

**A LITERATURE REVIEW OF THE EFFECTS OF
OFF-ROAD VEHICLES ON DESERT BIOTA,
WITH EMPHASIS ON UTAH BLM LANDS**

Submitted to:

The Southern Utah Wilderness Alliance

Submitted by:

**Allison Jones,
Conservation Biologist
The Wild Utah Project**

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0. INTRODUCTION

To produce this comprehensive literature review on the effects of off-road vehicles (ORVs) on the desert biota of Utah's BLM lands, I searched eleven ecological and biological data bases, including the ORV data base provided by the Wildlands Center for Preventing Roads, and I consulted with 14 regional scientists and researchers who have conducted studies on this topic.

Though I aimed to focus my literature search on Utah and BLM studies, it is important to present the existing evidence that ORVs are deleterious to desert plants and animals. This body of literature is extensive and undisputed, and is generally reviewed in Section 1. Section 2 focuses on a few of Utah's "flagship" species (all of which are federally listed species or candidates for federal listing) that are known to suffer various effects of ORV use. Section 3 addresses other ORV impact studies performed in Utah, though these studies focus on resources other than federally listed species. The review closes with Section 4 which describes BLM-authored studies that document ORV effects on desert systems and animals.

4.0 GENERAL EFFECTS OF ORVS ON DESERT SYSTEMS

Physical and biological effects of ORVs range from reduction of soil stability to destruction of vegetation, wild animals, and their habitat. The capability of modern ORVs to damage the environment varies according to vehicle design and operation, but it is not possible to drive vehicles on natural terrain that has a soil cover without causing damage, no matter how careful the vehicle operator.

The least surface disturbance is caused when vehicles are driven slowly in a straight line on a dry, firm surface. Under these conditions, typical motorcycles will impact one (cumulative) acre in 20 miles of travel, and ATVs and sport utility vehicles (SUVs) will do the same in only 6 miles. Damage is incurred much more rapidly under conditions of high speed on erratic courses, and on terrain that is more susceptible to erosion (Wilshire 1977, 1992).

Physical Impacts of ORVs

Initial physical impacts of ORVs result in stripping the surface of small plants and mechanical crusts, which stabilize the soil (Wilshire 1983, Belnap 1995). At the same time that the land is denuded, soils are compacted. Maximum compaction of typical sandy loam soils of western arid lands is attained in only 10 passes of a motorcycle on a dry, level surface (Webb 1983). Soil compaction takes place in a cylinder beneath the tracks, reaching depths of 30 cm, and soil loosening (by shear) takes place in shallow

zones on both sides of the cylinder of compaction. Loss of the insulating effects of plant cover and changes in the heat capacity of compacted soils causes soil temperatures to increase by as much as 10° C in daytime and decrease by as much as 3° C in nighttime (Webb et al. 1978, Wilshire et al. 1978). Soil compaction further reduces infiltration of water, resulting in ponding in tracks and rapid evaporation, or shedding of incident precipitation by runoff. Either way, the shallow subsurface soil biota are denied their normal moisture supply. As with soil compaction, the reduction of infiltration rates quickly reaches a maximum after only 10 or so passes of a motorcycle (Webb 1983).

Most southwest desert soils are susceptible to the above documented effects of ORVs. The USGS conducted an 18 month study on 200 ORV sites in California, Utah and Nevada, and found that all soil types examined were vulnerable to ORV damage, except certain dry lake deposits and clay rich soils with <10% slopes (CEQ 1979).

Erosion of soil is accelerated in ORV use areas directly by the vehicles and indirectly by increased runoff of precipitation, and by creating conditions favorable to wind erosion (Wilshire 1980). Knobby and cup-shaped protrusions from ORV tires that aid the vehicles in traversing steep slopes are responsible for major direct erosional losses of soil. As the tire protrusions dig into the soil, forces far exceeding the strength of the soil are exerted to allow the vehicles to climb slopes. The result is that the soil (and any small plants) is thrown downslope in a "rooster tail" behind the vehicle. This is known as mechanical erosion, which on steep slopes (about 15° or more) with soft soils may erode as much as 40 tons of soil per mile of travel (Wilshire 1992). Erosion is also greatly accelerated by rainfall and wind action on surfaces stripped by ORVs. Common soil types in western U.S. arid lands erode readily when stripped of plant cover. Use of slopes with more resilient soils commonly results in gullyng of adjacent unimpacted areas to which runoff from the trails is diverted, or scouring and enlargement of downstream parts of the drainage basin due to increased volume of water (Wilshire 1992). The rates of erosion measured in ORV trails on moderate slopes exceed natural rates by factors of 10 to 20 (Iverson et al. 1981, Hinckley et al. 1983), whereas use of steep slopes has commonly removed the entire soil mantle, exposing bedrock. Measured erosional losses in ORV areas range from 1.4-242 pounds/ft² (Wilshire et al. 1978) and 102-614 pounds/ft² (Webb et al. 1978). Ultimately, increased erosion caused by ORV use can lead to increased siltation in nearby streams (Wilshire and Nakata 1976).

In his book *Deserts on the March*, Paul Sears observed that "soil in place is our friend, and soil on the move our enemy" (personal communication with Howard Wilshire). Indeed, sediment yielded by erosion of ORV use areas may be redeposited in the immediate area where it buries vegetation and the more fertile upper soil layer of undamaged soils, thus extending the damage. Smaller sediment particles can be carried long distances by running water, and subsequently pollute that same water. Wind-borne dust from ORV areas at times has produced dust plumes visible from space (Nakata et al. 1976). Dust exacerbates respiratory ailments in humans and domestic animals, and may have a deleterious effect on wildlife (Saint-Amand et al. 1986, Wilshire et al. 1981). More serious consequences may arise from spread of diseases endemic in arid land soils, such as valley fever (Medical World News 1978, Wilshire et al. 1996).

Impacts of ORVs on Desert Biota

Vehicular impacts on vegetation range from complete denudation of large staging areas to selective kill-off of the most sensitive plants. Ultimately, web-like networks of ORV trails coalesce into broad areas largely denuded of vegetation. Large shrubs and trees 15-20 feet tall have been destroyed by root exposure caused by adjacent ORV traffic, and at one locality 10-foot junipers were destroyed by direct impact (personal communication with Howard Wilshire). Seedlings, and seeds germinating within the ground, are some of the most sensitive organisms to ORVs and are easily killed outright or buried (Bury 1977, CEQ 1979). Indirect impacts on young plants include the upsetting of water storage, soil infiltration rates, and thermal structure of soils; these are all ORV related deficiencies that can disrupt seed germination and seedling growth (Davidson and Fox 1974).

