in all locations except Barter Island where no mosquitos were cuaght until after July 3. Sticky traps caught mosquitos in 1983 between June 30 and July 10 on the coast, June 17-26 on the plains, and June 25-30 in the foothills. In the 1985 field season the peak mean sweep net mosquito capture (17.1 mosquitos per 100 sweeps) occurred on July 2 on the coast (n = 96), on July 3 (65.6 per 100 sweeps) in the plains (n = 225), and on July 7 (7.2 per 100 sweeps) in the foothills cell (n = 240). Peak mean sweep net capture in 1984 occurred on July 8 in the coast cell (8 mosquitos per 100 sweeps), on July 7 in the plains (191 per 100 sweeps), and on July 12 in the foothills (187 per 100 sweeps). The 1983 catch peaked between 26-30 June while the plains and coast peaked approximately the same time as in 1984.

Mosquito Activity

Sweep capture data taken during coinciding days (comparison period) at all sites in 1984 suggests that mosquito activity increased progressively from the coast to the foothills. Analysis of the 1985 sweepnet catch data taken on similar dates in all three cells did not confirm this trend. In 1985, sweepnet catch indicates that the coast experienced the most mosquito activity of the three cells during the comparison period ($x = 1.3$, $s = 5.5$). The foothills ranked second in mosquito activity ($x = 1.0$, $s = 2.4$); while the plains had the lowest catch ($x = 0.4$, $s = 1.5$) during the comparison period. It is noted, however, that the assembly of the data set for the comparison period required the elimination of days when data was not collected at all trap locations in all cells. Thus the peak day of activity for the plains cell was excluded. The mean sweepnet catch in the plains cell on July 3, 1985, exceeded all other mean sweepnet catch per day values in all cells during the 1985 field season (Appendix C). Also of note is the appearance that weather conditions (warm air temperature and low wind speed) on the coast on July 2, 1985, were unusually conducive to mosquito activity and resulted in an atypically high sweepnet catch (Appendix E-I). These data were used during the comparison period. The sweepnet catch in the plains and foothills on this day did not show a similar trend.

Following the procedure from 1984, trapsites in all three cells were ranked by sweepnet and sticky trap catches to test the hypothesis that mosquito activity is affected by site characteristics (Table 4 and Figure 2). Coastal trapsites in 1984 and 1985 were established on a grid designed to test the hypothesis

Table 4. Ranked mean mosquito numbers caught by sweep nets and sticky traps and the environmental characteristics of each insect trapsite in the Arctic National Wildlife Refuge, Alaska, 1985.

Trap-site number	Insect habitat code	Sweep captures Mean	Sweep captures Rank	Sticky traps Mean	Sticky traps Rank	Landcover class		Moisture	Distance to coast (km)	Distance to river (km)	Topography Elevation (m)	Topography Slope (°)	Topography Aspect (°)	Terrain
Coast														
102	IH	4.67	1	1.66	2	CIVa	Tundra complex	Wet	2.6	1.0	ASL			Coast Plain
106	IH	4.38	2	2.10	1	BIIIb	Wet graminoid	Very wet	1.8	2.0	ASL			Coast Plain
103	IH	3.50	3	0.30	8	CIVa	Tundra complex	Wet	2.5	2.0	ASL			Coast Plain
105	IH	1.78	4	1.21	3	BIIIb	Wet graminoid	Very wet	1.8	2.0	ASL			Coast Plain
108	IH	1.00	5	0.60	4	BIIIb	Wet graminoid	Very wet	1.5	1.0	ASL			Coast Plain
113	IR	0.14	6	0.43	7	CVc	*Dryas* river terrace	Dry	4.2	0.0	ASL			Coast Plain
107	IR	0.12	7	0.58	5	EIXh	Scarcely veget. floodplain	Moist/well drained	2.5	0.0	ASL			Coast Plain
104	IR	0.11	8	0.26	10	EIXh	Scarcely veget. floodplain	Moist	2.9	0.0	ASL			Coast Plain
101	IR	0.00	9	0.51	6	EXa	Barren fldplain	Dry	3.3	0.0	ASL			Coast Plain
109	IR	0.00	9	0.28	9	CVc	*Dryas* river terrace	Dry	1.2	2.0	ASL			Coast Plain
110	IR	0.00	9	0.08	11	EIXh	Scarcely veget. floodPlain	Moist	1.5	0.0	ASL			Coast Plain
111	IH	0.00	9	0.06	12	BIIIa	Wet graminoid	Very wet	0.7	0.8	ASL			Coast Plain
112	IR	0.00	9	0.08	11	CVc	*Dryas* river terrace	Dry	0.0	1.5	ASL			Coast Plain
Plains														
208	1H	6.32	1	2.25	6	CVb	Tussock	Moist/well drained	24.0	1.8	210	5	135	Plain
204	IH	5.39	2	2.14	7	CVb	Tussock ridge	Moist/well drained	24.0	2.2	200	5	225	Plain
212	IH	5.06	3	5.06	1	CVb	Tussock ridge	Moist/well drained	24.8	1.7	220	5	90	Plain
207	IH	3.05	4	4.78	2	BIIIa	Wet graminoid	Wet	24.8	0.7	200			Plain
202	IR	2.89	5	2.99	4	CVc	*Dryas* river terrace	Dry	25.2	0.3	200			Plain
211	IH	2.78	6	0.59	9	BIIIa	Wet graminoid	Wet	25.2	1.0	200			Plain
203	IH	2.72	7	1.53	8	BIIIa	Wet graminoid	Wet	24.0	1.6	200			Plain
206	IR	2.35	8	3.66	3	CVc	*Dryas* river terrace	Dry	25.6	0.3	200			Plain
210	IR	1.00	9	2.37	5	CVc	*Dryas* river terrace	Dry	25.6	0.2	200			Plain

Table 4. (Continued)

Trap-site number	Insect habitat code	Sweep captures Mean	Sweep captures Rank	Sticky traps Mean	Sticky traps Rank	Landcover class		Moisture	Distance to coast (km)	Distance to river (km)	Topography Elevation (m)	Topography Slope (°)	Topography Aspect (°)	Terrain
Plains (continued)														
205	IR	0.20	10	0.36	10	EXa	Barren fldplain	Dry	25.6	0.1	200			Plain
209	IR	0.11	11	0.09	12	EXa	Barren fldplain	Dry	26.8	0.5	200			Plain
201	IR	0.05	12	0.11	11	EXa	Barren fldplain	Dry	25.2	0.1	200			Plain
Foothills														
321	IH	1.47	1	1.64	1	CVb	Moist graminoid tussock	Moist/well drained	70.4	24.8	840	5	270	Valley
311	IH	1.05	2	0.37	6	CVIIa	Mesic erect shrub	Moist	71.2	25.6	960	10	225	Valley
341	IH	0.74	3	0.36	7	EIXa	Alluvial deciduous scrub	Dry	69.2	23.6	975	0	0	Valley
331	IH	0.53	4	0.00	10	CVb	Moist graminoid tussock	Moist/well drained	68.0	22.4	870	15	180	Valley
332	IR	0.42	5	1.20	2	EIXj	Scarcely veget. scree	Dry	69.6	24.0	1170	10	180	Slope
312	IR	0.40	6	0.00	10	CVd	Dry prostrate	Dry	71.2	25.6	1110	25	270	Slope
342	IH	0.21	7	0.50	4	CVIIb	Moist dwarf shrub	Moist/well drained	69.2	23.6	1080	5	315	Slope
323	IR	0.19	8	0.45	5	EXd	Scarcely veget. scree	Dry	70.4	24.8	1305	0	0	Ridge
322	IR	0.11	9	0.12	9	CVd	Dry prostrate	Dry	70.4	24.8	1050	30	270	Slope
313	IR	0.10	10	0.32	8	EIXj	Dwarf shrub	Dry	71.2	25.6	1260	0	270	Ridge
333	IR	0.05	11	0.89	3	EXd	Scarcely veget. scree	Dry	70.0	24.4	1275	0	0	Ridge
343	IR	0.00	12	0.37	6	EXd	Scarcely veget. scree	Dry	70.0	24.4	1305	0	0	Ridge

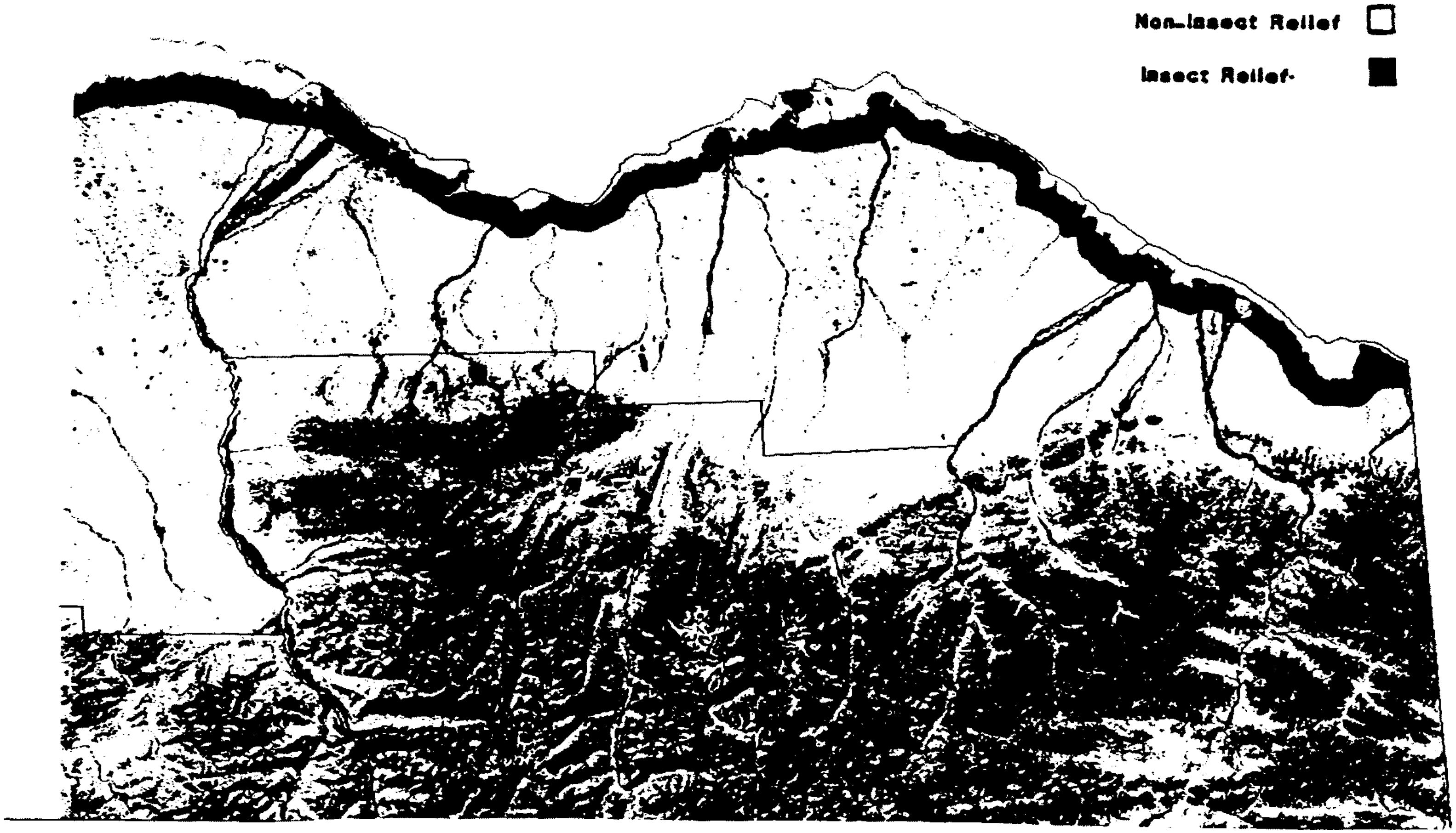


Figure 2. Insect Relief areas based on landcover characteristics and proximity to the coast in the Arctic National Wildlife Refuge.

Alaska F & W Research Center - Region 8
Division of IRM - GIS - Region 7
US Fish & Wildlife Service
1011 East Tudor Road
Anchorage, Alaska 99503

that mosquito activity is affected by site characteristics (Table 4). A zone of insect relief habitat extending along the coastline of ANWR is believed to exist (Figure 2). The width of this zone varies depending on weather factors. Minimal data in 1985 did not permit valid statistical analysis of the effects of distance from coast and distance from river in the coastal cell (Table 5). Of three trapsite visit days with positive sweepnet catch (catch greater than or equal to 1) only one day (July 2, 1985) contained data from all 13 trapsites. Sweepnet catch at the coast trap locations on 2 July 1985, is illustrated on the schematic diagram in Figure 3. The diagram suggests that the distance from coastal <u>and</u> riparian areas may interact to affect mosquito activity, and further suggests the possibility of a coastal/riparian insect relief zone.

Table 5. Sweepnet catch by day and distances from coastal and riparian habitat at coast cell in 1985.

