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Use of Off-road Vehicles and Mitigation of Effects in Alaska Permafrost Environments: A Review

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ABSTRACT / Use of off-road vehicles (ORVs) in permafrost-affected terrain of Alaska has increased sharply over the past two decades. Until the early 1960s, most ORV use was by industry or government, which employed heavy vehicles such as industrial tractors and tracked carriers. Smaller, commercial ORVs became available in the 1960s, with the variety and number in use rapidly increasing. Wheeled and tracked ORVs, many used exclusively for recreation or subsistence harvesting by individuals, are now ubiquitous in Alaska. This increased use has led to concern over the cumulative effects of such vehicles on vegetation, soils, and environmental variables including off-site values.

Factors affecting impact and subsequent restoration include specific environmental setting; vegetation; presence and ice content of permafrost; microtopography; vehicle design, weight, and ground pressure; traffic frequency; season of traffic; and individual operator practices. Approaches for mitigating adverse effects of ORVs include regulation and zoning, terrain analysis and sensitivity mapping, route selection, surface protection, and operator training.

Use of off-road vehicles (ORVs) in North America has accelerated dramatically over the past two decades. Use of motorcycles, snowmobiles, and four-wheel-drive vehicles in rural landscapes can have adverse environmental and social consequences, attracting the attention of conservationists, scientists, and land managers (cf., Propst and others 1977, Sheridan 1979, Graham 1980, Webb and Wilshire 1983). ORV use has increased rapidly in the permafrost-affected terrain of central and northern Alaska (Brown 1976). From the advent of mechanization through the early 1960s, most ORV use in Alaska was by industry or government, which employed large, heavy vehicles such as Nodwell-type tracked carriers and Caterpillar[1] tractors pulling sleds or trailers ("cat-trains"). A small, resident population had relatively few off-road vehicles for personal use; most were military-surplus tracked or modified four-wheel-drive units. Commercially manufactured ORVs became more evident in the 1960s. The variety available and number in use has increased steadily to the present (Table 1). Low-ground-pressure wheeled or tracked vehicles, many used exclusively for recreation, are now common in Alaska. More than 15,000 ORVs are in use in central and northern Alaska (Fairbanks North Star Borough Trails Commission, personal communication, August 1986). Most are low-ground-pressure, one-passenger machines such as snow machines and motorized three- and four-wheel ORVs with a gross weight of less than 500 kg.

These and larger wheeled and tracked ORVs (500–1500 kg gross weight) are widely used in subsistence harvesting, sport hunting, recreation, and general transportation. Heavy ORVs (1500–10,000 kg gross weight) are used primarily by industrial and government operations. In some Alaska villages, small- and medium-sized ORVs are the main form of travel to subsistence hunting areas in summer. The use of ORVs and the designation of ORV trails has become a major policy issue in Alaska, particularly in areas where conflict exists between native subsistence

KEY WORDS: Permafrost; Off-road vehicles; ORV; Trails; Impacts; Effects; Mitigation

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**We regret the untimely death of Gunars Abele on August 27, 1989; he was a valued colleague and good friend.

[1]The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by USDA of any product to the exclusion of others that may be suitable.

Table 1. Representative off-road vehicle characteristics.[a]

Class	Weight (kg)	Ground pressure (kg/cm²)	Remarks
I. Small—personal use			
Three-wheeler all-terrain cycle	90–120	0.10	1 passenger, three-wheels, knobby or cleated tread
Four-wheeler all-terrain cycle	110–170	0.10	1 passenger, four wheels, knobby tread
Coot or Pug	500–600	0.70	2–4 passengers, four wheels, four-wheel drive, cleated tread
Trackster	450	0.04	2 passenger, rubber tracks
Argo, Hustler, Max, Sidewinder	400–600	0.18	2–4 passengers, cleated tread
II. Medium—personal and industrial use			
Weasel	1200	0.07	2–6 passengers, tracked, skid steering
Bombardier Bombi	1100	0.06	2 passengers, tracked, skid steering
Jeep	1180	2.24	4 passengers, four-wheel drive, may be equipped with oversized tires
Thiokol IMP	1200	0.06	Rubber track, steel-cleated, skid steering
Pasquali 993 tractor	815	0.84	4 wheels, cleated tires, articulated steering
III. Large—industrial use			
Nodwell RN-110	5400	0.09	Rubber tracks, steel cleats, skid steering
Rolligon (Houston)	6800	0.25	6 wheels, ribbed tires
Bombardier Muskeg Tractor	3200	0.09	Rubber tracks, steel cleated, skid steering
Rolligon (CATCO)	11,700	0.35	8 wheels, smooth tires
Caterpillar D-7	15,800	0.70	Prime mover, steel cleated tracks