Few detailed studies have been made of the effects of ORV soil compaction on plant form and function. Such studies of human trampling and of single passes of tanks on maneuver in the Mojave Desert, however, show that such effects are certain to occur (D. Prose, unpublished data). Prose's detailed studies of annual plants show long-term effects of both soil compaction and surface disturbance caused by a single pass of a tank on typical Mojave Desert soil. These effects include larger numbers of annual plant species growing within tracks compared to adjacent undisturbed areas, but the plants in the tracks are much smaller and provide less cover for the soil than individuals of the same plant species in control areas. Further, the species composition shifts so that annual plants with lateral root spreading grow more easily within the tracks than those with vertical tap roots, because a veneer of sediment accumulates in the track depressions resting on a zone of compacted soil less than a centimeter below the surface.

ORVs can have disastrous effects on cryptobiotic crusts. Cryptobiotic crusts, which were historically widespread in western U.S. arid lands, are being rapidly depleted across rangelands today. These crusts increase the stability of otherwise easily erodible soils, increase water infiltration in a region that receives limited precipitation, and increase fertility of soils often limited in essential nutrients such as Nitrogen and Carbon (Johansen 1993, Belnap et al. 1994). ORVs are highly destructive to these fragile cryptobiotic crusts that exist within many BLM lands. A single pass of an ORV through cryptobiotic crusts will increase wind and water erosion of surface soils that were previously protected by the crusts (personal communication with Howard Wilshire). This in turn can trigger rapid loss of the underlying topsoil, which can take up to 5,000 years to naturally reform in arid regions such as those that typify Utah BLM lands (Webb 1983). The destruction of cryptobiotic soils by ORVs can reduce nitrogen fixation by cyanobacteria, and set the nitrogen economy of these nitrogen-limited arid ecosystems back decades. Even small reductions in crusts can lead to diminished productivity and health of the associated plant community, with cascading effects on plant consumers (Davidson et al. 1996). In general, the deleterious effects of ORV use on cryptobiotic crusts is not easily repaired or regenerated. The recovery time for the lichen component of crusts has been estimated at about 45 years (Belnap 1993). At this time the crusts may appear to have regenerated to the untrained eye. However, careful observation will reveal that the 45 year-old crusts will not have recovered their moss component, which will take an additional 200 years to fully come back (Belnap and Gillette 1997).

Additionally, radical reduction of soil biota, including bacteria and fungi, results from compaction. Soil microorganisms in desert soils exposed to ORV use are typically reduced from about 4 to less than 1 million/g, which in turn reduces bacterial oxidation that forms nitrates available to plants (Liddle 1997). A severe loss of nitrates to plants is significant in typically Nitrogen poor arid environments, and may even eventually lead to desertification (Belnap 1995).

Effects of ORVs on wildlife are extensive and well-documented. ORV use can lead to reduced density and diversity of small mammal populations (Bury 1977, BLM 1978, CEQ 1979, Liddle 1997). Often this effect on mammals can be attributed to a reduction in plant diversity, simplification of plant structure, and reduction in ground cover, all of which are results of ORV activity (CEQ 1979). Also, harassment of wildlife may place a considerable energy strain on wildlife, both due to general stress, and due to attempts to escape harassment (Bury 1977). For example, ORVs can disturb animals to the point that wildlife will change their activity patterns or foraging sites in the vicinity of "play areas," and at the times of day when recreation is at its peak (EDF 1995). A study of bird behavior in the Mojave desert showed that most birds left the area on Friday afternoons when ORVs began to arrive (personal communication, Howard Wilshire). Surprisingly they did not return as soon as the weekend fun-seekers left, but waited until the following Thursday. Thus, the 2-day presence of ORVs was sufficient to drive off much of the bird population for 5 days.

During winter and daytime hours in hot, desert weather most animals (with the exception of birds and larger mammals) seek shelter below ground or beneath or within objects resting on the surface. Included are mice, kangaroo rats (*Dipodomys* spp.), ground squirrels, lizards, snakes, desert tortoise (*Gopherus agassizii*), amphibians, soil-nesting insects, spiders, and other arthropods. At such times, the biomass of all these sequestered animals, including eggs in developmental stages, might approach 80 to 90 percent of the total biomass of animals in an area, and perhaps 75 percent of the biomass would be located between the surface and a depth of one foot. Their shelters and burrows are fragile. How much life expires beneath the wheels of ORVs is not known, but the figure must be staggering. A study of small mammal populations in the start area of the 1974 annual Barstow-Vegas race was made before and after the event, with a follow-up study one year later (BLM 1975, Hicks 1976). Major reduction in numbers of mammals was measured immediately after the race, and densities of small mammals in the start area one year later were found to be as much as 8 times lower than in nearby control areas (Hicks 1976). This indicated a significant reduction in habitat quality due to the ORV event.

Other studies have documented the deleterious effects of ORV noise on desert animals (Brattstrom and Bondello, 1983). For example, the sensitive hearing systems of kangaroo rats can be impaired for weeks by exposure to motorcycle noise, thus making them vulnerable to predators. Couch's spadefoot toad (*Scaphiopus couchi*) can burrow to depths of 20 inches, thereby escaping the environmental extremes of the desert surface. This animal emerges from its burrow with the first summer thunderstorms and individuals gather at pools where mating occurs. The timing of emergence during thunderstorms is of critical importance to reproductive success, because the supply of body moisture is insufficient for the animals to return to deep burrows in the absence of rainwater. The trigger that identifies

approaching rain apparently is the sound of thunder, a sound simulated closely enough by dune buggies to encourage emergence and certain death (Brattstrom and Bondello 1983).