Site No.	Dist. from Riparian Habitat (km)	Dist. from Coast Habitat (km)	Date									
			June 30	July 1	2	3	4	5	6	7	9	10
101	0.0	3.3	0	0	0	0	0	0	0	0	0	0
102	1.0	2.6	6	0	36	0	0	-	0	0	-	0
103	2.0	2.5	5	-	22	0	0	-	0	0	-	0
104	0.0	2.9	0	0	1	0	0	0	0	0	-	0
105	1.0	2.0	5	0	11	0	0	0	0	0	-	-
106	2.0	1.8	3	-	32	0	0	0	0	0	-	0
107	0.0	2.5	1	-	0	0	0	0	0	0	-	0
108	1.0	1.5	8	-	0	0	0	0	0	0	-	0
109	2.0	1.2	-	-	0	-	0	0	0	0	-	0
110	0.0	1.5	-	-	0	-	0	0	-	0	-	0
111	0.8	0.7	-	-	0	-	0	0	-	0	-	0
112	1.5	0.0	-	-	0	-	0	0	-	0	-	0
113	0.0	4.2	-	-	1	0	0	0	0	0	-	0

The plains cell showed a significant relationship between distance from riparian habitat and mosquito activity (Table 4). Regression analysis of sweep capture data from 1984 and 1985 indicates that insect activity increases with distance from some riparian areas ($r^2 = 0.81$ and $r = 0.72$). Sweepnet catches from the plains cell were grouped and compared by landcover class to determine the extent of the relationship between landcover and mosquito activity (Table 6). Catch frequency suggested that data from Table 6 was not normally distributed and the non parametric Kruskall-Wallis rank test was utilized to reveal any significant differences in sweepnet catch between plains landcover types. Both 1984 and 1985 data from the plains cell were tested using Kruskall-Wallis. Although both data sets gave the appearance of a relationship between landcover and sweepnet catch, however results from

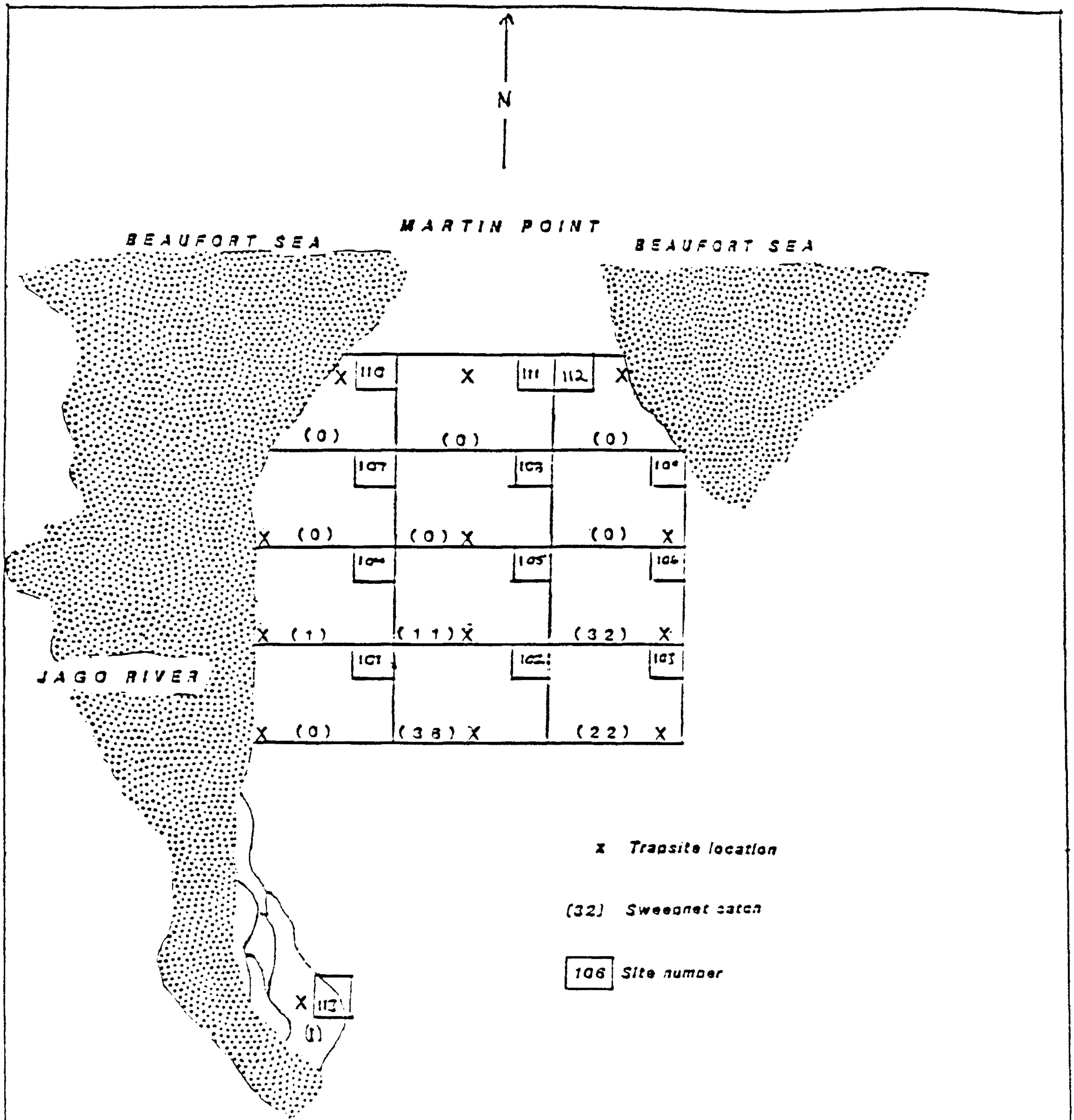


Figure 3. Relative locations of trap/data collection sites and the sweepnet capture per site on 2 July 1985 in the Arctic national Wildlife Refuge. Alaska National Wildlife Refuge. Alaska.

Scale 1:47520

Table 6. Contrasts in total sweepnet catch between landcover and date in the plains cell in the Arctic National Wildlife Refuge, Alaska, 1985.

		Date														
Landcover	Site #	June 25	26	27	28	29	30	July 1	3	4	5	6	7	8	Site Totals	Landcover Totals
Scarcely Veg. Floodplain	201	0	0	0	0	0	0	0	1	0	0	0	0	0	1	= 7
	205	0	0	0	0	0	2	0	2	0	0	0	0	0	4	x = 0.18
	209	0	0	0	0	1	1	0	0	0	0	0	0	0	2	s = 0.50
Dryas River Terrace	202	0	2	0	0	0	5	0	46	0	0	0	0	0	53	= 101
	206	0	0	0	0	0	2	0	29	0	0	0	0	0	31	x = 2.59
	210	0	1	0	0	3	2	0	11	0	0	0	0	0	17	s = 8.7
Wet Graminoid	203	0	0	0	0	0	3	0	25	0	0	0	0	0	28	= 80
	207	0	2	0	0	0	4	3	8	0	0	0	0	0	17	x = 2.05
	211	2	0	0	0	2	0	0	31	0	0	0	0	0	35	s = 6.35
Moist Tussock	204	0	0	0	0	0	2	0	53	0	0	0	0	0	55	= 258
	208	0	0	0	2	0	12	0	102	0	0	0	0	0	116	x = 6.62
	212	0	0	0	0	1	0	0	86	0	0	0	0	0	87	s = 22.4
Daily Totals		2	5	0	2	7	33	3	394	0	0	0	0	0	446	

Kruskall-Wallis indicated that the null hypothesis could not be rejected, probably because of the zero catch which occurred during most days in 1985.

Mean sweepnet catch in the plains in 1984 was higher than in 1985 (n = 13 in both cases). Similarities between 1984 and 1985 appear in that floodplains in both cases is the lowest ranked landcover in terms of sweepnet catch. In 1985 Dryas river terrace and wet graminoid landcovers had a similar total catch (x = 101, 80 respectively). In 1984, when mosquito activity and abundance appeared to be much higher, the differences in sweepnet catch between landcovers was more pronounced. Dryas river terraces in 1984 ranked third in total catch (400 mosquitos) while wet graminoid ranked second with total sweepnet catch of 1310 mosquitos.

The proportion of days with positive sweepnet catch values within landcover categories was calculated. The wet graminoid landcover class had the highest percentage of positive catch days (27.2%) but a relatively low mean sweepnet catch (x = 2.05, s = 6.4). Dryas river terraces ranked high in the percentage of days of positive catches (23.0%) and also had a higher mean sweep net catch (x = 2.59, s = 8.7) than wet graminoid sites. Moist tussock areas in the plains had the highest mean sweepnet catch (x = 6.62, s = 22.4) but ranked third in proportionate days of positive catch (17.9%). Scarcely vegetated floodplains had both the lowest mean sweepnet catch and the fewest days during which mosquitos were active (x = 0.18, s = 0.5, and 12.8%) (Table 7).

Table 7. Weather, sweepnet catch and days of positive sweepnet catch in the plains cell, Arctic National Wildlife Refuge, Alaska, 1985.

Landcover	Mean Sweepnet Catch	Percent of Days with Catch _1	Mean Wind Speed (kph)	Mean Ambient Air Temp. (°c)
Floodplain	0.2	12.8	8.9	13.8
Dryas	2.6	23.0	9.6	14.8
Wet Gram	2.1	27.2	9.3	14.6
Tussock	6.6	17.9	9.9	13.5

Variation in sweepnet catch over time was evident and weather variables were suspected of having influenced mosquito activity within the landcover categories. Study of weather variables across landcover types failed to explain the differences in catch between landcover categories. For example, moist tussock areas had the highest sweepnet capture of mosquitos despite the fact that it also experienced the lowest mean temperatures and highest mean windspeeds, however, variation in sweepnet catch between days appears to be strongly dependent on weather parameters. On July 3, 1985, the plains cell apparently experienced conditions that were ideal for mosquito activity, and sweepnet capture was high compared to all other days. Ambient air temperatures were high (x = 22.6°c, s = 3.9) and windspeeds were low (x = 4.7 kph, s = 2.5). Peak total sweepnet catch (394) occurred on this day. During the days immediately following July 3, sweepnet catch plummetted and no mosquitos were caught on days when all trap locations were visited (Table 6). Weather conditions during this period consisted of high winds (x = 13.1 kph, s = 3.7) and comparitively lower ambient air temperatures (x = 10.3, s = 4.1).

Moisture regimes associated with the landcover classes (Walker et al. 1983) at each trapsite were compared with sweepnet catch to evaluate differences in insect activity at sites with differing moisture classifications. Moisture regimes at trap locations included dry, moist, moist well-drained, wet and very wet classifications. One-way analysis of variance was used to distinguish significant differences in sweepnet catch at these moisture levels. ANOVA's indicate that insect activity in the coast cell does not differ significantly between individual moisture classes ($p \gtrsim 0.05$). Moisture classes tested at coast sites fell under the dry, moist, wet, and very wet categories. All moisture regimes similarly tested at the 0.05 level in the plains and foothills cells showed significant differences in sweepnet catch in these moisture regimes. Categories tested were dry, moist and wet in the plains and dry and moist in the foothills (Table 8).

Table 8. Results of one way analysis of variance and least significant difference of sweepnet catch between moisture regimes in the coast, plains, and foothills, Arctic National Wildlife Refuge, Alaska, 1985.

Location	Moisture Regime	(n)	Mean Sweepcatch	Standard Deviation	Degrees Freedom	F Test	Least Sig. Dif.
Coast	Dry	26	0.04	0.20			
	Moist	22	0.91	0.29	3	2.50	3.79
	Wet	17	4.12	0.85			
	Very Wet	30	1.97	6.23			
Plains	Dry	56	2.14	7.54			
	Moist	26	11.73	27.55	2	3.33	0.79
	Wet	28	5.82	12.49			
Foothills	Dry	64	0.50	1.35	1	7.59	0.16
	Moist	32	1.88	3.53			

Total sweepnet catch in the foothills was grouped by date, terrain and aspect (Table 9). There were differences in sweepnet catch between the terrain treatments as well as variation between days. Valley sites ranked highest in terms of sweepnet capture of mosquitos (x = 1.4, s = 3.0). Slopes were second (x = 0.5, s = 1.2) and Ridge sites had the least amount of activity (x = 0.1,

Table 9. Total sweepnet catch from foothills, Arctic National Wildlife Refuge, Alaska, 1985.
Catch is grouped by date, terrain type and aspect.

Terrain	Aspect	Trap Location Number	Date: JUNE 24	26	27	28	29	30	JULY 1	2	4	5	6	7	8	Site Totals	Terrain Values
Valley	N	331	0	0	0	0	0	2	0	0	0	0	0	8	0	10	= 73
	NW	341	0	0	0	2	1	2	1	0	0	0	0	7	1	14	x = 1.4 s = 3.0
	W	321	3	0	0	0	0	0	3	0	1	0	6	2	13	28	
	SW	311	0	0	0	0	0	1	1	0	7	0	0	12	0	21	positive catch days = 35%
Slope	N	332	1	0	0	0	0	4	0	0	0	0	0	3	0	8	= 26
	NW	342	0	0	0	0	0	0	0	0	0	0	0	4	0	4	x = 0.5 s = 1.2
	W	322	0	0	0	0	0	0	2	0	0	0	4	0	0	6	
	SW	312	0	0	0	0	2	0	1	0	0	0	0	5	0	8	positive catch days = 17%
Ridge	N	333	1	0	0	0	0	0	0	0	0	0	0	0	0	1	= 3
	NW	343	0	0	0	0	0	0	0	0	0	0	0	0	0	0	x = 0.06 s = 0.30
	W	323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	SW	313	0	0	0	0	0	0	0	0	0	0	0	2	0	2	positive catch days = 4%
Totals			5	0	0	2	3	9	8	0	8	0	10	43	14	102	

s = 0.3). Thirty-five percent of sample-site days in valleys resulted in positive sweepnet catch. Seventeen percent positive catch days occurred on slopes, while only ten percent of the days sampled on ridges resulted in sweepnet catches greater than or equal to one mosquito per 100 sweeps. Each positive catch days occurred on slopes, while only ten percent of the days sampled on ridges resulted in sweepnet catches greater than or equal to one mosquito per 100 sweeps. Each terrain category was sampled equally. Variation in catch size between days, however, was not explained by terrain type which remains constant across time. Because variation between days must be attributed to inconstant variables, weather parameters were thought to be possible factors. The relationship between insect harassment of caribou with windspeed and ambient air temperature has been documented (White et al. 1975). Single weather variables were plotted against sweep net catch. Very little relationship was apparent in attempts to attribute individual weather variables to mosquito activity. Dau (1986) inferred that relationships between weather and insect activity were most likely to be a function of at least two weather variables. The relationship between weather parameters and terrain from 1985 foothills data was considered. Specifically, ambient air temperature and windspeed were compared between valleys, slopes, and ridge trap locations. Results suggest that ridges incur higher windspeeds (x windspeed = 22.0 kph, s = 17.8) than slopes (x windspeed = 12.7, s = 10.6) or valleys (x windspeed = 5.2, s = 5.6). Ambient air temperatures also decrease from valleys to slopes to ridges (x temperatures 11.4, 10.2, 9.4 and s = 4.1, 3.7, 3.5, respectively). The proportion of days with lower ambient air temperatures to days of higher temperatures was calculated for the entire foothills study site as well as within each terrain category. Overall, seventy percent of the days sampled in the foothills experienced average ambient air temperatures equal to or exceeding 8.0°C. Fifty-nine percent of the sample days had windspeeds exceeding 8.0 kph. For an overview of mean windspeeds and temperatures on different terrain type see Table 10 and Figure 4. Ridges experienced more days of high winds (18 kph or greater) than slopes or valleys. Ridges had fewer days of high temperatures (8.0°C or greater) than did valleys and more days of cool temperatures (less than 8.0°C) than valleys. Slopes, however, were proportionally cooler than ridges (more days of cool temperatures and fewer days of high temperatures than ridges) although mean temperatures of slope locations were warmer than those of ridge locations. Several days with no sweepnet catch occurred in the foothills. Days with no catch at any trap locations typically occurred during periods of higher windspeeds and lower temperatures than those days when sweepnet capture was noticeably higher. Sweepnet catch from Table 6 was plotted against windspeeds and ambiant temperature (Figure 5). It was noted that several days appeared to have ideal weather conditions for mosquito activity in terms of temperature and windspeed however low catch was apparent. Heavy rain occurred on those days.

