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Airphoto Analysis of Winter Seismic Disturbance in Northeastern Alaska

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ABSTRACT. Airphoto interpretation was used to quantify the extent of disturbance caused by seismic exploration on the 60 000 ha coastal plain of the Arctic National Wildlife Refuge during the winters of 1984 and 1985. The relationships of vegetation type, trail location and traffic pattern to the amount of disturbance were investigated. Approximately 20% of the seismic trails were photographed at 1:6000 scale, using color infrared film. Ground data collected at 194 sites were used to develop a photo interpretation key describing the photo signatures of seven vegetation types and four disturbance levels. Vegetation types and disturbance levels were determined for 4914 circles of 3 mm diameter on the aerial photos (18 m ground distance). Fourteen percent of the points were interpreted as having no disturbance (level 0), 57% had level 1 disturbance (low), 27% had level 2 (medium) and 2% had level 3 (high). Wet or partially vegetated areas were the least susceptible to disturbance. Vegetation types with mounds, tussocks, hummocks or high-centered polygons and dryas terraces were more heavily disturbed. Camp move trails and overlapping seismic and camp move trails created in 1984 caused more disturbance than other trail types due to multiple passes of vehicles over narrow trails. U.S. Fish and Wildlife Service monitors were more successful at minimizing disturbance the second year by requesting that vehicle operators avoid multiple passes on the same trail, sensitive vegetation types and areas of low snow cover.

Key words: airphoto analysis, winter seismic exploration, seismic trails, vegetation disturbance, traffic patterns, Alaska, Arctic National Wildlife Refuge, arctic coastal plain

RÉSUMÉ. On s'est servi de l'interprétation de photos aériennes pour quantifier l'importance de la perturbation causée par l'exploration sismique dans les 60 000 ha de la plaine côtière du Arctic National Wildlife Refuge au cours des hivers de 1984 et de 1985. On a étudié les rapports entre la végétation type, l'emplacement de la piste, les schémas de circulation et l'importance de la perturbation. Environ 20 % des pistes sismiques ont été photographiées à une échelle de 1/6000 avec une pellicule couleurs infrarouge. Les données recueillies au sol à 194 emplacements ont été utilisées pour créer un modèle d'interprétation de photos, qui décrit les signatures photographiques de sept types de végétation et de quatre niveaux de perturbation. Les types de végétation et les niveaux de perturbation ont été déterminés pour 4914 cercles de 3 mm de diamètre sur les photos aériennes (18 m de diamètre au sol). Pour 14 % de ces endroits, on n'a noté aucune perturbation (niveau 0); à 57 % de ces endroits, on a attribué le niveau de perturbation n° 1 (bas), à 27 %, le niveau n° 2 (moyen) et à 2 % le niveau n° 3 (élevé). Les zones humides ou en partie recouvertes de végétation étaient les moins propices à la perturbation. Les types de végétation avec des monticules, des touffes d'herbes, des hummocks ou bien avec des buttes polygonales et des terrasses de dryades avaient subi la perturbation la plus importante. On a trouvé que les pistes utilisées pour le déplacement des camps de 1984 et les pistes utilisées à la fois pour l'exploration sismique et le déplacement des camps causaient plus de perturbations que les autres types de pistes, à cause du passage répété des véhicules sur une piste étroite. Les agents du U.S. Fish and Wildlife Service ont mieux réussi à minimiser les perturbations la deuxième année, en demandant aux conducteurs de véhicules d'éviter de passer plusieurs fois sur la même piste, sur des types de végétation fragile et dans des zones où la couverture de neige était peu épaisse.