There is yet another way that ORVs can impact wildlife habitat, though rather indirectly. This is through the dispersal of weed seeds that can attach and ride on ORVs. Vehicles, through the tracks left behind, can also create seedbeds for weeds, thus further promoting their dispersal. This can in turn facilitate the spread of exotic weeds which often outcompete the native flora. More than 50% of the west, including Utah, is now dominated by alien weeds, and greater than 300,000 acres of habitat are irrevocably converted to alien annual grasslands each year (Belnap 1998). The grass that has been the main culprit in this virtual type conversion on western rangelands is cheatgrass (*Bromus tectorum*) which, because of its tolerance to both grazing and fire, has taken over millions of hectares of shrub steppe vegetation in the Great Basin (Billings 1990, D'Antonio and Vitousek 1992). Weeds are a major management issue on public lands throughout the west because of often profound impacts on floral and faunal diversity (Kummerow 1992). The effects of habitat conversion to exotic annual grasslands can radiate up through food chains; such adverse effects have been documented on pronghorn (*Antilocapra americana*), deer (*Odocoileus* spp.), small vertebrates, native birds and insects (Davidson et al. 1996). It is certainly not a stretch to assume that many of Utah's state and federally listed species are negatively affected by this weed epidemic as well.

2.0 SPECIFIC IMPACTS OF ORVS ON UTAH'S FEDERALLY LISTED AND CANDIDATE SPECIES

Any literature review that focuses on biota will also pay close attention to federally listed, and candidate, species. This is because these are the species that most biologists and land managers are most interested in reading about, and (not coincidentally) the species that have been studied most carefully.

Desert Tortoise

The Desert tortoise (*Gopherus agassizii*) was federally listed as a threatened species in 1990, and is currently known only in the southwest corner of Utah where the Mojave desert enters the state. A particularly long-lived and slowly reproducing species, the desert tortoise is quite sensitive to a variety of human influences.

At the time of listing and writing of the recovery plan, the U.S. Fish and Wildlife Service (USFWS) reported that tortoise declines in the Mojave region could be attributed to both habitat degradation, and injury and death by motor vehicles (USFWS 1994a). Clearly, these two factors directly implicate ORVs in the tortoise's decline that precipitated the listing process. In fact, ORV activities are among the most destructive, widespread, and best documented of threats to the survival of the desert tortoise, as well as to the integrity of its habitat (USFWS 1994a). Recent studies in the Mojave desert have documented the deleterious effects of ORV use on the tortoise and its habitat. These studies include the loss of plants and grasses important to desert tortoise (BLM 1975, Wilshire 1979); loss

of tortoise burrows due to ORVs (Burge 1983, Bury and Luckenbach 1986); and direct mortality of tortoise by crushing actions of ORVs (Bury and Luckenbach 1986, Berry 1990). Furthermore, ORVs can crush a number of vertebrates, resulting in an increase in ravens which can be voracious predators of juvenile tortoise (personal communication with Ted Owens).

There is an additional connection between ORVs and the issues threatening the desert tortoise. This connection implicates ORVs in exotic annual seed dispersal (see Section 1), thereby contributing to the ongoing weed epidemic in the Mojave desert. Many recent studies have documented the role of weed invasions in the alteration of the fire regime in the Mojave desert (personal communication with Todd Esque). Fires in ecosystems that are not adapted to fire pose problems for all native species in that area, but perhaps most of all for the tortoise. Wildfire can have significant short-term effects on tortoise populations, and may have long-term effects associated with habitat change in the Mojave and Sonoran Deserts (USFWS 1994a, Esque et al. 1994). In the short-term, tortoises die from exposure to excessive heat. Tortoise mortalities due to wildfire have been recorded in the northeast Mojave Desert as early as the 1940's (Woodbury and Hardy 1948) and as recently as 1993 (Esque et al. in preparation). The long-term effects of fires on desert tortoises are less understood, but certainly the habitat changes associated with wildfire alter food abundance, and the availability of plants for protection from thermal extremes and predators (Esque et al. 1997).

The desert tortoise recovery plan concludes that ORV use “destroys, degrades and fragments considerable areas of desert tortoise habitat” (USFWS 1994a). Because of this documented threat, the plan advocates prohibiting all vehicle activity off designated roads within Desert Wildlife Management Areas established for the species, because it considers unrestrained vehicle activity to be totally incompatible with desert tortoise recovery in the Mojave desert.

Coral Pink Sand Dunes Tiger Beetle

The Coral Pink Sand Dunes tiger beetle (*Cicindela limbata albissima*), known only to the Coral Pink Sand Dunes (CPSD) of southern Utah, has one of the smallest geographic ranges of any known organism (Conserv. Committee for the CPSDTB 1997). Currently a candidate for federal listing, the CPSD tiger beetle is typically the dominant invertebrate predator in habitats where it is found.

In 1994 when the USFWS released its findings on a petition to list the beetle as endangered, it pointed out that ORV activity “is destroying and degrading the species’ habitat,” and “is causing direct mortality of individual” beetles (USFWS 1994b). One of the chief ways ORVs can impact the beetle’s habitat is by reducing the already scarce plant cover on the dunes, which is the only food source for most of the tiger beetle’s prey species (Knisley and Hill 1994). ORVs can also loosen the sand and disrupt the thermal and moisture gradient important to tiger beetle larvae (Shultz 1988). In terms of direct impacts to the beetle, any physical encounter with a vehicle that does not result in death

will still cause certain injury, thereby effectively immobilizing the beetle and preventing it from avoiding predators, obtaining prey or successfully mating (Knisley and Hill 1994).

The Conservation Agreement and Strategy for the Coral Pink Sand Dunes tiger beetle (Conserv. Committee for the CPSDTB 1997) cites recent surveys (Knisley, multiple years) that indicate an overall pattern of absence from dunes with moderate to heavy ORV use. A study just released last year (Knisley 1998) illustrates that this trend has not been reversed, even with implementation of the conservation agreement. Knisley found densities of tiger beetle larvae to be much lower on the ORV trails than non-trail areas. He also found that overall numbers, and numbers of taxa of all invertebrates were greater in low-use ORV areas than in high-use ORV areas. The greater abundance and diversity of invertebrates in the low-use areas is an indicator of preferable tiger beetle habitat, because these areas clearly contain a more suitable and stable prey base.

Welsh Milkweed

Another rare species that can only be found within Utah's Coral Pink Sand Dunes formation is the federally threatened Welsh milkweed (*Asclepias welshii*). This milkweed has a severely restricted distribution, and is a unique species with no obvious close relatives. All known population locations occur on land administered by the BLM (Welsh and Chatterley 1985).