Diel Weather Patterns

For an overview of diel patterns of weather and mosquito activity during one, twenty-four period in the coast, plains, and foothills cells see Figures 6 and 7. Weather and mosquito activity data were collected over two twenty-four hour periods at the coast and three twenty-four hour periods at plains and foothills sites. For the purpose of contrasting patterns between cells,

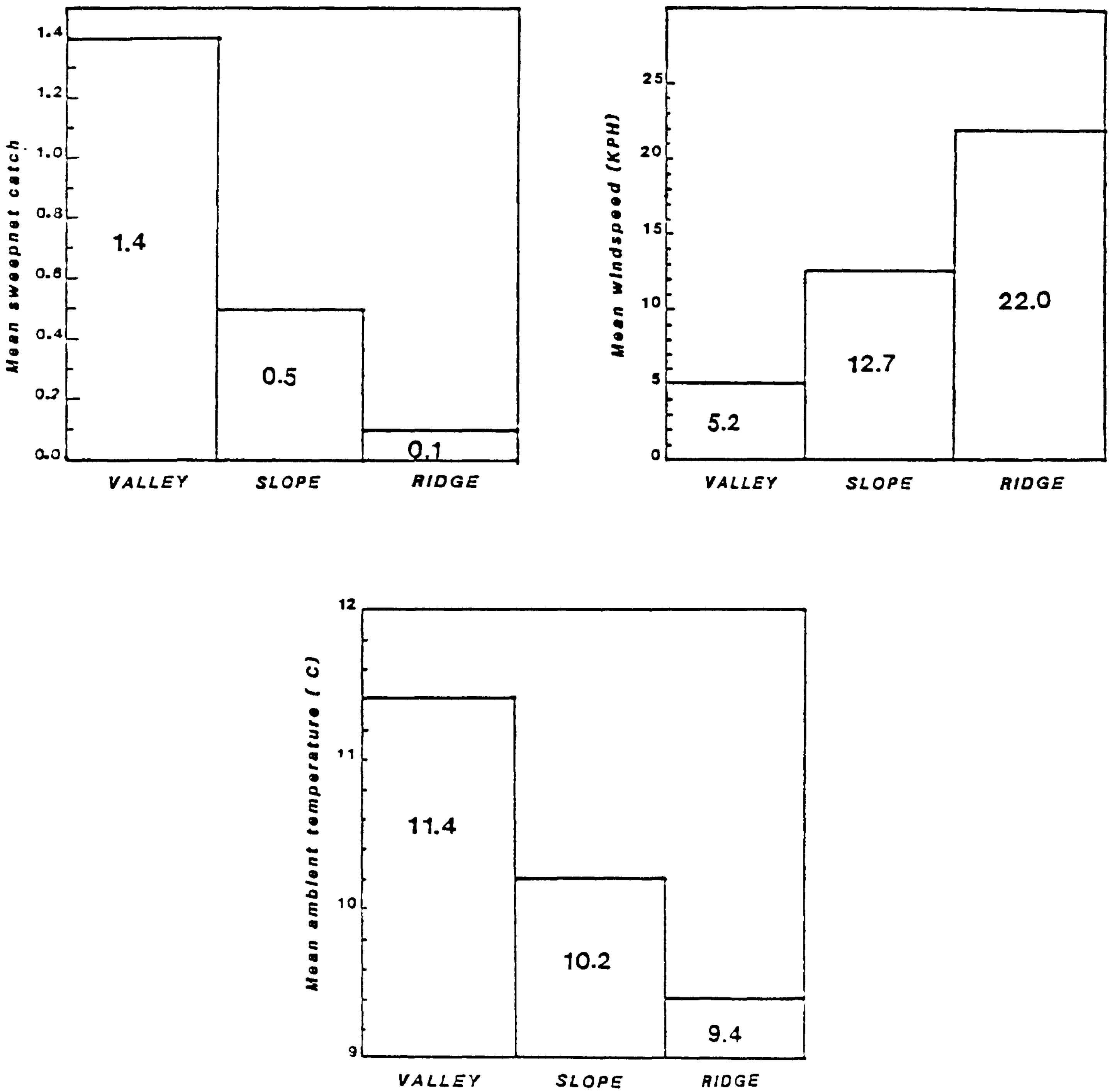


Figure 4 Sweepnet catch and weather relationships to terrain types in the foothills of the Arctic National Wildlife Refuge, Alaska 1985.

Table 10. Mean values for sweepnet catch, windspeed, and ambient air temperature on valleys, slopes, and ridges in the foothills cell in Arctic National Wildlife Refuge, Alaska, 1985.

	Mean Sweepnet Catch	Mean Windspeed (kph)	Mean Ambient Air Temp (°C)
Terrain Type	x, S, (n)	x, S, (n)	x, S, (n)
Valley	1.4, 3.0 (52)	5.2, 5.6 (52)	11.4, 4.1 (52)
Slope	0.5, 1.2 (52)	12.7, 10.6 (52)	10.2, 3.7 (52)
Ridge	0.1, 0.3 (52)	22.0, 17.8 (52)	9.4, 3.5 (52)

observers at all three sites collected data on coinciding hours was during one collection period. For inferences drawn within each cell, the full compliment of the twenty-four hour data base specific to the given cell was utilized.

In 1985, mosquito activity during the 24-hour sample periods on the coast did not correspond well with the time of day, and most quantifiable weather factors measured, aside from ambient air and soil temperature, appeared to be independant of hour. The conspicuous absence of mosquitos between 0600 and 1000 hours coincides with a period of peak windspeed and slowly rising ambient air temperature at the coast site. According to the available data, windspeed on the coast appears to peak in mid-morning hours, but ambient air temperature and soil temperature do not peak until much later in the day - between 1500 and 1900 hours. This is probably an artifact of the long periods of daylight during the arctic summer. The offset pattern of windspeed and temperature (early high winds, low temps.; late low winds, high temps.) would seemingly produce a pattern of low sweepnet catch during the early hours and a relatively high catch late in the day. The sweepnet catch counts during two twenty-four hour data collection periods at the coast site, vaguely suggest such a pattern, only through the absence of mosquitos during the four-hour morning period. The full data base for the coast suggests, however, that such a pattern may exist for mosquito activity. All trapsite visits before 1400 hours ($n = 38$) yielded a mean sweepnet catch of 0.3 mosquitos per 100 sweeps ($s = 1.1$) while visits after 1400 hours ($n = 49$) produced a mean of 2.5 mosquitos per 100 sweeps ($s = 7.6$). If such a pattern does exist on the coast it is probably related to weather variables. Windspeed was found to be higher before 1400 hours at trap location visits ($x = 20.00$ kph, $s = 8.2$). Trap location visits after 1400 hours recorded lower windspeeds ($x = 13.06$ kph, $s = 7.2$). Likewise, temperatures before 1400 hours proved to be lower ($x = 5.8$°C, $s = 2.5$) than those after 1400 hours ($x = 6.7$°C, $s = 2.5$). No other discernable patterns were noted from the data available from the coast.

Twenty-four hour data collected in the plains cell shows a peak in mosquito activity (sweepnet catch) between 1000 hours and 1500 hours (AST). Sweepnet catch varied at comparatively lower levels throughout the remaining hours,

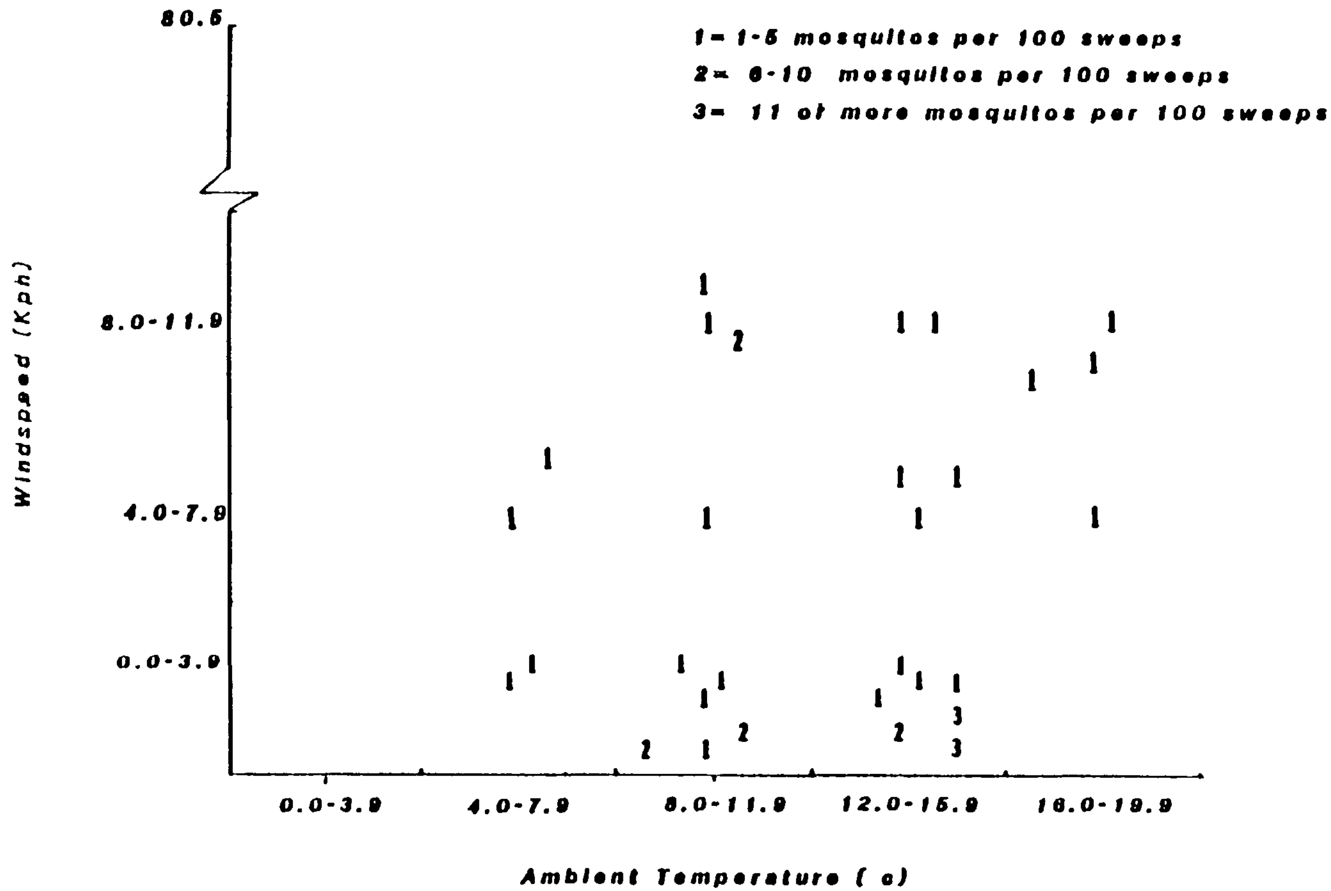


Figure 5. Sweepnet catch at various windspeeds and ambient temperatures in the foothills in Arctic National Wildlife Refuge, Alaska 1985.

