BIOLOGICAL IMPACTS OF OFF-ROAD VEHICLES IN ALASKA: A LITERATURE REVIEW.

Patricia Loomis

Robert Liebermann

Denali National Park and Preserve
P.O. Box 9
Denali Park, Alaska 99755

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Introduction

The use of off- road vehicles (ORVs) to access roadless areas of Alaska is increasing in many areas. ORVs allow users to access areas that would otherwise be accessible only to those persons who are physically fit for multiple day backpacking trips. In addition, these vehicles allow users to transport heavy loads into, and out of, remote areas. ORV use has been found to damage vegetation and soils, although the magnitude of these effects varies, depending on site characteristics. The type and level of impact by ORVs depends on characteristics of the soils and terrain, plant types, the amount of trail use and the type of ORV used (Sparrow *et al*., 1978; Ahlstrand & Racine, 1990; Happe *et al*., 1998).

In Alaska, environmental damage caused by ORVs has been documented in the literature since the early 1970's, although few experimental studies exist that use controlled treatments to examine the impacts and recovery times of vegetation and soils. Most of the existing literature produced by state and federal agencies focuses on management and environmental problems caused by ORV use on public lands (Meyer, 2002). In this report we define ORVs as any motor-driven, wheeled, tracked or air cushion vehicle that is primarily operated on off-road terrain. This includes, but is not limited to, small and medium sized ATVs such as four- and six-wheelers, Rangers, Argos, and Sidewinders, as well as larger vehicles such as Weasels, Bombardier and Muskeg Tractors.

The purpose of this document is to provide a synopsis of existing literature on the effects of ORVs on the environment in Alaska, and how that information relates to ORV use in Denali National Park and Preserve, with emphasis on the Broad Pass region. We will focus on the documented types and duration of ORV impacts in Alaska, and discuss the relative resilience or susceptibility of particular vegetation and soil types to disturbance by ORVs. We will also summarize management, monitoring and assessment practices for ORV use by other land management agencies in Alaska and elsewhere. Finally, we will relate the information obtained from the literature to the potential effects of ORV use in Broad Pass.

The vast majority of studies on the environmental effects of ORVs have focused on oil field development on the coastal plain of Alaska and Canada (Abele *et al*., 1984; Challinor & Gersper, 1975; Chapin & Shaver, 1981; Emers *et al*., 1995; Lawson, 1986; Rickard & Brown, 1974; Walker *et al*., 1987); and the majority of these studies were conducted in the 1970's. Research on ORV impacts in interior and south-central Alaska is relatively sparse. In interior Alaska, the adverse impacts of ORVs have been documented in the Denali Highway region on vegetation and soils (Sparrow *et al*., 1976; Sparrow *et al*., 1978; Wooding & Sparrow, 1978), and on archeological resources (Bureau of Land Management, 1979). The most extensive research on ORV impacts in central Alaska has been performed in Wrangell- St. Elias National Park and Preserve (Ahlstrand and Racine 1990; Happe *et al*., 1998; Racine and Ahlstrand, 1991). No studies specifically addressing effects of ORVs on wildlife in Alaska have been performed (Alaska Department of Fish & Game, 1996; Sinnott, 1990).

Impacts of ORVs on Vegetation

Overview

Direct impacts to vegetation from ORVs include reduction in plant cover, simplification of the vegetation structure, and alteration of the habitat for plant growth. Each of these modes of disturbance may have relatively far-reaching consequences for the natural vegetation of an area, including reducing productivity, changes in species composition, alterations in successional patterns and long term changes in the appearance of the vegetation of an area. The NPS documented conspicuous damage to both vegetation and soils from a single incursion into the Bull River region of Denali NP in 2003 (Roland & Van Horn, 2005). Elements of the plant and soil environment in this region of the Park are apparently susceptible to damage from very limited levels ORV use. Because this area is the site of most of the ORV use that occurs in the Park, we need to understand how this use may impact park ecosystems over time.

Even limited ORV traffic may cause substantial damage to vegetation. In fact, a study by Ahlstrand & Racine in Alaska (1990) showed that the majority of impacts often occur in the first 20 passes of ORVs. The severity of damage usually increases with the amount of passes made by ORVs, although this increase is not necessarily linear, because the level of impact varies among ORV types, soil types, and vegetative growth forms. ORVs abrade, compress, and shear vegetation and soils. Any damage to the roots or the rooting mat kills plants and opens soils to erosion. The cumulative amount of injury to plants is controlled by the amount of traffic, vegetation type and soil stability (Sparrow *et al*., 1978). Severe impact by ORVs results in heavy compaction and/ or slicing of the organic mat that supports plants. Significant surface depression occurs, particularly on wet sites, and the surface can continue to subside even years after the original impact (Alhstrand & Racine, 1990).

Effects on Vegetation

A single track trail of a 4-wheeler (no braids) disturbs about 1 acre of vegetation per mile, while on average, a braided track disturbs an average of 4 acres per mile (Meyer, 2002). Severely impacted areas with a large number of braids disturb much more area than this. The ORV incursion in the Dunkle Hills area of Denali NP that occurred during September 2003 impacted 8,405 m^2 (2.08 acres) of vegetation and soils (Roland & Van Horn, 2005). This footprint is a result of a single incident; future ORV incursions into this area can be expected to similarly expand the amount of affected vegetation. The most obvious impact to vegetation is a decrease in live plant biomass that results from removal or killing of plants by physical contact with the vehicles. An ORV impact assessment in Wrangell- St. Elias National Park & Preserve (Happe *et al*., 1998) reported that plots on trails with active use had 41% less vegetation cover than control plots, while plots on inactive trails had 13% less cover. On active trails, the amount of use the trail received significantly affected the amount of vegetative cover. On inactive trails, however, vegetation cover did not differ between trails with high, medium and low use, indicating that the process of recovery in inactive trails may not be affected by the amount of use. In addition to loss of vegetative cover, vegetation structure (i.e. height plus growth form) was reduced from several strata to principally one layer in ORV impacted areas in this study area. Trails with more use had the most simplified structure of vegetation. Vegetation structure was significantly impacted even by low use, and vegetation structure, and cover, continued to decline as use increased to greater than 50 passes. However, as use increased beyond this point to more than 100 passes per year, there was no further decline in vegetation structure and cover. The authors concluded that moderate use of trails can be equally as damaging to vegetation as heavy use.