In 1991 a colony of Welsh milkweed was observed growing in the intersection of two ORV trails on the sand dunes (Palmer 1999). In this population, stems were generally not as robust as those on plants on most other parts of the dunes. In addition, many stems were broken off or missing from individual plants. This population has been monitored since its discovery, and it has been found that fruit production has been very sparse (Palmer 1999). In 1995 only three fruits developed within the population, and in 1998 there were only five. In other years there have been no fruits. Dr. Palmer is not the only scientist with concerns about ORV impacts on this threatened species. Dr. Stan Welsh, local authority on Utah's rare endemic plants and namesake for this milkweed, considers ORVs to be a threat to *Asclepias welshii* (Welsh and Chatterley 1985).

Holmgren's Milkvetch

The Holmgren's milkvetch (*Astragalus holmgreniorum*) is a short-lived perennial herb endemic to the Virgin River Valley near St. George, UT. Considered to be one of the rarest plants in Utah, it is currently a candidate for federal listing, with an eminent listing likely (personal communication, Larry England).

A recent study by a BYU graduate student on the habitat characteristics of the milkvetch concluded that "ORV traffic...threatens most of the [known] habitat of the Holmgren's milkvetch" (Stubben 1997). The student found that over the course of his study, overall density of milkvetch plants within his study plots had declined. He partially attributed this decrease to increasing ORV use in his study area, noting "the two [study] sites with

the lowest density estimates have some of the heaviest ORV traffic” (Stubben 1997). Conversely, the only study plot that was completely isolated from ORV use had the highest average densities of Holmgren’s milkvetch.

Kodachrome Bladderpod

The kodachrome bladderpod (*Lesquerella tumulosa*) is an endangered species that is restricted in its distribution to Kane County, where it inhabits white shale outcrops derived from Winsor- Carmel Formation. The BLM has contracted with Renee Van Buren of Utah Valley State College to ascertain the demography and habitat characteristics of known populations of the bladderpod in and near the Kodachrome Basin (Van Buren 1997).

After initial study plots were established it was discovered that one of the plots known as the “east site” was much more accessible to ORVs than the other nearby site (called the “west site”). ORV activity was observed and recorded in much greater frequency at the east site (Van Buren 1998). When monitoring results were compared between these two plots, there were marked differences between number of dead bladderpod plants, numbers of individuals not relocated, and numbers of juvenile plants between 1997 and 1998 (See Table 1, following page). The results clearly implicate ORVs in the loss of individuals in the East Site study plot; “the individuals that were...found dead are individuals that were located in or around OHV tracks” (Van Buren 1998).

Dwarf Bear Poppy

The dwarf bear poppy (also known as the bearclaw poppy - *Arctomecon humilis*) is a critically endangered species endemic to the gypsiferous Moenkopi shale of Washington County, UT. It has been listed as a federally endangered species since 1979. The negative impact ORVs have on the dwarf bear poppy is not disputed. The most recent monitoring report for the poppy has revealed that ORV recreation at the Atkinville site has reduced that population’s ability to convert ovules to filled seeds by 65% (Harper and Van Buren 1997).

Yet even with documented ORV impacts to the existing populations and the most protective listing under the ESA, the remaining populations of the dwarf bear poppy are clearly not receiving adequate protection. In a 1992 letter to Valori Armstrong of the BLM, BYU scientist Kimball Harper calls attention to the White Dome, Price Hills, Shinabkaib, Knoll, and Atkinville poppy populations which were being severely disturbed by ORV traffic:

“populations of adult plants at those sites have been severely depleted by the crushing action of vehicle wheels. We can expect that new seedlings will be similarly impacted by ORV traffic and most will probably die before they can flower and replenish the seedbank...prospects are that these populations will continue to decline and will eventually disappear completely.”

In this same letter Dr. Harper also documented occasional vehicle traffic at the Red Bluffs poppy site, even though a fence and warning signs had been erected at that location. Dr. Harper believed that continuing trespassing traffic at this site would result in cumulative effects on that population as well.

In a follow-up letter to Debbie Pietrzak of the BLM two years later, Dr. Harper and fellow botanist Renee Van Buren describe their visit to nine known locations for the dwarf bear poppy. They found that:

“ORV use appears to be unopposed in areas where restrictions currently exist. Tracks were observed in every direction throughout the known sites. There is no question as to the threat that ORV use imposes on this federally endangered species.”

And again, in a study published last year in the American Journal of Botany (Allphin 1998), the author laments the poor protection afforded the imperiled dwarf bear poppy:

“in response to increasing threats, several hundred acres of poppy habitat were closed to ORV use by the BLM and state of Utah. These closures included three populations (Red Bluff, Beehive Dome and Warner Ridge)...Although these areas are posted, the closures have not completely curtailed use by ORVs...These forces threaten the existence of the eleven extant populations of the species, especially the eight unprotected populations.”

The author concludes that this factor, combined with ongoing development in the region and the narrow endemism of the dwarf bear poppy, has caused this species to become one of the most critically endangered in the state. With so much evidence of the species' plight, combined with demonstrated failure of protection efforts, it is lamentable that federal agencies have not safeguarded populations under their jurisdiction more carefully.

Wright Fishhook Cactus

The Wright fishhook cactus (*Sclerocactus wrightiae*) is a federally threatened species that occurs in the Canyonlands Section of the Intermountain Region, where it follows a low-elevation trough around the south end of the San Rafael swell uplift. It is never abundant in locations where it is found to exist. It is almost certain that the fishhook cactus is negatively affected by ORV use, because the plant appears to be associated with presence of a well-developed cryptobiotic crust (USFWS 1985). The susceptibility of crusts to ORV damage is well documented (Belnap 1993, 1995, 1996; Belnap and Gillete 1997).

The Wright fishhook cactus recovery plan identifies the cactus populations in the Caineville-Hanksville area (especially Goblin Valley, Factory Butte and Notom) as being susceptible to ORV use (USFWS 1985). It also predicts ORV impacts on the Emery populations, primarily because of rapid growth in Castle Valley. A proportionately high percentage of town residents own trail bikes and other ORVs, which are often used locally. Clearly, the authors of the recovery plan assume adequate protections are not in place on the public lands where populations of the Wright fishhook cactus are known.

Despain Pediocactus

Known distribution of this federally endangered cactus is restricted to a small portion of the San Rafael Swell. Currently, only four or five populations of *Pediocactus despainii* are known (personal communication with Larry England). Habitat for this diminutive cactus is open pinyon-juniper on exposed Carmel Limestone Formations between 6000 and 6200 feet.