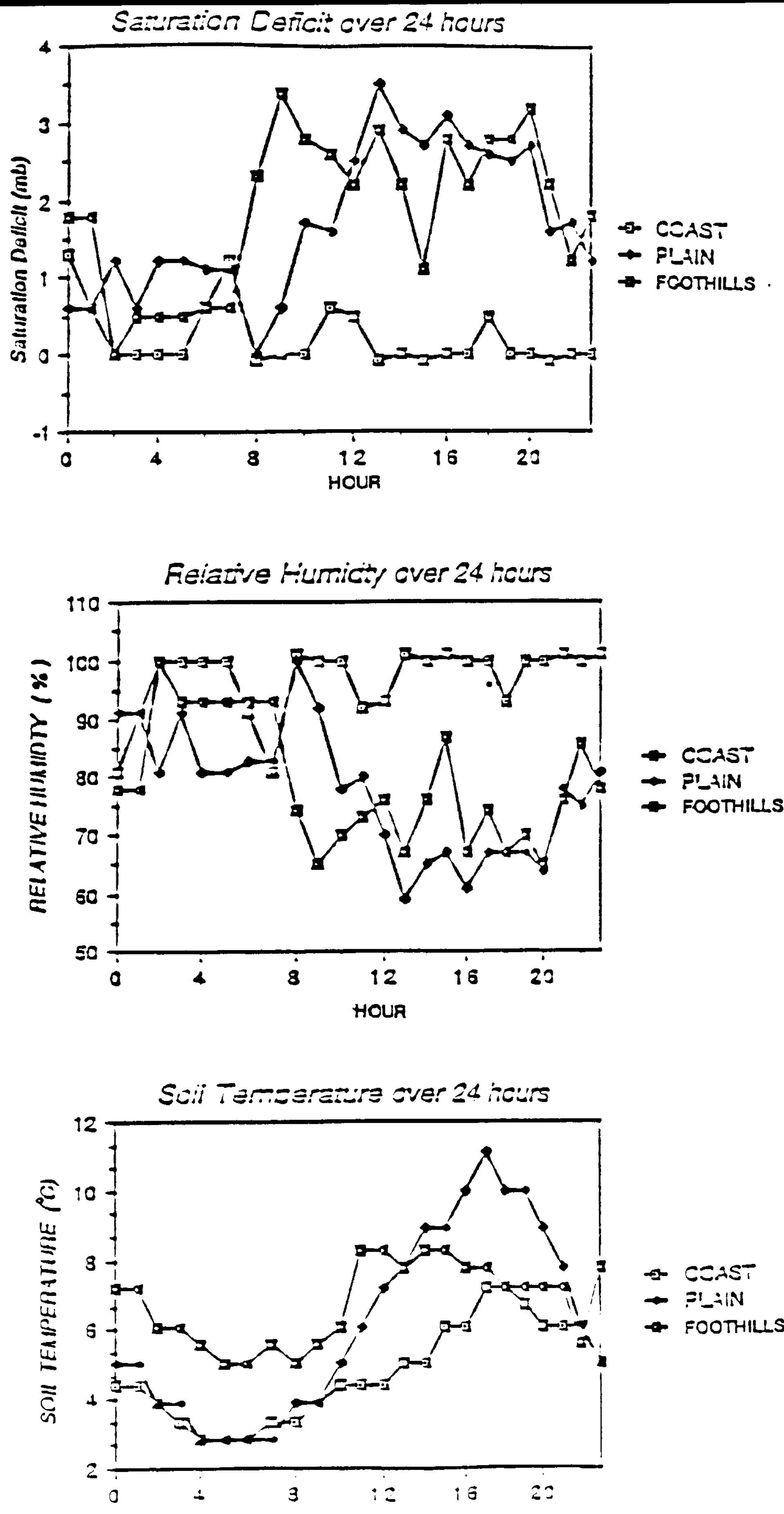
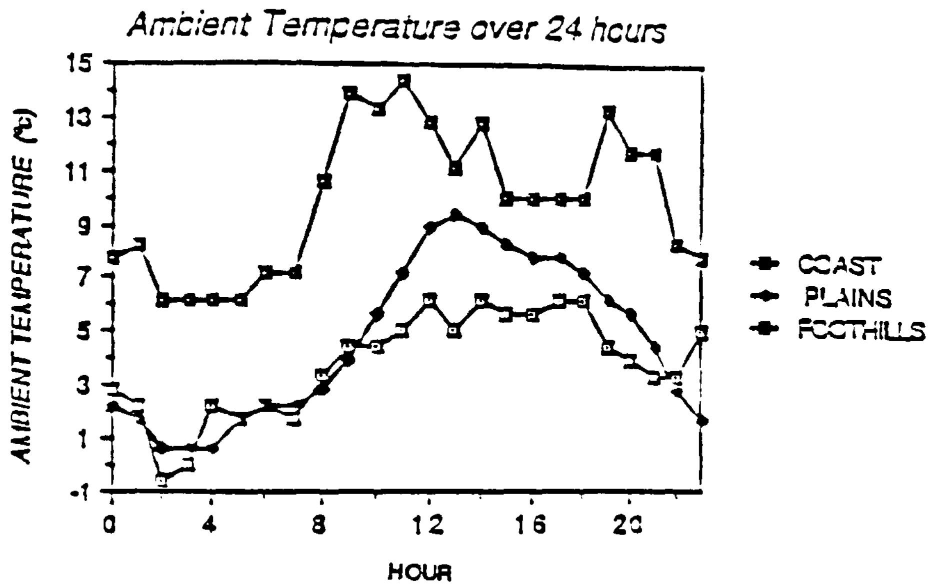
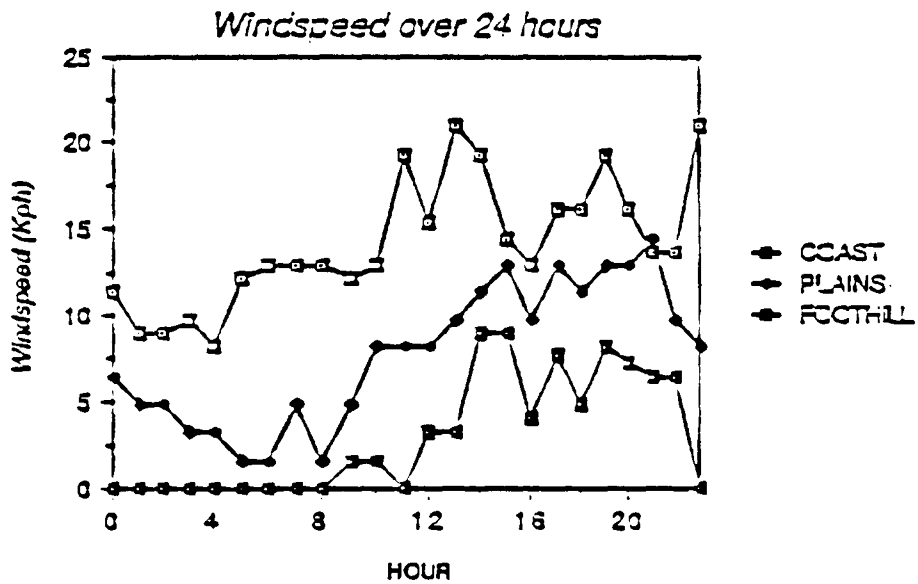


Figure 8. Diel patterns of weather data from the coast, plains, and foothills of the Arctic National Wildlife Refuge, Alaska 1985





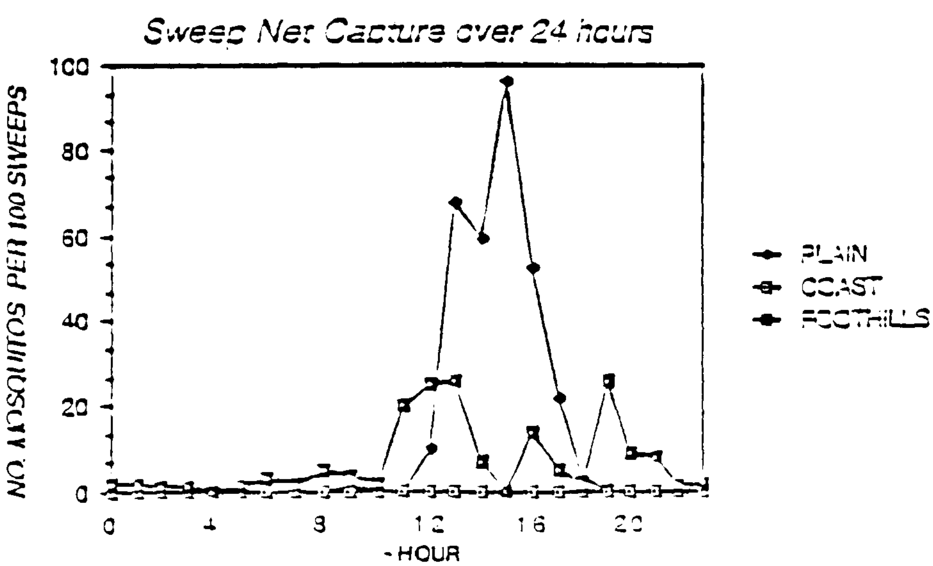


Figure 7. Diel patterns of weather and sweepnet catch data from the coast, plains, and foothills of the Arctic National Wildlife Refuge, Alaska 1985.

both before and after the mid-day peak. Windspeeds also peaked in the plains during the period of high catch, however, a substantial rise in mean ambient air temperature also occurring between these hours may have diminished the negative effects of increased windspeed on mosquito activity. No corresponding diel weather or mosquito activity patterns were discovered in the analysis of plains trap location data. The existence of a peak mosquito activity period between 1000 and 1500 hours was not verified by mean sweepnet catches during this period. Windspeeds between these hours during the rest of the 1985 data collection period were actually slightly higher and ambient air temperatures were slightly lower than during other times.

Foothills sweepnet catches peaked between 1000 and 1400 hours. Two increases in catch of shorter duration occurred at 1600 and 1900 hours. At the time of peak mosquito activity windspeed was low but began building after 1100 hours. Mean sweepnet catch rose sharply between 1000 and 1100 hours possibly in response to low windspeed and increasing ambient air temperature. Following 1100 hours, catch began to taper off and finally declined with increasing windspeed. It appears that brief decreases in windspeed during a period of consistently high ambient air temperature allowed the two increases in sweepnet catch at 1600 and 1900 hours. Higher wind speeds between 1100 and 1600 hours may be an established pattern in the foothills, however. Because nearly all trap location data from the foothills were collected between these hours, it would be difficult to contrast with the small data base existing beyond this window.

No diel patterns of change in relative humidity and saturation deficit were detected at the coast where relative humidity, in particular, varied only by 20% at any particular time. Relative humidity at the coast was consistently high and saturation deficit was almost always low. Relative humidity appeared to decline after 1100 hours in the foothills and increased from 0000 hours. Relative humidity leveled off after 0600 hours. No pattern in relative humidity was detected in the plains. Both the foothills and plains study sites reached peak saturation deficit during mid-day between 0900 and 1500 hours.

Soil temperature it all study sites rose fairly consistently throughout daylight hours and begans to decline after 1900 hours.

Caribou Observations

Fifty-one caribou/insect/habitat interactions were observed in the coast, plains, and foothills cells in 1985. Seventy-three percent of the observations were made before the first appearance of the mosquitos on the plains on 24 June. Between 24 June and 8 July, 19 observations were recorded (Table 11). Insect harassment of caribou was observed in seven of these sightings. Positive sweep net catches confirmed that mosquitos were active in four of the seven cases where insect harassment was observed. Harassment by oestrids was not observed in 1985. Caribou were heading into the wind in 77% of the samples when mosquitos were active and wind direction and direction of caribou movement was noted. Caribou headed into the wind in 71% of the samples before mosquitos became active. Sample size was inadequate to contrast harassment with landcover and weather variables as the majority of

Table 11. Caribou-insect-habitat interactions observed between 20 June and 8 July at coast, plains and foothills locations in the Arctic National Wildlife Refuge, Alaska, 1985.

					Wind		Caribou			Mosquito harassment of caribou			
Date	Time	Location	Land Cover[1]	Temp (°C)	Km/Hr	Dir.	No.	Activity[2]	Heading	HH	ObHC	PrHc[3]	Mosquitos per 100 sweeps
6-20	0735	Plains	BIIIa	--	--	--	30	W,F,R	ENE	--	0	--	0
	0750	Plains	BIIIa	--	--	--	30	W	ENE	--	0	--	0
	0940	Plains	CVc	18.3	1.6	NNW	10	S,F	--	0	0	2	0
	1045	Plains	CVc	14.4	6.4	NNW	6	S,F	--	0	0	2	0
	1155	Plains	BIIIa	16.1	4.8	NNW	3	W,F	--	0	0	2	0
	1220	Plains	CVb	15.6	6.4	NNW	60	S,F	--	0	0	2	0
	1250	Plains	CVb	15.0	6.4	N	60	W,F	--	0	0	2	0
	1430	Plains	CVc	13.3	6.4	N	20	L,S	--	0	0	2	0
	1520	Plains	BIIIa	15.0	6.4	NE	20	W,F	--	0	0	2	0
	1550	Plains	CVb	12.8	6.4	ENE	10	S,F	--	0	0	1	0
6-21	0815	Plains	EXa	7.2	4.8	WNW	20	S,F	ENE	0	0	1	0
	0900	Plains	CVb	10.0	1.6	NW	20	S,F	ENE	0	0	1	0
	1000	Plains	EXa	7.2	4.8	WNW	60	S,F	--	0	0	1	0
	1015	Plains	EXa	8.9	1.6	NNW	60	S,F	--	0	0	1	0
	1100	Plains	CVb	10.0	1.6	NW	1	W,F	--	0	0	1	0
	1125	Plains	CVb	10.6	1.6	NW	1	W,F	--	0	0	1	0
	1340	Plains	CVc	11.7	3.2	E	15	W,F	--	0	0	1	0
	1345	Plains	CVc	11.7	3.2	E	30	W,F	--	0	0	1	0
	1405	Plains	CVc	11.7	9.7	NE	30	W,F	--	0	0	1	0
	1415	Plains	BIIIa	11.7	9.7	ENE	20	W,T	N	0	0	1	0
	1530	Plains	BIIIa	11.7	9.7	ENE	65	W,F	--	0	0	1	0
	1600	Plains	BIIIa	--	--	--	65	W,F	--	--	0	--	0
6-22	0945	Plains	EXa	10.6	11.3	E	45	S,F	--	0	0	1	0
	1010	Plains	EXa	11.1	11.3	E	45	S,F	--	0	0	1	0
	1025	Plains	CVc	12.2	12.9	ENE	40	W,T	NNE	0	0	1	0
	1045	Plains	CVb	12.8	11.3	E	50	W,T	NNE	0	0	1	0
	1100	Plains	CVc	12.2	12.9	ENE	50	W,T	NNE	0	0	1	0
	1110	Plains	BIIIa	11.7	11.3	E	30	W,T	NNE	0	0	1	0
	1125	Plains	CVb	12.8	11.3	E	8	S,F	--	0	0	1	0
	1145	Plains	CVb	12.8	9.7	E	20	S,F	--	0	0	1	0
	1225	Plains	CVc	13.9	12.9	E	65	S,F	--	0	0	1	0
	1420	Plains	CVb	13.9	11.3	ENE	4	S,F	--	0	0	1	0

(continued)

Table 11. (continued)

Date	Time	Location	Land Cover[1]	Temp (°C)	Wind		Caribou			Mosquito harassment of caribou			Mosquitos per 100 sweeps
					Km/Hr	Dir.	No.	Activity[2]	Heading	HH	ObHC	PrHc[3]	
6-24	0230	Plains	CVc	--	--	--	20	W,F	N	--	0	--	0
	0235	Plains	CVc	--	--	--	100	W,T	N	--	0	--	0
	0750	Plains	CVc	--	--	--	7	S,F	N	--	1	--	0
	0810	Plains	CVc	--	--	--	7	T	N	--	1	--	0
	1035	Plains	EXa	18.9	1.6	NE	35	W,F	--	1	0	2	0
	1130	Plains	EXa	20.6	8.0	NE	40	W,T	N	0	0	2	0
	1200	Plains	BIIIa	20.6	9.7	ENE	6	S,F	--	0	0	2	0
6-25	1050	Plains	BIIIa	14.4	8.0	WNW	8	T	NNE	0	1	2	0
6-26	1300	Plains	CVc	11.1	4.8	W	8	T	NNE	1	0	1	2
	1745	Plains	CVc	11.7	9.7	NE	1	T,F	N	0	1	1	1
6-27	2130	Plains	CVc	21.7	5.6	ENE	4	T	--	1	0	2	0
6-28	1940	Plains	CVc	18.9	0.0	--	50	S,F	--	1	1	2	1
	2125	Plains	BIIIa	--	--	--	100	T	N	--	2	--	15
6-29	1929	Coast	EXa	5.0	16.1	ENE	1	L	--	0	0	0	0
	1939	Coast	EXa	5.0	16.1	ENE	1	L	--	0	0	0	0
	2000	Coast	EXa	5.0	16.1	ENE	1	L,R	--	0	0	0	0
7-1	1345	Foothills	CVIIb	8.3	6.4	NE	4	W,F	W	1	0	1	0
7-7	1100	Foothills	CVIIa	13.9	9.7	N	3	S,F	S	0	0	2	0
7-8	1035	Foothills	CVb	15.6	1.0	N	1	T	None	2	3	2	13

[1] Walker et al. 1983

[2] Activity codes:

W = walking S = standing
R = ruminating F = feeding
L = lying T = trotting

[3] HH = Human harassment levels 0-3 (Curatolo and Murphy 1983).
ObHc = Observed caribou harassment levels 0-3 (Thompson 1973).
PrHc = Predicted caribou harassment levels 0-2 based on model (White et al. 1975).

observations were made before mosquitos appeared on 24 June 1985.