The impact of ORV use varies among vegetation types (Happe *et al*., 1998; Wooding & Sparrow, 1978, Roland and Van Horn 2005). Wetlands are extremely sensitive to ORV incursions. Photographs documenting ORV damage within Denali NP made clear that a reduction in vegetative cover is a conspicuous result of even limited use of these vehicles in wetland areas of Broad Pass (Roland and Van Horn 2005). The vegetation types with the most cumulative impacts of ORVs in Wrangell- St. Elias National Park & Preserve are open low shrub-sedge tussock bog and mesic herbaceous vegetation communities. Vegetation recovery was highest in the spruce woodland and low shrub communities, and lowest in the open spruce forest types (Happe *et al*., 1998). The Broad Pass region of Denali NP is predominantly covered by tall willows, herbaceous wetland meadows, and low birch-ericaceous shrub (Roland & Van Horn, 2005); all of these vegetation types are highly susceptible and easily damaged by low levels of ORV travel (Ahlstrand & Racine, 1990; Sparrow *et al*., 1978; Racine & Johnson, 1988).

Individual species show high susceptibility to ORV impacts. Both shrub birch (*Betula glandulosa*) and willows (*Salix* spp.) become severely damaged after minor amounts of traffic (Wooding & Sparrow, 1978; Racine & Johnson, 1988), and 20 passes by an ORV are as detrimental as 300 passes (Ahlstrand & Racine, 1990). Tall shrubs are more vulnerable to damage by ORVs than dwarf shrubs (Sparrow *et al*., 1976). Mat-forming evergreen shrubs such as crowberry (*Empetrum nigrum*) and lingonberry (*Vaccinium vitis-idea*) appear to show the most resilience to ORV travel (Alhstrand & Racine, 1990). However, mountain avens (*Dryas octopetala*), which is one of the most common alpine species, has low resistance to ORV use (Happe *et al*., 1998), and has a long recovery time; ORV tracks through *Dryas* tundra are still visible after 20 years (Everett *et al*., 1985). Sedge tussocks become more damaged as they are driven over by vehicles of increasing weight. Once flattened to the point of being submerged, these plants have difficultly recovering (Sinnott, 1990). Sedge tussocks often take the brunt of ORV impact because they extend above the general surface of the ground. Under low usage, ORV traffic compresses tussocks to half their height; once these tussocks are destroyed, vegetation cover is destroyed and deep ruts will develop (Racine & Johnson, 1988). Herbaceous plants (forbs) are significantly reduced in ORV tracks after light disturbance (Happe *et al*., 1998; Felix & Raynolds, 1989).

Non-vascular species have shown particular sensitivity to ORV disturbance because they are slow-growing and thus have long recovery times. Lichens grow at a rate of a just a few mm per year (B. Sveinbjornsson, pers. comm.). In a study in Wrangell- St. Elias National Park & Preserve, lichens and shrubs were the most sensitive to ORV disturbance followed by mosses and forbs (Happe *et al*., 1998). On dry tundra near Anaktukuk Pass, shrub mats and sedges survived ORV impacts but lichens were severely impacted after a single pass (Ahlstrand *et al*., 1988; Racine & Johnson, 1988). Most mosses are highly affected by ORV disturbance (Felix & Raynolds, 1989).

Graminoids, including cottongrass (*Eriophorum* spp.), other sedges (*Carex* spp.), and grasses (particularly *Calamagrostis* and *Arctagrostis* spp.), were found to be the most resistant to repeated ORV impacts in both south-central Alaska (Ahlstrand & Racine, 1990) and arctic tundra (Chapin & Shaver, 1981; Challinor & Gersper, 1975, Everett *et al*., 1985). This is because these species are rhizomatous and vegetatively expand into disturbed areas once the disturbance stops. This relative resilience translates to a competitive advantage for some graminoid taxa, and the result is often reflected in a change in species composition in areas disturbed by ORVs. In Wrangell- St. Elias National Park & Preserve, graminoid cover was greater in both active and inactive ORV trails relative to the surrounding vegetation, with the exception of heavily impacted trails where all vegetation was completely removed (Happe *et al*., 1998). Even though the relative cover of graminoids increases after disturbance by ORVs, the total number of plant species still decreases, because other growth forms, such as forbs and shrubs, decline sharply in abundance when compared to natural vegetation (Chapin & Shaver, 1981).

Damage to vegetation by ORVs varies seasonally, depending on patterns of precipitation and soil freeze- thaw. During spring melt, tussock sedges are highly vulnerable to ORV damage, because soil under tussocks thaws more quickly than inter-tussock soil. This creates a boundary zone between frozen, impermeable soil and thawed soil; therefore impacts to the protruding tussocks are intensified. Typically, ORV travel is most damaging during periods of high precipitation (Ahlstrand & Racine, 1990; Sparrow *et al.,* 1976). In the Broad Pass area, subsistence use mainly occurs during August and September. At the Denali NP Headquarters, 28% of annual rainfall typically occurs during these two months. In the Matanuska Valley, however, which is climatically more similar to the Broad Pass region, 33% of annual rainfall occurs during August and September. Therefore, the Broad Pass region typically receives significant weather events during these two months, and travel through wetlands during this time is most likely going to increase the amount of damage caused by low and dispersed use. This is illustrated by the ORV incursion that occurred during September of 2003 (Roland & Van Horn, 2005).