Dr. Stan Welsh, local authority on Utah's rare endemic plants, considers ORVs to be one of the primary threats to the despair pediocactus (Welsh and Chatterley 1985). Indeed, there have been problems with ORVs leaving designated trails, which in turn leads to vehicles digging out and crushing cactus. The most well-documented of these instances occurred in the middle San Rafael Canyon Area of Critical Environmental Concern, within the (BLM) San Rafael Resource Area. Managers here have documented loss of despair cactus to ORVs, and have concluded that this indiscriminate kind of recreation is having severe impacts on the cactus population (BLM 1992).

3.0 OTHER ORV IMPACT STUDIES PERFORMED IN UTAH

In addition to the previously outlined evidence that ORVs negatively influence Utah's federally listed species and their habitats, there are other studies recently performed in Utah that describe deleterious effects of ORVs on other important desert resources and functions. Though some of the studies described below do not directly relate ORV use to desert biota, it can be assumed that these kinds of impacts will indirectly affect Utah's sensitive plants and animals.

The Role of ORVs in Exotic Plant Invasions in Utah

Studies have shown that exotic species are the second greatest cause of species extinction in the U.S., after outright persecution (Flather et al. 1994, Wilcove et al. 1998). While there is not a wealth of experimental data definitively tying ORV use to the spread of exotic weeds, there is considerable evidence that ORVs can contribute to the dispersal and germination of exotics in the arid west, and thus contribute to an epidemic considered by conservation biologists to be one of the worst threats to biodiversity of the intermountain region.

In order to determine those factors most responsible for exotic plant invasions in the arid west, a masters student at Duke University recently investigated causative factors involved in exotic species presence in 674 field sites in eastern Nevada and southern Utah (Gelbard 1999). The Utah sites were located in Canyonlands National Park and surrounding BLM lands, and in Grand Staircase National Monument and surrounding public lands. Gelbard used a classification tree analysis and a spatial partial regression

technique to determine factors most strongly correlated with the degree of invasion of those filed plots.

Gelbard found that in plots where cryptobiotic soils had been disturbed, the degree of exotic invasibility was greater. This study agrees with findings reported by other researchers that have explored the relationships between cryptobiotic crusts and exotics (Rosentreter 1994, Stohlgren et al. 1997). He also found that these impacts (concentrations of exotics) tended to be concentrated within jeep tracks, and would extend out roughly two meters on either side of the trails (Gelbard 1999). He concluded that invasibility of arid rangelands was significantly correlated with disturbances caused by *outdoor recreationists* (emphasis added) and cattle grazing.

Moab Soil Impact Studies by Jayne Belnap

A name that has become synonymous with impact analysis on Utah's desert soils and their crusts is Jayne Belnap of the USGS-Biological Resources Division. Most of her research takes place in the deserts near Moab. In particular, three of her recent studies (Belnap 1995, 1996; Belnap and Gillette 1997) implicate ORVs in both surface soil and cryptobiotic crust disturbance, with profound ecological consequences for the surrounding ecosystem.

One of Dr. Belnap's findings is that disturbed sites (which includes ORV disturbance) have higher soil bulk densities than undisturbed sites (Belnap 1995). Increased soil bulk densities in deserts can lead to decreased soil microbial populations and decreased microbial activity levels (Torbert and Wood 1992). Greater soil bulk densities also contribute to decreased soil infiltration rates, and thus, increased runoff (Webb and Wilshire 1980). Increased runoff in turn deprives communities of available water, causing water stress for plants (Dregne 1983).

Dr. Belnap also found that Nitrogenase activity levels in cryptobiotic crusts were dramatically reduced in disturbed plots relative to undisturbed plots (Belnap 1996). Nitrogenase activity decreased in disturbed plots anywhere from 30 to 100%. This occurred regardless of the type of disturbance (vehicular, or trampling). Dr. Belnap's findings are important because the cryptobiotic crusts' ability to fix nitrogen for use by desert plants is particularly helpful in desert systems where natural sources of free Nitrogen are comparatively low (Fisher et al. 1988).

Yet another discovery from the Moab plots is that threshold friction velocities (the force required to detach soil particles from the surface) were significantly higher in undisturbed cryptobiotic crusts than in disturbed plots (Belnap and Gillette 1997). This finding illustrates how smaller threshold friction velocities caused by ORV use or other disturbance will lead to increased erodibility of desert soils by wind.

Lastly, Dr. Belnap found that biomass of both active bacteria and microarthropods in undisturbed plots were two to three times greater than in disturbed plots (Belnap 1995).

She also found that there were fewer species of microarthropods in disturbed sites compared to undisturbed areas. This is important because any changes in the soil food web may slow down decomposition rates and render fewer nutrients available to plants (Liddle 1997). Overall, Dr. Belnap's studies conclusively show that Utah's arid regions are susceptible to appreciable ORV damage to soils and their crusts, with cascading effects on Utah's biota.

ORV Destabilization of Hillslopes in Ogden

In this study, researchers quantified the role of ORV use in a debris flow that was triggered by heavy rains in Ogden (Nakata 1979). This debris flow was of sufficient size to block the Brigham - Ogden canal. The research team found that the most destabilized areas in the slide were hillclimbs that had been stripped of their vegetative and soil cover by ORVs, and as a result had been altered both physically and chemically. The team also found evidence of increased soil bulk density and decreased infiltration rates as a consequence of ORV activity in the area. Furthermore, their analysis showed that a previously established study plot (established prior to slide) that had received moderate ORV use lost 10 m³ of topsoil in the event, whereas a plot that had previously experienced light ORV traffic lost only 4 m³ of topsoil. The researchers concluded that the denuded areas resulting from ORV activity were extremely susceptible to erosion, and the material that eroded from ORV gullies combined with rain runoff to form the debris flow that blocked the Brigham-Ogden canal.

4.0 ORV IMPACT STUDIES AND REPORTS WRITTEN BY BLM STAFF AND SCIENTISTS

It is interesting to document the few (known) reports written or contracted by the BLM that investigate ORV effects on southwest desert biota. Seeing that this is the agency that oversees the majority of ORV use on America's public lands, one would think there would be more BLM studies and reports on this topic. However, my extensive search of the existing literature produced only these few outlined below.

Evaluation Report for the Barstow to Las Vegas Motorcycle Race

This report describes BLM's evaluation and determination of the ecological effects of the 1974 Barstow to Las Vegas motorcycle race in the Mojave desert (BLM 1975). The race involved 3,000 participants in what was advertised as the world's largest motorcycle race. The race traversed over 155 miles, most of which was off-road or on lightly traveled jeep trails, and primarily on BLM land.