[a]Adapted from Abele and others 1984; Racine, in preparation; and manufacturers' specifications.

hunting rights and wilderness management regulations.

Much of the ORV literature on northern landscapes has been concerned with how well a vehicle performs in cross-country travel or freight movement, rather than with consequences for the landscapes traversed (Anonymous 1974, Thomas 1975). Documentation of ORV impact on northern landscapes is limited, and most reports are about the larger industrial-class vehicles (e.g., Hok 1969, Radforth 1972). The current number of personal ORVs has caused concern over the cumulative effects of such vehicles on vegetation, terrain, and environmental values.

This report reviews summer-season ORV use in Alaska and is primarily concerned with lighter-weight ORVs rather than large, industrial machines.

Effects and Evaluation Procedures

The consequences of ORV traffic in northern landscapes result from impacts on the soil and the vegetation that the soil supports. Van Cleve (1977) states that, "Probably the oldest and most widespread cause of substantial disturbance of arctic ground surfaces has been the movement of heavy track vehicles to remote sites. . . ." "Impact" is considered as effects on vegetation and the underlying soil; by implication, impact includes effects on surface albedo and energy exchange at the ground surface, and, consequently, effects on frozen ground or massive ice in the substrate. Effects on animals, which may be directly or indirectly impacted by ORVs, are not considered in this report.

Variables affecting impact and subsequent ecosystem recovery may include characteristics of the site, the vehicle, and the operation. Impact and recovery may vary with specific environmental setting (alpine tundra, wet coastal tundra, taiga uplands, interior lowlands), soils (parent material, particle size, surficial organic layer, moisture content, profile development), vegetation (species, age, size, community structure), permafrost conditions (discontinuous or continuous permafrost, thaw-stable or thaw-unstable substrate), mesotopography and microtopography (slope, aspect, roughness, and stability), and season of use. Impact is influenced by vehicle weight, ground clearance and width, ground pressure of the track or wheel, tread design, and vehicle configuration (rigid frame or articulated, tracked or wheeled). Operation characteristics that can affect impact include season of use, frequency of traffic, route selection, and operator practices and training.

Documenting ORV Impact

In both Arctic and taiga settings, ORV traffic affects vegetation and the underlying soil. In both environments, ecosystem resistance and resilience to a specific disturbance are functions of local site factors and type and severity of the disturbance. Several procedures have been proposed to rate the impacts of vehicles on permafrost-underlain terrain. Walker and others (1977) propose a vehicle-impact rating scheme for the Arctic Coastal Plain that incorporates a range of initial disturbances from vegetation compression to vegetation displacement. Lawson (1982) proposes a more generalized disturbance rating format in which the initial modification ranges from compaction of vegetation through complete removal of vegetation and surficial materials. Felix and Jorgenson (1984) and Walker and others (1985) describe a similar impact-rating system based on procedures of the Muskeg Research Institute (1970). Walker and others (1985) developed a corollary rating system for terrain recovery after disturbance. These ratings were not developed for the warmer discontinuous-permafrost taiga, nor do they explicitly incorporate depth of soil thaw or soil thermal status as a variable.