Duration of Impacts

The duration of ORV impacts is a crucial component to managing ORV use. The extent of ORV impacts on a trail varies, depending on how great the impact was before the trail was abandoned, and on several environmental variables of the area. These variables include slope, aspect, soil moisture, hydrological regime, soil morphology and vegetation type (Meyer 2002). The passage of a single ORV in some landscapes can leave a visual imprint that lasts indefinitely (Ahlstrand & Racine, 1990; Forbes, 1998). For example, 20 out of 25 plots on ORV trails still showed visible effects of ORVs after being abandoned for 30- 40 years near Barrow, Alaska (Rewa, 2003). This same study also reported that impacted areas had 12 less species of plants than undisturbed areas, although one species, *Bryum cyclophyllum*, was found in the disturbed plots and not in the undisturbed areas. Areas of moderate moisture were the most heavily impacted relative to both dry and wet areas. However the "moderate" moisture reported in this report is most likely analogous to a wetland area, based on the dominant plant species (*Eriophorum angustifolium*, *Eriophorum scheuchzeri*, and *Dupontia fischeri*), all of which are hydrophiles. 20 years later, the test lanes established in 1984 & 1985 in Wrangell- St. Elias NP (Ahlstrand & Racine, 1990) are still visible (D. Rosenkranz, pers. comm.). Impacts from the single ORV incursion in the Dunkle Hills area are expected to be visible for 20 years (Roland & Van Horn, 2005).

The length that ORV impacts are visible is not the same for all plant community types. For example, during 1958 and 1962, ORVs (mainly Weasels) were used heavily in the Ogotoruk Creek basin, in northwestern Alaska (Everett *et al*., 1985). These trails bisected every vegetation type in the region, including *Dryas* steppe and fell fields, sedge wet meadows, sedge tussock meadows, and ericaceous polygons. 20 years later, the authors returned to the area, and reported that vehicle trails were still visible in both alkaline and acidic tundra. The sedge meadows showed much higher recovery in percent cover, although species diversity was reduced to primarily *Eriophorum angustifolium* and *Carex aquatilis* (Everett *et al*., 1985).

The duration of impacts from low or dispersed use on vegetation is also variable. A single pass in shrub vegetation, lichen-dwarf shrub vegetation or wetland sedge meadows may be visible for a year but may subsequently recover (Roland & Van Horn, 2005). However, if the driver makes sharp turns or accelerates recklessly, then the effects of even low use will be more pronounced (Rickard & Brown, 1974; Ahlstrand & Racine, 1990; Sinnott, 1990). ORVs that are used for hunting typically carry more than 1 passenger and/or gear. Successful hunters transport hundreds of pounds of meat, and often pull trailers (Sinnott, 1990). These factors increase the impact and the duration of damage (Alhstrand & Racine, 1990).

Sensitivity of Individual Vegetation Types

Wetlands are particularly susceptible to damage by ORVs (Meyer, 2002; Rickard & Brown, 1974). In wet tundra, trails are extremely visible because standing water fills in the troughs created by ORVs, and even low usage rarely results in no impacts to the vegetation (Racine & Johnson, 1988; Racine, 1979). A common dynamic in areas of even moderate ORV use is the formation of reticulate trail networks. These occur when users spread out and forge new trails to avoid getting stuck in already mucky and damaged trails, resulting in a multiple- tracked footprint up to 100 m wide (Meyer, 2002; Happe *et al*., 1998; Bane, 2001). Therefore, wetlands are both sensitive to ORV damage and typically the magnitude of damage in wetlands is greater than in other vegetation types due to the persistent braiding that occurs once the main trail becomes difficult to travel. Wetlands represent high quality habitat for moose (*Alces alces*) and other large game mammals because these areas consist of large amounts of willow and sedge forage. Hunters focus on accessible areas where populations of game animals are high (Sinnott, 1990). This creates a great potential for wetlands to be invaded by ORV users.

On the other hand, wetlands typically have high recovery rates. In arctic tundra, recovery takes about 20 years after ORV incursions completely cease (Rewa, 2003; Everett *et al*., 1985). The <u>resistance</u> of a plant community to disturbance is not the same as <u>resilience</u> (Walker *et al*., 1987). A resistant community can withstand disturbance without change, whereas a resilient community can return to its pre-disturbance condition after change occurs. Walker *et al*. (1987) also emphasized the difference between a <u>complete recovery</u>, which is a return to the original ecosystem, and a <u>functional recovery</u>, which is when a functional ecosystem develops after disturbance but it differs from the original. The mechanism for recovery in wetlands is most likely vegetation expansion by sedge tillers. Although the vegetation may completely infill the affected area, the microtopography, underlying soils, hydrological pathways, and species of plants may still differ from undisturbed areas (Rewa, 2003). Since the post-disturbance trajectory of vegetation and soils may differ from the pre-disturbance trajectory, a definition of the phrase 'full recovery' should be developed in order to manage ORV usage over the long term. If Park management intends wetlands in Broad Pass to remain in their current state, then the Park should heavily consider the notion that documented outcomes of ORV use on vegetation suggest that these communities have both low resistance (i.e. low use can damage vegetation) and low resilience (i.e. most studies document a change in plant community composition and diversity after ORV disturbance), which means they are more likely to undergo a functional recovery (Ahlstrand & Racine, 1990; Forbes, 1998).

Impacts of ORVs on Soils

<u>Overview</u>

The effects of ORVs on soils are well documented in the literature. Consistently, ORV impacts on soils include abrasion, shearing, compaction, displacement (to the outward edges at curves), soil removal (e.g., erosion or splashing), and horizon mixing (Meyer 2002). The type, severity, and duration of ORV impacts on soils varies, according the physical characteristics of both the soil environment, and to vehicle-user factors, such as vehicle type, driving style and use patterns. Extensive damage occurred to soils after a single incursion into the Bull River region of Denali NP in 2003 (Roland & Van Horn, 2005). The following section provides details on the factors and components of the soil environment, and their interaction with ORV impacts. ORV impacts on soils are not exclusive of impacts on vegetation. There is a large degree of correlation between soil effects and plant effects; areas where this overlap occurs that have already been discussed in this paper will not be fully described in this section.

It is critical to have a solid knowledge of soils because they are the underlying, base material for any ORV trails, and therefore are the most important factor in determining if a trail will be sustainable or not. Soils are shaped by both physical and biotic factors. Physical factors include parent material, particle size, porosity, bulk density, structure, topography and hydrological regime. Biotic factors include soil fauna, microbial communities, and organic inputs from plant and root litters. Soil formation is mediated by the interaction among physical, biotic factors and climate. At high latitudes, such as Alaska, decomposition processes are temperature limited (Hobbie, 1996); therefore, soil develops slowly, and may have a reduced potential for recovery from disturbance. In these ecosystems, the rooting zone is shallow, and exists mostly within the narrow band of the organic horizon, in the top 25 cm of soil. This mat of roots and organic soil stabilizes the soil surface; when removed, the underlying soils are highly vulnerable to erosion (Sparrow, *et al.*, 1978). Because of this, the potential for ORV use to damage soils in these ecosystems is great.

