ECOLOGICAL IMPACTS ON BACKCOUNTRY CAMPSITES IN GRAND CANYON NATIONAL PARK

Final Report

March 1985

David N. Cole

Systems for Environmental Management

P. O. Box 8868

Missoula, Montana 59807

Sponsored by the National Park Service

Cooperative Agreement No. CA8000-4-0001

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Government.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF FIGURES	iii
LIST OF TABLES	iv
EXECUTIVE SUMMARY	v
INTRODUCTION	1
STUDY AREA	2
FIELD AND LABORATORY METHODS	4
DATA ANALYSIS	6
EXPERIMENTAL TRAMPLING OF CRYPTOGAM CRUSTS	7
RESULTS AND DISCUSSION	9
How much change has occurred on campsites?	9
How do these changes compare to those found elsewhere?	19
To what extent do impacts vary with amount of use?	22
To what extent do impacts vary between vegetation types?	29
How does cryptogam crust respond to trampling?	33
CONCLUSIONS AND MANAGEMENT IMPLICATIONS	38
Major implications of results	38
Current management programs	41
Future opportunities	44
LIMITATIONS OF THE STUDY	45
A RECOMMENDED MONITORING PROGRAM	47
The overall program	47
A rapid impact assessment system	48
REFERENCES CITED	56
APPENDIX I - Literature review	64
APPENDIX II - Complete statistics for campsite conditions and amount of change	72
APPENDIX III - Plant species found on campsites and controls	84
APPENDIX IV - Detailed instructions for repeat measurements	88

ACKNOWLEDGEMENTS

Much of the credit for the undertaking of this project must go to Jennifer Burns. She recognized the need for a study of this type and helped the author get acquainted with the Grand Canyon backcountry and its management situation and problems. Financial support was provided by the Western Regional Office of the National Park Service; Dennis Fenn was Regional Chief Scientist when the project was initiated. Logistical support, within the Park, was provided by Richard Marks, Superintendent; Steve Hodapp, Chief of Resources Management; and Chuck Lundy, Backcountry Subdistrict Ranger.

I greatly appreciated the field help provided by the staff of both resources management and the backcountry rangers. David Sharrow was a great help with the identification of plant species. Russell Beuch did some preliminary number-crunching and Joseph Glassy provided computer assistance.

LIST OF FIGURES

Page

Figure 1. The high use desert scrub campsite at Cedar Spring illustrates (a) the small core area surrounded by the little-disturbed perimeter, and (b) the barren, compacted surface of the core. 20

Figure 2. Median amount of impact in relation to campsite use level and location. 26

Figure 3. The cryptogam crust (a) is highly disturbed along the trampling lanes but was similar to the undisturbed crust in foreground, prior to trampling. The technique for measuring vertical distance and ground cover is illustrated in (b). 34

Figure 4. Compression of cryptogam crusts in relation to amount of trampling. 35

Figure 5. Percent cover of undisturbed cryptogam soil, disturbed cryptogam soil, and bare mineral soil in relation to amount of trampling, using (a) tennis shoes and (b) lug-soled boots. 36

Figure 6. A completed campsite survey data form. 50

LIST OF TABLES

	Page
Table 1. Locations of campsites selected for study.	3
Table 2. Median changes on campsite cores.	10
Table 3. Median changes on campsite perimeters.	11
Table 4. Differences in the mean relative cover of growth forms and non-native plants on the campsite perimeter and controls.	13
Table 5. Frequency, mean cover, and mean relative cover of non-native species.	14
Table 6. Frequency, mean cover, and mean relative cover for common native species that have higher coverages on campsites than controls.	14
Table 7. Frequency, mean cover, and mean relative cover for common native species that have much lower coverages on campsites than controls.	15
Table 8. Frequency, mean cover, and mean relative cover of common native species that are neither particularly resistant nor susceptible.	16
Table 9. Densities on campsites and controls for common shrubs.	18
Table 10. Campsite conditions in relation to amount of use.	23
Table 11. Amount of change in relation to amount of use.	24
Table 12. Campsite conditions on different vegetation types.	30
Table 13. Amount of change on campsites in different vegetation types.	31
Table 14. Median campsite core area in relation to both amount of use and vegetation type.	32

EXECUTIVE SUMMARY

The Backcountry Management Plan for Grand Canyon National Park, implemented in October 1983, calls for a research and monitoring program to look at, among other things, backcountry campsites--their distribution, condition, and how condition varies with use levels and location. In response to this need, this study examined a sample of backcountry campsites, in detail, and proposes a system for inventorying all sites in the backcountry and monitoring change in their number and condition over time.

Specific objectives were to:
(1) Estimate how much change has occurred on a sample of 24 backcountry campsites, outside of the Cross-Canyon and river corriders;
(2) Compare amount of impact on high and low use campsites;
(3) Compare amount of impact on sites located in the three common vegetation types: pinyon-juniper, catclaw and desert scrub;
(4) Determine, through experimentation, the rate at which trampling destroys cryptogam crusts in pinyon-juniper woodland; and
(5) Recommend a campsite inventory and monitoring program.

Campsites generally consist of a core area of mineral soil and some rock, totally devoid of vegetation and organic matter. This core has been severely altered. In addition to removal of vegetation and litter, the mineral soil has been highly compacted. Bulk density and penetration resistance are very high. Loss of porosity greatly reduces water infiltration rates. Less water entering the soil leads to low soil moisture content and increased surface runoff. This can aggravate surface erosion. Reduction in moisture, loss of shrubs, cryptogams, and organic matter--the major contributors to site fertility and productivity--and compaction of soil to levels at which new plants cannot get established and roots cannot elongate, make these campsite cores essentially devoid of life.

Although core disturbance of campsites is severe, core areas are unusually small, with a median area of only 32 m^2 on the 24 sites examined. Moreover, the perimeter of the campsites, the area just beyond the core, has not been highly altered. Rough terrain and thorny vegetation discourages use of the perimeter of most sites. Some trampling damage occurs but groundcover changes and soil deterioration are minimal; impact is only pronounced on the informal trails that provide access to the main trail, other campsites, and water sources.

When high use sites are compared with low use sites, most types of impact are more pronounced on the high use sites. However, there is considerable variability from site to site and many of these differences are not statistically significant. Nevertheless, in comparison to low use sites, the barren cores of high use sites are much larger, have much higher bulk densities and penetration resistances, and much lower soil moisture levels. Differences in these properties are sufficiently pronounced to suggest the value of maintaining low use levels on campsites where this is feasible. Observations and limited use data suggest sites can be used no more than about 10-20 nights per year before they approach impact levels characteristic of high use sites.

There are few consistent differences between campsites on the three vegetation types. The most pronounced difference is the much larger barren core area of pinyon-juniper sites. The importance of this difference is diminished by the fact that soil deterioration on pinyon-juniper cores is below average. Other differences suggest the value of tailoring site management to different problems in each vegetation type, particularly site expansion in pinyon-juniper and peripheral trailing and trail erosion in catclaw.

Cryptogam crusts are created by algae, lichen, fungi and/or moss intermixed with surface soils. They often form conspicuous black pedestaled surfaces and have an important role in the ecosystem, improving water relations and site fertility and increasing soil stability. They are extremely fragile; as few as 15 people walking over an area of crust will eliminate over one-half of the crust. This is the most fragile groundcover ever reported in the literature. It contrasts profoundly with the relatively high resistance of desert vegetation in areas without conspicuous crusts. This fragility needs to be considered when locating trails and designating campsites. It also should be emphasized in visitor education programs, along with an explanation of why these crusts are so important.

Overall this study suggests that the current backcountry management program at Grand Canyon has been very successful at controlling impact on campsites. Most of the backcountry is virtually undisturbed and recent implementation of zoning in the backcountry should maintain this favorable situation. Even in popular places, use limitations and designation of sites minimizes the number of severely impacted sites. Site designation is clearly the best policy in consistently used places with small numbers of desirable campsites. However, the low level of soil deterioration on low use sites suggests the value of trying to spread use over a number of sites in less popular areas. In addition to allowing at-large camping, this can be actively promoted by encouraging visitors to camp on resistant, non-vegetated, largely unimpacted sites, as opposed to obviously impacted sites in vegetated areas. With such a program, campsite inventory and monitoring is important to make certain that site proliferation does not occur.

Although a high level of resource protection has already been achieved, the program could be strengthened in several ways. The current lack of specific objectives in the Grand Canyon Backcountry Management Plan makes it difficult to objectively and consistently judge which problems demand management attention. Campsite impact is inevitable; what can be controlled are the number of sites, their distribution, and to some extent, their condition. Specific objectives related to these factors would improve the consistency of management. Moreover, the monitoring program proposed in this report provides a simple means of collecting the information needed both to develop objectives and to evaluate progress toward meeting objectives.

Management could also be improved by relaxing restrictions not needed to protect the resource. Although social problems and visitor preferences need to be considered as well, there are probably some opportunities for increasing use levels, particularly in threshold zones. From the standpoint of resource protection, increased use levels in places with designated sites would have little effect on how severely sites were impacted; it would only add to the number of impacted sites. A few more sites--representing a minimal increase in deterioration--might be worth the opportunity to turn fewer people away, particularly if new sites could be located away from clusters of campsites. Again more specific objectives would make it easier to evaluate whether or not this would be desirable.

Another restriction that could be relaxed, without incurring substantial increases in impact, is the current requirement that visitors plan and adhere to fixed itineraries. This restrictive means of controlling use distribution could probably be replaced by trailhead quotas, at least in most of the backcountry. This would increase visitor freedom and spontaneity and result in little additional resource damage or negative impact on visitor experiences. Experience with trailhead quotas elsewhere in the Park Service (e.g. at Yosemite and Sequoia-Kings Canyon National Parks) could be tapped to successfully apply the system at Grand Canyon.

INTRODUCTION

Grand Canyon National Park is best known for spectacular views from rim overlooks that are readily accessible by car. However, the vast majority of the Park (1,179,700 acres or 96% of the park) has been classified as backcountry. Long-range goals for these lands (U.S. Department of the Interior 1983) are "(1) to maintain and perpetuate the natural ecosystem processes at work in the park's backcountry, (2) to protect and preserve important historic and prehistoric cultural resources, and (3) to provide and promote a variety of backcountry recreational opportunities for the greatest number of visitors compatible with resources protection and visitor safety."

Concern about increased use and the potential for deterioration of park resources led to the development of a new backcountry management plan (U.S. Department of Interior 1983) in October 1983. This plan includes the following measures: division of the backcountry into use-areas; zoning of backcountry use-areas as either developed, threshold, primitive, or undeveloped; establishment of use limits for each area; and mitigation of some impacts through limitations on certain user activities, site restoration and rehabilitation, educational programs, orientation, interpretation and law enforcement. Many of these actions were taken to control impacts on campsites -- the primary foci of environmental deterioration in the backcountry.

Due to a lack of backcountry research at the time the plan was implemented, the actions taken were based primarily on managerial opinions of campsite condition and trend. In fact very little information is available anywhere on campsite impacts in arid environments (refer to Appendix I for a review of relevant literature). For these reasons a program of research and monitoring of campsite impacts was a mandated part of the backcountry management plan.

A thorough research and monitoring program should provide information on current conditions, trend, and use and environmental factors that influence amount of impact. As the first step in such a program, this report describes, in detail, the condition of a sample of campsites, relates impact levels to amount of use and vegetation type, and suggests campsite monitoring procedures that will lead eventually to a complete inventory of sites and an ability to evaluate trends in condition over time.

Specific objectives of the study reported on here were to:

(1) Estimate how much change has occurred on a sample of 24 backcountry campsites, outside of the Cross-Canyon and river corridors;

(2) Compare amount of impact on high and low use campsites;

(3) Compare amount of impact on sites located in the three common vegetation types: pinyon-juniper, catclaw, and desert scrub;

(4) Determine, through experimentation, the rate at which trampling destroys cryptogam crusts in pinyon-juniper woodland; and

(5) Recommend a campsite inventory and monitoring program.

STUDY AREA

To accomplish objectives 1 to 3 above, 24 backcountry campsites were targeted for study. All sites were along trails accessible from the South Rim, between Bass Canyon and Hance Creek and had either been used recently or were judged to have been in use for many years. No river sites or sites in developed zones were included. Twelve of these were high use sites and twelve were low use sites. The twelve campsites within each use category were further stratified into three vegetation types. Table 1 gives the location of the sample sites in each category of use and vegetation type.

The three vegetation types studied, using the digitized classification system of Warren et. al. (1982), were the Pinus edulis-Juniperus osteosperma (pinyon-juniper) association (122.414), the Acacia greggii-Baccharis spp.-Fallugia paradoxa (catclaw) vegetation association (253.4221), and the Mohave Desertscrub (153.1) series. These three types are at different levels of specificity. Sites in the pinyon-juniper type were located in two separate vegetation associations, Coleogyne ramosissima-Pinus edulis-Juniperus osteosperma-Ephedra viridis (122.4147) and Juniperus osteosperma-Pinus edulis-Ephedra viridis-Glossopetalon nevadensis (122.41411). The catclaw sites are all within one vegetation association within the mixed scrub series of the Mohavian Interior Strand (Warren et. al.1982). The desert scrub sites are within two different vegetation associations, Coleogyne ramosissima-Ephedra spp.-Yucca baccata (153.1211) and Gutierrezia sarothrae-Ephedra viridis-Agave utahensis (153.11011), within two different desert scrub series--blackbrush and mormon tea. Nomenclature for species follows Lehr (1978).

The pinyon-juniper sites are characteristic of sites between the rim and the Tonto Platform. The four high use sites were all designated sites on Horseshoe Mesa, at 1460 m elevation. The four low use sites were at 1585 m, two on the Esplanade above Bass Canyon and two on a Supai platform about one-half way down the Boucher Trail. Natural vegetation is characteristically an open woodland with an understory of evenly spaced evergreen sclerophyllous shrubs and succulents. About one-half of the ground surface, under undisturbed conditions, is exposed mineral soil. Median control coverages, which provide a description of undisturbed conditions, can be found in Table 11, Appendix II.

The catclaw sites are among the most popular backcountry destinations, as they are typically located along the Tonto Trail, on alluvial terraces above drainageways with permanent or seasonal water. Elevation varies between 850 and 1100 m. Two high use sites were designated sites at Monument Creek; the other two were the popular sites where the Boucher Trail meets Boucher Creek. Two low use sites were at Hance Creek, on the east side of the creek across from the popular sites; the other low use sites were below the Tonto Trail at Serpentine Canyon, and on the terrace west of Boucher Creek just below its confluence with Topaz Canyon. Undisturbed vegetation consists of relatively closely-spaced catclaw trees and a highly variable understory of shrubs and grasses. Vegetation cover is high; litter layers are thick under catclaw trees; and exposed mineral soil is uncommon.

Table 1. Locations of campsites selected for study.

	USE LEVEL	
VEGETATION TYPE	HIGH USE	LOW USE
Pinyon-Juniper	Horseshoe Mesa	Bass Trail Esplanade
	Horseshoe Mesa	Bass Trail Esplanade
	Horseshoe Mesa	Boucher Trail (in Supai)
	Horseshoe Mesa	Boucher Trail (in Supai)
Catclaw	Monument Creek	Hance Creek
	Monument Creek	Hance Creek
	Boucher Creek	Boucher Creek-Topaz Canyon
	Boucher Creek	Serpentine Canyon
Desert Scrub	Cedar Spring	Bass Canyon
	Salt Creek	Serpentine Canyon
	Horn Creek	Ruby Canyon
	Lonetree Canyon	Turquoise Canyon

The desert scrub sites are located in drier places than catclaw along the Tonto Trail. They are generally on colluvial deposits or bedrock sites, above seasonal water sources. The four high use sites are designated sites at Cedar Spring, Salt Creek, and Horn Creek on the Hermit Loop and an at-large site at Lonetree Canyon. The low use sites are along the Tonto Trail in Bass, Serpentine, Ruby, and Turquoise Canyons. Elevations range between 915 and 1065 m. Undisturbed vegetation is usually characterized by regularly spaced shrubs and a groundcover of grasses. However, the Horn Creek site is under a Celtis reticulata (net-leaf hackberry) tree, the Serpentine site is under a Quercus undulata (wavy-leaf oak) tree, and several sites had scattered catclaw. Desert scrub sites, although highly variable, are intermediate between the pinyon-juniper and catclaw sites in terms of vegetation and mineral soil cover.

Unfortunately, site-specific use data is not available for most campsites. In 1982, the Cedar Spring, Salt Creek, and Horn Creek use areas, each with one legal campsite, had 79, 213, and 314 party nights of use, respectively. Observations and use-area-specific records suggest that, with the probable exception of the site at Lonetree Canyon, all high use sites that were sampled receive at least as much use as Cedar Spring. Therefore, use levels on high use sites range from about 75 nights to over 300 nights per year. These are among the 20-30 most frequently used sites outside of the Cross-Canyon and river corridors. The very heavily-used sites at Hermit Creek were not studied because they had been so heavily modified through site maintenance and rehabilitation.

Low use sites were located away from popular use areas, but were not in the most remote parts of the Park. Most of the sites have either no water or only seasonal water. The only exceptions were the two campsites examined at Hance Creek, a popular destination area. The sites examined here were infrequently-used sites, across Hance Creek from the main use area. Observations and use-area specific records suggest that these low use sites are used between 0 and about 20 nights per year. Sites that have only been camped on a few times ever were not included in this study.

FIELD AND LABORATORY METHODS

Each sample site consisted of both a campsite and an undisturbed control site in the vicinity. A point was established near the center of the disturbed core area of the campsite. The distances from this arbitrarily established center point to the first significant amount of vegetation were measured along 16 cardinal directions. This defined the campsite core area. Within this core, four 1 m^2 quadrats were located to the right of the N, S, E, and W transects, one-half way to the edge of the core. Percent cover of organic litter was visually estimated in each quadrat, using the following coverage classes: <1, 1-5, 6-25, 26-50, 51-75, 76-95, and 96-100 percent. Ten penetration resistance readings were taken in each quadrat with a pocket soil penetrometer.

Next to each quadrat a soil sample was taken for estimating bulk density and measuring infiltration rates. Volumes for bulk density calculations were determined by measuring the amount of water required to fill a hand-excavated, cellophane-lined hole about 9-cm in diameter and about 3.5-cm deep. The excavated soil was placed in plastic bags that were then sealed to prevent

moisture loss and carried out of the Canyon for weight determination. In the laboratory, soils were put through a 2 mm sieve. The >2 mm fraction was discarded after its volume was determined. The <2 mm fraction was weighed, dried for 24 hours in a 105 degree C oven and weighed again. Volume of the <2 mm fraction was determined by subtracting the volume of the coarser fragments from the volume measured in the field. Stone-free bulk density is the ratio between dry weight and volume of the <2 mm sample. Stone-free bulk density was used because stone content was variable and, where stone content is high, estimates of compaction are low. Gravimetric moisture content is the ratio between amount of moisture (moist weight minus dry weight) and the dry weight of the <2 mm sample, expressed as a percentage.