The BLM's analysis revealed that two-thirds of the comparison samples taken after the race indicated marked soil compaction, as well as increases in soil bulk density. In addition, there were multiple instances of "surface pavement" destruction, with

subsequent loss of protection from wind erosion. Vegetation analyses revealed heavy impacts to plants in the parking areas. Many seedlings that had germinated before the race were decimated. Wildlife impact analyses involved before-and-after sampling for small mammals on two study plots located near the start of the race. When plots were visited after the race, they found that the small mammal population in the area had been reduced by 90%. A reduction of this size is sure to have a cascading effect on local raptors, for whom desert rodents are key prey.

Effects of ORV sounds on desert vertebrates

This important study is the result of a contract funded entirely by the BLM. The purposes of this study were to provide the BLM desert plan staff in California with a comprehensive review of the existing literature concerning noise and its effects on vertebrates, as well as experimental data regarding the impact of ORV sounds on three different small vertebrates (Bondello and Brattstrom 1979). The three species studied (Couch's spadefoot toad - *Scaphiopus couchi*, Mojave fringe-toed lizard - *Uma scoparia*, and the desert kangaroo rat - *Dipodomys deserti*) all suffered deleterious effects from moderate exposures to ORV sounds. These effects, which included both hearing loss and misinterpretation of important environmental cues, are described below.

The researchers discovered that motorcycle sounds of intermediate intensity elicits the emergence of the burrowed Couch's spadefoot toad. Though seeming at first to be a strange response, the reproductive biology of this species sheds light on this interesting finding. Apparently the toads can mistake the motorcycle noise for thunder, at which time they emerge from their burrows expecting a summer thundershower and try to gather at newly formed pools where mating occurs. However, instead of finding a mate, the deceived spadefoot toad will most likely be killed by ORVs.

The fringe-toad lizard experiments revealed particularly heavy hearing loss after the lizards were exposed to dune buggy sounds of comparatively moderate intensity and short duration. This illustrates that this species is perhaps one of the most sensitive desert vertebrates to ORV noise.

Desert kangaroo rats were exposed to dune buggy sounds for 8+ minutes. These sounds immediately reduced hearing sensitivities, by as much as 10 dBl in one subject. Correlations with striking ranges of rattle snakes indicated that kangaroo rats become vulnerable to nocturnal predation due to a reduction of auditory predator reduction ranges.

A BLM Comprehensive Report ORV Effects on Desert Biota

In 1980 the BLM produced a critical review of existing information and studies on the various effects of disturbance on desert soils, wildlife and vegetation, with emphasis on ORV impacts (Rawlands 1980). A key chapter in this review (Hall 1980) reports alarming statistics on the impacts of ORVs to vegetation in the Mojave desert.

Specifically, Hall documents an 80% to 90% loss in vegetal cover that is attributed to ORV activity, as well as a 20% to 80% reduction in plant diversity. Loss of habitat diversity in any region is problematic because diversity can promote stability and persistence of many different guilds within a community. Hall also reports that density of native annuals was reduced by 80% to 90% in ORV use areas compared to non-use areas. This reduction was attributed to soil compaction and reduced soil infiltration rates triggered by ORV use.

Impacts of ORVs on Birds in the Mojave Desert

Through a contracted study, the BLM sought to quantify the impacts of ORV use on the avifauna found in the BLM-managed Afton Canyon in the Mojave desert (Weinstein 1978). The study showed significant differences between high-use and non-use ORV areas in terms of native bird abundance, variety and distribution. Specifically, high-use areas generally supported fewer species and numbers of birds than a similar nearby area that was closed to vehicles. Importantly, there was also a significant difference **within** the high-use plots between days when ORVs were being used and days when none were used (67% of bird species studies exhibited a decrease in the high-use zone during ORV activity). This finding effectively rules out any confounding factors in this analysis.

The BLM's overall finding that the high-use areas support fewer birds on both use and non-use days suggests both short-term and long-term effects on the use-area as suitable habitat for birds. These results in turn point to profound ecological consequences for birds in this area. When birds are forced out of an area due to disturbance, they may be abandoning a nest, or perhaps a territory that would be important for breeding success. Also, a bird that leaves a home range only to impinge on another bird's established territory faces certain aggression and perhaps fierce competition, and will probably have to move on to very marginal habitat.

5.0 SUMMARY

This literature review outlines many general effects of off-road vehicles on desert plants and animals of the southwest, as well as their physical habitats. It also focuses special attention on documented impacts of ORVs on federally listed and candidate species within Utah. Lastly, it considers many reports written by the agency (BLM) that oversees most of the western lands where ORV activity occurs.

It is perhaps this last category of papers that is most important to consider. One might assume that, since the BLM has traditionally taken little or no action to curtail the use of ORVs on its holdings, the BLM is unaware of the vast amount of evidence that shows that ORVs are highly destructive to native biota and habitats. On the contrary, this review has demonstrated that not only has the BLM conducted literature reviews on this topic, it has conducted its own experiments that conclusively point to deleterious effects of ORVs. It could go much further towards conducting more of these studies. By and

large, the unregulated or scarcely regulated ORV use on BLM lands constitutes what many scientists would consider a vast uncontrolled experiment on desert lands, with almost certain negative repercussions for a variety of plants and animals. The BLM needs to conduct more monitoring of ORV use on these important desert resources.