Mots clés: analyse de photographies aériennes, exploration sismique d'hiver, pistes sismiques, perturbations de la végétation, schémas de circulation, Alaska, Arctic National Wildlife Refuge, plaine côtière arctique

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INTRODUCTION

The Arctic National Wildlife Refuge, located in the northeastern corner of Alaska, was established for the primary purpose of conserving wildlife habitat, including that of the Porcupine caribou herd, migratory birds, polar bears, grizzly bears, muskoxen, wolves and wolverines. The future of the arctic coastal plain of the Arctic Refuge is presently being debated by the U.S. Congress, with proposals ranging from designating the area as wilderness to leasing it for oil and gas development. The Alaska National Interest Lands Conservation Act of 1980 (U.S. Public Law 96-487) required baseline studies of the area's fish and wildlife resources (Garner and Reynolds, 1986) to provide Congress with information on the possible biological effects of oil and gas development. Limited geological studies, including seismic exploration, were authorized to assess the oil and gas potential of the arctic coastal plain.

Winter seismic exploration was conducted on the coastal plain of the Arctic Refuge in 1984 and 1985, as authorized by Congress. Approximately 2000 km of seismic lines, arranged in a 5 × 10 km grid pattern, were completed between January and May of both years. The drilled shothole technique, using buried dynamite to create seismic waves, was used in 1984. The vibrator technique, utilizing large trucks (vibrators) to provide an energy source, was used in 1985. Collection of data along each seismic line required multiple passes by tracked vehicles, including drills or vibrators, small personnel carriers (Bombardiers), geophone trucks and a recording vehicle. Ski-mounted camps pulled by D-7 Caterpillar tractors created a second series of trails, sometimes following separate routes through areas of deeper snow. U.S. Fish and Wildlife Service monitors accompanied the seismic crews to enforce regulations and permit stipulations developed to minimize impacts to wildlife and their habitats.

Vehicle trails from as long ago as the 1940s are still visible on the tundra west of the Arctic Refuge (Lawson *et al.*, 1978; Walker *et al.*, 1987). Vehicle disturbance decreases plant cover on trails and can cause short- and long-term species composition changes due to the relative resistance and resilience of different species (Bliss and Wein, 1972; Hernandez, 1973; Chapin and Chapin, 1980). Increased biomass or nutrient changes in some plant species have also been documented on vehicle trails (Challinor and Gersper, 1975; Chapin and Shaver, 1981). Subsidence of trails due to melting of permafrost occurs on more heavily disturbed trails (Haag and Bliss,

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1974; Gersper and Challinor, 1975; Chapin and Shaver, 1981).

Many of the previous studies focused on trails that were severely disturbed due to summer travel over thawed ground or bulldozing of trails. Seismic trails created in the winter generally cause less damage but have been found to crush and break vegetation and disturb areas with higher microrelief, such as tussocks and hummocks, resulting in decreases in plant cover (Hernandez, 1973; Reynolds, 1982). The few studies that have focused on winter seismic trails were site-specific (Hernandez, 1973; Reynolds, 1982; Densmore, 1985) and did not provide sufficient data to develop guidelines for seismic exploration on the coastal plain of the Arctic Refuge.

The use of airphoto interpretation allowed us to determine the effects of winter seismic exploration at a large number of sites throughout the Arctic Refuge coastal plain. Airphoto interpretation and other remote-sensing techniques have often been used in Alaska to investigate large areas that are otherwise inaccessible (Brooks and O'Brien, 1986). A number of researchers have interpreted tundra vegetation types from color infrared aerial photography (e.g., Swanson *et al.*, 1983; Walker *et al.*, 1983). Color infrared film was particularly appropriate for our purposes, as it discriminates between vegetative cover types and indicates the effects of stress or disturbance better than color or black-and-white film (Avery, 1977:11-12).

The objectives of this study were to determine the extent of disturbance caused by winter seismic exploration on the Arctic Refuge coastal plain and to investigate the major factors controlling the amount of disturbance occurring at a site, such as vegetation type and traffic pattern. The results provide information that will be valuable for monitoring or regulation of any future vehicle traffic in the arctic tundra.

STUDY AREA

The study area included over 600 000 ha of the coastal plain of the Arctic Refuge, between 142°W and 147°W and north of 69°34'N (Fig. 1). The area is in northeastern Alaska and is bordered by the Beaufort Sea on the north, the Brooks Range on the south, the Aichilik River on the east and the Canning River on the west. It is located in the Low Arctic Tundra (Murray, 1978) and is vegetated by low-growing plants, including dwarf shrubs, sedges, grasses, forbs, mosses and lichens. Shallow soils are underlain by 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.