Infiltration rates were measured with a double ring infiltrometer. After adding water to the outer ring, 6 cm of water were added to the inner ring. The rate that the first cm entered the soil was called the initial rate, while the rate for the fifth cm was called the final rate. Both were expressed in cm/min. Measurements were terminated after 20 minutes, regardless of how much water entered the soil. Where less than 5 cm entered the soil in 20 minutes, the final rate was based on the time it took for the last cm to infiltrate.

About 25 1 m^2 quadrats were randomly located along transects around the campsite perimeter, immediately outside of the core area (see Appendix IV for more detail on techniques). Within each quadrat, cover of live vascular vegetation, cryptogams, organic litter, mineral soil, and rock was estimated. The previously-mentioned coverage classes were used for this purpose. The cover of each species was estimated and the number of shrubs or shrub clumps rooted in each quadrat was counted, by species. Two penetration resistance readings were taken in each quadrat and soil samples and infiltration rates, similar to those in the core, were taken in four randomly-selected quadrats.

Control sites were circular with an area of 50 m^2. Within this area all rooted shrubs or shrub clumps were counted by species and the cover of live vascular vegetation, cryptogams, organic litter, mineral soil, rock, and each individual species was estimated. Soil samples and infiltration rates were taken 2 m from the center of each control along N, S, E, and W axes. Finally, 40 regularly-distributed penetration resistance readings were taken.

At the Lonetree site there was no suitable control and at the Horn Creek site there was no suitable perimeter for comparison to the core. Therefore only limited data were collected at these sites. Complete data were collected from all other sites.

Permanent stakes were buried at each campsite and control so that all sample units can be precisely relocated at a future date. This will permit long-term, detailed monitoring of changes on these sites (refer to Appendix IV for instructions).

Field work was conducted between late March and early May of 1984. This time period was selected to coincide with the emergence of most spring annuals. However, a pronounced drought during the winter prior to field work resulted in an abnormally sparse annual flora.

DATA ANALYSIS

Distances to the edge of the core were plotted on scaled maps and a planimeter was used to determine core area. On the few sites where there were satellite sites, core area is the sum total of all devegetated areas. Core litter cover is the mean of four litter cover estimates, using the midpoints of coverage classes. Core bulk density, gravimetric moisture, initial and final infiltration rates are also the means of four measurements. Core penetration resistance is the mean of forty penetration resistance measurements.

Perimeter bulk density, gravimetric moisture, initial and final infiltration rates are means of four measurements, as they were on the core. Penetration resistance is the mean of 40 measurements again. Perimeter cover values for vegetation, cryptogam, litter, mineral soil, rock, and individual species are means of about 25 cover estimates. The exact number of estimates used to calculate the means is the number of perimeter quadrats on the site. Shrub densities were calculated by summing all shrubs on the quadrats and then dividing by the total number of quadrats, usually 25. This expresses density as shrubs per square meter and was done for both all species and individual species.

Control measures are single estimates of vegetation, cryptogam, litter, mineral soil, rock, and individual species cover. Shrub density is the total number of shrubs on the 50 m^2 control, divided by 50 m^2. Soil measures are means of four bulk density, gravimetric moisture, initial and final infiltration rates, and forty penetration resistance readings, as on the core and perimeter.

The amount of change that has occurred is inferred by comparing core and perimeter measures with control measures. There are two ways of doing this. One is to calculate absolute change--the difference between the measure on the campsite, either core or perimeter, and the measure on the control. The other is to calculate relative change--the absolute change expressed as a percent of the measure on the control. For example if vegetation cover is 50 percent on the control and 25 percent on the perimeter, the absolute change is 25 percent--50 percent minus 25 percent. However, this represents a loss of half of the vegetation. This is reflected in the relative change value of 50 percent--50 percent minus 25 percent, divided by 50 percent. Where control conditions vary greatly from site to site, relative change provides a more valid basis for comparison than absolute change. For example, consider two sites, one with vegetation cover of 10 percent on the control and 0 percent on the perimeter, the other with 100 percent on the control and 90 percent on the perimeter. In both cases absolute change is 10 percent, a figure that hides the pronounced difference in impact between these two sites. A much better index is relative change; for these two sites relative change is 100 percent and 10 percent, respectively.

Change in species composition on the campsite perimeter was estimated by comparing the species composition of the perimeter and the control. To quantify differences the following coefficient of floristic dissimilarity was calculated:

$$FD = 0.5 \Sigma |P_1 - P_2|$$

where P_1 is the relative cover of a given species on the control and P_2 is the mean relative cover of the same species on the campsite perimeter (Cole 1978). Relative cover is the percent of total cover accounted for by a given species (i.e., one species' cover divided by the total cover of all species).

Two different analyses were used to determine the statistical significance of results. The first analysis involved testing whether the campsite core and perimeter were significantly different from each other and from controls. Some parameters met the assumptions for parametric tests; others did not. Consequently, both parametric paired t-tests and nonparametric Wilcoxon matched-pairs, signed-ranks tests (SPSS, Inc. 1983) were used to test the null hypothesis that campsites were identical to controls. Generally results are comparable. A significance level of 0.05 was selected, but all probabilities are listed in the tables.

The second set of tests determined whether amount of impact was related to amount of use or vegetation type. To test the null hypothesis that amount of use had no effect on amount of impact, parametric t-tests and non-parametric Mann-Whitney U tests were used. To test the null hypothesis that vegetation type had no effect on amount of impact, parametric analysis of variance tests and non-parametric Kruskall-Wallis tests were used.

Complete statistics are provided in Appendix II. The tables in the text are more abbreviated to increase readability. They only report medians as measures of central tendency and the results of nonparametric tests; these are the more generally applicable statistics. Only one measure of change, either absolute or relative, is reported for each impact parameter. Absolute change is reported where control values were not highly variable; relative change is reported where they were variable.

EXPERIMENTAL TRAMPLING OF CRYPTOGAM CRUSTS

To determine how rapidly cryptogam crusts are destroyed by trampling, a simple experiment was conducted in an area of well-developed cryptogam crust in the Coleogyne ramosissima-Pinus edulis-Juniperus osteosperma vegetation association (122.4147) on the Esplanade above Bass Canyon. Two lanes, about 6 m long and 0.4 m wide were delineated with stakes of PVC pipe and string. One lane was trampled by a 75 kg person in tennis shoes; the other was trampled by an 86 kg person in lug-soled boots. Measurements were taken prior to trampling and after 5, 15, 25, and 50 passes--a pass being one walk down the lane at a normal gait. The lane trampled with lug-soled boots was trampled another 200 times, for a total of 250 passes.

Each lane was sampled along 5 transects, oriented perpendicular to the lane and located 1 m apart. Each transect consisted of 10 measurement points, 2 cm apart, in the central part of the lane. At each point along the transect, the

vertical distance between a horizontal pipe (temporarily connecting the stakes at each end of the transect) and the ground surface was measured. Then the surface at that point was described as either undisturbed crust, disturbed crust, or bare ground. Data consist of mean distances between horizontal pipe and ground surface and mean percent cover of undisturbed crust, disturbed crust, and bare ground, based on 50 observations per lane, for each measurement period. Compression of the crusts was evaluated by subtracting the distance between pipe and ground before trampling from the distance after trampling. Stakes were left in place to permit recovery to be monitored.

RESULTS AND DISCUSSION

How much change has occurred on campsites?

The area of the barren campsite core varied between 8 and 142 m^2, with a median of 32 m^2 (Table 2). This is a relatively small area, equivalent to that of a circle with a diameter just over 20 ft. Essentially this entire area is exposed mineral soil with some rock. Less than one percent of the ground is covered by organic horizons, despite a median control litter cover of 60 percent. This amounts to a 99 percent loss (relative change) of litter on the core. Vegetation and cryptogam cover is generally absent. Only 6 of the 24 sites had any vegetation at all on the core and on only two sites did it amount to more than 5 percent cover, despite median cover on controls of 60 percent. The most common species on the core were two non-native annuals, Bromus rubens (red brome) and Erodium cicutarium (filaree), and the native shrub, Gutierrezia sarothrae (broom snakeweed).

In addition to this pronounced loss of vegetation and organic matter, the core is characterized by highly compacted soils. Median bulk density is 1.60 g/cm^3, 0.24 g/cm^3 denser than controls. Penetration resistance values are more than three times as high on cores as on controls. On many sites, values exceeded 4.5 kg/cm^2, the highest value the instrument could record. Bulk densities and penetration resistances of such a magnitude have been shown to impede root penetration of soils. This is likely to inhibit seedling establishment and growth, making site revegetation difficult. Reduced porosity and surface crusts created by compaction reduce both initial and final infiltration rates to about one-quarter of control rates. Such low infiltration rates mean that less water enters the soil, where it is available to plants, and more runs off across the surface, eroding organic and mineral soil. These effects are likely to be particularly pronounced during the torrential thunderstorms of summer, when large quantities of rain fall over short periods of time. Decreased infiltration may also explain the lower moisture content of core soils. Median gravimetric moisture levels on the core are only 3.8 percent, compared with 5.5 percent on controls.

Impact on the core is significantly greater than impact on the perimeter, for all variables. However, in comparison to controls, the only statistically significant changes on the perimeter have been a reduction in vegetation and litter cover and an increase in soil penetration resistance (Table 3). Vegetation loss on the perimeter is relatively minor; median absolute loss is only 8 percent--a relative loss of 12 percent of inferred pre-camping amounts. Moreover, there is relatively little change in species composition. The median floristic dissimilarity between perimeters and controls, which theoretically can vary from 0 (no difference) to 100 (completely different) percent, is only 31 percent. This is less than the difference typical of two undisturbed stands in the same vegetation type. Median floristic dissimilarity for 15 comparisons between controls within the same vegetation type was about 50 percent. Dissimilarity of only 31 percent, therefore, suggests very little compositional change resulting from recreational use.

Table 2. Median changes on campsite cores.

Impact Parameter	Camp	Control	Absolute Change	Relative Change	1 Sign.
				--percent--	
Area (m^2)	32				
Litter Cover (%)	<1	60	-60	-99	< .001
Bulk Density (g/cm^3)	1.60	1.27	0.24	20	< .001
Soil Moisture (%)	3.8	5.5	-1.2	-21	.002
Initial Infiltration Rate (cm/min)	0.5	1.9	-1.3	-73	<.001
Final Infiltration Rate (cm/min)	0.15	0.56	-0.46	-79	< .001
Penetration Resistance (kg/cm^2)	2.8	0.7	2.0	337	< .001

1- Probabilities are based on the one-tailed Wilcoxon matched-pairs, signed-ranks test; values ≤ 0.05 are significant. A two-tailed test was used for soil moisture.

Table 3. Median changes on campsite perimeters.

Impact Parameter	Camp	Control	Absolute Change	Relative Change	Sign.[1]
				--percent--	
Floristic Dissimilarity (%)	31				
Vegetation Cover (%)	55	60	-8	-12	.026
Cryptogam Cover (%)	2	3	0	-22	.068
Litter Cover (%)	51	60	-8	-14	.019
Mineral Soil Cover (%)	15	10	2	36	.464
Rock Cover (%)	7	3	3	30	.060
Bulk Density (g/cm^3)	1.21	1.27	0.01	1	.429
Soil Moisture (%)	4.9	5.5	0.1	2	.761
Initial Infiltration Rate (cm/min)	1.9	1.9	-0.1	-5	.455
Final Infiltration Rate (cm/min)	0.54	0.56	-0.07	-24	.057
Penetration Resistance (kg/cm^2)	0.9	0.7	0.1	33	.003

1- Probabilities are based on the one-tailed Wilcoxon matched-pairs, signed-ranks test; values ≤ 0.05 are significant. A two-tailed test was used for soil moisture.

To better evaluate the compositional changes that have occurred, the mean relative cover of different growth forms and of non-native species on the campsite perimeters and controls were compared (Table 4). Relative cover is one species' cover as a percent of the combined cover of all species--an indicator of the relative importance of each species. The only statistically significant differences between perimeters and controls are a slight increase in the relative importance of shrubs and a slight decrease in the importance of forbs on the perimeter of campsites. This suggests that shrubs are slightly more resistant and forbs are slightly more fragile than other growth forms. These unusually small shifts underscore the lack of change reflected in the floristic dissimilarity values. The lack of a significant loss of cryptogams or a pronounced increase in the cover of non-native plants is also surprising. Loss of cryptogams on campsite perimeters is generally low because they are usually only found underneath shrubs, where they are protected from trampling.

Five non-native plants--all annuals or biennials--were found on campsites (Table 5). Bromus rubens and Erodium cicutarium are among the five most common species on campsites. Of the non-natives, only Hordeum leporinum (wild barley) and, to a lesser extent, Erodium cicutarium respond positively to camping disturbance, increasing in relative importance on campsite perimeters. Bromus rubens is equally abundant both on and off campsite perimeters. In fact, Bromus rubens covers more ground, even on undisturbed sites, than any other species--probably in the entire Grand Canyon. Therefore, the finding that camping does not lead to a great increase in non-natives, as it often does elsewhere, is largely a reflection of the abundance of non-natives on undisturbed sites.

Seven common species (Table 6) generally have higher coverages on campsite perimeters than on controls. All are shrubs and trees. Although all of these species are relatively resistant to trampling, their survival also reflects a tendency for people to walk around or between these large shrubs and trees. It is unlikely that any of these species respond positively to trampling; they merely survive more frequently than other species and may, to some extent, grow more abundantly in places that tend to be selected as campsites. These species are good choices for revegetation, if they can be propagated, because they are resistant.

Six common species have much lower coverages on campsites than controls (Table 7). All are small plants that commonly grow in bare soil between shrubs--where they are frequently stepped on. None of these have a significant coverage, even under undisturbed conditions. Their high frequency on campsites relative to controls shows that they are seldom eliminated by trampling. This suggests that although they are unusually fragile and lose cover when trampled, they can tolerate some trampling stress and are unlikely to be eliminated except on the core, where all species are eliminated. The most important and striking result of this examination of differences in species composition is that most species are little affected by the level of trampling stress that occurs on campsite perimeters (Table 8).

Table 4. Differences in the mean relative cover of growth forms and non-native plants on the campsite perimeter and controls.

Growth Form	Mean Relative Cover	
	Camp	Control
	-------percent-----	
Shrubs - Trees	55.7	52.0
Cacti	0.4	0.5
Shrubs[1]	39.9	34.7
Trees	15.4	16.7
Grasses - Total	33.3	33.7
Annuals	29.2	27.9
Perennials	4.1	5.8
Forbs - Total[1]	3.5	5.3
Annuals	1.8	2.3
Perennials	1.7	3.0
Cryptogams	7.0	8.3
Non-natives	28.9	26.7

1 - Differences between campsites and controls are significantly different -- based on a two-tailed t test -- at the 0.05 level.

Table 5.[1] Frequency, mean cover, and mean relative cover of non-native species.

Species	Frequency		Mean Cover		Mean Relative Cover	
	Camp	Control	Camp	Control	Camp	Control
	---number---		----------percent----------			
Grasses						
Bromus rubens	22	21	24.2	31.2	26.3	26.5
Bromus tectorum	2	2	0.2	5.0	0.1	3.9
Hordeum leporinum	4	2	8.5	0.3	11.9	0.2
Forbs						
Erodium cicutarium	14	7	0.3	0.3	0.4	0.2
Tragapogon dubius	2	0	<0.05	0	<0.05	0

1 - Frequency is the number of campsites or controls on which the species was found. Mean cover was based on that number of sites -- not all 24. Mean relative cover is the proportion of all cover accounted for by a given species.

Table 6. Frequency, mean cover, and mean relative cover[1] for common native species that have higher coverages on campsites than controls.

Species	Frequency		Mean Cover		Mean Relative Cover	
	Camp	Control	Camp	Control	Camp	Control
	---number---		----------percent----------			
Trees and Shrubs						
Chrysothamnus nauseosus	2	5	1.6	1.2	1.2	1.2
Coleogyne ramosissima	6	7	13.0	11.6	36.7	30.1
Cowania mexicana	5	3	3.0	0.7	7.1	2.5
Ephedra spp.	21	20	8.5	7.5	9.8	8.0
Juniperus osteosperma	5	6	12.8	10.6	21.3	18.2
Rhus trilobata	4	2	2.9	1.1	2.6	0.7
Yucca baccata	3	6	1.6	1.1	3.5	3.3

1 - Frequency is the number of campsites or controls on which the species was found. Mean cover was based on that number of sites -- not all 24. Mean relative cover is the proportion of all cover accounted for by a given species.

Table 7. Frequency, mean cover, and mean relative cover[1] for common native species that have much lower coverages on campsites than controls.

Species	Frequency		Mean Cover		Mean Relative Cover	
	Camp	Control	Camp	Control	Camp	Control
	---number---		----------percent----------			
Grasses						
Erioneuron pulchellum	5	4	0.1	0.3	0.1	0.4
Sitanion hystrix	5	5	0.1	0.3	0.2	0.4
Forbs						
Arabis perennans	3	6	<0.05	0.4	<0.05	1.0
Cryptantha spp.	6	4	0.1	0.3	0.1	0.3
Descurainia pinnata	10	6	0.1	0.3	0.1	0.2
Draba cuneifolia	7	5	0.1	0.3	0.1	0.2

1 - Frequency is the number of campsites or controls on which the species was found. Mean cover was based on that number of sites -- not all 24. Mean relative cover is the proportion of all cover accounted for by a given species.

Table 8. Frequency, mean cover, and mean relative cover[1] of common native species that are neither particularly resistant nor susceptible.

Species	Frequency		Mean Cover		Mean Relative Cover	
	Camp	Control	Camp	Control	Camp	Control
	---number---		----------percent----------			
Shrubs and Trees						
Acacia greggii	11	10	17.6	27.0	16.5	19.5
Encelia frutescens	5	6	1.3	1.7	1.4	1.9
Glossopetalon nevadense	7	6	5.0	9.4	11.2	15.0
Gutierrezia sarothrae	21	19	2.8	3.5	3.8	4.8
Grasses						
Bouteloua curtipendula	7	5	1.8	1.9	1.9	3.1
Muhlenbergia porteri	3	3	0.6	1.4	0.7	1.2
Poa bigelovii	10	4	0.2	0.4	0.2	0.3
Poa fendleriana	8	8	0.4	0.9	1.0	1.7
Sporobolus cryptandrus	6	9	0.9	1.3	1.0	1.7
Stipa arida	8	8	1.5	1.9	2.6	2.8
Vulpia octoflora	11	9	0.4	0.6	0.5	0.8
Forbs						
Astragalus nuttallianus	12	9	0.3	0.6	0.4	0.7
Gilia flavocincta	5	3	0.5	0.6	0.6	1.0
Lepidium lasiocarpum	11	9	0.3	0.4	0.3	0.3
Parietaria hespera	5	4	0.6	1.0	0.5	0.9
Plantago purshii	13	13	0.6	0.7	0.6	0.6
Sphaeralcea grossulariaefolia	15	14	0.5	0.6	0.5	0.7
Cryptogams	18	15	6.9	10.7	8.4	9.6

1 - Frequency is the number of campsites or controls on which the species was found. Mean cover was based on that number of sites -- not all 24. Mean relative cover is the proportion of all cover accounted for by a given species.