Sampling Protocol

Following mosquito emergence, access to large numbers of caribou was limited, resulting in a reduced date base with which to accurately contrast predicted harassment with landcover and weather variables in 1985. In 1983 and 1984, limited ground access and the absence of caribou at intensively monitored sites limited the sample size. The use of a helicopter in 1984 resolved access problems, though landcover and weather variables were limited by an inadequate distribution of caribou across all the variables. Further intensive sampling is required before harassment of caribou can be reliably contrasted with landcover and weather. The available data from 1984 and 1985, however, was grouped and analyzed, and did indicate some degree of relationship between landcover and harassment of caribou by insects. Landcovers representing insect-relief habitat (river gravels and Dryas tundra) produced lower mean values for human harassment, observed caribou harassment, and predicted caribou harassment than those landcovers considered to be representative of insect habitat. Sweep net capture was also lower in insect relief habitat than in insect habitat (Table 4).

The four techniques of measuring mosquito activity were evaluated in 1983, 1984, and again in 1985. Sticky traps provided an objective interval estimate of mosquito activity in the absence of an attractant. Sweep nets also provided an objective interval estimate, but in the presence of a mammalian attractant.

The level of harassment to humans provided a subjective ordinal measure of harassment in the presence of mammalian attractant. The empirical model (White et al. 1975) gave an ordinal estimate of caribou harassment on the basis of wind and temperature. Contrasts between these techniques, except for sticky traps, the only non-point estimator, are listed in Table 12. All contrasts involving predicted harassment of caribou in 1985 were drawn from data obtained after the first appearance of mosquitos on 24 June. Data obtained before this date was considered invalid in contrasting agreement with predicted harassment, as the model, which is based on wind and temperature variables, assumes the presence of mosquitos to predict harassment. All techniques contrasted with predicted harassment resulted in low agreement in 1985. Of the three techniques contrasted with predicted caribou harassment, sweep net capture had the highest agreement (50%). Agreement between predicted caribou harassment and other estimators of mosquito activity might be improved with increased sample size. Sweep net capture contrasted with observed harassment of caribou resulted in the highest level of agreement (92.2%) and was noted as the most desirable technique in terms of objectivity and repeatability. Sweep catch contrasted with human harassment also resulted in a high level of agreement (90.7%). Human harassment contrasted with observed harassment of caribou showed a fairly high level of agreement (86.0%). Agreement between these techniques is summarized in Table 12.

Agreement between predicted harassment with other estimators could probably be improved given two amendments: (1) landcover is incorporated into the model, and (2) sample size is increased to include a range of temperatures and

Table 12. Percent agreement (n) between techniques to assess and predict the presence or absence of harassment by mosquitos.

	1983		1984		1985	
Contrasts	Caribou observ.	All observ.	Caribou observ.	All observ.	Caribou observ.	All observ.
HH vs. PrHC	67(18)	77(120)	78(23)	76(690)	43.0(14)	51.2(888)
HH vs. Sw			85(20)	84(836)	90.7(43)	84.7(910)
Sw vs. PrHC			70(20)	67(688)	50.0(14)	63.0(888)
HH vs. ObHC	83(18)		78(23)		86.0(43)	
Sw vs. ObHC			95(20)		92.2(51)	
PrHC vs. ObHC	61(18)		65(23)		36.0(14)	

HH = Harassment of humans (0, 1-3)
ObHC = Observed harassment of caribou (0, 1-3)
Sw = Sweepnet catch
PrCH = Predicted harassment of caribou (0, 1-2), White et al. 1975

windspeeds across landcover variables.

Conclusions

1. Levels of mosquito activity are usually highest in the plains and lowest on the coast. Activity in the foothills is usually intermediate. If high ambient air temperatures and low windspeeds coincide, at the coast, relatively high levels of mosquito activity may result.

2. Weather conditions allowing high levels of mosquito activity are most consistent in the plains. These conditions occur least frequently along coastal areas of ANWR. In the foothills weather parameters favoring mosquito activity occur most frequently in valleys and on slopes and only rarely on exposed ridges and summits.

3. Emergence of mosquitos occurs earlier on the plains and in the foothills than on the coast. Timing of emergence appears to be related to ambient air temperature and possibly soil temperature.

4. There is some evidence indicating a relationship between landcover and mosquito activity. Landcovers (Walker et al. 1983) associated with high insect activity were moist tussock sedge (CVb), wet sedge tundra (BIIIa), wet graminoid tundra complex (CIVa), and moist shrubland (closed riparian shrubland)(DVIIIc). Landcover classifications providing relief from insects include barren scree (EXd), partially vegetated scree (EXIj), partially vegetated floodplains (EXa), and wet barren floodplain (EIXh). Landcovers associated with large arctic drainages, e.g. floodplains and Dryas river terraces, generally provide important corridors of insect relief on the plains. Mosquito activity on the coast is primarily

affected by weather variables; landcover appears to be at least secondary in its effects.

5. Mosquito activity is closely correlated with conditions associated with topographic relief. Protected valleys ranked high as insect habitat, slopes were areas of intermediate insect activity, while exposed ridges supported very little mosquito activity. Landcover suitable to concentrations of mosquitos appeared only in valleys and occasionally on slopes (moist graminoid tussock, Alluvial deciduous scrub, and mesic erect shrub). Landcovers considered indicative of insect relief habitat are common on ridges and alpine areas (scarcely vegetated scree, and dwarf shrub). Weather conditions favoring mosquito activity more commonly occur in valleys than on ridges.

6. Weather conditions appear to exert a good deal of influence over mosquito activity, to the extent that weather related effects confound nearly all other suspected relationships between mosquito activity and "constant" factors. The ability to separate out the complex of weather interactions occuring under field conditions will probably prove paramount to quantifying the relationship between mosquitos and landcovers, distances from rivers and coasts, and terrain. There is little correlation between individual weather variables and mosquito activity, however, interaction between weather variables is evidently important. Low windspeeds and high ambient air and soil temperatures are conducive to activity while the reverse inhibits mosquito activity. It is probable that in years when weather conditions allow high levels of mosquito activity the differences in activity between landcovers are accentuated. Weather variables confound the association between landcover and activity.

7. Non-attractant sticky traps provide useful information concerning the time of appearance and the absence of mosquitos, however, non-attractant traps give little real information concerning relative numbers of mosquitos in different environments. Sticky traps seem to catch the vagrant mosquitos that are wind carried within an area as well as from one area to another. They have no ability to actively draw mosquitos from their immediate surroundings. An attractant estimator, such as a human using a sweepnet, draws mosquitos from within an area that is limited by the insect's ability to sense attractants. In this way the attractant method is actively sampling the available population at a given spatial and temporal point. The non attractant method is less selective in that it is sampling the odd mosquito flying or being blown in the direction of the trap at any point in time.

   Human harassment provides a relatively reliable point ordinal estimate of mosquito activity, however, some bias is probably introduced in the higher levels of the estimate. There is little question about levels 0 (mosquitos not present, not biting) and 1 (mosquitos present but not biting). However, technician bias is introduced when distinguishing between levels 2 (present, and biting) and 3 (present and intolerable) as individual tolerence to actively feeding mosquitos varies.

   The observed caribou harassment technique contains similar advantages and disadvantages as the human harassment method if one assumes that caribou will display behaviors that vary with the degree of individual tolerance.

Agreement was highest when the sweepnet method was contrasted with other techniques. The lowest levels of agreeement occurred when predicted caribou harassment was compared to other methods.

8. White's 1975 model for the predicted harassment of caribou could be improved by incorporating quantified information on other factors that interact to affect the level of mosquito activity. While many of the individual factors investigated in this report revealed only minor relationships to the relative activity of mosquito populations, it is evident that mosquito activity is the result of a complex interaction of these individual factors. The ability to quantify these interactions is necessary to improve the ability to predict mosquito activity and thus the harassment of caribou.

Acknowledgements

L. Pank originated and executed the project; supervised data collection and added valuable insight regarding the analysis. D. Douglas reviewed and edited the paper and contributed his ideas toward the analysis of the data. S. Amstrup provided statistical assistance and advice.

Literature Cited

Dau, J. 1986. Distribution and behavior of barren ground caribou in relation to weather and parasitic insects. Master of Science Thesis, University of Alaska, Fairbanks.

Pank, L. F., E. Freidman, C. Curby and A. Jones. 1984. Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the ANWR. Pages 570-586. In G. W. Garner and P. E. Reynolds (eds.). 1983 Update Report, baseline study of fish and wildlife and their habitats. U.S. Fish and Wildlife Service, Anchorage, Alaska.

Pank, L. F., C. Curby, B. Nankivell, C. Simon and R. Wright. 1985. Spatial and temporal distribution of biting and parasitic insects on the coastal plain and adjoining foothills of the ANWR. Pages 695-724. In G. W. Garner and P. E. Reynolds (eds.). 1984 Update Report, baseline study of fish, wildlife and their habitats. U.S. Fish and Wildlife Service, Anchorage, Alaska.

Taylor, L. R. 1962. The efficiency of cylindrical sticky insect traps and suspended nets. Ann. appl. Biol. 50: 681-685.

Thompson, L. R. 1973. Behavior and activity of caribou at Prudhoe Bay. In Aspects of feed intake and heat production of Rangifer in the arctic tundra (by R. G. White and J. R. Luick). Progress Rept. U.S. Tundra Biome Program.

Walker, D. A., P. J. Webber and K. R. Everett. 1983. 1:63,360 scale geobotanical mapping studies in the Arctic National Wildlife Refuge, Alaska. Institute of Arctic and Alpine Research. Univ. of Colorado, Boulder. Final Report to U.S. Army, CRRE. 125pp.

White, R. G., B. R. Thompson, T. Skoogland, S. J. Person, D. F. Holleman and J. R. Luick. 1975. Ecology of caribou at Prudhoe Bay, Alaska. In Ecological Investigations of the Tundra Biome in the Prudhoe Bay region, Alaska. pp. 150-201. Univ. of Alaska-Fairbanks. Biological Papers of the Univ. of AK. Special Rept. No. 2.

Wright, J. M. 1980. Spring and summer vegetation preferences of semi-domestic reindeer on the Northwest Seward Peninsula. In E. Reimers, E. Gaare and S. Skenneberg (eds.) Proc. 2nd Int. Reindeer/Caribou Symp., Roros, Norway, 1979. Part A: 167-173. Direktoratet for Vilt og Ferskvannsfisk, Trondheim.

Appendices

AFWRC Progress Report Sub-work Unit 5

Appendix A. Weather and insect data collection schedule for individual trap sites in the Arctic National Wildlife Refuge, Alaska, 1985.

Location	Trapsite Number	June 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	July 1	2	3	4	5	6	7	8	9	10	11
Coast	101															W	W	W	24	W	W	W	W	W	H	24	*-
	102															W	W	W	.	W	W	W	WP	W	.	.	WP
	103															W	*-	W	.	W	W	W	W	W	.	.	WP
	104															W	W	W	.	W	W	W	WP	W	.	.	WP
	105															W	W	W	.	W	W	W	WP	W	.	.	WP
	106															W	*	W	.	W	W	W	W	W	.	.	WP
	107															W	*	W	.	W	W	W	WP	W	.	.	WP
	108															W	*	W	.	W	W	W	W	W	.	.	WP
	109															-	-	W	.	*	W	W	W	W	.	.	WP
	110															-	-	W	.	*	W	W	*	W	.	.	WP
	111															-	-	W	.	*	W	W	*	W	.	.	WP
	112															-	-	W	.	*	W	W	*	W	.	.	WP
Plain	201					W	W	W	W	24	W	WP	W	W	W	W	W	24	W	WP	W	W	W	W	H	24	WP
	202					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	.	WP
	203					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	WP	*
	204					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	.	WP
	205					W	W	W	W	.	W	WP	W	W	W	W	W	W	W	WP	W	W	W	W	.	.	WP
	206					W	W	W	W	.	W	WP	W	W	W	W	W	W	W	WP	W	W	W	W	.	.	WP
	207					W	W	W	W	.	W	WP	W	W	W	W	W	W	W	WP	W	W	W	W	.	WP	*
	208					W	W	W	W	.	W	WP	W	W	W	W	W	W	W	WP	W	W	W	W	.	.	WP
	209					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	.	WP
	210					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	.	WP
	211					W	W	W	W	.	W	WP	W	W	W	W	W	.	W	WP	W	W	W	W	.	.	WP
	212					W	W	W	W	.	W	WP	W	W	W	WP	W	.	W	WP	W	W	W	W	.	.	WP
Foothills	311	W-	W-	W-	W-	W-	W-	W-	-	W-	24	W-	W-	W-	W	W	W	W	24	W	W	W	W	W	H	24	W
	312	W-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	313	W-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	321	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	322	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	323	W-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W*	W	W	W	W	.	.	W
	331	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	332	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	333	W-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W*	WP	W	W	W	.	.	W
	341	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	WP	W	W	W	.	.	W
	342	*-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W
	343	W-	W-	W-	W-	W-	W-	W-	-	W-	.	W-	W-	W-	W	W	W	W	.	W	W	W	W	W	.	.	W

W = Weather and Sweep Data Collected, Sticky Traps Checked.
P = Sticky Paper Changed.
* = Sweep Data Not Collected.
- = Sticky Traps Not Set.
H = Landcover/Insect/Weather Survey.

Appendix B. Number of mosquitoes caught per trap day on sticky traps in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as mean, standard deviation, and (number of trap days).