METHODS

Color infrared airphotos (1:6000 scale) were acquired in late July 1985 for approximately 20% of the 1984 and 1985 seismic trails. Line segments (16 km) were randomly selected within three strata: west of the Sadlerochit River, east of the Sadlerochit River and the eastern foothills (Fig. 1). Camp move routes associated with each line segment were also photographed.

A key describing the photo signatures of eight vegetation types (based on Walker *et al.*, 1982) and four levels of surface disturbance was developed using ground data collected in 1984 and 1985 (Table 1). Ground data included point frame cover data by species for 24 sites (Felix and Raynolds, 1989a), line intercept cover data for 38 additional sites (Felix and Raynolds, 1989b) and qualitative vegetation community descriptions for another 132 sites. Three agreement tests were conducted as the key was being developed. Discrepancies between interpreters and between interpretations and ground data were examined, and the key was modified to maximize consistency and accuracy of interpretation.

Two interpreters used the key to analyze the airphotos, determining the dominant vegetation type and disturbance level in 4914 3 mm circles (18 m ground distance) located every 2.5 cm (150 m ground distance) along the trails. The traffic pattern was classified as seismic trail, camp move trail or overlapping trails, where both seismic lines and camp move

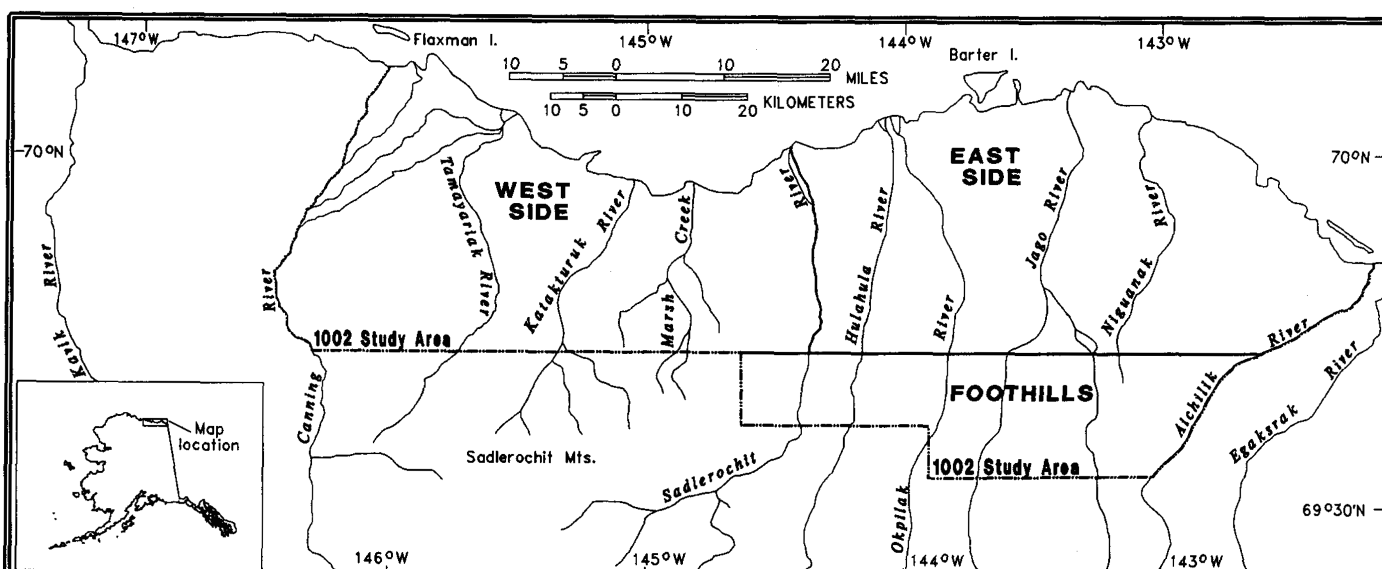

FIG. 1. Map of 60 000 ha study area on the coastal plain of the Arctic National Wildlife Refuge, Alaska. A 5 × 10 km grid of seismic lines (approx 2000 km total) was completed on this area during the winters of 1984 and 1985.