Shrub densities on the campsite perimeter are actually higher than on controls, although this difference is not quite significant ($p=0.06$). Median density is 0.98 shrubs/m^2 on the campsite perimeter compared with 0.79 shrubs/m^2 on controls. Most of this difference is accounted for by an increase in the density of Gutierrezia sarothrae on the perimeter (Table 9). Gutierrezia seedlings are unusually abundant in lightly disturbed places. The same is true for Cowania mexicana (cliff rose), Fallugia paradoxa (Apache plume), and Haplopappus acradenius (alkali goldenbush), although these species are less widely distributed. These species might be good choices for revegetating lightly disturbed sites. The only common shrub or tree to exhibit a pronounced decrease in density on campsites is Juniperus osteosperma (Utah juniper). Juniperus seedlings were common on controls and uncommon on perimeters. Apparently here, as elsewhere, coniferous tree seedlings are particularly susceptible to trampling damage. Again, most species are little affected either positively or negatively.

In sum, vegetation loss and change in species composition is relatively minor beyond the edge of the barren core. Some trailing and vegetation loss is evident but of little ecological importance in most places. The same is true for cryptogam cover (Table 3). Some cryptogam cover is lost on the campsite perimeter, but much of it survives under shrub clumps. The generally low cryptogam cover on controls--median of 3 percent--keep losses small. Although loss of cryptogams on perimeters is generally insignificant, it can be locally pronounced; on one campsite perimeter cryptogam cover was reduced from 60 to 13 percent. Moreover, cryptogams are eliminated completely on campsite cores. The fragility of cryptogams is evaluated more fully in the trampling experiment.

Litter cover loss is also relatively minor; the median perimeter value is 51 percent compared with 60 percent on the control. On catclaw sites, however, there can be a significant loss of litter volume. Undisturbed organic horizon thicknesses of over 5 cm are not uncommon under Acacia trees and much of this is removed by trampling on the campsite perimeter. Finally, penetration resistance values increase about one-third from a median control value of 0.7 kg/cm^2 to a median perimeter value of 0.9 kg/cm^2. This increase is not likely to have much ecological effect, and is clearly minor when compared with the core value of 2.8 kg/cm^2.

None of the other impact parameters--mineral soil cover, rock cover, bulk density, moisture content, initial or final infiltration rate--exhibit significant differences between the perimeter and controls (Table 3). As expected, mineral soil cover, rock cover, and bulk density are generally higher and moisture content, initial and final infiltration rates are generally lower on perimeters than on controls. However, these changes are all small in comparison to site-to-site variability. Impact is occurring but it is both relatively small and variable. Even when just high use sites are analyzed, none of these differences are statistically significant on the perimeter.

Table 9. Densities on campsites and controls for common shrubs.[1]

Species	Frequency		Median	
	Camps	Controls	Camps	Controls
	----number----		-#/square meter-	
Increasers				
Cowania mexicana	4	3	0.04	0.02
Fallugia paradoxa	3	3	0.96	0.35
Gutierrezia sarothrae	21	19	0.32	0.18
Happlopappus acradenius	4	3	0.38	0.12
Decreasers				
Juniperus osteosperma	4	5	0.04	0.12
Unaffected Species				
Acacia greggii	11	10	0.08	0.08
Coleogyne ramosissima	6	7	0.29	0.32
Encelia frutescens	4	6	0.08	0.06
Ephedra spp.	18	20	0.09	0.10
Glossopetalon nevadense	6	6	0.12	0.16
Yucca baccata	3	6	0.06	0.04

1 - Frequency is the number of campsites or controls on which at least one rooted individual was found. Medians were based on that number of sites -- not all 24.

In sum, the median campsite has a small core area almost entirely devoid of vegetation and litter cover (Fig. 1). The exposed mineral soil cover is highly compacted, a change that inhibits vegetation establishment and growth, and drastically reduces infiltration rates. This leads to decreased soil moisture content and increased runoff and potential for erosion. Beyond the core, disturbance is low. Trampling of access trails causes loss of vegetation and litter and a corresponding increase in mineral soil cover but changes are small, typically less than 10 percent. Little change in species composition occurs, suggesting that most species are equally tolerant of the level of trampling that occurs on perimeters. A few shrubs even respond positively to light disturbance by establishing more seedlings. Soil deterioration has also been minimal on the perimeter, although it can be locally serious on some access trails.

How do these changes compare to those found elsewhere?

An improved perspective on the significance of these changes can be gained by comparing amount of impact on Grand Canyon campsites to impacts on campsites studied elsewhere. The median core area of 32 m^2 is larger than the barren area of 14 m^2 on sites in montane forests and grasslands in the Bob Marshall Wilderness, Montana (Cole 1983a). However, core area is much smaller than the 87 m^2 found on sites in subalpine forests in the Eagle Cap Wilderness, Oregon (Cole 1982a). The major contrast with Bob Marshall sites is that in the Grand Canyon most disturbance is confined to the core, while in the Bob Marshall the median disturbed area is huge, exceeding 400 m^2. In forests in the Boundary Waters Canoe Area, Minnesota, mean campsite size is 220 m^2 (Marion 1984). Several factors that contribute to the relatively small size of Grand Canyon sites include the prohibitions on stock and campfires, relatively resistant vegetation, thorny shrubs and rough terrain that contain use and impact, and lack of historical use of a particularly destructive nature (e.g. very large parties using "frontier-style" camping techniques).

The nearly complete loss of organic litter on the core is more pronounced than has been reported in any other study. On sites in the Eagle Cap, Bob Marshall, and in subalpine forests in Sequoia National Park, California (Stohlgren 1982), at least some patchily-distributed litter remains on the core. The near-complete elimination on Grand Canyon sites reflects the paucity of litter on undisturbed sites. Since much of a soil's fertility is derived from organic material, this total elimination is a serious change.

The median core bulk density of 1.60 g/cm^3 is also higher than has been recorded elsewhere. Values elsewhere range from 0.93 g/cm^3 on forested Rhode Island developed camp and picnic sites (Brown *et. al.* 1977) to 1.49 g/cm^3 on developed campsites in Rocky Mountain National Park, Colorado (Dotzenko *et. al.* 1967). The highest mean value on backcountry sites was 1.35 g/cm^3 in Sequoia (Stohlgren 1982). On semi-arid river sites in Dinosaur National Monument, Utah-Colorado, Jerry (1977) reports variable bulk densities from 0.85 to 1.92 g/cm^3 (compared to a range of 0.60-2.21 g/cm^3 on Grand Canyon sites). In a developed campground at Chiracahua National Monument, Arizona, Post (1979) reported a median bulk density of 1.47 g/cm^3.

(a)



(b)



Fig. 1. The high use desert scrub campsite at Cedar Spring illustrates (a) the small core area surrounded by the little-disturbed perimeter, and (b) the barren, compacted surface of the core.

Although core bulk densities are unusually high on Grand Canyon sites, so are the bulk densities of undisturbed soils. Consequently, the median absolute and relative increases, 0.24 g/cm^3 and 20 percent, are only moderately high. In comparison, bulk densities on Sequoia campsite cores increased 0.85 g/cm^3 (170 percent); in Chiracahua, densities increased 0.56 g/cm^3 (62 percent). Increases at Grand Canyon are comparable to those found on off-road-vehicle tracks in California (Webb et. al. 1978) where surface densities increased a median 0.26 g/cm^3 (22 percent). The high bulk densities both on and off campsites reflect, among other things, the paucity of organic matter, both on the surface and in the mineral soil.

The median Grand Canyon core penetration resistance, 2.8 kg/cm^2, is intermediate between values that range from 2.1 kg/cm^2 in the Rattlesnake Wilderness, Montana (Fichtler 1980) to 3.7 kg/cm^2 in the Boundary Waters Canoe Area (Marion 1984). However,the relative increase in core penetration resistance of over three times (337 percent) is the highest reported anywhere. Along with the high bulk density values this suggests that soil compaction on the core of Grand Canyon sites is unusually severe.

Infiltration rates are difficult to compare because methods are variable and results differ greatly depending upon methodology. The median final infiltration rate, 0.15 cm/min, is probably most directly comparable to other studies, where rates range from a median of 0.1 cm/min in the Bob Marshall to a mean of 0.28 cm/min on campsites in Canada's Rushing River Provincial Park (James et. al. 1979). Grand Canyon rates are considerably lower than the range of 0.22-2.00 cm/min reported for Dinosaur sites (Jerry 1977). The decrease in infiltration rates on Grand Canyon cores, 0.46 cm/min or 79 percent, is intermediate between sites in the Eagle Cap (0.09 cm/min or 33 percent decrease) and developed sites in Rhode Island (6.1 cm/min or 97 percent decrease). They are remarkably similar to the decreases that occur on Bob Marshall sites (Cole 1983a).

Finally, soil moisture on Grand Canyon cores, 3.8 percent, is low. Values recorded elsewhere range from 5.1 percent at Rocky Mountain to 29.4 percent in Kings Canyon National Park (Simon 1978). However, this is primarily a reflection of the dry desert environment,. because the relative decrease in moisture of 21 percent is lower than anywhere else except the Boundary Waters Canoe Area, where only a 7 percent decrease was recorded. Stohlgren (1982) reports a 65 percent loss on the core of Sequoia campsites. Nevertheless, because water is such a limiting factor in the desert, any reduction at all should be considered a serious impact.

Vegetation loss on the perimeter can only be compared with results from the Bob Marshall, Eagle Cap, and Sequoia, where it is possible to distinguish between a devegetated core and a peripheral disturbed area. The median relative vegetation loss of 12 percent in the Grand Canyon is low compared with losses of 65 percent, 82 percent, and 40 percent on the periphery of Bob Marshall, Eagle Cap, and Sequoia sites, respectively. Moreover, the change in species composition is unusually low as well; floristic dissimilarity is only 31 percent compared with values of 63, 59, and 88 percent on Bob Marshall, Eagle Cap, and Boundary Waters Canoe Area sites. Only on sites in the Rattlesnake Wilderness, has a lower value been recorded--27 percent (Fichtler 1980).

No comparable measures of litter loss exist. However, from observations elsewhere, it appears that the relative litter losses of 99 percent on cores and 14 percent on perimeters are unusually high. Again this would reflect naturally thin litter layers that are easily disturbed. Litter loss on cores is a serious impact; loss on perimeters is not. It is the litter concentration under shrubs that is critical for retaining fertility (Garcia-Moya and McKell 1970, Wallace et. al. 1980) and this is little disturbed on the perimeter.

Only Stohlgren (1982) measured soil conditions on campsite perimeters. He found an increase in bulk density of 40 percent and a decrease in moisture of 23 percent. The increase in bulk density of 1 percent and decrease in soil moisture of 2 percent on Grand Canyon site perimeters suggests unusually low soil deterioration outside of the core.

In comparison to campsite impacts elsewhere, impacts on Grand Canyon sites are confined to an unusually small core area. Outside of this core, impact is minimal. On the core, however, impacts are unusually severe. Of particular significance are the high level of compaction, the complete loss of litter, and the serious reduction in water infiltration and soil moisture content. Problems related to three important attributes of desert ecosystems--the scarcity of water, the small amounts and patchy distribution of organic matter and nutrients, and the importance of cryptogamic soil crusts--are severely aggravated by impacts on the core of campsites. In sum, impacted areas are small but, where impact occurs, it is severe.

To what extent do impacts vary with amount of use?

Characteristics of high and low use sites are compared in Table 10. Amount of change on these sites is compared in Table 11. Only median values for one measure of change are presented here. More complete statistics can be found in Tables 5-7 in Appendix II.

From Tables 10 and 11, the types of impact that are significantly more pronounced on the core of high use sites are core area, litter loss, increase in bulk density and penetration resistance, and decrease in soil moisture content and final infiltration rate. None of the other core impacts and none of the perimeter impacts, except loss of soil moisture, are significantly more serious on high use sites.

The difference in the size of the devegetated core is particularly pronounced, with median values of 50 m^2 on high use sites and 22 m^2 on low use sites. Since most impact is confined to the core and impact on the core is severe, the size of the core is an important indicator of impact. Although the core is over twice as large on high use sites, high use sites probably receive about 10 times as much use as low use sites. In other words, in comparison to low use sites, sites receiving about 10 times as much use are just over twice as large.

Although more litter is lost on high than low use sites, differences are too small to be of any ecological significance. Organic matter is virtually eliminated on the core of both high and low use sites. One percent is left on high use sites, while 3 percent remains on low use sites.

Table 10. Campsite conditions in relation to amount of use.[1]

Impact Parameter	Amount of Use: High	Low	Sign.
	----median----		
Core Area (m^2)	50	22	.002
Vegetation Cover (%)			
Perimeter	55	50	.249
Floristic Dissimilarity (%)	36	29	.204
Cryptogam Cover (%)			
Perimeter	<1	5	.087
Litter Cover (%)			
Core	1	3	.002
Perimeter	54	51	.415
Mineral Soil Cover (%)			
Perimeter	15	14	.500
Rock Cover (%)			
Perimeter	7	6	.162
Bulk Density (g/cm^3)			
Core	1.68	1.49	.007
Perimeter	1.31	1.20	.415
Soil Moisture (%)			
Core	4.7	2.9	.028
Perimeter	5.1	4.1	.020
Initial Infiltration Rate (cm/min)			
Core	0.4	0.5	.201
Perimeter	1.9	1.9	.474
Final Infiltration Rate (cm/min)			
Core	0.17	0.14	.343
Perimeter	0.58	0.51	.371
Penetration Resistance (kg/cm^2)			
Core	4.0	1.4	.001
Perimeter	1.1	0.7	.098

1 - Significance was evaluated with a one-tailed Mann-Whitney U test. Probabilities ≤ 0.05 are significant.

Table 11. Amount of change in relation to amount of use.[1]

Impact Parameter	Amount of Use: High	Low	Sign.
	----median----		
Vegetation Cover (R-%)			
Perimeter	-14	-5	.230
Cryptogam Cover (A-%)			
Perimeter	0	-3	.103
Litter Cover (R-%)			
Core	-99	-95	.001
Perimeter	-23	-5	.194
Mineral Soil Cover (A-%)			
Perimeter	6	5	.088
Rock Cover (A-%)			
Perimeter	4	1	.109
Bulk Density (A-g/cm^3)			
Core	0.54	0.20	.009
Perimeter	0.01	0.03	.300
Soil Moisture (R-%)			
Core	-39	-14	.006
Perimeter	-6	29	.024
Initial Infiltration Rate (R-%)			
Core	-77	-57	.136
Perimeter	-20	5	.146
Final Infiltration Rate (R-%)			
Core	-82	-67	.047
Perimeter	-32	-24	.178
Penetration Resistance (A-kg/cm^2)			
Core	3.5	1.0	.001
Perimeter	0.4	0.1	.064

1 - The measures of change are absolute (A) or relative (R). Absolute change is the difference between campsites and controls; relative change is absolute change as a percent of control values. Positive values indicate an increase on campsites. Significance was evaluated with a one-tailed Mann-Whitney U test. Probabilities ≤ 0.05 are significant.

Soil compaction, another serious problem on the core of Grand Canyon sites, is much higher on high than low use sites. Increases in both bulk density and penetration resistance are around three times greater on high use sites. Low use sites have bulk density and penetration resistance values of 1.49 g/cm^3 and 1.4 kg/cm^2. Although this still represents a significant level of soil deterioration, these compaction levels should be less inhibitive to plant growth and should permit relatively rapid recovery. On some of the most lightly used sites, compaction levels may remain sufficiently low to permit some plant growth, even on the core. The three sites with at least 5 percent vegetation cover on the core had low median bulk density and penetration resistance values of 1.35 g/cm^3 and 0.5 kg/cm^2.

One of the consequences of compaction is a reduction in infiltration rates and, therefore, a reduction in soil moisture content. Moisture content, in particular, is strongly affected by amount of use. Moisture content on the core of low use sites is only 14 percent less than on controls. Although this is only about one-third of the loss on high use sites (39 percent), any loss of moisture is likely to be significant to vegetation in desert environments. Annuals, in particular, are highly sensitive to moisture fluctuations. For example, they were notably sparse during the field season on account of unusually low precipitation the preceding winter. On perimeters, moisture decreases 6 percent on high use sites and increases 29 percent on low use sites--a statistically significant difference. This increase in moisture on low use perimeters is not totally unexpected. Light trampling of dry sandy soils can lead to increased soil moisture content (Lutz 1945, Liddle and Greig-Smith 1975) due to an increase in water-holding capacity caused by an increase in capillary pore space following compaction.

Final infiltration rates were reduced more dramatically on high than low use sites. Initial infiltration rates responded the same way but differences were too variable to be statistically significant. Perhaps a larger sample size would have allowed the difference in initial rates to be judged significant as well. Certainly the regular decline in relative change values from high use core to low use core to high use perimeter to low use perimeter (Table 11) suggests that impact is related to amount of use. However, differences between control and core values, regardless of amount of use, are much greater than differences between high and low use sites. Even on low use sites, core infiltration rates are less than one-third of those on controls.

For most other variables, high use sites are more impacted than low use sites but differences are not statistically significant. Again a larger sample size might have resulted in statistically significant differences. However, statistical significance is of little relevance if the magnitude of difference is small. For example, with a large sample size the difference in mineral soil increase between high use sites (6 percent) and low use sites (5 percent) might be judged significant. Yet, it would be foolish to consider use reductions on campsites to take advantage of this small difference in amount of impact. It appears that the only impact parameters that differ significantly between high and low use sites--using a managerial as well as statistical measure of significance--are core area and bulk density, penetration resistance, and moisture content of core soils.