The suitability of soil for ORV exposure is determined by its bearing strength (load capacity) and cohesion (ability to resist displacement); these factors are related to soil texture and moisture level (Meyer, 2002). Finely textured soils are mostly made up of silt, clay and organic matter; these soils have a poor bearing capacity. Alternatively, coarsely textured soils are mostly sand and gravel, and therefore have good drainage characteristics, low shrink-swell potential, and are a much better substrate for ORV travel than finely textured soils (Meyer, 2002). Soil moisture acts as a lubricant and affects the structural stability of the soil. The interaction of soil texture and moisture affects the durability of soil substrates. Finely textured soils store and retain water, which dramatically reduces their load bearing capacity. Soils that are both fine- textured and have high moisture are extremely susceptible to damage by ORVs (Wooding & Sparrow, 1978).

Effects on Soils

The most obvious effect of ORVs on soils is compaction. Compaction is a common result of soil disturbance in both arctic (Gersper & Challinor, 1975; Abele *et al.*, 1984; Rewa, 2003) and interior Alaska (Sparrow *et al.*, 1976; Happe *et al.*, 1998; Alhstrand & Racine, 1990). Compaction is the process by which the pore space in soils is decreased due to physical force, and bulk density of the soil is increased. The result of compaction is a reduced permeability of water and gas, which impairs the ability of roots to function. Soil microbes (mainly bacteria and fungi), are the decomposers in these ecosystems; they release nutrients from dead material and control the amount of nutrients available to plants. Compaction can cause a decrease in sub-surface microbial activity, which could result in increased nitrogen (N) export from the affected area (Torbert & Wood, 1992). Growth of plants is N- limited in Alaska (Hobbie & Chapin, 1998); compaction therefore has the potential to further decrease the nutrient status of plants adjacent to ORV trails. Susceptibility of soils to compaction is dependent upon particle size of the soil, the composition of aggregates (i.e. soils with a variety of particle sizes usually have a lower bulk density), the degree of water saturation, the amount of organic matter, and frozen or unfrozen status. Soil types vary in their susceptibility to compaction; sandy, gravelly or rocky soils are more durable than silty substrates.

Post- disturbance, soil can continue to subside, particularly in wetland areas. In Wrangell- St. Elias NP&P, subsidence occurred for at least two years after being driven over by ORVs in a wet sedge meadow (Ahlstrand & Racine, 1990). Subsidence from compaction can be compounded by multi-year traffic; tire lanes further deepened during the second year of a two year impact treatment. The severity of impact (number of passes of an ORV) directly affects the amount of subsidence and the ability of soil to rebound. These authors observed that 10% of test tracks showed some rebounding of the track depression in the first year; however, all of these tracks had been subject to a 10- or 20-pass treatment. Trails with 50 – 300 passes either did not rebound or continued to subside.

Similar to vegetation, the vulnerability of soil to compaction varies seasonally. Ahlstrand and Racine (1990) found the effects of compaction to be greater when ORV incursions were spaced over a ten-week period during summer, relative to having the same number of passes concentrated into short periods, at either the beginning or end of the snow-free period. Dispersed use over a four month period may therefore have less of an environmental impact in the form of soil compaction than concentrated use within a short season, such as during the month-long moose-hunting season.

Another obvious effect of ORVs on soils is churning. This disturbance has more severe impacts on both soils and vegetation, and depending on the severity of the incident, the duration of the impacts may be long-lasting. Usually the uppermost soil horizons, including the organic horizon and the upper mineral layer, are those impacted by churning (Sparrow *et al.*, 1976 & 1978). Churning can result in increased decomposition rates within the track. The mechanical process of churning exposes soils to warmer temperatures; visibly, soil will look darker and more mucky relative to the undisturbed area (Sparrow, *et al.*, 1976).

Soil erosion has significant implications for landscape-level dynamics, and is a serious concern, particularly on slopes. Erosion is typically a function of slope, soil type, and drainage factors. Even level surfaces can be subject to wind erosion. Compaction of the soil surface can increase erosion, since it reduces the rate of permeability of the soil, and thus a greater amount of water runoff occurs over the surface. Often ORV tracks are more prone to channelized water flow and the subsequent erosion (Sparrow *et al.*, 1976). This can usually result in increased erosion within the track, and altered hydrology down-slope of the trail, if the trail runs across the slope. Erosion of a trail continues to be a disturbance factor after abandonment. Off the Denali Highway, on an abandoned ORV trail located on a 15˚ slope, a ravine developed that was approximately 10' deep and 20-25' wide due to alluvial erosion. In an area where this same abandoned trail had developed into a braided trail, the trail eroded into a channel that was approximately 3' deep and 10-12' wide (Sparrow, *et al.*, 1976). Micro-scale topographic features of the landscape, such as surficial rocks, pits, mounds, permafrost polygons, previous vehicle paths, or rivulet depressions, also influence the directional force of an ORV on soil and vegetation. These micro-variations can affect the capacity of a soil to erode. Wind-blown dust may also affect surface hydrology, soil temperature, and vegetation adjacent to the trail (Walker *et al.*, 1997; Moorhead *et al.*, 1996). Additionally, dust may be picked up and dispersed by wind on ORV trails with exposed soil in dry periods, even in the absence of ORV traffic (Meyer 2002).