Date (Julian day)	Coast		Plains		Foothills		Row Totals	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)								
17 June (168)								
18 June (169)								
19 June (170)								
20 June (171)			0.0,0.0(6)	0.0,0.0(6)			0.0,0.0(6)	0.0,0.0(6)
21 June (172)			0.0,0.0(6)	0.0,0.0(6)			0.0,0.0(6)	0.0,0.0(6)
22 June (173)			0.0,0.0(6)	0.0,0.0(6)			0.0,0.0(6)	0.0,0.0(6)
23 June (174)			0.0,0.0(6)	0.0,0.0(6)			0.0,0.0(6)	0.0,0.0(6)
24 June (175)			0.3,0.5(4)	0.0,0.0(1)			0.3,0.5(4)	0.0,0.0(1)
25 June (176)			0.1,0.3(6)	0.3,0.3(6)			0.1,0.3(6)	0.3,0.3(6)
26 June (177)			2.5,4.4(6)	2.3,2.7(6)			2.5,4.4(6)	2.3,2.7(6)
27 June (178)			2.8,2.3(6)	10.1,13.3(6)			2.8,2.3(6)	10.1,13.3(6)
28 June (179)			1.5,1.8(6)	5.0,5.7(6)			1.5,1.8(6)	5.0,5.7(6)
29 June (180)			1.1,0.9(6)	3.0,2.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.5,0.8(12)	1.5,2.0(12)
30 June (181)	0.0,0.0(3)	0.0,0.0(5)	2.7,2.5(6)	5.7,3.0(6)	1.3,2.7(6)	0.6,0.6(6)	1.6,2.4(15)	2.2,3.2(17)
1 July (182)	0.7,0.9(2)	9.0,4.2(2)	3.3,3.4(6)	5.1,3.7(6)	1.8,1.8(6)	0.7,0.6(6)	2.2,2.6(14)	3.7,4.0(14)
2 July (183)	1.2,1.7(7)	1.7,1.7(6)	1.5,2.1(6)	3.8,3.1(2)	1.7,1.7(6)	1.0,0.9(6)	1.4,1.6(15)	1.7,1.8(14)
3 July (184)			8.0,11.2(6)	14.1,27.9(6)			8.0,11.2(6)	14.1,27.9(6)
4 July (185)	0.0,0.0(4)	2.1,1.9(5)	4.2,5.5(6)	2.9,1.8(6)	0.5,0.6(6)	0.4,0.6(6)	1.8,3.7(16)	1.8,1.8(17)
5 July (186)	0.4,0.4(7)	0.0,0.0(6)	0.4,0.6(6)	0.2,0.5(6)	0.9,1.1(6)	0.8,1.2(6)	0.5,0.7(19)	0.3,0.8(18)
6 July (187)	0.7,0.6(7)	1.7,3.2(6)	0.2,0.4(6)	0.2,0.4(6)	1.4,1.5(6)	1.9,3.0(6)	0.7,1.0(19)	1.2,2.5(18)
7 July (188)	0.0,0.0(5)	0.0,0.0(5)	3.2,2.9(6)	0.5,0.6(6)	1.5,1.9(6)	1.8,2.0(6)	1.8,2.4(18)	0.5,0.6(16)
8 July (189)	0.0,0.0(7)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	1.4,1.8(6)	2.7,3.4(6)	0.5,1.2(19)	0.9,2.3(18)
9 July (190)								
10 July (191)	0.0,0.0(1)			1.0,0.0(2)			0.0,0.0(1)	1.0,0.0(2)
11 July (192)	0.0,0.0(6)	0.2,0.3(6)	0.2,0.3(6)	0.3,0.3(4)			0.1,0.2(12)	0.2,0.3(10)
Column Totals	0.3,0.8(49)	1.1,2.4(47)	1.6,3.7(114)	2.8,7.8(111)	1.2,1.6(54)	1.1,1.8(54)	1.3,1.8(218)	2.2,3.6(211)
Grand Totals	1.0,1.8(96)		2.2,6.1(225)		1.3,1.8(108)		1.7,2.8(429)	

Appendix C. Number of mosquitos per 100 sweeps caught during site visits in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as mean, standard deviation, and number of trapsite visits.

Date (Julian day)	Coast		Plains		Foothills		Row Totals	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					0.0,0.0(5)	0.0,0.0(1)	0.0,0.0(5)	0.0,0.0(6)
17 June (168)					0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)
18 June (169)					0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)
19 June (170)					0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)
20 June (171)			0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(7)	0.0,0.0(12)	0.0,0.0(13)
21 June (172)			0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(12)	0.0,0.0(12)
22 June (173)			0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(12)	0.0,0.0(12)
23 June (174)			0.0,0.0(6)	0.0,0.0(6)			0.0,0.0(6)	0.0,0.0(6)
24 June (175)			0.0,0.0(4)	0.0,0.0(1)	0.3,0.5(6)	0.5,1.2(6)	0.2,0.4(10)	0.4,1.1(7)
25 June (176)			0.0,0.0(6)	0.3,0.8(6)			0.0,0.0(6)	0.3,0.8(6)
26 June (177)			0.5,0.8(6)	0.3,0.8(6)	0.0,0.0(6)	0.0,0.0(6)	0.3,0.6(12)	0.2,0.6(12)
27 June (178)			0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(12)	0.0,0.0(12)
28 June (179)			0.0,0.0(6)	0.3,0.8(6)	0.0,0.0(6)	0.3,0.8(6)	0.0,0.0(12)	0.3,0.8(12)
29 June (180)			0.7,1.2(6)	0.5,0.8(6)	0.3,0.8(6)	0.3,0.5(6)	0.5,1.0(12)	0.4,0.7(12)
30 June (181)	0.3,0.6(3)	5.4,1.8(5)	2.0,1.7(6)	3.5,4.5(6)	0.7,1.6(6)	0.8,1.0(6)	1.2,1.6(15)	3.1,3.3(17)
1 July (182)	0.0,0.0(2)	0.0,0.0(2)	0.0,0.0(6)	0.5,1.2(6)	0.2,0.4(6)	1.2,1.2(6)	0.1,0.3(14)	0.7,1.1(14)
2 July (183)	0.3,0.5(7)	16.8,15.7(6)	0.0,0.0(2)	0.0,0.0(2)	0.0,0.0(6)	0.0,0.0(6)	0.1,0.4(15)	7.2,12.9(14)
3 July (184)			14.8,18.8(6)	50.8,36.8(6)			14.8,18.8(6)	50.8,36.8(6)
4 July (185)	0.0,0.0(4)	0.0,0.0(5)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	1.3,2.8(6)	0.0,0.0(16)	0.5,1.7(17)
5 July (186)	0.0,0.0(7)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(19)	0.0,0.0(18)
6 July (187)	0.0,0.0(7)	0.2,0.4(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	1.7,2.7(6)	0.0,0.0(19)	0.6,1.6(18)
7 July (188)	0.0,0.0(5)	0.0,0.0(5)	0.0,0.0(6)	0.0,0.0(6)	1.7,2.1(6)	5.5,4.4(6)	0.6,1.4(17)	1.9,3.6(17)
8 July (189)	0.0,0.0(7)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	0.0,0.0(6)	2.3,5.2(6)	0.0,0.0(19)	0.8,3.1(18)
9 July (190)								
10 July (191)	0.0,0.0(1)			37.0,22.6(2)			0.0,0.0(1)	37.0,22.6(2)
11 July (192)	0.0,0.0(6)	0.0,0.0(6)	3.2,6.3(6)	16.3,18.0(4)			1.6,4.6(12)	6.5,13.3(10)
Column Totals	0.1,0.2(49)	2.7,7.7(47)	1.1,5.4(114)	4.3,15.3(111)	0.2,0.7(119)	0.7,2.1(116)	0.8,2.9(282)	4.4,12.1(279)
Grand Totals	1.3,5.5(96)		3.2,11.5(225)		0.4,1.6(235)		2.6,9.0(561)	

Appendix D. Mosquito harassment of humans recorded during trapsite visits as level 0 to 3 in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as median, mean, standard deviation and sample size.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					0,0.0,0.0,5	0,0.0,0.0,1
17 June (168)					0,0.0,0.0,6	0,0.0,0.0,6
18 June (169)					0,0.0,0.0,6	0,0.0,0.0,6
19 June (170)					0,0.0,0.0,6	0,0.0,0.0,6
20 June (171)			0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,7
21 June (172)			0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6
22 June (173)			0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6
23 June (174)			0,0.0,0.0,6	0,0.0,0.0,6		
24 June (175)			.5,0.5,0.6,4	0,0.0,0.0,1	0,0.3,0.5,6	0,0.3,0.5,6
25 June (176)			.5,0.5,0.6,6	0,0.2,0.4,6		
26 June (177)			0,0.3,0.5,6	1,0.8,0.4,6	0,0.0,0.0,6	0,0.2,0.4,6
27 June (178)			.5,0.5,0.6,6	0,0.3,0.5,6	0,0.0,0.0,6	0,0.0,0.0,6
28 June (179)			.5,0.5,0.6,6	1,1.0,0.0,6	0,0.0,0.0,6	0,0.2,0.4,6
29 June (180)			1,0.7,0.5,6	.5,0.5,0.6,6	1,0.8,0.4,6	0,0.3,0.5,6
30 June (181)	1,0.7,0.6,3	1,0.8,0.5,5	1,1.0,0.0,6	1,1.2,0.4,6	0,0.3,0.5,6	1,0.8,0.4,6
1 July (182)	0,0.0,0.0,2	0,0.0,0.0,2	0,0.3,0.5,6	.5,0.5,0.6,6	0,0.3,0.5,6	1,0.8,0.4,6
2 July (183)	0,0.3,0.8,7	2,1.3,1.0,6	0,0.0,0.0,2	.5,0.5,0.7,2	0,0.2,0.4,6	0,0.2,0.4,6
3 July (184)			1,1.2,0.4,6	2,2.0,0.0,6		
4 July (185)	0,0.0,0.0,4	0,0.0,0.0,5	0,0.3,0.5,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.7,1.0,6
5 July (186)	0,0.0,0.0,7	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.2,0.4,6
6 July (187)	0,0.1,0.4,7	.5,0.5,0.6,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	1,0.8,0.8,6
7 July (188)	0,0.0,0.0,5	0,0.0,0.0,5	0,0.0,0.0,6	0,0.0,0.0,6	0,0.3,0.5,6	2,1.8,0.4,6
8 July (189)	0,0.0,0.0,7	0,0.0,0.0,6	0,0.0,0.0,6	0,0.0,0.0,6	0,0.2,0.4,6	1,1.3,0.5,6
9 July (190)						
10 July (191)	0,0.0,0.0,1			2,2.0,0.0,2		
11 July (192)	0,0.2,0.4,6	0,0.3,0.5,6	1,1.0,0.0,6	1,1.3,0.5,4		
Column Totals	0,0.1,0.4,49	0,0.4,0.6,47	0,0.3,0.5,114	0,0.5,0.7,111	0,0.1,0.3,119	0,0.4,0.6,116

Harassment levels: 0 = mosquitos not present; 1 = mosquitos present not biting;
1 = mosquitos present not biting; 3 = mosquitos so numerous they are easily inhaled.

Appendix E. Ambient air temperatures (degrees Celcius) at insect trap sites in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as mean, standard deviation and sample size.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					7.0,1.9,(5)	9.4,0.0,(1)
17 June (168)					6.5,1.4,(6)	8.5,1.5,(6)
18 June (169)					10.6,1.1,(6)	10.9,1.4,(6)
19 June (170)					9.5,1.1,(6)	12.1,1.3,(6)
20 June (171)			14.1,0.6,(6)	14.7,1.2,(6)	6.9,1.2,(6)	8.5,1.3,(7)
21 June (172)			10.7,2.1,(6)	12.5,4.3,(6)	8.6,1.4,(6)	9.8,1.4,(6)
22 June (173)			12.0,1.3,(6)	12.9,0.9,(6)	11.7,2.4,(6)	12.4,2.5,(6)
23 June (174)			13.1,1.4,(6)	13.6,0.6,(6)		
24 June (175)			19.7,1.3,(4)	20.6,0.0,(1)	15.2,1.2,(6)	17.1,1.0,(6)
25 June (176)			15.0,0.4,(6)	14.5,0.4,(6)		
26 June (177)			10.5,2.4,(6)	12.1,0.9,(6)	11.8,1.7,(6)	11.9,1.9,(6)
27 June (178)			7.1,1.3,(6)	6.6,0.4,(6)	4.0,1.1,(6)	5.2,2.2,(6)
28 June (179)			18.8,2.8,(6)	18.8,1.3,(6)	12.5,0.9,(6)	14.2,1.7,(6)
29 June (180)			9.9,1.4,(6)	7.7,0.7,(6)	9.8,1.6,(6)	9.6,2.1,(6)
30 June (181)	8.1,1.1,(3)	12.8,3.5,(5)	14.6,1.1,(6)	17.8,0.7,(6)	11.6,0.6,(6)	14.1,2.1,(6)
1 July (182)	8.1,0.4,(2)	8.9,0.8,(2)	9.5,1.9,(6)	9.0,0.9,(6)	7.9,1.9,(6)	9.3,1.9,(6)
2 July (183)	5.7,0.5,(7)	9.9,2.9,(6)	11.4,1.3,(2)	12.5,0.4,(2)	6.3,1.1,(6)	7.5,0.9,(6)
3 July (184)			17.6,1.1,(6)	16.1,1.3,(6)		
4 July (185)	5.3,0.6,(4)	5.5,0.3,(5)	12.6,3.1,(6)	11.6,1.2,(6)	7.9,1.3,(6)	7.8,2.0,(6)
5 July (186)	5.4,1.3,(7)	6.1,1.1,(6)	5.7,1.8,(6)	4.9,0.8,(6)	6.0,1.5,(6)	6.7,1.7,(6)
6 July (187)	6.3,0.6,(7)	6.1,0.5,(6)	10.6,0.5,(6)	9.8,0.3,(6)	10.0,1.4,(6)	10.6,2.5,(6)
7 July (188)	4.1,0.7,(5)	4.5,1.2,(5)	4.3,3.3,(6)	2.7,1.7,(6)	11.0,1.7,(6)	11.1,2.1,(6)
8 July (189)	4.8,0.7,(7)	5.6,0.5,(6)	10.7,0.4,(6)	9.7,0.3,(6)	14.5,2.2,(6)	16.5,1.9,(6)
9 July (190)						
10 July (191)	1.1,0.0,(1)			13.6,2.0,(2)		
11 July (192)	4.8,1.4,(6)	6.0,1.1,(6)	9.6,1.3,(6)	10.6,0.8,(4)		
Column Totals	5.5,1.5(49)	7.1,3.0(47)	11.7,4.2(114)	11.6,4.4(111)	9.5,3.2(119)	10.7,3.5(116)
Grand Totals	6.3,2.3(96)		11.9,4.3(225)		10.1,3.4(235)	