The results of several ORV impact trials are summarized in Table 2. More information is available from Arctic locations than from subarctic (taiga) settings. This reflects the attention paid to Alaska's Arctic Coastal Plain in connection with petroleum exploration and development from the 1940s through the 1970s. The research reported by Hok (1969), Rickard and Brown (1974), Gersper and Challinor (1975), and Felix and Jorgenson (1984), among others, on the Arctic Coastal Plain and by Everett and others (1985) at Cape Thompson stemmed from early observation of deleterious consequences of ORV use. Abele and others (1984) specifically include the visual impact, or "signature," of ORV traffic on Arctic tundra.

Less documentation is available concerning ORV use in interior Alaska, the discontinuous-permafrost taiga. DeLeonardis (1971) reviews experience in Alaska with erosion stemming from fire control lines constructed in permafrost terrain by Caterpillar tractor (a particularly disruptive ORV); accelerated erosion and thermokarst terrain development were undesirable consequences. Similar effects are documented for mining access trails in central Alaska (Stephenson 1976). Bolstad (1971) recommends ameliorative measures for tractor-constructed fire control lines, including seeding, fertilizing, and installing of water bars. Knapman (1976) subsequently expanded on these recommendations and stresses avoiding use of tractor lines in fire control where possible, minimizing vegetation removal in control lines or trails, and immediate reclamation by replacing the organic material on the cleared line or trail. Use of all-terrain vehicles in fire-control operations was recommended as a way to reduce the negative aspects of fire-line construction and fire-control access in remote areas (Rosenkranz 1976).

Rickard and Slaughter (1973) and Sparrow and others (1978) analyze existing trails created or used by off-road vehicles in the taiga. Thaw depth (from ground surface to top of frozen ground) beneath an ORV trail over permafrost increased by up to 290% after three years of summer traffic by medium-size ORVs (Rickard and Slaughter 1973). Soil thaw and consolidation under an ORV trail in open coniferous woodland (permafrost-underlain) in central Alaska is shown in Figures 1 and 2. That trail was first used in 1975, with heavy traffic (at least five trips per week) in the summers of 1975–1977; thaw was measured in September 1981. Sparrow and others (1978) studied existing ORV trails of indeterminate age, subject to frequent ORV traffic by sport anglers and hunters, in the taiga highlands of the Denali Highway; they noted that the type and severity of impact differs with soil, terrain, vegetation, and vehicular traffic characteristics. Poorly drained soils underlain by permafrost are often most heavily damaged by ORV traffic. Selected data from Sparrow and others (1978) are incorporated into Table 2.

Mitigation Measures

ORV Regulation

Regulating ORV traffic is one way to control adverse consequences on environmental values. Management and regulation have been widely attempted on public lands such as national forests (USDA Forest Service, 1977a,b) and beaches (Graham 1980). ORV traffic is prohibited in national parks and national monuments—probably the simplest and most effective (if enforced) way to reduce impacts. In areas of

Table 2. Summary of documented ORV impacts in Alaska tundra and taiga settings.

Location (source) and vehicle type	Setting and number of passes made by vehicle	Subjective impact rating (1 = low; 8 = high) for[a]			
		Microrelief	Soils	Vegetation	Cumulative impact
Prudhoe Bay, Alaska (Walker and others 1985)	Moist, nontussock sedge; dwarf-shrub tundra				
Rolligon	1	2	1	2	5
	30	5	5	5	15
	Wet sedge tundra				
	1	4	4	6	13
	30	7	8	9	24
Barrow, Alaska (Abele and others 1984)	Wet sedge meadow (drained lake bed)				
Rolligon (Houston)	5	4	2	2	8
	15	7	5	5	17
Weasel	5				
	50				
Nebesna, Alaska (Racine and Ahlstrand 1985)	Moist, tussock sedge; dwarf-shrub tundra				
Three-wheel Honda	10	2	1	3	6
	50	3	1	3	6
	150	4	3	5	12
Six-wheel Sidewinder	10	2	1	3	6
	50	5	3	6	14
	150	7	6	8	23
Weasel	10	2	2	5	9
	50	5	4	6	15
	150	8	7	8	23
Denali Highway Region, Alaska (Sparrow and others 1978) Uncontrolled ORV use; three-wheeler up to weasel-size vehicles.					
Tangle Lakes Site 201[b]	Dry tundra ("light use")	5	5	5	15[c]
Tangle Lakes Site 202[b]	Dry tundra ("light use")	7	8	6	21[d]
Landmark Gap Trail, Site 301[b]	Moist tundra ("medium use")	4	4	6	14[c]
Glacier Lake Trail, Site 402[b]	Moist tundra ("medium use")	8	7	8	23[d]
Butte Lake Trail, Site 502[b]	Alpine tundra ("heavy use")	8	8	8	24[d]
Butte Lake Trail, Site 502A[b]	Alpine tundra ("heavy use")	4	5	6	15[c]
Chatanika, Alaska (Slaughter, unpublished)					
Weasel-sized ORV	Open coniferous woodland ("heavy use")	4	7	8	23