Soil that is saturated with water is highly likely to be greatly impacted by ORV use (Meyer, 2002). This particularly includes wetland soils. These soils are unstable and are easily churned into impassible muck holes (Happe *et al.*, 2002, Ahlstrand & Racine, 1990; Sparrow *et al.*, 1978). The effects on soils in wetlands are similar to those on vegetation. These soils are more easily compacted, pushed into ridges, splashed and thrown, and lifted on vehicle tracks and tires (Meyer 2002). As mentioned previously, saturation is usually greatest at spring melt and after significant precipitation events; during these periods, soils are most vulnerable to damage. Permanently saturated soils often have a less resilient root system associated with soft hygrophilous vegetation, and are therefore more susceptible than less saturated soils (Ahlstrand and Racine 1990). Due to the instability of wetland soils, drainage and surface permeability become impeded and a mucky quagmire easily develops (Wooding and Sparrow, 1978). Permanently- or semi-permanently saturated areas of ORV paths become excessively widened through braiding, which is the development of multiple parallel trails. Braids dramatically increase the impacted footprint (Meyer, 2002; Vannice *et al*., 1980; Sinnott, 1990). ORVs can modify the soil surface enough to cause localized damming, which can increase the area of saturated soils and feedback to further soil susceptibility to ORV traffic; or cause channelized water flow and increased erosion (Meyer 2002). Additionally, ORV use in wetlands can cause ponding, both in vehicle tracks and near trails. Ponding can compound the damage caused by ORVs, cause drivers to select parallel paths, and can affect the success and rate of vegetation recovery (Abele *et al.*, 1984). Ponding alters the thermal properties of the soil, increases the depth of thaw and slows the rate of freeze during early winter, which compounds the susceptibility of the soil to ORV damage (Sinnott, 1990). Rewa (2003) found that areas of ORV paths on the North Slope that had sustained ponding still showed significant differences in active layer permafrost depth decades after the traffic had ceased.

On ground underlain by permafrost, the insulating layer of vegetation is critical to maintenance of the active layer thermal regime, and damage to vegetation and soils will initiate a series of changes lasting long after the initial vehicle traffic. Increased depth of thaw in ORV tracks is attributed to damage or removal of the insulating organic mat, compaction of microrelief, and the decreased albedo of tracks. In the early thaw season, active layer permafrost and seasonally frozen soils that are partially thawed may have only a few centimeters of thawed soil above a frozen layer, and this thawed layer is saturated with water. Although this may facilitate a reduction of ORV impact on the lower, frozen part of the soil, it also concentrates the vehicle's forces on a reduced vertical portion of the soil. This results in localized, intense damage to the upper soil layers and the rooting zone of plants (Ahlstrand and Racine 1990).

Well-drained soils with a majority of gravel and rock are the most suitable soils for ORV trails (Meyer, 2002). These soils are the least affected and are the most sustainable, and trails on these soils are less likely to become braided. A trade-off exists between vegetation and soils in choosing the best route for an ORV trail, because well drained, stable soils are often covered in dwarf birch and willow vegetation, which is easily killed by ORVs. However, a trail through these soils is unlikely to become churned and braided (Happe, *et al.*, 1998), making these areas a good option for sustainability. The most suitable areas for ORV trails in Denali NP are on gravel river bars, which are highly resistant to ORV impacts (Meyer, 2002).

We compared studies in permafrosted tundra on the north slope (Abele *et al.*, 1984; Gersper & Challinor, 1975; Forbes, 1998; Rewa, 2003) with a study conducted in Big Cypress National Preserve (BICY) in Florida (Duever, *et al.*, 1986). BICY contains mixed hardwood swamps, mangroves, marshes, pinelands, and supports an highly diverse number of plant and animal taxa. Although the climate, mean annual temperature, annual rainfall, permafrost regime (or lack thereof), and a host of other factors varies between the two areas, the duration of ORV trails in heavily impacted wetlands did not. Trails with the greatest amount of damage did not recover, while trails with light damage did. Because recovery did not vary across this extreme climatic and latitudinal gradient, we suggest that heavily impacted ORV trails will also be slow to recover in Denali NP and the Broad Pass area.

Impacts on Wildlife

ORVs potentially have a large effect on wildlife populations, although this has not been specifically studied in Alaska (Sinnott, 1990). Studies in the contiguous 48 states have shown that ORVs alter habitat, can harass animals and can scare animals away from their typical range area (Sinnott, 1990). In Alaska, ORVs are used extensively for hunting (ADFG, 1996). Therefore ORV users will be deliberately seeking out animals, which increases the potential and likelihood for ORVs to negatively effect wildlife.

Loss of habitat is probably the most far-reaching effect of ORV use on wildlife. As written previously, wetland areas can experience significant loss of vegetation after just 1 pass of an ORV; on a single track, up to 1 acre per mile of habitat can be impacted (Meyer, 2002). The primary large game species in wetland habitats is moose. Depending on the population size of these animals, losing an acre per mile of forage may be a significant stressor to moose. The effect of ORVs on vegetation in both alpine and arctic tundra has been described. These areas are habitat for caribou, and a habitat loss of an acre per mile could also detrimentally effect these species. Caribou calve in early summer; if calving grounds experience a significant loss of forage, this could have a negative effect on survival of both cows and calves. Any impact on large ungulates has potential negative feedback effects on predator species, particularly wolves and bears. If ORV trails are located in areas where the vegetation can sustain impact without injury, then the loss of habitat for wildlife will be minimized. In areas where ORV trails cross or run adjacent to streams, sedimentation from trails can cause runoff, which could impact fish habitat (ADFG, 1996).

Hunters concentrate on areas where moose or caribou congregate when hunting (Sinnott, 1990). These areas therefore have a greater potential to experience the adverse impacts of ORVs. Additionally, use of ORVs expands the area a hunter can access to seek out game, and overall, can increase hunting pressure on a game population to a level where it is detrimental to its long term success (Sinnott, 1990). When this occurs, the Alaska Department of Fish and Game (ADFG) often closes that area to ORV use for hunting. This is further discussed in the section on management by other agencies. Areas where populations are concentrated, such as near salt licks or watering holes, are particularly vulnerable to vehicle disruptions.