Evidence for this conclusion is presented graphically in Figure 2. For most impact parameters, the most dramatic differences in amount of impact are

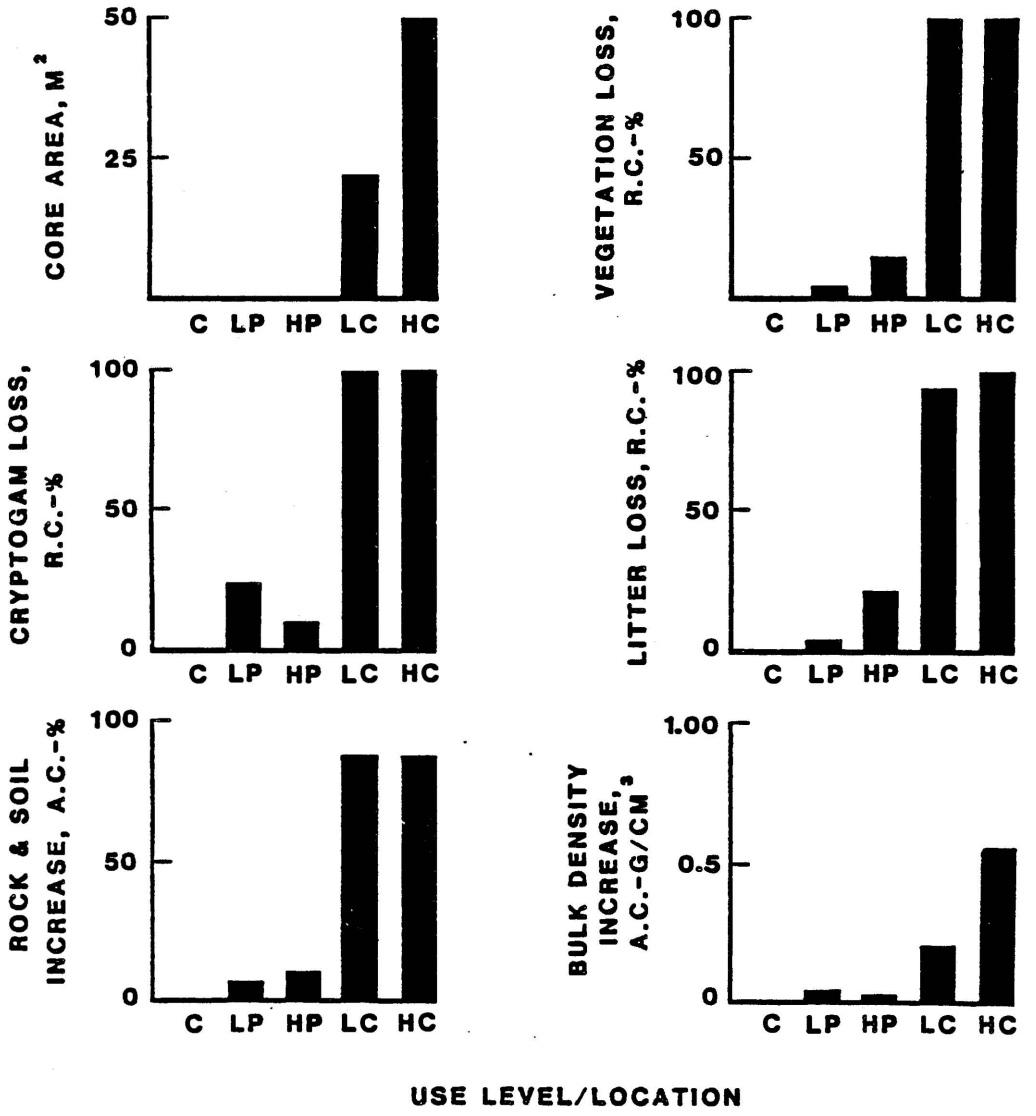


Fig. 2 . Median amount of impact in relation to campsite use level and location. Use level/locations are controls (C), low use perimeters (LP), high use perimeters (HP), low use cores (LC), and high use cores (HC). R.C. is relative change; A.C. is absolute change.

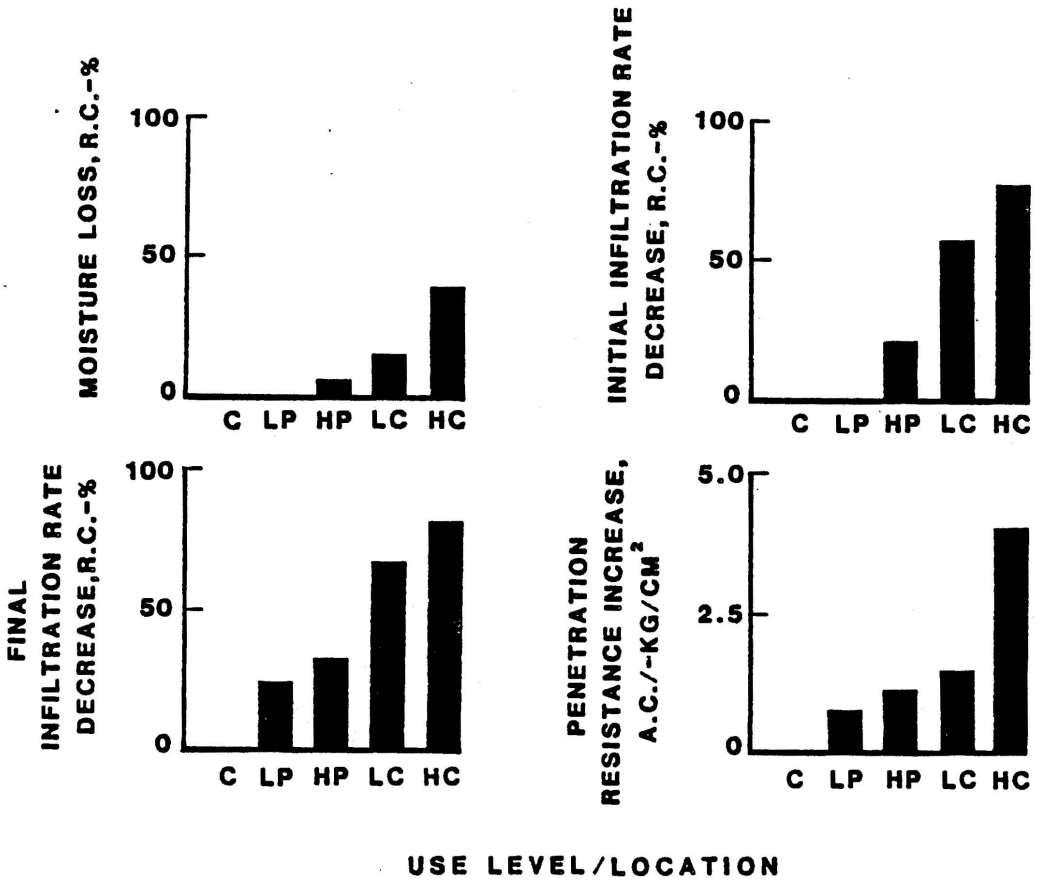


Fig. 2. Median amount of impact in relation to campsite use level and location. Use level/locations are controls (C), low use perimeters (LP), high use perimeters (HP), low use cores (LC), and high use cores (HC). R. C. is relative change; A. C. is absolute change.

(cont.)

between perimeter and core locations, regardless of amount of use. Only for core area, bulk density, penetration resistance, and moisture content is the greatest difference between high and low use core locations. Compared to the other types of impact, it takes more use for these to increase dramatically. One might say that Grand Canyon campsites resist these types of impact more readily than other types. Grand Canyon sites are least resistant to loss of cryptogam cover and reductions in final infiltration rates, both of which are pronounced even on the perimeter of low use sites.

Although differences between high and low use sites, in vegetation and litter loss on the perimeter, are not significant for all sites, they are significantly different for catclaw sites. On high use catclaw sites, median relative vegetation and litter loss are 27 and 22 percent, respectively; comparable values on low use sites are 12 and 2 percent. Groundcover disturbance around the perimeter of high use sites is more serious in catclaw--where vegetation and litter cover is unusually high--than on other vegetation types where most trailing occurs on bare mineral soil between shrubs. Mineral soil cover also increases significantly on catclaw perimeters, despite the lack of a significant increase on sites in other vegetation types. This difference in fragility of the vegetation types is discussed in more detail in the following section.

In sum, campsite perimeters are little affected by use, regardless of its frequency, except that loss of vegetation and litter, resulting in exposure of mineral soil, is more pronounced on the perimeter of high use catclaw sites. When comparing cores, however, low use sites have suffered substantially less impact than high use sites. Compared to high use sites, they are typically less than one-half the size and soil compaction and moisture loss problems that inhibit plant growth and site recovery are not severe. This suggests that where it is feasible to avoid heavy use, without incurring a substantial increase in the number of consistently-used sites, this would be worthwhile.

Generally these results support hypotheses suggested by previous studies. Core area was also much smaller on low use sites in the Eagle Cap (Cole 1982a). Significantly lower bulk density and penetration resistance values have been found on low use undeveloped sites in the Boundary Waters Canoe Area (Marion 1984), Kings Canyon National Park (Simon 1978), Rushing River Provincial Park (James et. al. 1979) and developed campsites in Illinois (Young and Gilmore 1976) and South Carolina (Dunn et. al. 1980). Simon (1978) and Dunn et. al. (1980) also found that moisture content declined significantly as use increased. James et. al. (1979) and Dunn et. al. (1980) both report that infiltration rates decrease as use increases, but in both cases over 95 percent of the change occurs on the most lightly used sites.

One unique finding on Grand Canyon sites relates to changes in the cover of vegetation, litter, and mineral soil. In the vegetation types studied before--primarily coniferous forests--vegetation is fragile and disappears quickly with very light use; litter layers, in contrast, are thick and substantial amounts of mineral soil are only exposed with high use (Frissell and Duncan 1965, Cole and Fichtler 1983, Marion 1984). In the Grand Canyon, exposure of mineral soil occurs at least as rapidly as vegetation loss. This reflects both resistant vegetation and a sparse litter layer that is quickly removed by trampling and water running across compacted soils.

Despite a general concurrence with previous work, campsites in the Grand Canyon seem more likely to profit from low use levels than campsites in backcountry areas previously studied. There are two likely reasons for this. One is the relatively resistant vegetation. This serves to confine impact to a small area, the size of which is strongly related to amount of use. This effect is also enhanced by the rough, rocky topography around campsites. Elsewhere, large areas are affected, even by low use levels. The second reason is that the most serious impacts on Grand Canyon sites result from soil compaction, which only becomes pronounced on high use sites. Elsewhere, serious impacts to groundcover vegetation and trees occur even with low use, generally suggesting that confining use to a small number of high use sites is preferable to spreading use--and impact--over a large number of low use sites.

To what extent do impacts vary between vegetation types?

Another factor contributing to variability in amount of impact is campsite location. Some sites are undoubtedly much more durable than others. In particular, there has been considerable concern with impact to riparian sites. The importance of this source of variability was evaluated by comparing amount of impact on sites in the three vegetation types most frequently used for camping: pinyon-juniper, catclaw, and desert scrub. Of these, the catclaw sites are the ones located in the riparian areas of foremost concern. The other major riparian type, cottonwood, was not studied due to an insufficient number of potential study sites that were not more highly disturbed by periodic flooding than by recreational use.

Campsite conditions and amount of change on these three vegetation types is compared in Tables 12 and 13. The size of the core area differs significantly between vegetation types. Pinyon-juniper sites are more than twice the size of catclaw or desert scrub sites, which are similar in size. This difference is particularly pronounced at low use levels (Table 14). Confining impact to a small core area is much easier in catclaw and desert scrub, where thick and thorny shrubs and rough terrain make expansion difficult, than in pinyon-juniper, where these limitations on expansion are less prevalent. While low use catclaw and desert scrub sites are likely to be small, even low use pinyon-juniper sites are large.

Significant differences in vegetation, litter, and mineral soil cover, final infiltration rates, and penetration resistance (Table 12) merely reflect similar differences on undisturbed control plots (see Table 11 in Appendix II). When amounts of change are compared (Table 13) none of these differences are statistically significant.

As mentioned earlier, vegetation and litter loss on catclaw perimeters is significantly higher on high than low use sites; these differences are not significant on other vegetation types. Also, only on catclaw sites is mineral soil exposure significantly higher on the perimeter than controls. In Table 13, vegetation loss and increase in mineral soil is higher on catclaw sites than elsewhere. All of this indicates that catclaw sites are more prone to perimeter groundcover disturbance than other vegetation types. Catclaw sites have more informal access trails leading off the site to the main trail, other sites, and water sources. These trails are also more frequently badly eroded than trails in other types. The more obvious trailing in catclaw is primarily

Table 12. Campsite conditions on different vegetation types.[1]

Impact Parameter	Vegetation Type: Pinyon-Juniper	Catclaw	Desert Scrub	Sign.
	---------median----------			
Core Area (m^2)	56	24	24	.044
Vegetation Cover (%)				
Perimeter	32	66	58	.001
Floristic Dissimilarity (%)	36	20	66	.144
Cryptogam Cover (%)				
Perimeter	3	<1	12	.060
Litter Cover (%)				
Core	<1	<1	2	.091
Perimeter	27	73	51	<.001
Mineral Soil Cover (%)				
Perimeter	57	6	12	<.001
Rock Cover (%)				
Perimeter	5	7	9	.217
Bulk Density (g/cm^3)				
Core	1.54	1.74	1.63	.171
Perimeter	1.38	1.17	1.21	.319
Soil Moisture (%)				
Core	4.2	2.6	4.1	.235
Perimeter	4.6	5.0	8.5	.664
Initial Infiltration Rate (cm/min)				
Core	0.4	0.4	0.7	.422
Perimeter	1.9	1.9	1.8	.733
Final Infiltration Rate (cm/min)				
Core	0.11	0.19	0.18	.062
Perimeter	0.35	0.82	0.30	.011
Penetration Resistance (kg/cm^2)				
Core	2.1	2.8	3.3	.761
Perimeter	0.4	1.0	1.3	.046

1 - Significance was evaluated with the Kruskall-Wallis oneway analysis of variance test. Probabilities ≤ 0.05 are significant.

Table 13. Amount of change on campsites in different vegetation types.[1]

Impact Parameter	Vegetation Type: Pinyon-Juniper	Catclaw	Desert Scrub	Sign.
	---------median----------			
Vegetation Cover (R-%)				
Perimeter	-3	-18	8	.470
Cryptogam Cover (A-%)				
Perimeter	0	-1	-1	.443
Litter Cover (R-%)				
Core	-99	-99	-96	.214
Perimeter	-29	-9	-9	.653
Mineral Soil Cover (A-%)				
Perimeter	-5	5	-6	.320
Rock Cover (A-%)				
Perimeter	3	2	4	.837
Bulk Density (A-g/cm^3)				
Core	0.18	0.44	0.39	.221
Perimeter	0.04	-0.16	0.06	.284
Soil Moisture (R-%)				
Core	-9	-37	-28	.138
Perimeter	-3	20	-4	.899
Initial Infiltration Rate (R-%)				
Core	-60	-82	-70	.652
Perimeter	68	-22	-12	.096
Final Infiltration Rate (R-%)				
Core	-82	-67	-80	.497
Perimeter	-30	22	-63	.155
Penetration Resistance (A-kg/cm^2)				
Core	1.9	2.0	2.6	.681
Perimeter	0.1	0.0	0.4	.073

1 - The measures of change are absolute (A) or relative (R). Absolute change is the difference between campsites and controls; relative change is absolute change as a percent of control values. Positive values indicate an increase on campsites. Significance was evaluated with a one-tailed Mann-Whitney U test. Probabilities ≤ 0.05 are significant.

Table 14. Median campsite core area in relation to both amount of use and vegetation type.

Vegetation Type	Amount of Use	
	High	Low
	---square meters----	
Pinyon-juniper	66	50
Catclaw	44	12
Desert scrub	49	19

a result of higher vegetation and lower mineral soil coverages under undisturbed conditions. Although more vegetation is lost around the perimeter of catclaw sites, vegetation cover remains higher and mineral soil lower on catclaw sites than elsewhere. Moreover, most of the vegetation that is lost is Bromus rubens, a non-native plant. Therefore, this difference in impact is of more aesthetic than ecological significance.

Problems with eroding trails are more serious. This reflects the location of catclaw sites on alluvial terraces above water courses. Trails descend the terrace banks at steep grades and the alluvial material itself is probably particularly erodible. This situation is never found on pinyon-juniper sites. Desert scrub sites are usually on less erodible colluvium or bedrock and often lack steep banks into the water courses.

Finally, on high use campsite cores, bulk density increase is significantly greater on catclaw sites than on either of the other vegetation types. The median value for high use catclaw sites is 1.82 g/cm^3, a very dense soil. This may reflect more frequent trampling of moist soils or a wider range of particle sizes on the alluvial terraces where the catclaw sites are usually located. Either of these characteristics make a soil prone to compaction.

In sum, there is little variation in the durability of these three vegetation types. Pinyon-juniper sites tend to be large, even when only lightly used, but the severity of impact on these sites is not particularly pronounced. Measures of soil deterioration on these sites are generally below median values for all sites. Catclaw and desert scrub sites are much smaller. However, there is some evidence that soil deterioration is particularly severe on catclaw sites; several measures of change exceed median values for all campsites. Perimeter disturbance on catclaw sites also exceeds median values for all sites. These differences are particularly pronounced on high use sites. This suggests that where use is high, locating sites in desert scrub may be preferable to locating sites in catclaw. Since mineral soil is more abundant naturally, trailing is less obvious; moreover compaction is likely to be less severe. However, conditions vary substantially even within the same vegetation type and differences between types are small in relation to control-campsite differences. Consequently, overall differences in durability appear to be less important than differences in amount of use.

How does cryptogam crust respond to trampling?

In the trampling experiment, cryptogam crusts were destroyed extremely rapidly (Fig. 3). Figure 4 depicts the compression of crusted soil pedestals with increasing trampling. Lug-soled boots caused significantly more compression than tennis shoes at less than 50 passes but, even with tennis shoes, compression was rapid. Pedestals were compressed one-fourth after 5 passes and almost three-fourths after just 15 passes. After 50 passes, further trampling caused no additional compression; crusts had already been pulverized.

Groundcover on the trampling lanes was described as either undisturbed cryptogamic crust, disturbed (detatched) cryptogamic crust, or bare mineral soil. Changes in the percent cover of these three groundcover categories, following different numbers of trampling passes, are presented in Figure 5.

(a)



(b)



Fig. 3. The cryptogam crust (a) is highly disturbed along the trampling lanes but was similar to the undisturbed crust in the foreground, prior to trampling. The technique for measuring vertical distance and groundcover is illustrated in (b).

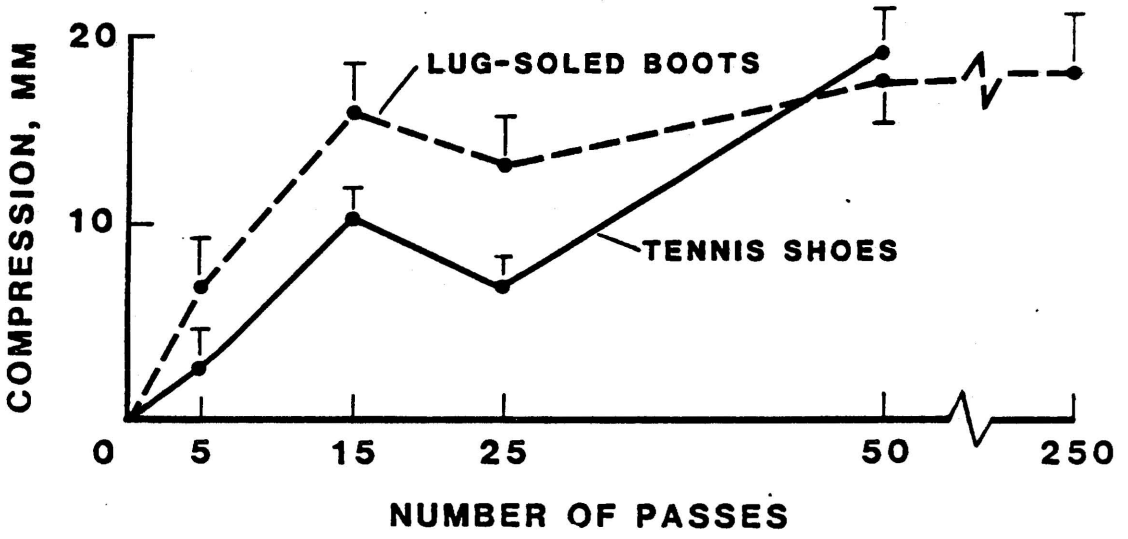


Fig. 4. Compression of cryptogamic crusts in relation to amount of trampling. Vertical bars represent one standard error.