Appendix F. Soil temperatures (degrees celcius) at insect trap sites in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as mean, standard deviation and sample size.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					10.2,0.9,(5)	9.4,0.0,(1)
17 June (168)					10.0,2.9,(6)	7.2,2.1,(6)
18 June (169)					10.6,0.8,(6)	9.7,2.1,(6)
19 June (170)					10.2,0.7,(6)	10.6,3.1,(6)
20 June (171)			15.1,4.3,(6)	12.0,3.9,(6)	8.0,1.5,(6)	7.6,2.1,(7)
21 June (172)			13.6,5.0,(6)	9.4,2.0,(6)	8.2,1.7,(6)	7.4,1.9,(6)
22 June (173)			10.9,2.9,(6)	8.8,2.4,(6)	13.4,1.6,(6)	10.1,4.6,(6)
23 June (174)			12.5,3.3,(6)	8.5,2.0,(6)		
24 June (175)			16.0,5.7,(4)	15.0,0.0,(1)	12.8,2.0,(6)	10.3,2.0,(6)
25 June (176)			16.7,6.2,(6)	6.5,2.0,(6)		
26 June (177)			11.5,4.6,(6)	8.2,2.3,(6)	11.2,1.2,(6)	9.6,2.3,(6)
27 June (178)			7.7,2.4,(6)	5.0,2.2,(6)	4.4,0.7,(6)	4.6,1.2,(6)
28 June (179)			14.1,4.7,(6)	7.0,1.8,(6)	8.8,1.0,(6)	8.6,1.5,(6)
29 June (180)			10.5,2.9,(6)	6.3,2.5,(6)	9.8,1.4,(6)	8.8,1.8,(6)
30 June (181)	9.8,0.9,(3)	1.6,1.8,(5)	12.3,2.2,(6)	8.3,2.4,(6)	9.9,1.6,(6)	9.6,4.7,(6)
1 July (182)	11.2,0.8,(2)	2.8,0.8,(2)	10.5,3.1,(6)	6.3,2.0,(2)	10.1,0.5,(6)	9.3,2.1,(6)
2 July (183)	5.6,2.7,(7)	3.0,1.6,(6)	10.0,3.1,(2)	6.4,2.0,(6)	7.6,1.4,(6)	7.2,1.1,(6)
3 July (184)			17.7,3.5,(6)	7.4,2.6,(6)		
4 July (185)	5.9,1.7,(4)	2.1,1.2,(5)	10.8,2.7,(6)	6.9,2.8,(6)	7.4,0.9,(6)	6.4,1.6,(6)
5 July (186)	4.6,2.0,(7)	2.0,1.7,(6)	5.8,2.3,(6)	2.9,0.8,(6)	7.3,1.1,(6)	6.8,1.7,(6)
6 July (187)	4.5,1.5,(7)	2.7,1.0,(6)	8.8,3.1,(6)	5.4,1.7,(6)	8.4,1.2,(6)	6.6,2.2,(6)
7 July (188)	6.4,2.2,(5)	2.4,1.8,(5)	5.9,2.9,(6)	1.9,1.4,(6)	9.8,0.5,(6)	9.3,1.4,(6)
8 July (189)	4.0,1.2,(7)	2.7,1.6,(6)	11.1,2.6,(6)	8.5,2.2,(6)	13.5,3.2,(6)	10.6,2.7,(6)
9 July (190)						
10 July (191)	4.4,0.0,(1)			8.4,0.8,(2)		
11 July (192)	5.4,1.7,(6)	3.5,1.9,(6)	10.6,2.6,(6)	8.5,1.8,(4)		
Column Totals	6.2,2.5,(49)	2.5,1.5,(47)	11.6,4.7,(114)	7.5,3.1,(111)	9.6,2.6,(119)	8.4,2.7,(116)
Grand Totals	4.4,2.6,(96)		9.6,4.6,(225)		9.0,2.7,(235)	

Appendix G. Relative humidity (percent) at insect trap sites in the Arctic National Wildlife Refuge, Alaska in 1985, expressed as mean, standard deviation and sample size.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					52.2,7.3,(5)	45.0,0.0,(1)
17 June (168)					61.2,8.6,(6)	57.5,8.1,(6)
18 June (169)					56.2,5.8,(6)	57.5,4.3,(6)
19 June (170)					57.8,8.0,(6)	53.0,7.9,(6)
20 June (171)			65.8,4.8,(6)	61.3,13.8,(6)	79.0,14.0,(6)	82.9,10.5,(7)
21 June (172)			72.0,3.4,(6)	67.8,5.0,(6)	77.8,4.3,(6)	72.8,8.4,(6)
22 June (173)			59.3,4.9,(6)	59.3,4.9,(6)	50.2,4.2,(6)	54.0,8.4,(6)
23 June (174)			64.3,5.0,(6)	66.3,2.2,(6)		
24 June (175)			48.0,3.3,(4)	55.0,0.0,(1)	30.5,1.9,(6)	34.8,4.9,(6)
25 June (176)			53.0,3.2,(6)	59.0,2.0,(6)		
26 June (177)			68.0,8.9,(6)	69.7,4.0,(6)	43.2,8.6,(6)	49.5,7.2,(6)
27 June (178)			88.7,7.8,(6)	91.8,6.9,(6)	84.0,9.4,(6)	78.2,13.6,(6)
28 June (179)			52.5,10.4,(6)	56.7,5.0,(6)	34.2,4.1,(6)	40.5,9.3,(6)
29 June (180)			92.3,6.4,(6)	97.7,3.6,(6)	77.8,9.0,(6)	81.7,12.3,(6)
30 June (181)	95.7,8.4,(3)	92.0,8.8,(5)	80.5,6.1,(6)	70.7,3.1,(6)	72.5,6.8,(6)	67.5,7.7,(6)
1 July (182)	96.5,5.0,(2)	100.0,0.0,(2)	93.3,5.8,(6)	90.7,3.6,(6)	84.8,9.4,(6)	78.7,8.2,(6)
2 July (183)	100.6,0.5,(7)	97.0,5.5,(6)	97.0,4.2,(2)	94.0,8.5,(2)	90.7,2.8,(6)	86.2,6.9,(6)
3 July (184)			60.8,8.1,(6)	66.5,9.8,(6)		
4 July (185)	98.5,4.4,(4)	96.8,7.7,(5)	73.8,12.6,(6)	80.5,9.8,(6)	61.5,15.1,(6)	74.3,17.0,(6)
5 July (186)	95.4,6.5,(7)	88.8,6.2,(6)	82.7,7.2,(6)	83.7,4.6,(6)	59.0,6.1,(6)	64.0,13.7,(6)
6 July (187)	92.9,5.7,(7)	97.8,3.8,(6)	45.0,3.1,(6)	44.0,2.5,(6)	32.0,2.5,(6)	39.0,3.0,(6)
7 July (188)	100.6,0.6,(5)	95.6,6.4,(5)	74.5,16.5,(6)	81.8,11.0,(6)	41.5,9.7,(6)	43.2,9.9,(6)
8 July (189)	98.3,4.0,(7)	91.2,7.4,(6)	69.3,3.6,(6)	74.0,0.0,(6)	41.5,6.5,(6)	40.0,7.0,(6)
9 July (190)						
10 July (191)	101.0,0.0,(1)			54.0,15.6,(2)		
11 July (192)	100.8,0.4,(6)	101.0,0.0,(6)	64.5,3.0,(6)	65.0,2.8,(4)		
Column Totals	97.6,5.2,(49)	95.1,6.8,(47)	69.7,15.7,(114)	71.4,15.0,(111)	59.4,19.9,(119)	60.7,18.7,(116)
Grand Totals	96.9,6.0,(96)		70.6,15.4,(225)		59.7,19.3,(235)	

Appendix H. Windspeeds (km per hour) and prevailing wind directions (degrees) at insect sites in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as mean, standard deviation, sample size and modal direction.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					3.7,2.2,(5)NW	0.0,0.0,(1)NW
17 June (168)					8.1,4.7,(6)NE	7.8,6.6,(6)NE
18 June (169)					6.2,4.1,(6)NE	5.6,3.0,(6)NE
19 June (170)					6.7,5.3,(6)E	4.1,2.8,(6)E
20 June (171)			6.7,1.2,(6)ENE	6.4,1.0,(6)NE	5.0,4.3,(6)E	4.0,3.2,(7)E
21 June (172)			5.9,3.4,(6)NE	4.0,3.8,(6)NW	11.8,11.7,(6)NE	6.4,5.3,(6)NE
22 June (173)			12.4,0.8,(6)E	11.3,1.0,(6)E	17.7,11.3,(6)NE	7.9,4.6,(6)NE
23 June (174)			8.8,2.9,(6)ENE	9.7,1.5,(6)ENE		
24 June (175)			5.2,4.2,(4)N	9.7,0.0,(1)	9.3,3.4,(6)S	4.9,3.0,(6)S
25 June (176)			6.7,1.9,(6)NW	10.8,1.4,(6)WNW		
26 June (177)			5.9,2.8,(6)	8.1,2.1,(6)ENE	25.5,11.0,(6)NE	4.8,5.3,(6)NE
27 June (178)			6.4,4.0,(6)S	3.2,1.4,(6)WSW	27.4,8.7,(6)W	12.8,10.0,(6)NW
28 June (179)			9.7,1.5,(6)E	9.4,0.7,(6)E	25.5,16.6,(6)S	0.5,11.2,(6)S
29 June (180)			6.1,2.6,(6)N	5.6,1.7,(6)N	6.1,3.3,(6)S	3.7,3.3,(6)NW
30 June (181)	7.5,3.8,(3)WNW	6.8,3.5,(5)	3.7,3.3,(6)ESE	10.7,3.5,(6)NW	10.1,4.0,(6)W	4.8,3.8,(6)N
1 July (182)	13.3,0.5,(2)	10.5,1.1,(2)SE	9.4,0.7,(6)E	7.7,0.7,(6)ENE	0.0,0,0,(6)NE	2.8,3.1,(6)
2 July (183)	10.6,1.7,(7)W	5.8,3.8,(6)W	11.3,2.3,(2)	9.7,2.3,(2)	15.6,11.5,(6)W	9.4,8.9,(6)W
3 July (184)			4.3,2.8,(6)ENE	5.1,2.4,(6)NNW		
4 July (185)	14.0,3.0,(4)NW	14.7,1.8,(5)NW	11.5,7.6,(6)WNW	15.6,3.3,(6)WNW	47.2,26,8,(6)SW	11.8,13.1,(6)SW
5 July (186)	31.7,3.5,(7)WNW	27.1,4.1,(6)WNW	14.2,1.2,(6)WNW	11.8,1.7,(6)W	34.1,11.9,(6)W	16.0,10.1,(6)W
6 July (187)	18.5,4.4,(7)NW	10.3,1.4,(6)NW	16.1,3.4,(6)NW	15.6,1.7,(6)WNW	27.9,5.7,(6)W	7.6,4.0,(6)SW
7 July (188)	22.2,2.9,(5)E	18.8,1.3,(5)E	12.1,2.7,(6)ENE	8.6,0.9,(6)E	7.3,4.4,(6)NE	1.1,2.6,(6)E
8 July (189)	20.2,3.0,(7)E	18.7,1.1,(8)ESE	14.0,0.8,(6)ENE	13.2,1.6,(6)ENE	11.6,3.5,(6)E	7.1,4.7,(6)N
9 July (190)						
10 July (191)	11.3,0.0,(1)			9.7,0.0,(2)ENE		
11 July (192)	9.8,1.4,(6)NE	9.3,1.9,(6)ENE	10.5,0.9,(6)ENE	10.1,0.8,(4)NE		
Column Totals	17.4,8.0,(49)	14.0,7.2,(49)	9.0,4.5,(114)	9.3,3.9,(111)	15.4,14.9,(119)	7.0,7.0,(115)
Grand Totals	14.6,7.7,(96)		9.2,3.9,(225)		10.8,12.4,(235)	

Appendix I. Cloud cover coded as levels 0 to 5 at insect trap sites in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as median, mean, standard deviation and sample size.

Date (Julian day)	Coast		Plains		Foothills	
	Insect Relief	Insect	Insect Relief	Insect	Insect Relief	Insect
16 June (167)					1,1.0,0.0,(5)	0,1.0,0.0,(1)
17 June (168)					0.5,0.5,0.6,(6)	1,0.8,0.4,(6)
18 June (169)					2,1.7,0.5,(6)	1,1.5,0.8,(6)
19 June (170)					2.5,2.5,0.6,(6)	2.5,2.5,0.6,(6)
20 June (171)			2,1.6,0.5,(6)	2,1.8,0.4,(6)	4,4.0,0.0,(6)	0,4.0,0.0,(7)
21 June (172)			1,1.0,0.0,(6)	1.5,1.5,0.5,(6)	3,2.8,1.2,(6)	3,2.8,1.2,(6)
22 June (173)			1,1.0,0.0,(6)	1,1.0,0.0,(6)	1,1.3,0.5,(6)	1,1.3,0.5,(6)
23 June (174)			1,1.0,0.0,(6)	1,1.0,0.0,(6)		
24 June (175)			1,1.0,0.0,(4)	*,1.0,0.0,(1)	2,2.0,0.0,(6)	2,2.0,0.6,(6)
25 June (176)			1,1.0,0.0,(6)	1,1.0,0.0,(6)	2,2.7,1.0,(6)	
26 June (177)			3,2.7,1.4,(6)	1,1.6,0.4,(6)	4,3.7,0.5,(6)	2.5,2.7,1.2,(6)
27 June (178)			4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,3.7,0.5,(6)	3.5,3.5,0.6,(6)
28 June (179)			4,3.8,0.4,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,3.8,0.4,(6)
29 June (180)			4,3.5,1.2,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)
30 June (181)	3,3.3,0.6,(3)	4,4.0,0.0,(5)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,3.5,0.8,(6)
1 July (182)	4,4.0,0.0,(2)	4,4.0,0.0,(2)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)
2 July (183)	4,4.0,0.0,(7)	4,4.0,0.0,(6)	4,4.0,0.0,(2)	4,4.0,0.0,(2)	4,4.0,0.0,(6)	4,4.0,0.0,(6)
3 July (184)			2,2.0,0.0,(6)	1.5,1.5,0.6,(6)		
4 July (185)	4,4.0,0.0,(4)	4,4.0,0.0,(5)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)
5 July (186)	4,2.7,1.6,(7)	4,3.5,1.2,(6)	4,3.7,0.5,(6)	4,4.0,0.0,(6)	1,0.7,0.5,(6)	1,1.0,0.0,(6)
6 July (187)	4,3.7,0.5,(7)	1.5,1.8,1.2,(6)	4,4.0,0.0,(6)	4,4.0,0.0,(6)	3,3.0,0.0,(6)	2.5,2.5,0.6,(6)
7 July (188)	0,0.0,0.0,(5)	0,0.0,0.0,(5)	0.5,1.5,2.0,(6)	3.5,3.3,0.8,(6)	0,0.0,0.0,(6)	0,0.0,0.0,(6)
8 July (189)	4,4.0,0.0,(7)	4,4.0,0.0,(6)	1,0.7,0.5,(6)	0,0.2,0.4,(6)	1,0.7,0.5,(6)	0.5,0.5,0.6,(6)
9 July (190)						
10 July (191)	* 4.0,0.0,(1)			0.5,0.5,0.7,(2)		
11 July (192)	4,3.6,0.8,(6)	2.5,2.8,1.0(6)	2,1.7,0.5,(6)	3,2.8,0.5,(4)		
Column Totals	4,3.3,1.4,(49)	4,3.1,1.5,(47)	2,2.5,1.5,(114)	3,2.6,1.5,(111)	3,2.5,1.5,(119)	3,2.5,1.4,(115)
Grand Totals	4,3.2,1.4,(96)		3,2.5,1.5,(225)		3,2.5,1.4,(235)	

Cloud code: 0 = No cloud cover. 1 = 1 to 25% cover. 2 = 26 to 50% cover. 3 = 51 to 75% cover. 4 = 76 to 100% cover.