6.0 LITERATURE CITED

- Allphin, L. 1998. Genetic diversity and gene flow in the endangered dwarf bear poppy. *Amer. Journal. Botany* 85: 1251-1261.
- Belnap, J. 1993. Recovery rates of cryptobiotic crusts: inoculant use and assessment methods. *Great Basin Naturalist* 53:89-95.
- Belnap, J. 1995. Surface disturbances—their role in accelerating desertification: *Environmental Monitoring and Assessment*. 37: 39-57.
- Belnap, J. 1996. Soil surface disturbances in cold desert: effects on Nitrogenase activity in cyanobacterial-lichen soil crusts. *Biol. Fertil Soils* 23: 362-367.
- Belnap, J. 1998. The biota and ecology of the Grand Staircase Escalante. Pp. 21-30 in: R. B. Keiter, S. B. George, and J. Walker (eds.) *Visions of the Grand Staircase Escalante*. Utah Museum of Natural History and Wallace Stegner Center, Salt Lake City, UT.
- Belnap, J. and D.A. Gillette. 1997. Disturbance of biological soil crusts: impacts on potential wind erodibility of sandy desert soils in SE Utah. *Land Degradation and Development* 8: 355-362.
- Belnap, J., K.T. Harper, and S.D. Warren. 1994. Surface disturbance of cryptobiotic soil crusts: Nitrogenase activity, chlorophyll content, and chlorophyll degradation. *Arid Lands Research and Rehabilitation*. 8:1-8.
- Berry, K.H. 1992. Relationships between tortoise population declines, levels of human use and impacts to habitats. *Proc. Symp. Desert Tortoise Council* 1982.
- Billings, W. D. 1990. *Bromus tectorum*, a biotic cause of ecosystem impoverishment in the Great Basin. G. M. Woodell. *The Earth in transition: patterns and processes of biological impoverishment*. Cambridge University Press, Cambridge UK. p. 301-322.
- BLM (Bureau of Land Management). 1975. Evaluation report, 1974 Barstow-Las Vegas motorcycle race. US Dept. Interior, BLM, Riverside, CA.
- BLM (Bureau of Land Management). 1992. San Rafael Resource Area final activity plan. San Rafael Resource Area, UT. 1-31-92

Bondello, M.C. and B.H. Brattstrom. 1979. The experimental effects of off-road vehicle sounds on three species of desert vertebrates. Report to the BLM, Final report of contract CA-060-CT7-2737. Washington DC, Dept of the Interior

Brattstrom, B.H. and M.C. Bondello. 1983. Effects of off-road vehicle noise on desert vertebrates. Pp. 7-206 in: R.H. Webb and H.G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Burge, B.L. 1983. Impact of Frontier 500 off-road vehicle race on desert tortoise habitat. Pp. 27-38, Proc. Symp. Desert Tortoise Council 1983.

Bury, R.B. and R.A. Luckenbach. 1986. Abundance of desert tortoises in natural and disturbed habitats. Unpubl. Draft Report. National Ecology Research Center, USFWS, Ft. Collins, CO.

Bury, R.B. 1977. Effects of off-road vehicles on vertebrates in the California desert. Washington, DC: Dept of the Interior: USFWS pub

Conservation Committee for the CPSDTB (Coral Pink Sand Dunes Tiger Beetle)1997. Conservation Agreement and Strategy for the Coral Pink Sand Dunes Tiger Beetle. Joint Publication, Utah Dept. of Natural Resources, U.S. Dept. of the Interior, and Kane County. March 31, 1997.

CEQ (Council on Environmental Quality). 1979. Off-road vehicles on public land. Council on Env. Quality, Washington, DC. PrEX 14.2: V53.

D'Antonio, C.M., and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23: 63-88.

Davidson, D.W, Newmark, W.D., Sites, J.W., Shiozawa, D.K., Rickart, E.A., Harper, K.T. and R.B. Keiter. 1996. Selecting wilderness areas to conserve Utah's biological diversity. Great basin Naturalist 56: 95-118.

Davidson, E. and M. Fox. 1974. Effects of off-road motorcycle activity on Mojave desert vegetation and soil. Madrono 22: 381-412.

Dregne, H.E. 1983. Physical effects of off-road vehicle use. Pp. 15-30 in: Webb, R.H. and Wilshire, H.G., (eds.), Environmental effects of off-road vehicles. Springer-Verlag, New York.

EDF (Environmental Defense Fund). 1995. Defending the desert: conserving biodiversity on BLM lands in the southwest. Spec. pub of the Env. Defense Fund. New York, NY. 1995.

Esque, T.C., T. Hughes, L.A. DeFalco, B.E. Hatfield, and R.B. Duncan. 1994. *Abstract*. Effects of wildfire on desert tortoises and their habitats. Pp. 153 - 154, in: Anne Fletcher, (editor), Proceedings of the 19th annual Desert Tortoise Council Symposium. Tucson, Arizona.

Esque, T. C. A. Burquez, and C. R. Schwalbe. 1997. *Abstract*. Effects of alien plant invasions, wildfire, and habitat change on the desert tortoise (*Gopherus agassizii*). Presented at the joint meetings of American Society of Ichthyologists and Herpetologists, Herpetologists' League, and Society for the Study of Amphibians and Reptiles. Seattle, Washington. Symposium proceedings.

Fisher, F.M., Zac, J.C., Cunningham, G.L., and W.G. Whitford. 1988. Water and nitrogen effect on growth and allocation patterns of creosote bush in the northern Chihuahuan desert. *J. Range Manage* 41: 387-391.

Flather, C.H., L.A. Joyce, and C.A. Bloomgarden. 1994. Species endangerment patterns in the United States. USDA Forest Service Rocky Mountain Forest and Range.

Gelbard, J.L. 1999. Understanding road impacts on exotic plant invasions in rangeland landscapes of the intermountain west. M.S. Thesis, Duke University, Nicholas School of the Environment, Durham, NC.

Hall, J. 1980. Direct impacts of off-road vehicles on vegetation. Pp. 63-74 in: (Rawlands, P.G., ed.) The effects of disturbance on desert soils, wildlife and vegetation, with emphasis on off-road vehicles: a critical review. Dept. of the Interior, BLM, Desert Plan Staff Spec. Pub. Riverside, CA.

Harper, K.T. and R. VanBuren. 1997. Monitoring report for 1997 for *Arctomecon humilis*, *Astragalus eremites* and *Astragalus holmgreniorum*. Report to the BLM. Dept. of Botany and Range Science, Brigham Young University, Provo, UT

Hicks, D. 1976. Impacts of Barstow-Las Vegas Motorcycle race on wildlife habitat. U.S. BLM. Mimeo, 46 pp.

Hinckley, B.S., Iverson, R.M. and B. Hallet. 1983. Accelerated water erosion in ORV-use areas. Pp. 81-96 in: Webb, R.H. and Wilshire, H.G., (eds.), Environmental Effects of Off-Road Vehicles. Springer-Verlag, New York.

Iverson, R.M., Hinckley, B.S., and R.H. Webb. 1981. Physical effects of vehicular disturbance on arid landscapes. *Science*. 212: 915-917.

Johansen, J.R. 1993. Cryptogamic crusts of semiarid and arid lands of North America. *J. Phycology* 29:140-147.

Knisley, C.B. 1998. Biology and conservation of the Coral Pink Sand Dunes tiger beetle, studies and a review of previous research. Report to the USFWS, Utah field office, Salt Lake City.