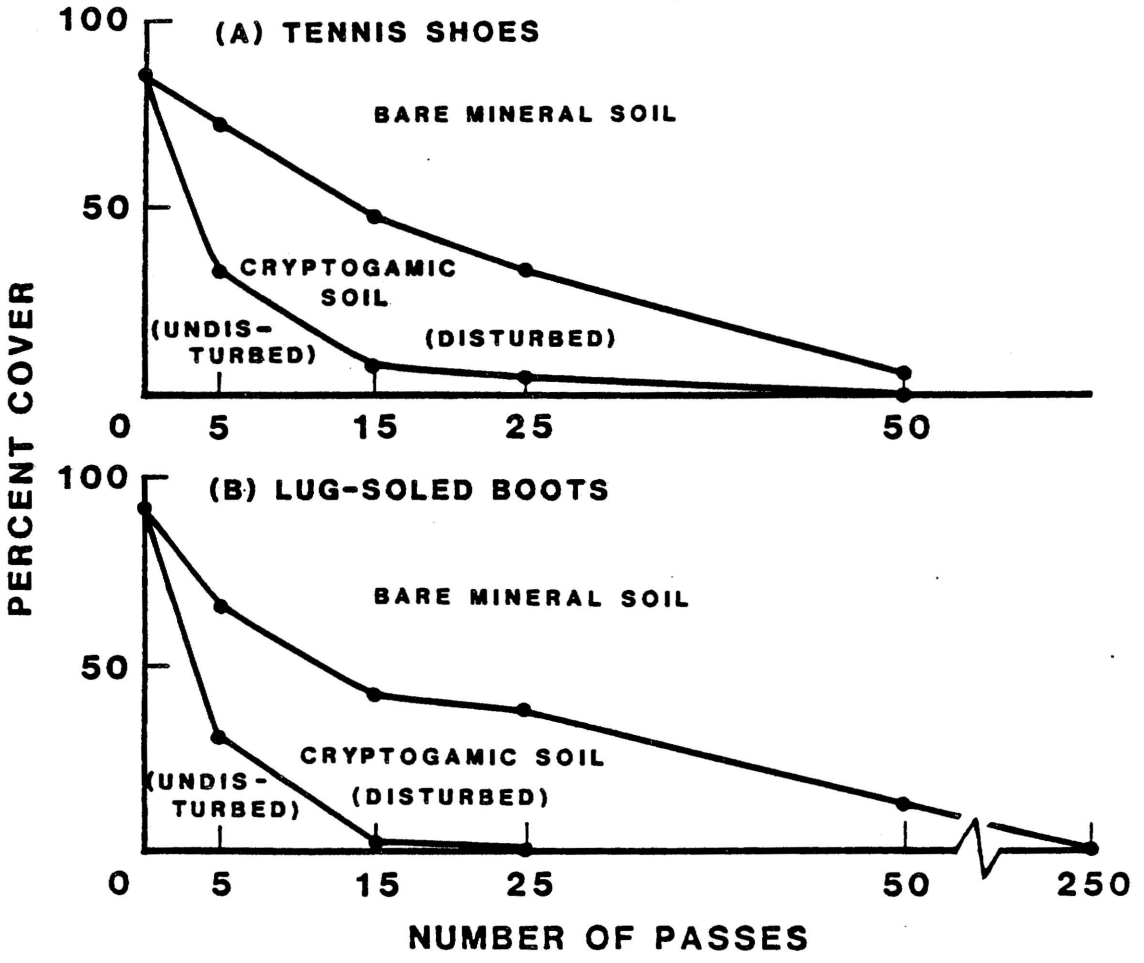


Fig. 5. Percent cover of undisturbed cryptogam soil, disturbed cryptogam soil, and bare mineral soil in relation to amount of trampling, using (a) tennis shoes and (b) lug-soles boots.

Differences in the rate of cryptogam disturbance caused by trampling with different types of footwear are minimal. In both cases, undisturbed crust decreases and bare soil increases as trampling increases. Disturbed crust increases at first and then decreases at higher trampling levels. Over one-half of the cryptogam crust was disturbed after just 5 passes. After only 15 passes, one-half of the crust was completely pulverized, exposing the mineral soil beneath. At a trampling level between 50 and 250 passes, the crust was completely destroyed, regardless of footware.

Similar trampling experiments have been conducted in many other vegetation types (Cole 1985). These cryptogam crusts are perhaps an order of magnitude more fragile than any groundcover experimentally trampled previously. One footprint is sufficient to disturb the crust and several will destroy it completely. Due to this fragility, random trampling could destroy large areas of crust. Given the importance of these crusts in desert ecosystems (refer to the literature review in Appendix I), destruction of large areas of crust could represent a significant environmental impact. In addition, evident trailing in areas of well-developed crust are a considerable aesthetic intrusion.

Problems with crustal disturbance can be dealt with in several ways. The most important is to educate visitors about the nature and fragility of crusts. They should be encouraged to avoid trampling or, where this is not possible, to only trample one path. Trails and designated sites should be located away from areas with well-developed crust. Where this is not possible, every effort should be made to confine traffic to one path. Often emphasizing development of one trail is sufficient. Where it is not, signs may be required to keep visitors from using other trails.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Major implications of results

In the Grand Canyon backcountry, the total area disturbed by camping is low. Partially-completed campsite inventories indicate that the number of disturbed sites is not extremely high and this study found the disturbed area of most campsites to be small. This suggests that the integrity of Grand Canyon ecosystems is not being substantially compromised by recreational use. The major possible exceptions to this are where impact is concentrated on rare ecosystem types or on the habitat of threatened or endangered species. In this study, we found no examples of the latter case. However, recreational use is highly concentrated close to water in riparian habitats. Even in this relatively rare ecosystem type, most of the habitat remains undisturbed. However, these locations should be--and indeed they already are--places of foremost concern. Where use levels are moderate to high, site designation and attention to the design and layout of trail and campsite systems, such that impact is confined to as small an area as possible, is important.

Although the area of disturbance is small, the intensity of disturbance, where it occurs, is high. Virtually all vegetation and litter is removed from the core of campsites, exposing mineral soil and rock that is frequently compacted to a cement-like surface. Such a compacted surface is probably stable since the hard surface resists erosion. However, life in such soil is severely impoverished. It is difficult to impossible for plants to get established or for the roots of existing plants to penetrate such dense soils. Moreover, the major source of fertility--organic litter--and water, two common limiting factors in the desert, are cut off through elimination of litter-producing shrubs, abrasion and erosion of surface litter, and reduced infiltration rates on compacted soils.

Two reasons for the high level of soil disturbance on these campsites can be suggested. First, many of these sites receive very high levels of use. Compaction is more pronounced on more heavily used sites and some of these sites are very heavily used year-round. Second, soils low in organic matter and with a wide range of particle sizes are particularly susceptible to compaction. Grand Canyon soils, except for those directly under trees such as catclaw and oak, are generally low in organic matter. Alluvial soils, particularly those far down in the Canyon, have a wide range of particle sizes. Thus they are prone to high levels of compaction.

The high level of soil deterioration on these sites suggests a need to be concerned about increases in the area of disturbance, either through the expansion of existing sites or the uncontrolled proliferation of new sites. On established sites, studies elsewhere suggest that the major change over time is site expansion (Merriam et. al. 1973, Marion 1984). Expansion can be controlled through design, maintenance, and rehabilitation, such as what has been done at Hermit Camp. Similar programs may be needed elsewhere. Visitor education, discussed in more detail below, can also focus attention on the need to avoid expansion. Finally, party size limits can have a pronounced effect on campsite area. During the campsite inventory, it would be valuable to assess each site's physical capacity in terms of the number of people it can hold without being enlarged. It might, then, be possible to direct large

parties and groups to sites large enough to accommodate them without causing further damage.

Site proliferation can be avoided by designating sites in areas of moderate to high use. Again, this action has already been taken in many parts of the Grand Canyon backcountry. Other places that could profit from such a policy will be identified after the campsite inventory. Two places examined in this study where site designation should be considered are Boucher Creek and Hance Creek. Proliferation can also be avoided through education, teaching people to choose resistant, little-used sites or to camp on sites that already have been well-impacted.

Currently the major problems with campsites appear to be more of a social and aesthetic nature than true ecological problems. Problems are most pronounced in locations where a number of campsites are clustered in close proximity to each other. The campsite clusters at Hermit and Monument are good examples. In these clusters, mazes of trails develop, linking barren compacted campsites to each other, the main trail, and water sources. Because several impacted sites are in close proximity to each other, impacts are highly obtrusive to visitors. Impact is not more pronounced--impact on an individual site at Monument is not any greater than impact at Salt Canyon, for example--it is just more spatially concentrated and, therefore, more obvious to visitors. This is a problem because management, at least according to Wilderness standards, attempts to keep man's imprint "substantially unnoticeable". An associated social problem is lack of solitude in these campsite clusters, where numerous parties camp within sight and sound of each other. Currently, clustered sites present what is probably the most significant campsite-related problem in the backcountry, but the problem is not really one of abnormally high levels of resource damage.

The generally low level of camping disturbance in the Grand Canyon backcountry can be attributed to several factors. First, the simple notion that the desert is unusually fragile is really much more complex than commonly assumed. Fragility consists of two components, resistance and resilience. Resistance is the ability to tolerate recreational use without being disturbed; resilience is the ability to recover from disturbance. Desert vegetation is relatively resistant, so disturbed areas are small. Desert soil, in contrast, is not very resistant. The desert vegetation's fragility lies in its low resilience. Once disturbance occurs, desert vegetation generally has a low capacity for recovery. Riparian vegetation is different. It tends to be less resistant but more resilient. Disturbance occurs more rapidly and is more obvious, but vegetation also recovers more rapidly. Little is known about the resilience of desert soils.

On the positive side, this suggests that sites can take a considerable amount of use before serious damage occurs. Particularly in lightly-used areas, it should be possible to avoid most impact. On the negative side, once damage does occur, it will be evident for a long time. Thus it would be prudent to adopt a conservative management stance, attempting to avoid impact before it occurs and particularly, to guard against the proliferation of campsites. Again, riparian sites are somewhat different from drier sites. Here mistakes are less costly because impacts heal more quickly. Management can be less conservative and less strict in its emphasis on resource protection. However, it is still important to monitor impacts so problems can be

identified and corrected.

Other factors contribute to the generally low level of camping disturbance. Prohibitions on campfires and stock keep disturbed areas small and avoid aesthetic problems attendant to both of these practices. A tendency for party sizes to be small has contributed to maintaining small impact areas. Finally, the fact that most of the backcountry was essentially unused until recently--after management had a chance to prepare for use and its effects--has been highly beneficial. A relatively aggressive and innovative management program at Grand Canyon has been highly successful in protecting the resource from camping disturbance.

In a comparison of sites receiving very different amounts of use, high use sites had substantially more impact than low use sites. In particular, low use sites were smaller and had much less highly compacted soils. Because campsite-specific use figures are not available, it is not possible to determine precisely how low use has to be to experience this benefit. It appears, however, that where use levels on individual sites can be kept below 10-20 parties per year, without greatly increasing the number of sites, that this would be desirable.

Generally, in terms of management, it seems appropriate to differentiate between high and low use areas. High use areas are those where use is too high and/or the number of desirable sites is too low to keep use levels on individual sites below 10-20 parties per year. In these areas, sites should be designated or, at least, visitors should be encouraged to use the same well-impacted sites over-and-over again.

Where use is lower, impacts on individual sites can be minimized by spreading use among a number of sites. Visitors should be encouraged to camp on resistant, preferably non-vegetated sites with little evidence of previous impact. This approach has several inherent difficulties. First, it may be difficult to convince visitors to use unimpacted sites, particularly if well-impacted sites are more desirable. Second, it may be difficult to teach visitors how to select resistant sites. Third, it may be difficult to teach visitors how to minimize their impact on campsites. Generally, this approach will only be successful as part of a strong educational effort. Its value lies in avoiding highly impacted sites and allowing visitors the freedom of selecting their own campsites. Existing well-impacted sites should be closed and revegetated to discourage further use.

The most likely negative consequence, if this program is unsuccessful, is site proliferation. Therefore, monitoring of sites is essential. If monitoring indicates proliferation is occurring, it will be necessary to strengthen educational programs, reduce use levels, or change over to a use concentration strategy.

In contrast to differences in impact related to amount of use, differences in the fragility of the three vegetation types studied were not pronounced. This suggests that there is little value in trying to locate sites in one or another of these types. On the other hand, each vegetation type is particularly prone to certain types of problems. Recognizing this can be useful in tailoring management to each of these vegetation types.

The primary problem in pinyon-juniper is site expansion. Even low use sites here are large. Therefore it is particularly important to designate sites wherever site proliferation is likely to occur. Better definition of sites on Horseshoe Mesa was an obvious high-priority need. Another area where proliferation could be a problem--judging from the campsite inventory data--is half way up the Tanner Trail. However, in many pinyon-juniper woodlands, areas of slickrock offer ideal low-impact campsites, if visitors can be convinced to use them.

Cryptogam crusts are also particularly well-developed in pinyon-juniper woodlands. Since these crusts are so fragile, proliferation of sites and trails can be particularly troublesome. This is a further reason for site designation in popular pinyon-juniper areas. The Esplanade above Thunder River is an example of a place where this might become a problem. Generally there are few problem areas in pinyon-juniper because visitor use is, with few exceptions, low.

Catclaw sites are very different. Low use catclaw sites are very small and lightly impacted when compared with high use sites that experience pronounced soil compaction and have problems with erosion of access trails. This suggests that it would be particularly worthwhile to keep use levels low. Unfortunately, this vegetation type--the one in which it is most advantageous to avoid heavy use--is the most popular destination for visitors and is a type where potential campsites are limited. Consequently, management will generally have to emphasize site designation and then use design and maintenance to avoid trail erosion. Where use levels are low, encouraging dispersal will be particularly beneficial in catclaw, where resilience is unusually high for desert environments.

Desert scrub sites are highly variable and intermediate in response, compared to the other vegetation types. Site expansion is a problem on some sites but not others. The site at Horn Creek is over twice the median size and the sites at Salt Creek and Ruby Canyon both have large satellites. Some of the sites also have very highly compacted soils. Designating sites and some attention to design and rehabilitation is important--and has been done--at high use places such as Horn and Salt Creeks. In low use areas, encouraging camping on slickrock or on sandy soils without vegetation is likely to minimize impact. In some of the canyons along the Tonto Trail between Bass and Boucher, site proliferation is beginning. Monitoring of these locations is important and may show the need to confine use and impact either directly, through designation of sites, or indirectly, through information, education, and design.

Current management programs

Any evaluation of management must include a certain element of personal opinion. The following discussion is no exception.

Generally, the good condition of campsites found in this study validates the existing management program at Grand Canyon. Localized vegetation and soil damage is the inevitable result of recreation use, but the area affected is insignificant in relation to the size of the Grand Canyon backcountry. The current system of zones and designation of sites in high use areas tolerates a

few localized areas of substantial impact, but most of the backcountry is virtually undisturbed.

In use areas with designated sites or where most at-large camping occurs on a few sites--usually those close to water--use limits effectively limit the number of campsites and, therefore, the area of disturbance. In such places, use limits have very little effect on how severely individual sites are impacted, however. Individual sites are already impacted to the point where further increases in use are unlikely to cause any further impact. Moreover, use levels would have to be reduced manyfold before any reduction in impact is likely to occur. In these areas, then, use limits primarily affect elements of the recreational experience, particularly the number of campsites and other campers that visitors encounter. Use limits could be increased without substantially damaging the resource. This may be desirable in some places, particularly in threshold zones, if clustering of sites can be avoided and social objectives, such as providing opportunities for solitude, are not jeopardized.

In at-large camping zones with numerous campsites, use limits have no direct effect on the number of sites because people are free to use and impact as many different sites as they want. However, use limits can prevent severe impact to campsites, if they keep sites from being used more than perhaps 10-20 nights per year. Since use limits can effectively minimize resource damage in these areas, they probably need to remain low. In order to minimize impact in low-use, at-large camping zones, necessary supporting actions include (1) an educational effort to guide campers to resistant sites and away from sites that, through excessive use, may deteriorate significantly, and (2) a monitoring program to determine if significant deterioration is occurring.

Although it appears that the resource is being protected to a high degree under current use levels, this does not mean that current use levels are optimal. Resource conditions could be improved somewhat with lower use levels (assuming necessary supporting actions are taken) or they could be allowed to deteriorate somewhat with higher use levels (primarily through an increase in the number of sites). With appropriate management there are probably places where resource conditions may improve, even with increases in use. In the absence of specific objectives for the number and condition of campsites, it is not possible to objectively determine optimal use limits. Therefore, development of objectives is critical to further refinement of the backcountry management plan. With development of objectives and completion of the campsite inventory, described later, it will be possible to objectively adjust use limits where needed.

Management of the Grand Canyon backcountry could be enhanced through a strong educational effort. The fact that visitors must contact rangers to obtain permits could make such an effort highly effective. Even area-specific information could be given to visitors. Again, significant strides toward such an effort have already been taken.

Three types of visitor education seem appropriate: (1) a general appreciation of fragile features of the desert ecosystem; (2) how to choose a low-impact campsite; and (3) how to behave such that impact to a site is minimal. Two serious impacts that could be reduced through visitor

appreciation of their significance are loss of shrubs and trampling of cryptogam crusts. Shrubs create stable "islands of fertility", high in moisture, nutrients, and biotic activity. Once destroyed, recovery can take centuries. This is why it is so important to avoid shrub loss and keep campsites small. The role of cryptogam crusts is described in the literature review, Appendix I. Crusts are important and extremely fragile. Appreciation of shrubs and cryptogams, their importance and fragility, should help reduce thoughtless impact of these features.

The choice of a low-impact campsite is quite site-specific. In areas with designated sites, visitors obviously should use a designated site. In relatively popular at-large camping zones, informing visitors of camping opportunities away from clustered sites would improve solitude. In the Boucher and Hance Creek areas, for example, parties tend to camp next to each other when there are other camping opportunities a short distance downstream. A survey of potential campsites close to popular campsite clusters in at-large camping zones could provide information useful in locally dispersing use.

In low use areas, visitors should be encouraged to select sites showing little evidence of previous use. Here it is important to select a resistant site as well and, particularly, to avoid damage to shrubs. The most resistant sites are on slickrock benches, dry washes, and beaches. The general recommendation should be to camp on patches of bare mineral soil, avoiding vegetation and, particularly, cryptogams and shrubs.

Most of these campsite selection suggestions are already mentioned in the backcountry trip planner. That source also mentions most of the on-site behavior required to avoid unnecessary impact. Stressing the importance of avoiding site expansion and multiple trailing is probably most important after obeying regulations, proper disposal of human waste, and not polluting water sources.

Another type of management that has been initiated, but that requires further emphasis is site design, maintenance, and rehabilitation. Most site clusters will need this type of work. The general objective is to control traffic flow in such a manner that the area of impacted trails and campsites is low and does not expand over time. "Improvement" of trails and campsites and planting rocks and plants on "closed" sites and trails should be tried first; "please keep off" signs may be necessary in some situations. Making people aware that this type of management is going on and why, while they are getting a permit, is likely to increase compliance with closures.