TABLE 1. Vegetation types and disturbance levels on winter seismic vehicle trails as recognized on color infrared aerial photographs (1:6000 scale), coastal plain, Arctic National Wildlife Refuge, Alaska

	Disturbance levels			
Vegetation type	0	1	2	3
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.	No impact.	Compression of standing dead emergent vegetation.		
Wet graminoid tundra — sedge- or grass-dominated communities on poorly drained, seasonally flooded sites. Low-centered polygons, strangmoor, tidal flats, lake and stream margins.	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. During wet years standing water apparent on trail that is not present in surrounding area.
Moist sedge-shrub tundra — sedge-willow meadows of upland slopes and flat or poorly developed high-centered polygons.	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. During wet years standing water apparent in trail that is not present in adjacent area.
Moist graminoid/barren tundra complex — moist tundra communities with over 30% cover of hummocks or frost scars and less than 15% tussocks.	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 organic or mineral soil 5-15%. Scraping of mound tops common.	Nearly all mound tops scraped. Over 50% vegetation damage. Over 15% soil exposed.
Moist sedge tussock tundra — areas with more than 15% cover of cottongrass tussocks.	No impact to slight scuffing of tussocks and breakage of shrubs.	Scuffing of tussocks or mound tops. Vegetation damage 5-25%. Exposed organic or mineral soil less than 3%.	Mound top destruction of tussocks over 30%. Common mound top scuffing. Vegetation damage 25-50%. Exposed organic 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 — shrub rich high-centered polygons and palsas.	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 — willow shrubland on gravel bars, floodplains and river banks.	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 — dry alkaline ridges, river terraces and bluffs.	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, vegetative mat mostly disrupted. Over 15% soil exposed or over 50% increase in bare ground.

trails overlapped. The year during which the disturbance occurred (1984 or 1985) was noted.

The proportion of trails in each disturbance level was calculated by tallying the interpreted points on each line segment, then determining the mean and standard deviation for all segments. The total distance of trail within each level of disturbance was estimated by multiplying the total kilometers of trail by the proportions in each disturbance level. Data are presented as means $\pm$ standard deviations. The total kilometers of trail was calculated as the sum of seismic lines (1910 km) and camp move trails (estimated by multiplying the total length of seismic lines by the ratio of camp moves to seismic lines based on numbers of photo-interpreted points).

Kruskal-Wallis analyses of ranked data (SPSS, 1986) were used to determine if the distribution of disturbance levels differed by vegetation type, location in the study area (east side compared to west side and foothills) and trail types (three traffic patterns, two years).

RESULTS AND DISCUSSION

Overall, 14% of the points examined were interpreted as having no disturbance (level 0), 57% as level 1 (low), 27% as level 2 (moderate), and 2% as level 3 (high) (Table 2). Extrapolating the proportions of disturbance levels in the sample to the total distance of seismic lines and camp move trails resulted in an estimate of 540 ± 424 km with no visible disturbance, 2050 ± 729 km with level 1 disturbance, 960 ± 605 km with level 2 disturbance, and 60 ± 172 km of trail with level 3 disturbance. This estimate is conservative because it includes seismic lines and the camp moves adjacent to seismic lines. It does not include the moves from one line to the next or other trails associated with exploration activities, such as supply routes and trails between camps and seismic lines, which were observed to have some of the highest levels of disturbance.