Knisley, C.B. and J.M. Hill. 1994. Coral Pink Sand Dunes tiger beetle, current status and biology. Unpubl. Status report on file with USFWS and BLM. Salt Lake City, UT. 36 p.

Kummerow, M. 1992. Weeds in wilderness: a threat to biodiversity. *Western Wildlands* 18: 12-17.

Liddle, M. 1997. Recreation ecology. Chapman & Hall, London. 639 pp.

Medical World News. 1978. California dust storm spreads fungus infection. *Medical World News*. 19: 44-45.

Nakata, J. K., Wilshire, H. G., and G. L. Barnes, 1976. Origin of Mojave Desert dust plumes photographed from space, January 1, 1973. *Geology*: 644-648.

Rawlands, P.G. (ed.) 1980. The effects of disturbance on desert soils, wildlife and vegetation, with emphasis on off-road vehicles: a critical review. Dept. of the Interior, BLM, Desert Plan Staff Spec. Pub. Riverside, CA.

Rosentreter, R. 1994. Displacement of rare plants by exotic grasses. Pages 170-175 In: Monsen, S.D., Kitchen, S.G., comps. Proceedings of the Symposium: Ecology and management of annual rangelands. Gen. Tech. Report INT-GTR-313, Ogden, UT.

Saint-Amand, P., Mathews, L.A., Gaines, C., and Reinking, R. 1986. Dust storms from Owens and Mono Valleys, California. Naval Weapons Center, China Lake, California. NWC TP-6731, 79 pp.

Shultz, T.D. 1988. Destructive effects of off-road vehicles on tiger beetle habitat in central Arizona. *Cicindela* 20:25-29.

Stohlgren, T.J, Belnap, J., Chong, G.W., and R. Reich. 1997. A plan to assess native and exotic plant diversity and cryptobiotic crusts in the Grand Staircase Escalante National Monument. Pp. 269 to 276, in: Learning from the land: GSENM science symposium proceedings. Cedar City, UT.

Stubben, C. 1997. Habitat characteristics of *Astragalus holmgreniorum*. M.S. Thesis, Dept. of Botany and Range Science, Brigham Young University, Provo, UT.

Torbert, H.A. and C.W. Wood. 1992. Effects of soil compaction and water-filled pore space on soil microbial activity and nitrogen losses. *Comm. Soil Sci. Plant Analysis* 23: 1321-1331.

USFWS (U.S. Fish and Wildlife Service). 1985. Wright fishhook cactus recovery plan. U.S. Fish and Wildlife Service, Region 6, Denver CO.

USFWS (U.S. Fish and Wildlife Service). 1994a. Desert tortoise (Mojave population) recovery plan. U.S. Fish and Wildlife Service, Portland, OR. 73 pages plus appendices.

USFWS (U.S. Fish and Wildlife Service). 1994b. 90-day finding for a petition to list the Coral Pink Sand Dunes Tiger Beetle as endangered and designate critical habitat. Federal Register Vol. 59, No. 178.

Van Buren, R. 1997. Kodachrome bladderpod (*Lesquerella tumulosa*) 1997 status report. Prepared for the BLM by R. Van Buren, Dept. of Life Sciences, Utah Valley State College, Orem, UT.

Van Buren, R. 1998. 1998 status report for *Lesquerella tumulosa*: demography and habitat characterization. Prepared for the BLM Richfield District Office. Contract Number J040-A7-0012.

Webb, R.H.. 1983. Compaction of desert soils by off-road vehicles. Pp. 51-79 in: Webb, R.H. and Wilshire, H.G., (eds.), Environmental effects of off-road vehicles. Springer-Verlag, New York.

Webb, R.H., Ragland, H.C., Godwin, W.H., and D. Jenkins. 1978. Environmental effects of soil property changes with off-road vehicle use. Environmental Management 2: 219-233.

Webb, R. H. and H. G. Wilshire. 1980. Recovery of soils and vegetation in a Mojave Desert ghost town, Nevada. Jour. Arid Environments 3: 291-303.

Weinstein, M. 1978. Impact of off-road vehicles on the avifauna of Afton Canyon, California. Report to the BLM. Final Report for Contract #CA-060-CT7-2734 Dept of the Interior, BLM.

Welsh, S.L and M. Chatterley. 1985. Utah's rare plants revisited. Great Basin Naturalist 45: 173-236.

Wilshire, H.G. 1977. Study results of 9 sites used by off-road vehicles that illustrate land modifications. U.S. Geological Survey, Open-File Report 77-601, 22 pp.

Wilshire, H.G. 1979. Study results of nine sites used by off-road vehicles on public land. Unpubl. Rep. U.S.G.S, Menlo Park, CA.

- Wilshire, H. G. 1980 Human causes of accelerated wind erosion in California's deserts. Pp. 415-433 in: D. R. Coates and J. B. Vitek (eds.), *Thresholds in geomorphology*. George Allen & Unwin, Ltd., London.
- Wilshire, H.G.. 1983. The impact of vehicles on desert soil stabilizers. Pp. 31-50 in Webb, R.H. and Wilshire, H.G., (eds.), *Environmental Effects of Off-Road Vehicles*. Springer-Verlag, New York.
- Wilshire, H.G. 1992. The wheeled locusts. *Wild Earth* 2:27-31.
- Wilshire, H.G., Howard, K.A., Wentworth, C.M., and H. Gibbons. 1996. Geologic processes at the land surface. U.S. Geological Survey Bulletin 2149. 41 pp.
- Wilshire, H.G. and J.K Nakata. 1976. Off-road vehicle effects on California's Mojave desert. *Calif. Geol.* 29(6):123-132.
- Wilshire, H.G., Nakata, J.K., and B. Hallet. 1981. Field observations of the December 1977 wind storm, San Joaquin Valley, California. Pp.233-251 in: Pewe, T. L., (editor), *Desert dust: origin, characteristics, and effect on man*. Geological Society of America Special Paper 186.
- Wilshire, H.G., Nakata, J.K., Shipley, S., and K. Prestegaard. 1978. Impacts of vehicles on natural terrain at seven sites in the San Francisco Bay area. *Environmental Geology* 2:295-319.
- Woodbury, A.M., and R. Hardy. 1948. Studies of the desert tortoise, *Gopherus agassizii*. *Ecological Monographs* 18:146-200.