[a]Total level of disturbance: greater than 20 = high, 10–20 = moderate; 3–10 = low.

[b]Extracted from Sparrow and others (1978); impact ratings based on original author's narrative.

[c]Original author termed impact "slight."

[d]Original author termed impact "severe."

heavy recreational ORV traffic, "sacrifice areas" may be established in which concentrated ORV use is allowed (Kockelman 1983), in hope of confining landscape degradation to a manageable level.

In Alaska, regulation of ORV use has probably lagged behind other regions because of the small population, attitudes of many residents who strongly resent any curtailment of individual actions, and a cau-

Figure 1. ORV trail in permafrost-taiga setting during summer 1977, after two season's traffic.

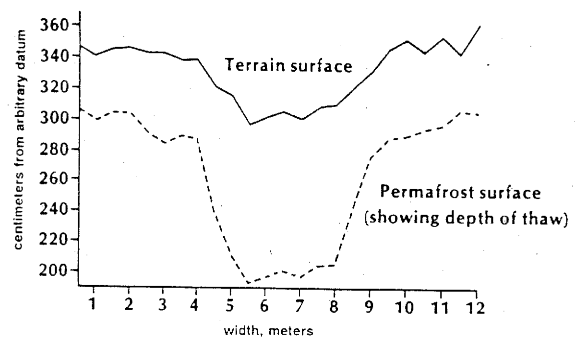

Figure 2. Measured subsidence and permafrost thaw in transect normal to trail shown in Figure 1, September 1981.

tious approach (at least in earlier years) on the part of regulatory and management agencies toward promulgating and then enforcing regulations that might prove unpopular. This appears to be changing (Nienhueser 1976). A simple case history of such change is provided by the Utility Corridor, which was established in the early 1970s for construction of the Dalton Highway and Trans-Alaska Pipeline (Kleven, personal communication, 9 December 1986).

The Dalton Highway was constructed from Livengood to Prudhoe Bay in 1974. In 1977, a Utility Corridor Management Framework Plan recommended that all lands within the Utility Corridor (about 8–10 km to either side of the Dalton Highway) be restricted for ORV use, with ORV operation by permit only during break-up, summer, and freeze-up. In October 1980, the State of Alaska published notice of closure to ORV traffic for all land within five miles (8 km) on either side of the Dalton Highway, with an exception for access to mining claims. In June 1981, notice was published in the *Federal Register* that ORV use on public lands in the Utility Corridor north of the Yukon River will be by permit only; ORV use in support of lawful mining activities is permitted if the operator has filed a Notice of Intent or a Plan of Operations, in advance, with the US Bureau of Land Management. The Bureau of Land Management is currently (1987) preparing a Resource Management Plan for the Utility Corridor; interim policy requires permits for all ORV use, except by ORVs weighing less than 680 kg, over snow cover at least 25 cm thick, or for ORVs used in mining.