As mentioned before, most problems are associated with the clustered campsites at popular destinations. Current management of such places is on the right track. The keys to management are: (1) site designation to control number of impacted sites; (2) design, maintenance, and rehabilitation work to confine impact and keep these areas as attractive as possible; (3) avoidance of site expansion by keeping party size limits in line with site capacities; and (4) looking for means to improve local dispersal to maximize opportunities for solitude and avoid the visual obtrusiveness of numerous adjacent sites. Maps of local areas could be used to direct large parties to certain campsites, to locate alternative sites a short distance from clustered sites, or to provide information on rehabilitation efforts, closed campsites, or other features of the area.

In the undeveloped zones and some of the primitive zones, sites should not be designated and visitors should be challenged to leave minimal traces of their visit. The key to this, beyond using non-destructive camping techniques, is choice of campsites. Sites that are already impacted should be avoided, if possible. Instead, non-vegetated sites with little evidence of use should be selected. If use levels can be kept low, impact will also be low--as this study illustrates. Visitors could be shown examples of resistant sites and even given maps showing where resistant sites can be found. Monitoring of these places is important, however. If use levels are too high or if parties do not choose low use, resistant sites, impacts are likely to proliferate.

Future opportunities

Although current programs are doing a good job of protecting the resource, there are shifts in management that might improve the situation. Several suggestions have already been mentioned, including looking for means of increasing localized dispersal away from clustered sites, defining specific objectives for campsite abundance and condition, and completing a campsite inventory. Two other changes that would reduce restrictiveness, increase public cooperation and enjoyment and, if done properly, not increase resource damage substantially are increasing use limits and avoiding fixed itineraries, at least in some places.

The key recreational problems in the backcountry--both social and environmental--appear to result from the excessive concentration of campsites and campers. Designating sites close to each other aggravates these problems, although in many cases this cannot be avoided. Any opportunity to locally disperse use should be explored. This could be done both in designated site and at-large camping situations. An inventory of potential camping places, near to popular destinations and water sources, is needed. This could be part of the inventory of existing campsites.

Objectives would make it possible to decide whether use limits could be raised. Currently, demand exceeds the supply of permits in certain use-areas at popular times. In the threshold zones, where demand is particularly high, use limits could be raised with little deterioration of social or environmental conditions, if campers could be directed to designated sites away from site clusters. The difference between threshold and primitive zones is generally small--and inconsistent--compared with the difference between threshold and developed zones or between primitive and undeveloped zones. Raising use limits in threshold zones, while maintaining strict control of use distribution, might more adequately differentiate threshold and primitive zones and allow more use. Consequences of such a change could be evaluated through monitoring and readjusted as necessary.

Requiring visitors to plan and maintain a fixed itinerary is one of the most disliked of backcountry regulations (Hendee et. al. 1978). Fixed itineraries are the most efficient way to distribute use; however, experience with rationed permit systems based on trailhead quotas, in places such as Yosemite National Park, suggest that such systems can be almost as efficient. Where trail systems are complex, trailhead quotas are set based on use simulations similar to those being employed on the Colorado River. In less complex situations--and this might apply to Grand Canyon--this is not necessary; permit data is usually adequate. Refer to Parsons et. al. (1981)

for a discussion of the technique. Trailhead quotas are set such that use concentrations in specific areas will not exceed critical levels. One problem with using trailhead quotas is that some areas act as "bottlenecks", unnecessarily restricting use of more remote areas. This problem can be handled by issuing "override" permits, allowing excess parties to pass through but not stay overnight in "full" areas. The only cost of such a change, assuming no change in use levels, would be a slight increase in number of campsites and in crowding on a few occasions in popular places. The benefits would be increased visitor freedom and spontaneity. There are also a number of possible intermediate compromise options such as keeping fixed itineraries in places with designated sites-- where it is important for an area's capacity not to be exceeded--and using trailhead quotas elsewhere.

Based on this study, the management actions with the greatest likelihood of improving management related to backcountry campsites are:

(1) development of specific objectives for campsite number and condition by zone;

(2) implementation of the campsite monitoring program;

(3) relaxation of restrictions--particularly increasing use levels and avoiding fixed itineraries--where possible;

(4) intense site-specific management of popular clusters of sites, especially designating sites, using design and rehabilitation work to confine impact, and encouraging local dispersal to maximize opportunities for solitude; and

(5) attempting, through education, to influence where people camp in low use areas, particularly to avoid concentrated use in favor of using many resistant, non-vegetated sites.

Of the management actions required to minimize camping impacts, the only ones not currently in place, at least to some extent, are monitoring of campsites in low use areas and promoting use dispersal in low use areas. Although low use areas are not currently "problems", now is the time to institute actions that will keep impacts low. These areas are likely to receive increased use in the future. Baseline data on the condition of these areas, before they are substantially disturbed, will improve the ability of managers to identify and correct future deterioration. Use dispersal, if accompanied by the necessary supporting actions, will be the most effective means of avoiding severe campsite impacts, as long as use levels remain low.

LIMITATIONS OF THE STUDY

The two major limitations the reader should be aware of are the imperfection of control sites and the lack of site-specific use data. Ideally control sites should be identical to the campsite before it was camped on. Clearly it is impossible to find such ideal controls. Consequently some of the campsite-control comparisons used to infer amount of change will overestimate amount of impact and others will underestimate amount of impact. Since there is no reason to believe that controls should consistently over- or underestimate impact, median absolute and relative change values should provide good estimates of amount of impact. Impact estimates for individual campsites can be misleading, however, if controls are inadequate. Cover differences, between perimeters and controls, for individual plant species found on only a few sites can also be misleading for the same reason. However,

estimates based on a number of sites should be quite accurate. Moreover, data on campsite conditions, without reference to controls, should accurately portray existing levels of impact.

With site-specific use data it would be possible to identify exact use levels above which near-maximum levels of impact occur. Where use levels are above these thresholds it is desirable to concentrate use on as few sites as possible. Below these thresholds, which are likely to vary between vegetation types, dispersal of use among a number of sites can keep impact levels low on all sites. From observations and some use-area-specific data, it was estimated that on Grand Canyon campsites this critical use level boundary is around 10-20 nights per year. This should be considered only a rough estimate, given the lack of site-specific use data. Over time, monitoring should indicate if the estimate is too high, too low, or about right.

A RECOMMENDED MONITORING PROGRAM

The Overall Program

A campsite monitoring program is an important element of any backcountry management program. It is a mandated part of the recently implemented backcountry management plan for Grand Canyon. Such a program fulfills two basic needs. First, it provides a characterization of the current situation, answering the questions: are objectives being met, and where, if anywhere, do problems exist? Second, it permits the identification of change over time, answering the questions: how effective are current management programs, and where, if anywhere, are changes in management needed? For campsites, both the number and distribution of sites and the condition of sites need to be considered in a monitoring program.

The detailed campsite study, described above, provides baseline information that can be used to characterize the condition of and follow change on a sample of 24 sites. This provides a useful characterization of typical levels of impact. The study's stratification by use level and vegetation type also permits the importance of these two variables to be assessed. Repeat studies of these campsites, perhaps at 5 year intervals, will provide useful, very precise measures of change on these sites. For this purpose, detailed explanations of techniques are included in Appendix IV and the field forms and summary statistics for each site have been filed with the Resources Management and Planning Division. However, only 24 sites were examined. This study provides no information on the number and distribution of sites and very little information on where problems exist or where changes in management are needed.

What is needed, then, is a means of surveying all campsites in the Grand Canyon, noting their location and condition. As noted in the Backcountry Management Plan, the monitoring system needs to be simple, efficient, and cost-effective. It will be accomplished by Canyon District rangers in cooperation with the Resources Management and Planning Division. Given the large backcountry acreage and number of sites, a monitoring form has been developed that can be completed in 5-10 minutes per site. It follows a format that is being used to monitor backcountry campsites in a variety of National Parks and wilderness areas (Cole 1983b). It will permit an assessment of current condition, in terms of both number of sites and level of impact, as well as change over time. These rapid estimates of impact will only identify pronounced changes on individual sites. Subtle changes can only be recognized by using detailed, time-consuming measurements such as those described in the earlier sections of this report.

Before explaining the form and how to fill it out, I would like to suggest two other types of monitoring that would add significantly to the program. As discussed previously, many of the most serious problem areas are the clusters of sites at popular destinations. Mazes of trails and campsites could be effectively monitored using aerial photographs of these clusters. These mazes of trails and sites are difficult to characterize with field measurements of individual sites. From photographs, however, it should be possible to measure trail distance, count number of campsites, and map the total bare area on trails and campsites. With repeat photographs, every few years, at the same

scale, changes in these impact measures could be assessed. Overlays could graphically portray change over time. This would point out where maintenance and rehabilitation of designated site areas is needed and where at-large camping areas need to be changed to designated site areas. Resources Management could take responsibility and evaluate the use of photography from either airplanes or helicopters. Only popular campsite clusters need this treatment. The most important places to photograph are Hermit Creek, Boucher Creek, Monument Creek, Horseshoe Mesa, Hance Creek, Deer Creek, and Upper Tapeats Creek. A few other places may also need to be photographed.

In the vicinity of these clusters, it would also be worthwhile looking for potential campsites to which use might be directed. These potential sites could be located on maps of the local area and given to visitors who might want to avoid crowds at the clustered sites.

A rapid impact assessment system

Since core size is variable, but impact on the core is usually severe, amount of impact is well-characterized by size of the core. Also, more shrubs have usually been killed on larger sites and this represents a serious impact. On the core, soil compaction was identified as a particularly severe impact. Thus size of the core and level of soil compaction are the most important indicators of campsite impact. Other impact parameters included are evidence of trailing, disturbance of shrubs and/or cryptogam crust on the campsite perimeter, broken branches on trees, and evidence of campfires and litter.

In addition to these impact parameters, information on certain campsite attributes is collected. These include locational information, including distance to the main trail and water source, and distance and screening from other campsites. Of particular importance is an estimate of the number of people a site could comfortably accommodate without site expansion. Finally, some information on the natural environment in which the site is located--parent material, vegetation type, and groundcover conditions--is included. The idea here is to characterize the site as it would have looked before it was ever camped on. This is useful in predicting site durability and likely problems. This information only needs to be collected once, although it might be worthwhile checking each time for accuracy.

Procedures for inventorying sites follows. Systematically search for all sites. In any area where you are working it is critical to look carefully for all sites. Once an area has been completely surveyed, the area should be noted on a map of areas for which the inventory has been completed. In future reassessments, when new sites are found it will then be reasonable to conclude that they are indeed new sites rather than old sites missed in the original survey.

For each site found, locate it on a topographic map. Identify each site with a unique combination of use-area code and number (e.g. BO-1 for the first site in the Boucher use-area). In areas of clustered sites, it will be necessary to draw a sketch map of the general area, noting the location of individual campsites and their boundaries. Where aerial photos exist, it is best to take photos into the field and note sites and their boundaries on the photos. This will facilitate relocation of sites as well as the originally defined boundaries between sites.

Defining how many sites exist in a cluster and where boundaries between sites should be drawn can be a problem. There is no "right way" to do this. One rule of thumb is to divide the area up into as many sites as could comfortably accommodate a party of 3. Because this is a subjective judgement, decisions should be made carefully and boundaries decided on should be documented on sketch maps and/or aerial photographs.

Deciding whether a place is a campsite or not can also be a problem. Generally, surface disturbance will be the primary clue. Many old burro wallows may look like but not be campsites. At this stage in the inventory, I think it is reasonable to only identify a place as a campsite if there is strong evidence of recreational use. Questionable sites--that may or may not be campsites--can be picked up in reassessments if they deteriorate. It would be worth noting the location of these questionable sites on maps both for future reassessments and also to add to information on the location of potential campsites. This is particularly important in places close to popular clusters of sites.

Fill out the data form (refer to Figure 6 for a completed form). General information includes the name(s) of recorder(s), the date of the assessment (month-date-year), campsite number (sequential number from 1 to the maximum number of sites in each use-area), use-area, the topographic quadrangle map on which the site is located, and a written description of the site's location (i.e. how to find it in relation to trails, drainages, other sites, and other landmarks).

Site attribute instructions, by number, are:

7.Distance to the main trail. Estimate the distance, in feet, between the campsite and the main trail. If distance is greater than one-quarter mile, write in > 1/4 mile.

8.Number of campsites within sight and sound. If other parties were camping in the vicinity, how many other sites would be occupied by parties that could be seen or heard? This number may have to be revised as more sites in the vicinity are located. It provides a measure of opportunities for campsite solitude.

CAMPSITE SURVEY DATA FORM

1. Recorder(s) Cole 2. Date 1/10/85

3. Campsite Number 8 4. Use-area Boucher 5. Quad Map Bright Angel

6. Location Terrace NW of Boucher Creek, just below confluence with Topaz Canyon

SITE ATTRIBUTES

7. Distance To Main Trail >¼ mile (ft) 8. Number Of Campsites Within Sight And Sound 0

9. Distance To Closest Campsite >¼ mile (ft)
Screening: (circle one) (1-Complete) 2-Partial 3-None

10. Distance To Water Source 1500 (ft)
Type: (circle one) 1-River (2-Creek) 3-Spring 4-Water pocket
Seasonality: (circle one) (1-Perennial) 2-Seasonal 3-Unreliable

11. Maximum Party Size Accommodated 4

12. Facilities (circle one)
1-Toilet Present (Absent)
2-Hanging Bar Present (Absent)

ENVIRONMENTAL SETTING (examine immediate vicinity to characterize undisturbed conditions)

13. Parent Material Alluvial terrace below the Tapeats

14. Vegetation Catclaw (Acacia - Haplopappus - Ephedra - Bromus rubens)

15. Vegetation 80 %
Cryptogam 3 %
Litter 10 %
Bare Soil 3 %
Rock 3 %
Ground Cover 100 %

IMPACT EVALUATION

		Rating
16. Core Area 250 (ft^2)	0:<50 2:50-200 (4:201-500) 6:501-1000 8:>1000	4
17. Core Soil Compaction	0:Minimal evidence of surface disturbance 2:Much of surface compacted and loosened; not cement-like (4:Most of surface cement-like in appearance)	4
18. Access Trails	0:No distinct trails (1:1-2 distinct trails) 2:>2 distinct trails	1
Number 1	Are any eroded >2 inches below the surface (0:No) 1:Yes	0
19. Perimeter Vegetation Disturbance	(0:Not apparent off access trails) 2:Apparent damage to shrubs, ground vegetation or cryptogams off trails	0
20. Tree Damage	(0:Not evident) 1:Old damage 2:New damage	0
21. Litter	(0:Not evident) 1:Small amounts 2:Large amounts	0
22. Campfire Remains	0:Not evident (1:Scattered) 2.Concentrated	1
	23. IMPACT RATING: Total	10

24. Photo Record: Roll-frame(s) 3-5, 6

Description View of camp from above; View of location from Boucher Creek

Fig. 6. A completed campsite survey data form.

25. Comments Infrequently used campsite located on terrace that is eroding away. It is not obvious, so it is unlikely that the site will get much use. This is probably good because the site is small, highly compacted, and further use would probably be damaging. There may be sites in the general area that offer an opportunity to divert some use away from the main Boucher camping area upstream.

26. Sketch Map (Show core boundaries, access trails, and any unique features)

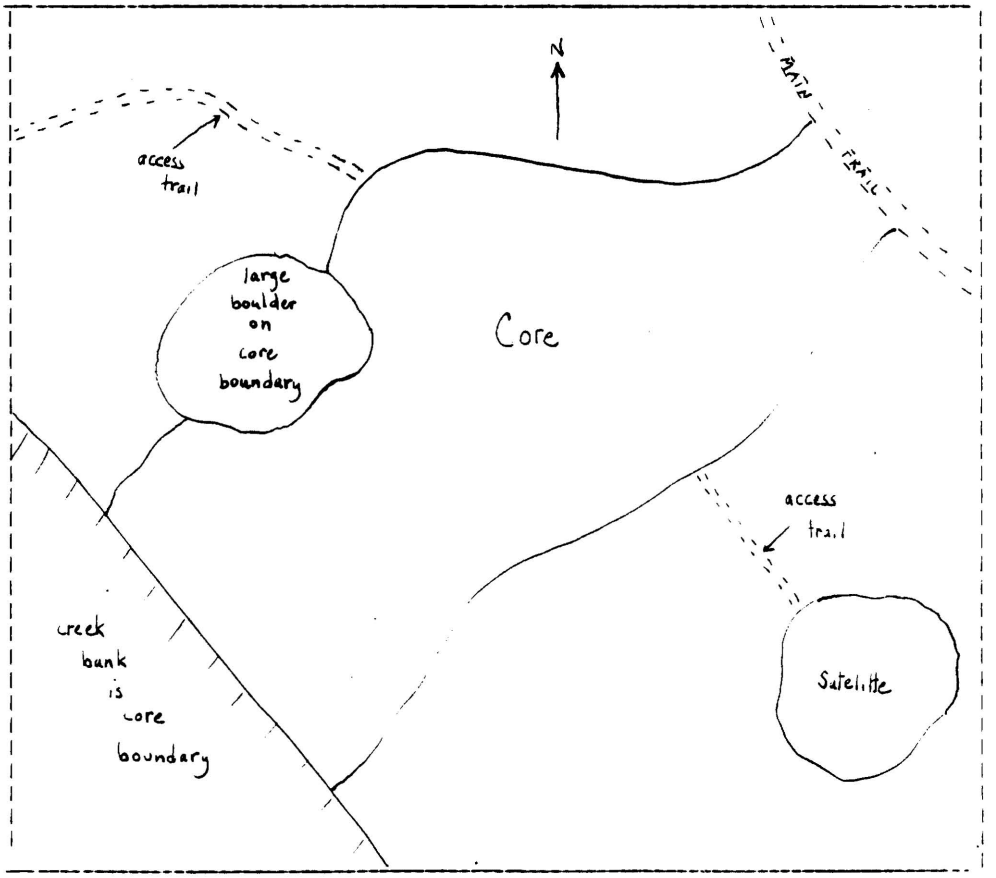


Fig. 6 (cont.). A completed survey data form (the back).

9.Distance to closest campsite. Estimate distance in feet. Be certain all sites in the vicinity are located before deciding which is closest. If no sites are located within one-quarter mile, write in > 1/4 mile. If this closest site and any party occupying it is entirely screened from the site by vegetation or topography, circle screened. Otherwise circle partial--if the site is partially obscured--or none.

10.Distance to water source. Estimate distance, in feet, to the closest water source. Circle the appropriate category for type of source and seasonality.

11.Maximum party size accommodated. Surveying flat areas where vegetation is already gone or flattened, estimate maximum party size. Base the estimate on two times the number of 2-man tents that could be erected. The intent is to estimate a site's capacity, so it will not be enlarged by parties or groups that are too large.

12.Facilities. Note whether toilets or bars for hanging food, away from animals, are present or absent.

Environmental setting information is intended to provide some idea of a site's likely durability. It should be collected on a site close to and similar to the campsite--not the campsite itself. Try to characterize the campsite as it would have been before being camped on.