Noise and related ORV activity can cause animals to move away from ORV traffic. Complaints on this issue have been made in Alaska to the ADFG (ADFG, 1996). In other states, concentrations of large mammals are often inversely proportional to road proximity or traffic intensity (Sinnott, 1990). Hunting from or near ORV trails is also likely to reinforce avoidance of these areas by animals, as is the noise produced by gunfire (Sinnott, 1990). On Ft. Richardson Military Base near Anchorage, Alaska, moose are negatively affected by noise from snowmobiles at 85-90 db; and grizzly bears will alter their behaviour at approximately 80 db (Vannice *et al.*, 1980). Most small wheeled ORVs that are popular have similar noise levels. Noise and other signs of vehicle traffic, even in areas not directly adjacent to ORV trails, may disturb avian species enough to cause nest abandonment (Sinnott 1990). The Palmer Hay Flats State Game Refuge (Game Management Unit 14A), a wetland area located in south-central Alaska, has experienced extensive damage by ORVs, and may have experienced loss of nesting and brooding cover (ADFG, 1996). This area is similar to the Broad Pass region of Denali NP; the projected impacts of ORVs in Broad Pass may be similar to those observed in this area. Extensive trail damage on shorelines can destroy sensitive shorebird habitat, as well as cause hydrological changes in surface water flow, which could further impact shorebirds and riparian zone species (ADF&G 1996).

Harassment of moose by ORVs is a concern of the ADFG (ADFG, 1996). In Unit 9, in southwestern Alaska, hunters have complained that displacement of moose by ORVs makes them more difficult or impossible to locate in areas formerly used for hunting. In Unit 18, in western Alaska, illegal chasing of muskoxen, caribou, and other animals to exhaustion for hunting is a common practice. ADFG officials have found several moose that were shot and never recovered in Unit 5, in the Yakutat area.

Impacts on the Ecosystem

The effects of ORVs at the ecosystem level are not clear. Whether or not ORVs can cause enough damage to alter the landscape, or landscape processes, at the ecosystem level is unknown. The following discussion describes the potential effects of ORVs on the whole ecosystem.

The hydrology of an area is a critical feature. The amount of water, and the pathways through which water flows, both at the surficial and sub-surface level, controls the habitat type, and thus the animal communities, that can exist in a given location. Linear trails can alter the hydrological paths of the area, particularly if they cut directly across slopes. ORV impacts include reduced percolation of water into the soil, and a loss of water-holding capacity (Meyer, 2002). Water can pool in ORV trails and be diverted along the trail, instead of flowing directly down-slope as it would on an undisturbed surface. If this occurs, the down-slope communities may experience a drought, which in the long term may change that community to one that can tolerate increased aridity.

Low exposure to ORVs (down to one pass) can crush standing dead plant litter, which releases nutrients, fertilizes new growth and results in a green bands of vegetation that stand out from the surrounding plants (Abele *et al*., 1984; Brown, 1974; Ahlstrand & Racine, 1990). These bands are highly visible and may also have a different species composition than what would exist in the absence of ORVs (Sinnott, 1990). Even a small amount of ORV traffic can tear the organic mat, depending on how the driver handles the machine (Ahlstrand & Racine, 1990). This physical damage can result in loss of organic soils and exposure of mineral soils. A disturbance that is large enough to cause removal of vegetation and plant litter will result in bare patches that contain less substrate for decomposition. Decomposition of litter in Alaska is limited by cold annual temperatures and the short growing season (Nadelhoffer *et al*., 1991); this results in low levels of soil nutrients available to plants during the growing season. Even dispersed amounts of ORV use across a landscape will likely result in areas of exposed soil, where litter inputs will be decreased and may lead to increased patchiness of soil- available nutrients to plants. Over the long term, this could lead to increased, unnatural heterogeneity of plant form over the landscape in relation to ORV trails. This alteration in patch dynamics could effect habitats for terrestrial herbivores (Forbes *et al.,* 1999). Impacts to vegetation and soils subsequently affects surface albedo and energy exchange, which can change the thermal regime of soils (Slaughter *et al*., 1990). While thermal effects are larger in permafrosted ecosystems, they may also effect sub-arctic and wetland ecosystems.

Moose exert control on riparian ecosystems in Alaska through herbivory. Browsing opens the canopy, warms, and dries soils. This causes a variety of changes, including increased pH, increased nutrient turnover, causes a decrease in the fine roots of plants, and affects the abundance and types of insects living in the understory (Kielland & Bryant, 1998). Wetland areas, particularly tall willow stands, are high quality habitat for moose. ORVs have a potential interaction with the dynamic between moose and the landscape, if high amounts of noise disturb moose and drive them out of these areas, or if ORVs cause increased hunting pressure, and reduced moose populations. However, whether or not ORVs can influence moose or the ecosystem at this level is unknown.

Trail corridors often become conduits for dispersal of exotic plant species (Benninger- Truax *et al*., 1992). ORV tires become a method of seed dispersal, and ORVs that drive over and through seeds of exotic plants, such as the dandelion, *Taraxacum officinale*, can increase the rate of invasion by exotic plants. The risk of ORVs as a vector for exotic plants has not been studied in Alaska.

ORV management, monitoring and assessment work by other agencies in Alaska

By the 1970's, multiple agencies in Alaska acknowledged that unrestricted use of ORVs was a growing problem. In 1988, 16 fish and wildlife agencies from the U.S.A. and Canada responded to a survey on ORVs conducted by the Alaska Department of Fish and Game (ADFG); all of the participants expressed concerns over ORV usage and management in their respective lands (Sinnott, 1990). Currently, ORV trails exist in nearly all of the major land management agency units in Alaska, varying from minor to severely degraded and braided trails (Bane, 2001). Management of ORVs varies among different land management entities. A summary of policy and actions among selected individual units follows.

Other Park units in Alaska have focused on inventorying and assessing ORV trails, particularly in Wrangell- St. Elias (Happe *et al.*, 1998; Ahlstrand & Racine, 1990) and in Gates of the Arctic (Racine & Johnson, 1988; Ahlstrand *et al.*, 1988). Most parks restrict ORV use to existing trails, although enforcement is difficult. Some parks, such as Wrangell- St. Elias, require permits for ORV use, although this is also difficult to enforce.