ORV traffic is also being regulated in other areas of interior Alaska. The Alaska Division of Parks and Outdoor Recreation operates the Chena River State Recreation Area east of Fairbanks; the division has designated six trails that are open to ". . . vehicles with more than one drive wheel *AND* less than 8 (eight) pounds per square inch ground pressure or less than 1500 pounds gross vehicle weight . . . ;" the remainder of that State Recreation Area is closed to all motorized vehicles (Alaska Division of Parks and Outdoor Recre-

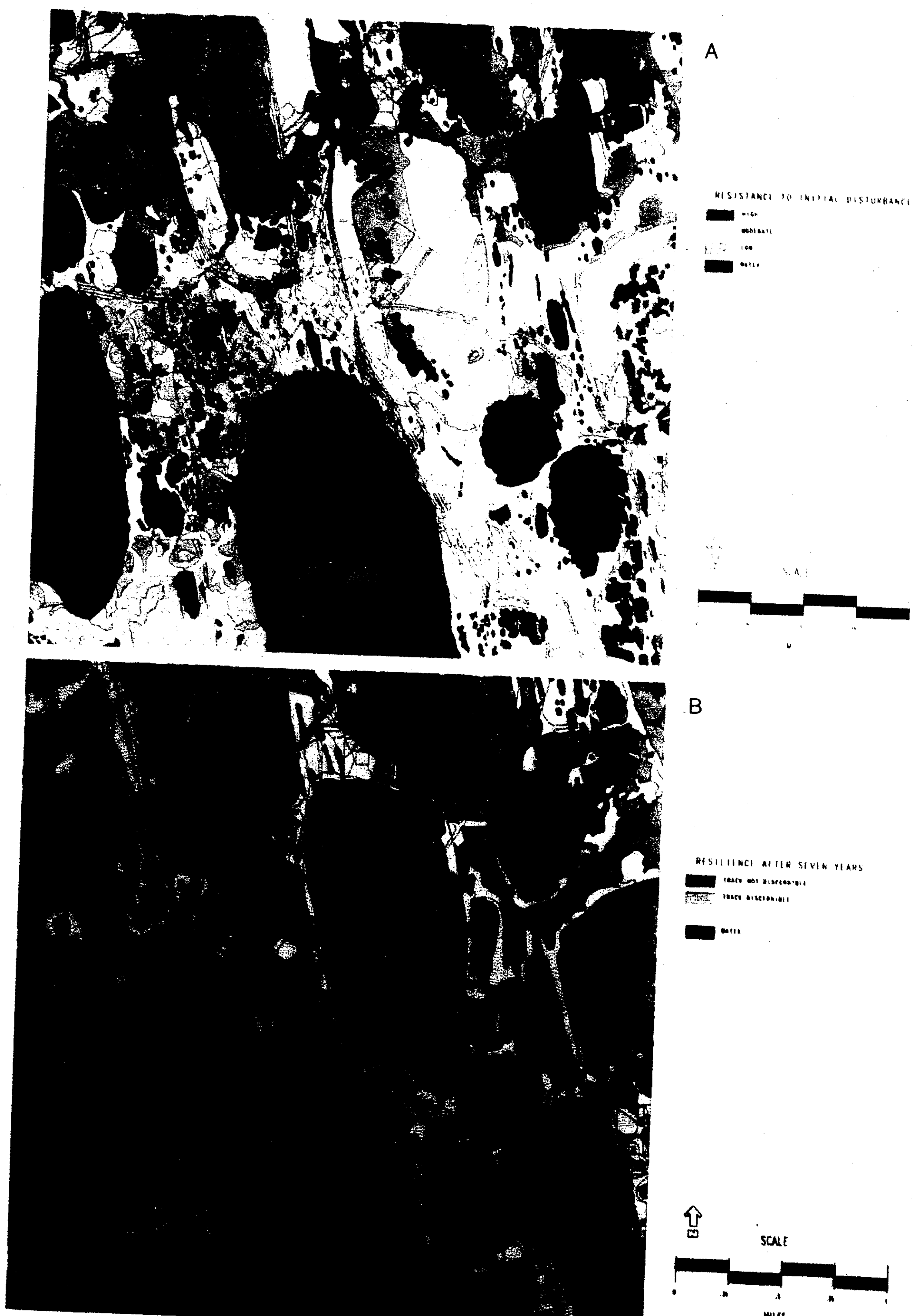

Figure 3. Terrain resistance (A) and resilience (B) following a single pass by a lightly loaded Rolligon at Prudhoe Bay, Alaska (Walker and others 1984).