13.Parent material. Record whether the site is bedrock, alluvium, or colluvium and rock type, if identifiable. Notes about topography (e.g. terrace, dry wash, or flat plateau) and whether soils are particularly sandy or gravelly is also valuable.

14.Vegetation. If possible note the vegetation association consistent with Warren et. al. (1982). Otherwise note prominent species, particularly trees and shrubs.

15.Ground cover. Estimate roughly the coverage of vegetation, cryptogam, litter, bare soil, and rock. Remember to do this on an adjacent site--not the campsite. Only count coverage if there is no other stratum above. For example, do not count litter, bare soil, or rock under vegetation. This will result in all coverages adding up to about 100 percent. For trees, only count coverage where branches are below breast height. Rocks are defined as being larger than 5 cm across. Estimate to the closest 10 percent. For example, if cover is between 56 and 65, write down 60. If cover is less than 5 percent, write down 3 percent. If cover is less than 1 percent, write down 0. Any of these latter values might mean that total coverage deviates slightly from 100. Estimate coverages carefully, but do not get "hung up" on precision.

The impact evaluation section is used to give each site an impact rating. This overall rating, the sum of ratings for items 16 through 22, is used to characterize site conditions. For each item, circle the appropriate category and place the corresponding value in the rating column on the right.

16.Core area. The core area is the central part of the campsite that is virtually devoid of vegetation. Sometimes it can be difficult to decide on the boundaries of the core. Generally it is defined by shrubs, although an isolated plant, less than 1 m^2 in area and surrounded by core, should be ignored. Sometimes large rocks, cliffs, terrace banks, or other features define the edge of the core. If deciding on boundaries is very difficult, note what you used for boundaries in the comments (item 25). Include the barren portion of any satellites in the total. Pace off the dimensions and use formulas for circles, rectangles, or right triangles to estimate area. Write in the estimated area, in square feet, circle the appropriate rating, and write the rating in on the right. For example, if the area was 750 ft^2, circle category "6:501-1000" and write "6" in the blank under "Rating". Finally, draw a sketch map of the core and the features used to define boundaries on the back of the form, item 26.

17.Core soil compaction. Assess soil disturbance on this core. If much of the surface is compacted into a hard, cement-like surface, circle "4". Sometimes this cement-like surface is partially covered with a thin layer of loose material. Give the site a "2" if the surface is obviously disturbed, but not cement-like. If disturbance is nothing more than footprints (i.e. neither compaction nor loosening is much more pronounced than off-site), rate the site a "0".

18.Access trails. Count the number of access trails, between the camp and main trail, water source, or other camps. Only count distinct trails with compacted soil or vegetation loss. Do not count the main trail if it goes right through camp. Write down the number and circle the appropriate category. Circle "Yes" or "No" concerning whether any of the access trails are eroded more than 2 inches below the ground surface. Write in ratings for both number of trails and presence/absence of erosion.

19.Perimeter vegetation disturbance. On most sites, vegetation damage is confined to the core and access trails. On some sites, however, areas adjacent to the core, but off the access trails, have been trampled sufficiently to cause damage to shrubs and loss of groundcover vegetation or cryptogams. If this is pronounced, give the site a "2".

20.Tree damage. Look for damage to trees or large shrubs, particularly broken branches. If such damage is readily evident (i.e. more than a few small broken branches), give the site a "1" (if the damage is more than one season old) or "2" (if the damage is new). Trees do not have to be on the site to be counted, as long as they can be seen from the site.

21.Litter. Stand in the middle of the campsite and quickly scan the site for litter. If you cannot see any in a few seconds, give the site a "0". Give the site a "1" if litter is obvious, but not present in large quantities. If you find large quantities, even out of sight, give the site a "2". Rate the site before cleaning it up.

22. Campfire remains. Again stand in the middle of the campsite and quickly scan it for campfire remains (blackened rocks or charcoal). Give the site a "0" if none is evident. Give the site a "1" if scattered charcoal is evident. Give the site a "2" if fire rings or concentrations of charcoal are present.

23. Impact rating. Total the ratings for items 16 through 22. Possible ratings range from a low of 0 to a high of 23.

Finally, it is important to photograph the site. At least one photograph should be taken to facilitate site relocation. Try to include some distinguishing feature. Photos from elevated positions, showing the entire site, can provide useful comparisons over time. Record roll number and frame of the photos (item 24) so they can be linked to the right site. If repeat photography is likely to be of interest, decribe each photograph briefly. Note the location where the photographer stood, as well as film type, camera and lens type.

On the back side, comment on anything that might be of managerial interest, such as pronounced problems or recommended management actions (item 25). If any evaluations were difficult to make, note the problem and how you handled it here. If the features you used to delineate the boundary of the core are not likely to be obvious to succeeding recorders, note them here. In item 26, draw a quick sketch map of the core and any satellite areas. Note features that were used to delineate the core boundary and the location of access trails.

Once this survey has been completed, it will be possible to map the distribution of all sites. This will suggest where site proliferation is a problem. By dividing the range of impact rating values into several categories, it will be possible to map lightly, moderately, heavily, and severely impacted sites. Such a map can also be useful in identifying problem areas. Ideally, objectives will be written for density and condition of sites to more objectively decide where problems do or do not exist. Reassessments on a 5-year basis would identify trends, showing where new management actions are needed and where management is successfully controlling impact. Information on campsite solitude can be used in assessing use limits. Information on maximum party size can be used to direct large parties or groups to sites that are less likely to be damaged through expansion.

With practice, this system should require no more than about 10 minutes per site. As part of a normal ranger patrol, this should not detract greatly from other duties. The problem is scheduling trips to the more remote areas. However, even this should not be too much of a burden if the inventory is done on a rotating basis, covering one-fifth of the area every year.

With this inventory, periodic detailed reassessments of the 24 sites studied in this report, and aerial photography of the principle clusters of sites, Grand Canyon should be able to answer the campsite-related questions posed for the research and monitoring program in the Backcountry Management Plan. This should allow managers to select the most effective and efficient means of protecting the resource. If more specific objectives are written, it will also be possible to more consistently and objectively evaluate problems. In concert with more information on the characteristics and preferences of users, management should be in a position to optimize both resource protection and visitor satisfaction.

REFERENCES CITED

Adams, J. A., A. S. Endo, L. H. Stolzy, P. G. Rowlands, and H. B. Johnson.
1982. Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California. J. Appl. Ecol. 19:167-175.

Anderson, D. C., K. T. Harper, and R. C. Holmgren.
1982a. Factors influencing development of cryptogamic soil crusts in Utah deserts. J. Range Manage. 35:180-185.

Anderson, D. C., K. T. Harper, and S. R. Rushforth.
1982b. Recovery of cryptogamic soil crusts from grazing on Utah winter ranges. J. Range Manage. 35:355-359.

Bratton, S. P., M. G. Hickler, and J. H. Graves.
1978. Visitor impact on backcountry campsites in the Great Smoky Mountains. Environ. Manage. 2:431-442.

Brotherson, J. D., and S. R. Rushforth.
1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo National Monument, Arizona. The Great Basin Natur. 43:73-78.

Brown, D. E., and C. H. Lowe.
1974. The Arizona system for natural and potential vegetation--illustrated summary through the fifth digit for the North American Southwest. J. Ariz. Acad. Sci. 9 (Suppl. 3):1-56.

Brown, D. E., C. H. Lowe, and C. P. Pase.
1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest. J. Ariz. Acad. Sci. 14 (Suppl. 1).

Brown, J. H., Jr., S. P. Kalisz, and W. R. Wright.
1977. Effects of recreational use on forested sites. Environ. Geol. 1:425-431.

Campbell, S. E.
1979. Soil stabilization by a prokaryotic desert crust: implications for Precambrian land biota. Origins of Life 9:335-348.

Carothers, S. W., and S. W. Aitchison (eds.).
1976. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Colorado River Tech. Rpt. No. 10, Grand Canyon Natl. Park, Ariz.

Carothers, S. W., R. A. Johnson, and R. Dolan.
1984. Recreational impacts on Colorado River beaches in Glen Canyon, Arizona. Environ. Manage. 8:353-358.

Christensen, E. M., and R. C. Brown.
1963. A blackbrush over 400 years old. J. Range Manage. 16:118.

Cole, D. N.
1978. Estimating the susceptibility of wildland vegetation to trailside alteration. J. Appl. Ecol. 15:281-286.

Cole, D. N.
1981. Vegetational changes associated with recreational use and fire suppression in the Eagle Cap Wilderness: some management implications. Biol. Conserv. 20:247-270.

Cole, D. N.
1982a. Wilderness campsite impacts: effect of amount of use. USDA For. Serv. Res. Pap. INT-284.

Cole, D. N.
1982b. Controlling the spread of campsites at popular wilderness destinations. J Soil and Water Conserv. 37:291-295.

Cole, D. N.
1983a. Campsite conditions in the Bob Marshall Wilderness, Montana. USDA For. Serv. Res. Pap. INT-312.

Cole, D. N.
1983b. Monitoring the condition of wilderness campsites. USDA For. Serv. Res. Pap. INT-302.

Cole, D. N.
1985. Effects of recreational trampling on six habitat types in western Montana. USDA For. Serv. Res. Pap. INT-(in press).

Cole, D. N., and B. Ranz.
1983. Temporary campsite closures in the Selway-Bitterroot Wilderness. J. For. 81:729-732.

Cole, D. N., and R. K. Fichtler.
1983. Campsite impact on three western wilderness areas. Environ. Manage. 7:275-288.

Coombs, E. A. K.
1976. The impact of camping on vegetation in the Bighorn Crags, Idaho Primitive Area. M. S. thesis, Univ. Idaho, Moscow.

Crawford, C. S., and J. R. Gosz.
1982. Desert ecosystems: their resources in space and time. Envir. Conserv. 9:181-195.

Crosswhite, F. S., and C. D. Crosswhite.
1982. The Sonoran desert. p. 163-295. In: Reference handbook on the deserts of North America, G. L. Bender (ed.), Greenwood Press: Westport, Conn.

Dotzenko, A. D., N. T. Papamichos, and D. S. Romine.
1967. Effects of recreational use on soil and moisture conditions in Rocky Mountain National Park. J. Soil and Water Conserv. 22:196-197.

Dregne, H. E.
1976. Soils of arid regions. Elsevier Scien. Publ. Co.: Amsterdam.

Dunn, B. A., B. G. Lockaby, and E. E. Johnson.
1980. Camping and its relationship to forest soil and vegetation properties in South Carolina. For. Res. Ser. No. 34, Clemson Univ., Clemson, SC.

Dykema, J. A.
1971. Ecological impact of camping upon the southern Sierra Nevada. Ph.D. diss., Univ. Calif., Los Angeles.

Echelberger, H. E.
1971. Vegetation changes at Adirondack campgrounds--1964-1969. USDA For. Serv. Res. Note NE-142.

Eckert, R. E., Jr., M. K. Wood, W. H. Blackburn, and F. F. Peterson.
1979. Impacts of off-road vehicles on infiltration and sediment production of two desert soils. J. Range Manage. 32:394-397.

Fichtler, R. K.
1980. The relationship of recreational impacts on backcountry campsites to selected Montana habitat types. M. S. thesis, Univ. Montana, Missoula.

Fletcher, J. E., and W. P. Martin.
1948. Some effects of algae and molds in the rain-crust of desert soils. Ecol. 29:95-100.

Friedmann, E. I., and M. Galun.
1968. Desert algae, lichens, and fungi. p. 165-212. In: Desert biology, vol. 2, G. W. Brown, Jr. (ed.), Academic Press: New York.

Frissell, S. S.
1973. The impact of wilderness visitors on natural ecosystems. Unpublished rpt., USDA For. Serv., Forestry Sci. Lab, Missoula, Mont.

Frissell, S. S., Jr., and D. P. Duncan.
1965. Campsite preference and deterioration in the Quetico-Superior Canoe Country. J. For. 63:256-260.

Garcia-Moya, E., and C. M. McKell.
1970. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecol. 51:81-88.

Hall, J. A.
1980. Direct impacts of off-road vehicles on vegetation. p. 63-74. In: The effects of disturbance on desert soils, vegetation and community processes with emphasis on off road vehicles: a critical review, P. G. Rowlands (ed.), USDI Bur. Land Manage., Desert Plan Staff Special Publ., Riverside, Calif.

Hendee, J. C., G. H. Stankey, and R. C. Lucas.
1978. Wilderness management. USDA For. Serv. Misc. Publ. No. 1365.

Holmgren, R. C., and S. F. Brewster, Jr.
1972. Distribution of organic matter reserve in a desert shrub community. USDA For. Serv. Res. Pap. INT-130.

Iverson, R. M., B. S. Hinckley, R. M. Webb, and B. Hallet.
1981. Physical effects of vehicular disturbances on arid landscapes. Sci. 212:915-917.

James, T. D. W., D. W. Smith, et. al.
1979. Effects of camping recreation on soil, jack pine, and understory vegetation in a northwestern Ontario park. For. Sci. 25:333-349.

Jameson, D. A., J. A. Williams, and E. W. Wilton.
1962. Vegetation and soils of Fishtail Mesa, Arizona. Ecol. 43:403-410.

Jerry, D. G.
1977. Impact of boaters on river campgrounds in Dinosaur National Monument. M. S. thesis, Colo. State Univ., Fort Collins.

Johnson, R. R., and S. W. Carothers.
1982. Riparian habitat and recreation: interrelationships and impacts in the Southwest and Rocky Mountain region. Eisenhower Consortium Bull. 12, USDA For. Serv., Rocky Mtn. For. and Range Exp. Stn., Ft. Collins, Colo.

Kleiner, E. F., and K. T. Harper.
1977. Soil properties in relation to cryptogamic groundcover in Canyonlands National Park. J. Range Manage. 30:202-205.

Kovda, V. A., E. M. Samoilova, J. L. Charley, and J. J. Skujins.
1979. Soil processes in arid lands. p. 439-470. In: Arid-land ecosystems: structure, functioning and management, vol. 1, D. W. Goodall, R. A. Perry, and K. M. W. Howes (eds.), Cambridge Univ. Press: Cambridge.

Lathrop, E. W.
1983. The effect of vehicle use on desert vegetation. p. 153-166. In: Environmental effects of off-road vehicles: impacts and management in arid regions, R. H. Webb, and H. G. Wilshire (eds.), Springer-Verlag: New York.

Legg, M. H., and G. Schneider.
1977. Soil deterioration on campsites: northern forest types. Soil Sci. Soc. Am. Proc. 41:437-441.

Lehr, J. H.
1978. A catalogue of the flora of Arizona. Northland Press: Flagstaff, AZ.

Liddle, M. J., and P. Greig-Smith.
1975. A survey of tracks and paths in a sand dune ecosystem. I. Soils. J. Appl. Ecol. 12:893-908.

Loope, W. L., and G. F. Gifford.
1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. J. Soil and Water Conserv. 27:164-167.

Lutz, H. G.
1945. Soil conditions of picnic grounds in public forest parks. J. For. 43:121-127.

Magill, A. W.
1970. Five California campgrounds--conditions improve after 5 years' recreation use. USDA For. Serv. Res. Pap. PSW-62.

Marion, J. L.
1984. Ecological changes resulting from recreational use: a study of backcountry campsites in the Boundary Waters Canoe Area Wilderness, Minnesota. Ph. D. thesis. Univ. Minn., St. Paul.

Marnell, L., D. Foster, and K. Chilman.
1978. River recreation research at Ozark National Scenic Riverways 1970-1977: a summary of research projects and findings. USDI Natl. Park Serv., Van Buren, Missouri.

Mayland, H. F., T. H. McIntosh, and W. H. Fuller.
1966. Fixation of isotopic nitrogen on a semiarid soil by algal crust organisms. Soil Sci. Soc. Am. Proc. 30:56-60.

Merkle, J.
1952. An analysis of a pinyon-juniper community at Grand Canyon, Arizona. Ecol. 33:375-384.

Merkle, J.
1962. Plant communities of the Grand Canyon area, Arizona. Ecol. 43:698-711.

Merriam, L. C., C. K. Smith, et. al.
1973. Newly developed campsites in the Boundary Waters Canoe Area--a study of 5 years' use. Stn. Bull. 511, For. Series 14, Agric. Exp. Stn., Univ. Minn., St. Paul.

Noy-Meir, I.
1973. Desert ecosystems: environment and producers. Ann. Rev. Ecol. and Syst. 4:25-51.

Parsons, D. J., and S. H. Debenedetti.
1976. Wilderness protection in the High Sierra: effects of a 15-year closure. p. 1313-1318. In: Proc. First Conf. Scientific Res. in Natl. Parks, R. M. Linn (ed.), USDI Natl. Park Serv. Transactions and Proceedings Ser. No. 5, Govt. Print. Off., Wash., D. C.

Parsons, D. J., T. J. Stohlgren, and P. A. Fodor.
1981. Establishing backcountry use quotas: an example from Mineral King, California. Environ. Manage. 5:335-340.

Post, D. F.
1979. Soil conditions on campsite and recreational areas with special reference to Bonita Campground, Chiracahua National Monument in Arizona. Coop. Natl. Park Res. Studies Unit Tech. Rpt. No. 4, Univ. Ariz., Tucson.

Rechlin, M.
1973. Recreation impact in the Adirondack High Peaks Wilderness. M. S. thesis, Univ. Mich., Ann Arbor.

Rogers, R. W., and R. T. Lange.
1971. Lichen populations on arid soil crusts around sheep watering places in South Australia. Oikos 22:93-100.

Rowlands, P. G.
1980. Soil crusts. p. 46-62. In: The effects of disturbance on desert soils, vegetation and community processes with emphasis on off road vehicles: a critical review, P. G. Rowlands (ed.), USDI Bur. Land Manage., Desert Plan Staff Special Publ., Riverside, Calif.

Rowlands, P. G., J. A. Adams, H. B. Johnson, and A. S. Endo.
1980. Experiments on the effects of soil compaction on establishment, cover, and pattern of winter and summer annuals in the Mojave desert. p. 135-164. In: The effects of disturbance on desert soils, vegetation and community processes with emphasis on off road vehicles: a critical review, P. G. Rowlands (ed.), USDI Bur. Land Manage., Desert Plan Staff Special Publ., Riverside, Calif.

Saunders, P. R.
1979. The vegetational impact of human disturbances on the spruce-fir forests of the Southern Appalachian Mountains. Ph. D. diss., Duke Univ., Durham, NC.

Schmidly, D. J., and R. B. Ditton.
1976. A survey and analysis of recreational and livestock impacts on the riparian zone of the Rio Grande in Big Bend National Park. Unpublished rpt, USDI Natl. Park Serv., Southwest Reg., Santa Fe, NM.

Schreiner, E. S., and B. B. Moorhead.
1979. Human impact inventory and management in the Olympic National Park backcountry. p. 203-212. In: Recreational impact on wildlands conference proceedings, R. Ittner et. al. (eds.), USDA For. Serv. Pac. Northwest Reg., R-6-001-1979.

Shields, L. M., and L. W. Durrell.
1964. Algae in relation to soil fertility. Bot. Rev. 30:92-128.