The distribution of disturbance levels varied by vegetation type (Table 2). Moist shrub tundra and dryas terrace had the highest levels of disturbance, followed by moist sedge tussock tundra, then moist graminoid/barren tundra complex (Kruskal-Wallis, $p < 0.05$). Shrub tundra, tussock tundra and barren complex have high micro-relief, such as hummocks, tussocks and high-centered polygons, which were easily scraped or crushed by vehicles. Wind redistribution of snow on the arctic coastal plain leaves these features with little protective snow cover (Felix *et al.*, 1987). Other studies have also noted that tussocks and shrubs have low resistance to winter disturbance (Hernandez, 1973; Lawson *et al.*, 1978; Reynolds, 1982). Dryas terraces have thin vegetative mats, consisting mostly of dwarf shrubs and mosses, which were easily disrupted and had little snow cover (Felix and Raynolds, 1989a). Barrett and Schulten (1975) also found *Dryas* to be especially sensitive to disturbance.

Moist sedge-shrub tundra had the next highest level of disturbance, which was close to the distribution of disturbance levels for all points. Riparian shrubland had the least amount of disturbance among those vegetation types with disturbance in all four levels (Kruskal-Wallis, $p < 0.05$). The high proportion of level 0 disturbance in riparian shrubland reflects the fact that vehicles were routed around this vegetation type unless deeper than average snow cover was present.

Most of the points in wet graminoid tundra were identified as level 1 disturbance (93%). Level 2 disturbance was not interpreted for this vegetation type, because it could not be differentiated on the photos. In subsequent field checking, 11% of the points in wet graminoid tundra were found to be level 2 on the ground (Raynolds and Felix, 1988). Based on this, wet graminoid tundra had less moderate and high level disturbance (levels 2 and 3) than the vegetation types discussed above. Only 1 out of 11 points in aquatic graminoid tundra had any visible disturbance (level 1). Other studies have also found that wet vegetation types had the highest resistance to disturbance by winter traffic (Hernandez, 1973; Lawson *et al.*, 1978; Reynolds, 1982). Nine percent of all points were located in water or partially vegetated areas and therefore had no disturbance (level 0).

The western half of the coastal plain (west of the Sadlerochit River) had a significantly higher level of disturbance (Kruskal-Wallis, $p < 0.05$) than the east side and foothill areas (Table 3). Vegetation types and snow depths also differed between these areas. The trails on the west side crossed 8% more tussock tundra (an easily disturbed vegetation type) and 16% less wet graminoid tundra (a less sensitive vegetation type). Snow depth in 1985 on the west side was also lower (25 cm average) than the east side (32 cm) (Felix *et al.*, 1987).

Camp moves in 1984 and overlapping camp moves and seismic lines in both years had significantly higher disturbance levels (Kruskal-Wallis, $p < 0.05$) than all other trail types (Table 4). The highest level of disturbance (level 3) was only found on trails where multiple passes of vehicles occurred over a narrow area.

TABLE 2. 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	Kruskal-Wallis category[a]
Water[b]	100				161	
Aquatic graminoid marsh[b]	91	9			11	
Wet graminoid tundra[c]	6	93		1	769	
Moist sedge-shrub tundra	10	62	26	2	1751	B
Moist graminoid/barren tundra complex	5	52	40	3	405	C
Moist sedge tussock tundra	1	52	44	3	1165	D
Moist shrub tundra	4	44	51	1	305	E
Riparian shrubland	41	37	22	1	74	A
Dryas terrace	9	27	36	27	11	E
Partially vegetated areas[b]	100				262	
Total					4914	
Percentage of all points	14	57	27[d]	2		

[a]Vegetation types with the same letter were not significantly different, $p < 0.05$.
[b]There was no level 1, 2 or 3 in water and partially vegetated areas and no level 2 or 3 in aquatic graminoid marsh.
[c]Level 2 was combined with level 1 in wet graminoid tundra.
[d]The overall percentage of level 2 disturbance may be underestimated, because levels 1 and 2 were combined for wet graminoid tundra.

TABLE 3. Percentage of disturbance levels for photo interpretation of winter seismic trails from two areas of the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985

Location	Disturbance level 0	1	2	3	Number of points interpreted
East side and foothills	12	68	19	0	2945
West side	19	39	38	4	1969

Distribution of disturbance levels differs significantly (Kruskal-Wallis, $p < 0.05$).