ation 1985). North of Fairbanks, the US Bureau of Land Management is preparing an ORV management plan for the Steese National Conservation Area: the plan restricts access, closes portions of the Steese/White Mountains National Recreation Area to all vehicular traffic, and restricts other areas to ORVs weighing less than 680 kg (US Bureau of Land Management 1986).

ORV management has different facets in more remote areas of Alaska. Many villages rely heavily on subsistence resource harvest, and residents use ORVs for summer and winter transportation in subsistence hunting. Attempts to impose regulation on ORV use, in the interests of protecting environmental values, become entangled in questions of traditional cultural values, control of the land and its resources, and implementation of the Alaska National Interest Lands Conservation Act (ANILCA) (Berger 1985, Schaeffer and others 1986).

Terrain Analysis

A landscape management tool applicable to ORV impacts is interdisciplinary terrain analysis (McHarg 1969; Crampton and Rutter 1980). Physical landscape information—slope, aspect, drainage patterns, administrative or political boundaries, cultural features—can be integrated with geological, biological, and ecological attributes such as soils, geology, permafrost conditions, periglacial features, vegetation, habitat type, or climatic parameters. Spatial integration can be accomplished qualitatively or semiquantitatively through use of sequential overlays of attribute information plotted on maps of the same scale (McHarg 1969; Walker and others 1980). Improved quantification and enhanced speed of operation in this integration and in subsequent analysis are being advanced through use of computer-based digital mapping coupled with analytical algorithms and models (Walker and others, 1985), an approach commonly termed geographic information systems (Burrough 1986).

Given adequate baseline attribute information coupled with detailed geobotanical mapping, cumulative landscape changes can be readily analyzed (Walker and others 1986). With analysis of historical response to known disturbances as a basis, maps of terrain sensitivity to specific perturbations can be developed (Walker and others 1980). An example is provided in Figure 3, a sector of the Arctic Coastal Plain mapped at 1:6000 scale that depicts both initial *resistance* (ability of a vegetation type to withstand change from its initial state) to disturbance by Rolligon ORV and long-term *resilience* (ability of a vegetation type to return to its predisturbance state) to the same disturbance. Although this is a relatively simple example in terms of landscape and ORV type, the principle and the techniques are applicable to more complex terrains and environments, such as those found in the discontinuous-permafrost taiga.

Route Selection: Avoiding Sensitive Sites

An effective way to minimize adverse ORV effects is to select a route over terrain that is relatively insensitive to vehicular traffic. Everett and others (1985) note that 20-year-old vehicle trails on dry uplands and ridges in northwestern Alaska were stable, even though not revegetated, but similar trails traversing mesic sites showed distinct changes in vegetation (enough to be highly visible from ground or air), subsidence in some areas, and extensive erosion on steeper (12–18%) slopes; the erosion was apparently still active in some trail sectors after 20 years of nonuse. Lawson (1986) studied disturbance to permafrost terrain in northern Alaska and concluded that ground containing little ice (ice-poor) is relatively more stable after thawing (consequent to disturbance by vehicular traffic or other agents) than is terrain comprised of ice-rich materials; the latter "... were extensively modified by a complex interaction of slumping, sediment flow, and thermal and mechanical erosion." The importance of local conditions and careful selection of routes with ORVs was noted for interior Alaska by Rickard and Slaughter (1973) and Sparrow and others (1978). Helmers (1976) proposes preplanning of access routes to remote areas to avoid sensitive terrain in fire-control operations.