The State of Alaska in general is lenient to ORV users. The official policy (11 AAC 96.020; http://www.dnr.state.ak.us/mlw/factsht/gen_allow_use.pdf) allows the use of ORVs up to 1,500 pounds on state land, as long as it doesn't cause or accelerate degradation of water quality, alter drainage systems, or cause significant ground disturbance, rutting or thermal erosion. The conditions for generally allowed uses are listed in 11 AAC 96.025 and are as follows: wheeled or tracked vehicles must be operated so that surface damage, disturbance of vegetation, soil stability and drainage systems is minimized; changing, polluting or introducing of silt and sediment into watercourses of any sort is minimized; and disturbance of fish and wildlife is minimized. Additionally vehicles must use existing roads and trails when possible (http://www.dnr.state.ak.us/mlw/factsht/gen_allow_use.pdf). The Department of Natural Resources, however, rarely enforces this policy (Sinnott, 1990). State parks, on the other hand, are more restrictive, although policies vary among parks. For example, in Denali State Park, ORVs are restricted to maintained roads and parking areas, and are not allowed on trails. In the Chugach State Park, ORV users are restricted to two trails. In the Chena State Recreation Area, ORVs are allowed on designated trails and in areas specifically designated for their use.

The Alaska Department of Fish and Game (ADFG) recognized the general negative impacts of ORV use on vegetation, soils, wildlife, and non-ORV users (particularly hunters) throughout Alaska by the early 1990's. The State of Alaska Board of Game (BOG) can legally limit ORV use as a means and method of hunting, trapping and transporting hunters and game when these activities cause or are likely to cause the following:

1. Soil erosion or compaction, or vegetation changes that affect wildlife habitat, distribution, or abundance;
2. Harvest levels that affect the condition, abundance or trophy size adverse to management goals;
3. Wildlife disturbance;
4. Chronic conflicts with other human user groups (ADFG 1996).

ADGF and the BOG have 9 areas in Alaska where the use of ORVs are prohibited in order to protect habitat in game refuges, critical habitat areas and game sanctuaries. It is interesting to note that ADFG has prohibited the use of ORVs for hunting purposes in parts of Game Management Unit 20A, located directly east of Denali National Park. Additionally, land adjacent to the Denali Highway in the Clearwater Creek Controlled Use Area is closed to ORVs for hunting (ADFG, 2004). These actions were taken because of concerns of both ADFG and the public that this area had unacceptable levels of ORV use, resulting in significantly reduced abundance of large game animals (Sinnott, 1990). In 1996, ADFG reported that Unit 13E, which includes Broad Pass east of the Park boundary, experienced heavy use by ORVs, to the point where some trails resembled dirt roads, and trails were continuing to expand yearly (ADFG, 1996). ADFG has conducted inventory and assessment of trails in the lower Kenai Peninsula, the Matanuska- Susitna Borough, and the Yakutat Forelands. Besides the actions just described, ADFG has done little else on ORV use (E. Simpson, pers. comm.).

The BLM in Alaska has made several efforts to manage ORV use on BLM lands. Personnel at the Steese National Conservation Area (SNCA) and the White Mountains National Recreation Area (WMNRA) have conducted inventory of trails through aerial and ground-based surveys. They have closed some trails with high levels of unsustainable use and re-routed trails in some heavily damaged areas. They have implemented trail mitigation in places, including using Geo-block materials, and run-out zones. The WMNRA performs photo monitoring of sites to document recovery of damaged areas (R. Goodwin, pers. comm.). Neither district has conducted much scientific research into the duration of ORV impacts to soils and vegetation; mostly because of logistical constraints. One issue with trail mitigation is that some ORV users prefer trails to be muddy and braided, because they prevent less-persistent users from accessing areas that are farther out (H. McClain, pers. comm.).

The Glennallen District of BLM addresses ORVs in their General Management Plan, which is currently in review. The preferred alternative under this plan will restrict ORVs to currently existing trails on State statute lands, and will allow BLM to designate trails with signs and maps for ORV use on Federal statute lands (T. Larzelere, pers. comm.). The Glennallen district has not conducted any long term work on the duration of ORV impacts. During 2001- 2002, they conducted aerial and foot inventories of existing trails (Bruehler & Sondergaard, 2004). Their current policy is to restrict ORVs to trails, particularly in the Tangle Lakes Archaeological District. They have also re-routed some badly damaged segments of trail to areas with well drained ground, and have seeded closed sections of trail with native seed to promote recovery (T. Larzelere, pers. comm.). This office employs 1 ranger to help enforce their ORV policy.

The U.S. Forest Service (USFS) has also enacted regulation of ORVs. The Chugach National Forest restricts ORV use to roads in developed areas, has some areas that are closed to ORVs while other areas are completely open to ORV use (http://www.fs.fed.us/r10/chugach/). The USFS prohibits operating ORVs in a manner that disturbs land, wildlife or habitat or damages roads or trails (Sinnott, 1990). ORVs are prohibited from wilderness or primitive areas.

U.S. Army bases in Alaska have restricted ORV use within their boundaries. In 1980, Fort Richardson published a report admitting that ORV use on base was a problem that could not be ignored. Fort Richardson was mandated to provide for ORV recreation (Executive Orders 11644, 11989 and AR 210-9) when compatible with resource management and requirements for military training (Vannice *et al.*, 1980). Unrestricted access caused damage to soils and vegetation, and produced illegal trails; these actions were the motivating factor for a restrictive policy on ORVs. Fort Richardson classifies "fragile natural areas" as areas highly vulnerable to excessive damage by ORVs: these include alpine and subalpine areas, wetlands and stream banks. Currently Fort Richardson limits ORVs to existing trails, and users must obtain a recreation permit. Fort Wainwright Army base also has restrictions on ORV use (http://www.usarak.army.mil/conservation/images/recreation/FWA_FGA/supplement0304.doc). ORVs and users must have a permit issued by the Base and must check in to areas of the base by telephone prior to entry. Additionally, several areas on base are prohibited to ORV users.

Agencies in the contiguous 48 states have dealt with increasing impacts by ORV users and pressures from both ORV and non-ORV users to manage the issue. In many cases, the minority of the user group causes the majority of the management issues. Currently, efforts are being made to educate users on responsible and ethical use of ORVs, and to encourage users to stay on designated trails (http://www.arra-access.com, http://www.nohvcc.org). This focus comes from both management agencies and ORV interest groups. In October 2004, Dale Bosworth, Chief of the USFS, named unmanaged motorized recreation one of the four key threats to USFS lands. The current, nationwide, position of the USFS is to begin to limit the use of ORVs to designated trails (http://www.fs.fed.us/publications/policy-analysis/unmanaged-recreation-position-paper.pdf). In this document, the USFS states it has taken this position because

> "Another trend is the uncontrolled proliferation of trails arising from repeated cross-country forays by OHV traffic. Unauthorized trails from motorized use cause much of the natural resource damage and some of the public safety concerns on national forests".