Appendix J. Weather and mosquito catch data for eight 24 hour periods in the Arctic National Wildlife Refuge, Alaska, in 1985, expressed as median, where appropriate, mean and standard deviation. Two 24-hour periods for the coast, and three each for the plains and foothills.

Hour	Ambient Air Temp (°C)	Wind Speed (KMP)	Relative Humidity (%)	Soil Temp (°C)	Cloud Cover	Human Harassment	Sweep Net Count
Coast							
0000	5.0,3.1	9.3,2.9	90.5,13.4	6.1,2.4	2.0,2.0,1.4	0.0,0.0,0.0	0.0,0.0
0100	5.0,4.0	8.4,0.6	95.5,6.4	5.8,2.0	2.0,2.0,1.4	0.0,0.0,0.0	1.0,1.4
0200	3.3,5.5	8.4,0.6	100.0,0.0	5.0,1.6	2.5,2.5,0.7	0.5,0.5,0.7	0.0,0.0
0300	3.9,5.5	8.9,1.2	96.5,5.0	5.0,2.4	2.5,2.5,0.7	0.0,0.0,0.0	0.0,0.0
0400	5.6,4.7	6.8,1.7	100.0,0.0	4.5,2.3	2.0,2.0,0.0	0.5,0.5,0.7	1.5,2.1
0500	7.0,7.4	9.3,4.0	91.0,12.7	4.8,2.8	2.0,2.0,0.0	0.5,0.5,0.7	2.5,3.5
0600	7.5,7.5	13.0,0.0	80.5,14.9	5.0,3.1	2.0,2.0,2.8	0.5,0.5,0.7	0.0,0.0
0700	6.2,6.2	17.7,7.0	90.5,13.4	5.0,2.4	2.5,2.5,2.1	0.0,0.0,0.0	0.0,0.0
0800	7.2,5.5	14.5,2.3	101.0,0.0	4.7,2.0	2.0,2.0,1.4	0.0,0.0,0.0	0.0,0.0
0900	9.2,6.7	20.6,12.0	85.0,21.2	5.3,2.0	2.5,2.5,2.1	0.0,0.0,0.0	0.0,0.0
1000	9.2,6.7	16.1,4.5	88.0,17.0	5.8,2.0	2.0,2.0,1.4	0.0,0.0,0.0	0.0,0.0
1100	9.5,6.3	16.1,4.5	84.0,11.3	5.6,1.6	1.0,1.0,0.0	0.5,0.5,0.7	1.0,1.4
1200	8.6,3.5	12.9,3.4	97.0,5.7	5.8,2.0	1.0,1.0,0.0	1.0,1.0,1.4	1.0,1.4
1300	9.2,5.9	15.3,8.0	91.5,13.4	6.1,1.6	1.0,1.0,0.0	1.0,1.0,1.4	2.0,2.8
1400	10.9,6.7	12.8,9.1	91.5,12.0	7.0,2.8	2.0,2.0,1.4	1.0,1.0,1.4	1.0,1.4
1500	10.6,7.1	9.7,6.9	89.5,16.3	7.5,2.0	2.5,2.5,2.1	1.0,1.0,1.4	1.5,2.1
1600	11.7,8.6	8.5,6.3	83.0,24.0	8.1,2.8	2.5,2.5,2.1	1.0,1.0,1.4	0.0,0.0
1700	10.6,6.3	9.7,9.1	91.5,12.0	8.6,2.0	1.5,1.5,0.7	1.0,1.0,1.4	0.0,0.0
1800	12.0,8.3	9.7,9.1	77.0,22.6	9.2,2.8	2.0,2.0,1.4	1.0,1.0,1.4	1.5,2.1
1900	10.8,9.1	13.7,8.0	83.0,24.0	8.9,3.1	2.0,2.0,1.4	1.0,1.0,1.4	0.5,0.7
2000	10.3,9.1	9.7,9.1	81.5,26.2	7.5,2.0	2.0,2.0,1.4	1.0,1.0,1.4	0.0,0.0
2100	8.9,5.5	8.6,5.3	93.0,13.0	8.0,1.6	2.3,2.0,1.5	1.0,1.0,1.0	1.7,2.1
2200	5.8,3.5	8.5,7.4	100.0,0.0	7.5,2.0	2.5,2.5,2.1	0.5,0.5,0.7	2.5,3.5
2300	5.2,2.0	13.9,9.4	100.3,0.6	6.1,2.4	2.0,1.0,1.7	0.0,0.0,0.0	0.0,0.0
Plains							
0000	7.0,4.2	8.6,6.7	86.0,10.4	8.0,2.6	2.0,2.3,1.5	1.0,1.0,1.0	9.7,16.7
0100	6.8,4.5	4.8,3.2	88.0,7.0	8.0,2.6	3.0,2.3,1.2	0.0,0.3,0.6	3.3,5.8
0200	6.5,4.2	4.3,4.0	82.7,9.6	4.3,4.0	3.0,2.3,1.2	0.0,0.7,1.2	6.3,11.0
0300	6.3,4.5	4.8,4.3	86.0,10.4	6.5,2.3	2.0,2.0,1.0	0.0,0.3,0.6	3.7,6.4
0400	7.0,4.6	4.3,3.3	78.3,10.3	5.9,2.7	2.0,1.7,0.5	0.0,0.3,0.6	15.0,25.9
0500	8.2,4.7	4.3,4.7	78.3,10.3	5.9,2.7	1.0,1.3,0.6	0.0,0.3,0.6	8.3,14.4
0600	9.4,4.3	3.7,3.7	74.7,9.1	5.7,2.5	1.0,1.0,0.0	1.0,1.3,0.6	6.0,7.2
0700	9.9,5.8	6.9,1.9	69.0,14.5	5.7,2.5	1.0,1.0,1.0	1.0,1.0,0.0	1.0,1.0
0800	10.2,6.4	7.0,4.7	76.3,21.2	6.3,2.1	1.0,1.7,2.1	1.0,0.7,0.6	3.3,5.8
0900	12.3,4.6	5.8,4.5	76.6,13.0	6.6,1.6	1.0,2.2,1.7	1.0,1.0,1.0	16.0,21.8
1000	12.4,5.3	4.8,3.2	76.7,24.0	6.5,1.3	4.0,3.0,1.7	1.0,1.0,0.0	5.3,5.0
1100	13.7,5.3	8.0,3.3	74.7,28.4	7.6,1.4	1.0,2.0,1.7	1.0,1.3,0.6	22.3,38.7
1200	14.6,5.6	9.6,2.8	73.7,26.1	8.3,1.0	1.0,2.0,1.7	0.0,0.7,1.2	19.7,34.1
1300	15.0,5.5	10.2,0.9	70.0,26.3	8.9,1.9	1.0,2.0,1.7	0.0,0.7,1.2	32.0,55.4

Appendix J. Continued.

Hour	Ambient Air Temp (°C)	Wind Speed (KPH)	Relative Humidity (%)	Soil Temp (°C)	Cloud Cover	Human Harassment	Sweep Net Count
Plains (continued)							
1400	14.3,5.0	12.4,1.9	73.3,23.6	10.6,2.9	1.0,1.7,2.1	0.0,0.7,1.2	17.3,30.0
1500	14.1,5.6	11.3,1.6	72.7,25.0	11.3,3.3	1.0,1.7,2.1	0.0,0.7,0.6	7.3,12.7
1600	14.3,5.5	9.1,1.0	69.7,20.4	11.3,2.3	1.0,1.7,2.1	0.0,0.3,0.6	1.0,1.7
1700	14.3,5.5	10.7,2.5	68.7,18.6	12.0,2.6	1.0,1.7,2.1	1.0,0.7.0.6	2.0,3.5
1800	14.4,5.9	7.0,4.9	66.7,15.5	11.3,2.3	1.0,1.7,2.1	1.0,0.7,0.6	17.3,30.0
1900	13.7,5.7	8.1,5.8	66.0,10.5	11.7,2.0	1.0,1.7,2.1	1.0,1.3,0.6	6.0,10.4
2000	13.4,7.9	7.5,4.7	60.0,5.7	10.9,2.0	1.0,1.7,2.1	1.0,1.0,1.0	9.3,16.2
2100	11.8,5.6	9.1,4.7	71.7,9.3	10.2,2.5	1.0,1.7,2.1	1.0,1.0,1.0	3.3,5.8
2200	10.9,6.0	7.0,2.5	75.0,7.0	9.4,3.1	1.0,1.7,2.1	1.0,1.0,1.0	6.0,10.4
2300	8.1,6.5	7.2,2.8	74.0,23.9	7.8,2.8	1.5,1.5,1.3	0.5,0.8,1.0	12.5,23.7
Foothills							
0000	7.8,0.6	0.0,0.0	74.3,12.9	5.7,1.4	0.0,2.7,1.5	0.0,0.3,0.6	0.7,1.2
0100	7.4,1.6	1.3,2.3	74.3,12.9	5.7,1.3	0.0,2.3,1.2	0.0,0.7,1.2	0.7,1.2
0200	5.0,1.1	0.0,0.0	84.3,9.2	5.2,0.9	0.0,1.7,0.6	0.0,0.3,0.6	0.3,0.6
0300	4.8,1.2	0.0,0.0	84.3,8.5	5.0,1.1	0.0,1.3,0.6	0.0,0.0,0.0	0.3,0.6
0400	4.1,1.8	0.0,0.0	89.3,5.5	4.8,0.9	0.0,1.3,0.6	0.0,0.0,0.0	0.0,0.0
0500	5.0,1.5	0.0,0.0	84.3,9.0	4.2,0.9	0.0,1.3,0.6	0.0,0.3,0.6	0.3,0.6
0600	5.9,1.4	2.9,5.1	84.7,8.0	3.9,1.5	0.0,1.3,0.6	0.0,0.7,1.2	1.0,1.7
0700	5.5,1.5	1.9,3.2	90.0,4.4	3.7,2.0	0.0,1.0,0.0	0.0,0.7,1.2	0.7,1.2
0800	9.1,1.3	4.8,4.5	70.7,4.2	4.1,1.1	0.0,1.0,1.0	0.0,0.3,0.6	1.7,2.9
0900	10.6,3.4	3.8,5.2	66.3,1.5	4.8,0.9	0.0,0.7,0.6	0.0,0.3,0.6	1.3,2.3
1000	11.3,1.8	0.5,0.9	66.7,4.2	5.0,1.1	0.0,0.7,0.6	0.0,0.3,0.6	0.7,1.2
1100	12.2,2.0	0.0,0.0	64.3,10.3	6.5,2.3	0.0,1.3,0.6	0.0,0.7,1.2	6.7,11.5
1200	11.5,1.2	4.6,5.4	61.7,15.0	6.3,2.0	0.0,1.7,0.6	0.0,0.7,1.2	8.3,14.4
1300	13.0,3.7	12.6,10.6	54.7,13.7	6.8,2.1	0.0,1.3,0.6	0.0,0.7,1.2	8.7,15.0
1400	11.7,3.0	13.7,16.6	65.7,10.5	7.0,2.3	2.0,1.7,0.6	2.0,1.7,1.2	2.3,4.0
1500	9.6,0.6	8.3,8.1	68.0,16.6	7.0,2.3	0.0,2.3,1.2	0.0,0.3,0.6	0.7,1.2
1600	10.4,1.7	5.1,5.7	58.3,7.6	7.2,1.4	0.0,2.7,1.5	0.0,0.7,1.2	5.7,7.4
1700	10.6,2.0	8.1,0.6	61.0,11.3	7.0,1.8	0.0,2.0,1.0	0.0,0.3,0.6	1.7,2.9
1800	10.7,3.4	7.0,2.5	61.0,8.1	7.0,0.9	0.0,2.3,1.5	0.0,0.3,0.3	0.3,0.6
1900	11.1,3.4	7.7,0.5	63.0,12.4	7.0,0.9	0.0,2.0,1.7	0.0,0.7,1.2	8.7,15.0
2000	9.5,3.0	5.1,4.4	67.3,2.5	6.8,0.6	0.0,2.0,1.7	0.0,0.7,1.2	3.0,5.2
2100	9.1,2.3	6.4,2.0	68.2,8.9	6.9,0.8	0.0,2.0,1.0	0.0,0.4,0.9	1.6,3.6
2200	8.0,2.8	3.2,3.2	76.7,21.6	5.8,0.3	0.0,2.7,1.5	0.0,0.3,0.6	0.3,0.6
2300	8.0,0.9	0.0,0.0	78.7,13.0	5.9,2.0	0.0,3.0,1.0	0.0,0.7,1.2	0.7,1.2

Cloud Codes:

1 = 0% cover
2 = 1 - 25% cover
3 = 26 - 50% cover
4 = 51 - 75% cover

Harassment Levels:

0 = Mosquitos not present
1 = Mosquitos present but not biting
2 = Mosquitos biting
3 = Mosquitos so numerous they are easily inhaled

U.S. GOVERNMENT PRINTING OFFICE: 1989—692-130/84,019 REGION NO. 8