The management strategy of avoiding sensitive terrain might be achieved through on-site control of ORV traffic (marked trails, warning signs) or through some combination of landscape zoning and enforcement of regulations. In areas of heavy public pressure, such enforcement may be difficult or even impossible (Wilshire 1983). The ability to predict landscape sensitivity, through individual experience and through the terrain analysis and mapping approaches described earlier, is important in applying such a strategy to extensive land areas.

Surface Protection

Providing protection for the terrain and then confining ORV traffic to the protected route can be an effective method of minimizing ORV impact. To provide but one example, many trails used by small ORVs in central Alaska traverse poorly drained terrain underlain by ice-rich permafrost—terrain susceptible to thaw, consolidation, and erosion if the thermal balance is disturbed. A trail or wearing surface can be constructed over such terrain to support ORV traffic and prevent thaw and erosion. This has been done by

Figure 4. ORV trail in taiga woodland, with surface protected by native timber "corduroy" and by sawn timber puncheon.

using native materials, sawn timbers, or used railroad ties to prepare a corduroy trail surface (Figure 4) or wood chips prepared from local material. The initial cost is high, but local resource values (including aesthetic considerations in public recreation areas) may justify the investment. Although it is preferable to construct such surface protection before ORV traffic occurs, that is not always possible; a similar approach can be taken after the fact to stabilize and rehabilitate degraded sections of ORV trails (YACC 1981). Rehabilitation may include seedling or planting vegetation, preferably utilizing native species to avoid future ecological problems (Johnson 1984), or merely stabilizing and fertilizing the degraded trail (Johnson 1976). This will be feasible only where ORV use has been concentrated in a single route and where the landowner or land manager can muster adequate resources to accomplish such rehabilitation.

Restricting ORV traffic in winter to snowpacks equaling or exceeding a given thickness and using augmented snow and ice for construction pads and winter roads are other examples of surface protection that is widely applied in the Arctic (Johnson and Collins 1980).

Operator Training

The attitude and skill of an individual vehicle operator may be crucial to minimizing (or maximizing) effects from ORVs. In complex terrain the ability of the operator to recognize sensitive terrain units, such as poorly drained sites probably underlain by thaw-unstable permafrost, may be more important than details of vehicle ground pressure or number of traffic passes. Our experience shows that skilled operators can produce markedly lower impacts from operating wheeled or skid-steer tracked vehicles than can insensitive operators; for example, skilled operators use wide-radius turns and avoid steep slopes and difficult terrain instead of seeing "how far we can go or how steep we can climb," minimize track or wheel spinning, and sometimes spread out the traffic to avoid repeated passes over a single site (Figure 5). Operator attitude is probably most important in recreational ORV use and is probably the most difficult factor to control.

Conclusions

ORV traffic can have undesirable effects on vegetation, soils, and ecosystems of permafrost-related landscapes. Local setting, season, traffic frequency, and practices of individual operators affect the kind and degree of ORV impact. ORV effects can be evaluated by using any of several disturbance-rating schemes. Adverse impacts of ORV traffic can include vegetation damage or destruction, changes in vegetation community composition and structure, substrate thermal change and permafrost thaw, and soil erosion and subsequent development of thermokarst features and terrain degradation. Such impacts may affect aesthetic or visual values and can have consequences for biological productivity and later use of affected landscapes. Initial (resistance) and long-term (resilience) response of environmental systems to disturbance and near- and long-term system recovery may be affected by the nature and severity of initial disturbance, subsequent repeated traffic or avoidance of the site, and by management or rehabilitation practices imposed.

Techniques to cope with ORV traffic in permafrost-related landscapes include regulation and zoning, terrain analysis, sensitivity mapping, appropriate route selection, surface protection and stabilization of vehicle trails, and operator training.

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Figure 5. Single-track (lower center) and multiple-track ORV trail near Anaktuvuk Pass, Alaska.

national Conference on Restoration and Vegetation Succession in Circumpolar Lands, September 7–13, 1986, Reykjavik, Iceland, organized by Comité Arctique International. Participation of C. W. Slaughter in that conference was partially supported by a grant from The German Marshall Fund of The United States.

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