The USFS addresses this topic in its strategic plan, which is under review (USFS, 2003). Currently, individual forests dictate policy on ORVs within their jurisdiction. The FS also acknowledges that unregulated ORV use results in unplanned roads and trails, watershed and habitat degradation, negative effects on wild animals, soil compaction and erosion, and that riparian areas are particularly vulnerable to ORVs (USFS, 2004). The Bureau of Land Management also recognizes that ORVs represent a national management issue. BLM has taken similar steps to the USFS, which are detailed in their national management strategy plan (BLM, 2001). ORV policy is still set at the level of the individual management district, however. Another national trend in ORV management is to designate areas specifically for ORV use and areas where ORVs are prohibited. This stratified management tactic provides the recreational opportunity for ORV use cross-country, while localizing the environmental impact to one area (Andrews & Nowak, 1980). Multiple units within both the BLM and the USFS, and at the state level use this method to manage ORV use.

ORV use is widespread in the NPS. Based on a survey conducted on 108 National Parks in 1999, 56 units have ORV use taking place within them, although only 23 Parks officially allow ORV use (Long *et al.*, 1999). Although multiple documents exist reporting ORV use and environmental impacts in these NPS units, we could not find any studies that examined the duration of these impacts. The long-term prognosis of natural areas within parks, after ORV incursions, is therefore unknown. Nationwide, few NPS units have such extensive impacts as Big Cypress National Preserve (BICY) in Florida. Unregulated ORV use in BICY resulted in over 22,000 miles of trails, many through fragile wetland areas (Wilkinson, 2001). After being sued by several environmental organizations, BICY began a regulated, permit-based trail system (http://www.nps.gov/bicy/newrules.htm; http://data2.itc.nps.gov/parks/bicy/pppressreleases/rod.htm), and increased regular ranger patrols (Wilkinson, 2001) to enforce ORV regulations. BICY was then sued by vehicle advocates in opposition to BICY's plan to close parts of the preserve to ORV use. In 2005, the federal court supported the preserve's legal right to restrict ORVs (http://www.eenews.net/Greenwire/include/print.php?single=02240516).

Concerns of ORV use specific to Broad Pass

The region is transitional between a continental and maritime climate and comprises a unique ecoregion in Denali NP. In Broad Pass, many plant species reach the northernmost extent of their distribution; and this region also functions as a dispersal corridor between Cook Inlet and the Interior of the state (Roland, 2004). The majority of Denali NP has a continental climate because the Alaska Range is a major biogeographic barrier. Although many of the plant taxa in Broad Pass are globally secure, they may be locally rare in Denali. The wetlands that occur in this region are also of this nature, because their distribution in Denali is limited to this area (Roland and Van Horn, 2005). Non-vascular plants (lichens, liverworts and mosses) are highly sensitive to disturbance by ORVs (Happe *et al.*, 1998; Felix and Reynolds 1989). To date, the diversity and distribution of non-vascular species has not been inventoried and is unknown in Denali NP, although we suspect that a significant portion of the Park's non-vascular diversity is located in the Broad Pass area (J. Walton, pers. comm.). The wetlands in this region also may represent significant habitat for birds. An avian inventory, however, has not been performed in this region, and the diversity and species richness of birds in this region is not known. ORVs have a high potential to disturb or increase the mortality rate of birds through habitat destruction (especially along shorelines) and through disturbance caused by loud noises (Sinnott, 1990; Vannice *et al.*, 1980; Long *et al.*, 1999). The potential for

ORVs to significantly affect both birds and non-vascular plants in this region is great, although the actual magnitude of the threat is unknown due to a lack of baseline data.

The wetlands in Broad Pass represent high quality habitat for moose, which may be why they are of such interest to hunters. Since subsistence users on ORVs are more likely to hunt in areas where moose congregate, the potential that these areas will be affected by ORVs is high. The damage caused by hunters in September of 2003 in the wetlands of this region demonstrates that low and dispersed use is damaging to soils, vegetation, and therefore habitat (Roland & Van Horn, 2005). If incursions of this nature continue each year in a dispersed manner in these wetlands, the amount of damage incurred each year may exceed the amount that land can recover each year, with the end result of large scale destruction of these areas. Based on the information collected in this literature review and the field data collected during the 2003 and 2004 assessments in the Dunkle Hills, we suggest that ORV will not be sustainable across these wetland areas unless:

1. ORV use is limited and dispersed throughout wetlands, and
2. Park management allows up to 20 years for wetland areas to recover;
3. Park management accepts the potential for these ecosystems to undergo a functional recovery (Walker *et al.*, 1987), with the end result being a visible change in cover of the dominant plant species and in species diversity.

Further, the literature suggests that sustainable ORV trails are those that are routed through vegetation and soils that are proven through previous research and assessment to be more sustainable. This includes well drained soils with a higher percentage of sand and gravel (Meyer, 2002), and plant communities that are more likely to be resilient to ORV impacts (i.e. unlikely to cause braiding of trails), such as dwarf shrub and open forest communities. Because open forest is rare in this region, we suggest that well- drained areas occupied by shrub birch be examined for their sustainability to ORV use.

Conclusion

The damage inflicted by ORV use on the natural landscape has been well documented, even in Alaska. Most agencies are formulating plans to manage ORV use within their units. Some vegetation and soil types are more resilient than others, and research in Broad Pass that assesses the suitability of each ecological unit in this region should be conducted prior to large-scale use by ORVs. The duration of impacts varies greatly, and, in the literature, is mostly documented in arctic areas. 20 years later, the test lanes established in 1984 & 1985 in Wrangell- St. Elias NP (Ahlstrand & Racine, 1990) are still visible. The potential for similar visible scarring to the landscape in Broad Pass is great, and therefore a careful scrutiny of the physiography of the region is needed by Park management.

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