TABLE 4. Percentage of disturbance levels within trail types from photo interpretation of winter seismic trails on the coastal plain, Arctic National Wildlife Refuge, Alaska, 1985

Trail type	Disturbance level 0	1	2	3	Number of points interpreted	Kruskal-Wallis[a]
1984 seismic	14	72	14	0[b]	957	B
1984 camp	17	48	30	5	1041	C
1984 overlapping	9	39	44	8	386	C
1985 seismic	5	70	25	0[b]	1265	B
1985 camp	28	43	29	0[b]	1217	A
1985 overlapping	0	60	40	0	48	C

[a] Trail types with the same letter were not significantly different, $p < 0.05$.
[b] These categories had 1-3 observations, much less than 1%.

Camp moves in 1984 caused more disturbance than 1984 seismic trails (Kruskal-Wallis, $p < 0.05$). Reynolds (1982), in a study of a western portion of the Alaskan arctic coastal plain, also found that camp move vehicles did more damage than seismic vehicles. Camp move vehicles were heavier than seismic vehicles.

Camp moves in 1985 resulted in significantly less disturbance than 1984 camp moves (Kruskal-Wallis, $p < 0.05$). Based on experience from the 1984 program, U.S. Fish and Wildlife Service monitors required that vehicles avoid narrow trails. As a result, the 1985 trails had almost no level 3 disturbance. Due to routing of camp moves through drainages with drifted snow, 1985 camp move trails also had more level 0 disturbance than other trail types. Camp moves were also routed to avoid sensitive vegetation types, and four times as much partially vegetated area was crossed by 1985 camp moves than by the 1984 camp moves. Camp moves in 1984 and 1985 had similar proportions of level 1 and 2 disturbance.

Disturbance on the 1984 seismic lines was not significantly different from that on the 1985 seismic lines (Kruskal-Wallis, $p < 0.05$). However, the 1985 seismic lines did have 11% more level 2 disturbance and 9% less level 0 disturbance than the 1984 lines. The vibrator units used in 1985 were heavier (4.5 psi) and their tracks dug more deeply into the vegetative mat than the drills (2.8 psi) used in 1984. Level 3 disturbance rarely occurred on either 1984 or 1985 seismic lines.

CONCLUSION

Winter seismic trails through vegetation types with high micro-relief (tussock tundra, shrub tundra and barren complex) and dryas terraces had the highest levels of disturbance. Wet vegetation types (aquatic graminoid and wet graminoid) and partially vegetated areas were the most resistant to disturbance. Vehicle trails on the east side of the coastal plain had a lower level of disturbance than trails on the west side due to higher snow cover and a higher proportion of wet vegetation types.

Less disturbance occurred in 1985 than in 1984. This was partly due to greater snow depths in 1985. Another major difference between the two years was that in 1985 additional stipulations designed to minimize disturbance were enforced by the U.S. Fish and Wildlife Service. Disturbance was reduced on camp move trails by requesting that vehicle operators avoid overlapping or narrow trails, sensitive vegetation types and areas of low snow cover. Seismic lines were less affected by the stipulations, since their straight line routes were determined by seismic data-gathering parameters and were not often changed.

Airphoto analysis proved a useful tool for evaluating the extent of disturbance over a large area. Subsequent ground checks revealed that the proportions of points in each vegetation type and disturbance level were similar to the proportions determined by photo interpretation, although the interpretation of any particular point was not always correct (75% accuracy for vegetation types, 66% accuracy for disturbance levels) (Raynolds and Felix, 1988). Therefore, photo-interpreted disturbance levels were representative of the actual disturbance on the ground and provided a good relative measure in different vegetation types, areas and traffic patterns.

This study provides baseline data for determining the long-term effects of winter seismic exploration. Aerial photography of the same areas was taken in 1988, and photo interpretation is presently in progress using a detailed key based on current ground data. The results presented in this paper and the results of future studies can be used to develop regulations to minimize disturbance due to winter vehicle traffic on tundra vegetation.

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