Simon, L.
1978. Soil physical properties of selected campsites under varying use levels in the Kearsarge-Bullfrog-Charlotte Lakes area of Kings Canyon National Park. Unpubl. rep., Sequoia-Kings Canyon National Park, Three Rivers, CA.

SPSS, Inc.
1983. SPSS X user's guide. McGraw-Hill: New York.

Stohlgren, T. J.
1982. Vegetation and soil recovery of subalpine campsites in Sequoia National Park, California. M. A. thesis, Calif. State Univ., Fresno.

Sutton, S. W.
1976. The impact of floaters on the Ozark National Scenic Riverways. M.S. thesis, Univ. Missouri, Columbia.

Taylor, H. M., and E. Burnett.
1964. Influence of soil strength on the root growth habits of plants. Soil Sci. 98:174-180.

Turner, R. M.
1982a. Great Basin desertscrub. Desert Plants 4:145-155.

Turner, R. M.
1982b. Mohave desertscrub. Desert Plants 4:157-168.

United States Dept. of the Interior, National Park Service.
1983. Backcountry management plan. Grand Canyon Natl. Park, Ariz.

Vollmer, A. T., B. G. Maza, P. A. Medica, F. B. Turner, and S. A. Bamberg.
1976. The impact of off-road vehicles on a desert ecosystem. Envir. Manage. 1:115-129.

Voorhees, W. B., D. A. Farrell, and W. E. Larson.
1975. Soil strength and aeration effects on root elongation. Soil Sci. Soc. Am. Proc. 39:948-953.

Wallace, A., E. M. Romney, and R. B. Hunter.
1980. The challenge of a desert: revegetation of disturbed desert lands. Great Basin Natur. Mem. 4:216-225.

Warren, P. L., K. L. Reichhardt, D. A. Mouat, and R. R. Johnson.
1982. Vegetation of Grand Canyon National Park. Cooperative National Park Resources Studies Unit Tech. Rep. 9.

Webb, R. H.
1982. Off-road motorcycle effects on a desert soil. Envir. Conserv. 9:197-208.

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

West, N. E.
1979. Formation, distribution and function of plant litter. p. 647-659. In: Arid-land ecosystems: structure, functioning and management, vol. 1, D. W. Goodall, R. A. Perry, and K. M. W. Howes (eds.), Cambridge Univ. Press: Cambridge.

West, N. E.
1981. Nutrient cycling in desert ecosystems. p. 301-324. In: Arid-land ecosystems: structure, functioning and management, vol. 2, D. W. Goodall, R. A. Perry, and K. M. W. Howes (eds.), Cambridge Univ. Press: Cambridge.

Whitson, P. D.
1974. The impact of human use upon the Chisos Basin and adjacent lands. Natl. Park Serv. Scien. Monogr. Ser. 4, Govt. Print. Off., Washington, D. C.

Wilshire, H. G.
1983. The impact of vehicles on desert soil stabilizers. p. 31-50. In: Environmental effects of off-road vehicles: impacts and management in arid regions, R. H. Webb and H. G. Wilshire (eds.), Springer-Verlag: New York.

Young, R. A., and A. R. Gilmore.
1976. Effects of various camping intensities on soil properties in Illinois campgrounds. Soil Sci. Soc. Am. J. 40:908-911.

APPENDIX I

LITERATURE REVIEW

LITERATURE REVIEW

Campsite Impacts

To date, few studies of backcountry campsites in arid environments have been conducted. Schmidly and Ditton (1976) studied sites along the Rio Grande River in Big Bend National Park and Carothers and Aitchison (1976) studied campsites along the Colorado River in Grand Canyon National Park. Both of these studies were qualitative in nature and do not provide much detailed information on how much change has occurred on these campsites. Interestingly, these two studies came to very different conclusions about the relationship between amount of impact and amount of use. In Big Bend, the more heavily used campsites were more heavily impacted; in Grand Canyon, however, there was no consistent relationship between amount of use and amount of impact.

Carothers et. al. (1984) studied aesthetic impacts on beach campsites in Glen Canyon National Recreation Area. They found more litter and charcoal and higher levels of sand discoloration on Glen Canyon beaches than on Grand Canyon beaches. They recommend a variety of management actions to deal with these problems.

The most detailed study of campsite impacts in an arid desert environment is Post's (1979) study of soil conditions on Bonita Campground, a developed campground in Chiracahua National Monument. He found that camping caused pronounced soil compaction: bulk density increased over 50%; the volume of large pores--the pores that allow proper aeration--decreased 50%; and perhaps of most importance, water infiltration rates decreased to about 10% of normal. He concluded that this is likely to increase water stress on the plants of the campground.

Jerry (1977) studied river campsites in the less arid environment of Dinosaur National Monument. She attempted to relate amount of impact to use levels and differences in vegetation type. She found fewer trails and paths and smaller barren areas on more lightly used sites; however, bulk densities and infiltration rates were not related to use levels. Variability was too high. Box elder sites were generally less impacted than pinyon-juniper or sagebrush sites. They had less bare ground, fewer paths and trails, more litter cover, lower bulk densities and higher infiltration rates. The largest disturbed areas were on the pinyon-juniper campsites.

Whitson (1974), in a study of human impact on the Chisos Basin part of Big Bend National Park, provides some data on vegetation change in the developed campground there. He found that total vegetation cover had been reduced and the species composition of the surviving cover was very different from that of undisturbed areas. In fact 40% of the vegetation cover was provided by non-native species. It is not clear to what extent similar levels and types of impact would occur on backcountry sites used by a very different clientele and at very different use frequencies.

Backcountry campsites have been studied in a number of other environments, including Great Smoky Mountains National Park, Tennessee-North Carolina (Bratton et. al. 1978; Saunders 1979), Eagle Cap Wilderness,

Oregon (Cole 1981, 1982a, 1982b), River of No Return Wilderness, Idaho (Coombs 1976), Sequoia and Kings Canyon National Parks, California (Dykema 1971; Simon 1978; Parsons and Debenedetti 1979; Stohlgren 1982), Lee Metcalf Wilderness, Montana (Frissell 1973), Selway-Bitterroot Wilderness, Montana (Cole and Ranz 1983), Bob Marshall Wilderness, Montana (Cole 1983a), Mission Mountains Tribal Wilderness and Rattlesnake Wilderness, Montana (Fichtler 1980), Boundary Waters Canoe Area, Minnesota (Frissell and Duncan 1965; Merriam et. al.1973 Marion 1984), Olympic National Park, Washington (Schreiner and Moorhead 1979), Sylvania Recreation Area, Michigan (Legg and Schneider 1977), Adirondack High Peaks, New York (Rechlin 1973), and the Ozark National Scenic Riverways, Missouri (Sutton 1976; Marnell et. al. 1978). Johnson and Carothers (1982) review literature on campsite impacts in riparian areas, particularly in the arid Southwest.

Of these, only the studies by Cole (1982a, 1983a), Cole and Ranz (1983), Coombs (1976), Dykema (1971), Marion (1984), Parsons and Debenedetti (1979), Fichtler (1980), Frissell and Duncan (1965), Stohlgren (1982), and Sutton (1976) were set up in such a way that it was possible to determine how much change has occurred on the campsites. Most of the others describe campsites but do not relate campsite conditions to conditions on undisturbed sites.

The types of change found on campsites are generally similar across this range of environmental conditions. Groundcover vegetation is lost and species composition of surviving vegetation is changed. Non-native weeds often invade the site. Overstory trees are damaged when visitors break branches and fell trees for firewood, thoughtlessly deface tree trunks with ax scars and nails, and tie packstock to tree trunks. Tree reproduction is usually all but eliminated on campsites.

Trampling of the site also removes organic horizons from the soil profile, exposing mineral soil beneath. The mineral soil is compacted and infiltration rates are reduced. Changes in soil organic matter and chemistry also occur, although these changes are not consistent between studies. Finally, in some cases accelerated erosion has been found.

Studies by Cole (1982a), Coombs (1976), Fichtler (1980), Frissell and Duncan (1965), Marion (1984), Simon (1978) and Sutton (1976) have made some progress towards a better understanding of the relationship between amount of use and amount of impact. The nature of this relationship depends upon the type of impact being examined, the environment in which the campsite is located, and the range of use intensities involved. In many cases near-maximum levels of impact are found on quite infrequently used campsites. This result argues for the wisdom of concentrating use on a small number of designated sites rather than allowing a large number of sites to be damaged. This result also suggests that limitations on use will do little to limit site damage. This makes site impact of little relevance in setting use limits. However, certain types of impact are more pronounced on more heavily used sites and in certain environments amount of use is an important determinant of amount of impact.

Several studies have shown that amount of impact differs greatly in different environments within the same backcountry area (see, for example, Cole 1981a, 1983a). This is a reflection of pronounced differences in the resistance and resilience of different environments.

Finally, we know nothing about the importance of ongoing change on established backcountry campsites. In the Boundary Waters Canoe Area, newly-opened campsites changed most rapidly in the first two years they were open; further changes were insignificant (Merriam et.al. 1973). Studies by Magill (1970) and Echelberger (1971) on California and New York car campgrounds also found ongoing changes to be slight.

Off-road Vehicle Impacts on Deserts

In contrast to the dearth of information on campsite impacts in deserts, there have been numerous studies of off-road vehicle impacts. These studies can be consulted for identifying ecosystem parameters for monitoring and appropriate measurement techniques. Soils have been studied in particular detail. Studies have documented increases in bulk density and penetration resistance (soil strength) as a result of compaction (Eckert et. al. 1979, Iverson et. al. 1981, Webb 1982, Adams et. al. 1982). Compaction decreases porosity, infiltration rates and hydraulic resistance to overland flow, increasing surface runoff and erosion (Eckert et. al. 1979, Iverson et. al., Webb 1982). Vehicle use also led to decreased soil moisture content (Webb 1982).

Several studies have also documented changes in vegetation as a result of off-road vehicle use. Use leads to a reduction of plant cover and usually density and diversity (Vollmer et. al. 1976, Hall 1980, Rowlands et. al. 1980, Lathrop 1983). These changes result from direct abrasion and uprooting of plants and indirectly from the difficulty plants have in germinating on compacted soils and tolerating the increased water stress resulting from physical changes to the soil. Certain types of plants react differently from others. For example, as opposed to perennial plants, annuals may increase in cover in response to low levels of disturbance (Lathrop 1983). Monocotyledonous plants, particularly annual grasses, are sometimes more successful in germinating in compacted soil than dicotyledonous plants. Such changes can lead to shifts in species composition on used areas.

Desert Ecology

An understanding of the ecology of Grand Canyon National Park, in particular, and of deserts, in general, is also crucial to understanding backcountry campsite impacts. The Grand Canyon flora has been treated frequently, but synecological work below the rim is less abundant. Studies by Merkle (1952, 1962) and Jameson et. al. (1962) do include descriptions of pinyon-juniper communities that can be extrapolated, with caution, to pinyon-juniper communities below the rim.

Extrapolation of information on desert ecology to Grand Canyon is also made difficult by the location of Grand Canyon along the ecotone between the warm Mohave and cold Great Basin deserts, an ecotone with a gradient made sharp by the tremendous local relief of Grand Canyon. Good state-of-the-art descriptions of the plant communities of these two deserts are found in Turner (1982a, 1982b). His discussion is organized around a vegetation classification system developed by Brown and Lowe (1974) and Brown et. al. (1979). This classification was also the basis for a vegetation map of the Grand Canyon. Warren et. al. (1982) describe the mapping procedure and provide floristic and physiognomic descriptions of 63 vegetation associations.

Three attributes of desert ecosystems--all susceptible to alteration as a result of camping--are of particular importance when examining the effects of use. These attributes are (1) the scarcity of water, (2) the small amounts and patchy distribution of organic matter and nutrients, and (3) the importance of cryptogamic soil crusts.

The chief deficiencies in desert soils from the standpoint of vegetation are water and available nitrogen (Noy-Meir 1973, Dregne 1976, West 1981, Crosswhite and Crosswhite 1982). Of these, water is usually more important and is considered to be the "dominant controlling factor for biological processes" (Noy-Meir 1973). Energy flow in desert ecosystems--primary productivity, plant growth, and consumption by animals and decomposers--is controlled by levels of available water. Water levels, for a given amount and temporal distribution of precipitation, are generally determined by how much water infiltrates the soil (as opposed to running off the surface), how much of this infiltration remains within the rooting zone of plants and does not evaporate from the surface soils, and how much of this water can be extracted for use by plants.

Camping can adversely affect water levels in a number of ways. Through compaction, infiltration rates are often reduced, so that less water enters the soil. Generally, the depth of wetting by rains is not greater than maximal rooting depth, so loss of water by deep percolation is limited (Noy-Meir 1973). Removal of vegetation through camping disturbance is likely to increase evaporative losses but this loss of vegetation should also decrease transpiration losses. Finally, compaction reduces the ability of plants to extract water. Destruction of macropores reduces aeration. Along with increased soil strength (penetration resistance), poor aeration reduces root elongation (Taylor and Burnett 1964, Voorhees et. al. 1975), making it more difficult for plants to utilize available water.

Although there is some disagreement (Crawford and Gosz 1982), the conventional wisdom is that nitrogen can limit productivity at times when water is not limiting. West (1981) notes, for example, that nutrients accumulate in the soil and support lush growth during a period of favorable moisture; however, when another favorable season follows the first, the soils are usually incapable of sustaining production on account of depleted fertility.

Much of the nitrogen and other nutrients comes from decomposing organic matter, particularly leaves shed by leguminous plants (Crosswhite and Crosswhite 1982), such as catclaw. Another major source is fixation of atmospheric nitrogen by cryptogamic soil crusts--a process discussed below.

Organic litter is relatively scarce in desert ecosystems. The organic matter content of soils is usually 0.1-0.7% (Kovda et. al.) and surface litter, in one study (Holmgren and Brewster 1972), was only 40 g/m^2. Most of this material is concentrated below shrubs. This concentration around shrubs creates "islands of fertility", where infiltration rates and nutrient contents are high. These are favored sites for seedling germination and establishment (West 1979). Wallace et. al. (1980) state:

> "Vegetation of the northern Mojave Desert really uses only about 10 to 20 percent of the soil area as a growth medium and the other 80 to 90 percent is used largely as a watershed. This results in the familiar shrub clump or "fertile island" structure characteristic of some deserts. These shrub clump sites have probably been in place for centuries and are just as structured and fertile as soil in more humid ecosystems. This means that the water coming into the system is used with the energy of photosynthesis, through decomposition, to maintain just a fraction of the total soil area as highly productive sites. The remainder of the soil serves as needed watershed, and it usually contains some roots. When this soil structure involved with shrub clumps is destroyed mechanically, centuries of the results of biological cycling is destroyed and, by itself, such a damaged desert ecosystem will recover very slowly."

Other ways in which shrub clumps contribute to fertility include (1) protection of soil from wind erosion through retarding the movement of soil and increasing the accumulation of fine soil particles around their bases, and (2) protection of understory vegetation from the effects of high temperatures, thereby helping retain surface nitrogen and adding organic matter to the soil (Garcia-Moya and McKell 1970). These clumps are stable features. Blackbrush, for example, can live to be over 400 years old (Christensen and Brown 1963).

Clearly, camping is likely to disturb shrub clumps. This will expose organic matter to loss from trampling abrasion and surface erosion, processes already aggravated by camping, and to loss by rapid oxidation. West (1981) notes that in desert ecosystems, "catastrophic losses of nutrients can be pronounced because of small pools of tightly structured, surface-concentrated components and slow recovery rates. Cycles are therefore less buffered and more susceptible to environmental extremes than in more mesic ecosystems."

Cryptogamic crusts are very common on desert soils and are important to ecosystem functioning. Organisms that live in these crusts include free-living blue-green algae, fungi, lichens, and mosses. Lichens and mosses are the most obvious crustal components, often forming conspicuous black pedestaled surfaces. In Grand Canyon these are particularly common in pinyon-juniper woodland. Algae are the primary components of most crusts, however, and they can be important even where crusts are inconspicuous.

These crusts have been the subject of numerous studies. Although none have been conducted in Grand Canyon, several have been conducted in Canyonlands National Park (Kleiner and Harper 1977, Campbell 1979, Anderson et. al. 1982a), Navajo National Monument (Brotherson and Rushforth 1983), and in pinyon-juniper woodlands in southeastern Utah (Loope and Gifford 1972).

Cryptogamic crusts are important ecosystem components for the following reasons:

(1) They increase soil stability, making soil less vulnerable to both wind and water erosion. This is critical in an environment where lack of vegetation and organic matter and sporadic torrential rainfall contribute to high erosion hazard. Soil surface particles are bound by the intertwining growth of algal and fungal filaments; moss and lichen constituents can also cover the surface with thalli and penetrate the soil surface with rhizoids (Brotherson and Rushforth 1983). The surface roughness created by the crusts also dissipates much of the erosive power of both wind and water. Decreased water erosion has been documented (Loope and Gifford 1972, Brotherson and Rushforth 1983) and the threshold friction velocity of crusted desert soils--the wind velocity necessary to cause erosion--has been shown to be higher than on bare soils (Rowlands 1980).

(2) Crusts generally also have high infiltration rates, although non-biologically crusted soils can have slow infiltration rates. Perhaps more important than their effect on infiltration is their ability to reduce surface evaporation. Cryptogams can also use water unavailable to higher plants, including nightly dew condensation (Friedmann and Galun 1968). This suggests that the water conservation role of these crusts may be as important as their role in preventing erosion (Brotherson and Rushforth 1983). Shields and Durrell (1964) found the soil moisture content of alga-stabilized crust to be 8.9% compared with 1.3% in bare soil.

(3) They act as a nutrient reservoir by contributing organic matter, exerting a solvent action on certain soil minerals, and maintaining a reserve supply of elements in a semi-available form for higher plants (Shields and Durrell 1964).

(4) Crusts fix nitrogen, providing a major source in the ecosystem. Nitrogen compounds are released into the soil and are mineralized when water becomes available. "A surface growth of algae thus represents a continuous supply of nitrogen"(Shields and Durrell 1964). Fletcher and Martin (1948) found crusted soils to be 400% higher in nitrogen than bare soils. Mayland et. al. (1966) calculated a nitrogen fixation rate of 9.6 lb/acre per year in a desert grassland near Tucson.

(5) Finally crusts also contribute to increased germination and growth of seedlings. Fletcher and Martin (1948) note "that when the microbial crust dried out considerable differential shrinkage caused the crust to crack and curl; seedlings were concentrated along the fissures where moisture conditions were most favorable. Subsequent rains only caused the crust to uncurl, again protecting the surface from erosion and yet allowing the infiltration of water into the soil. Because of cracking and curling the authors believe that seed would have an excellent chance of getting under the crust which would subsequently protect the seed from the elements and reduce temperatures and

rapid drying out of the site."

Although more needs to be learned about the roles of these crusts, they are clearly important. Moreover, they are easily destroyed. Destruction of crusts by grazing (Rogers and Lange 1971, Anderson et. al. 1982a) and by off-road vehicle use (Wilshire 1983) have been documented. Clearly camping will also destroy cryptogamic crusts. A critical question is how rapidly they are destroyed. If they are highly susceptible then random walking around campsites and at-large camping--where many sites may be lightly used--can have particularly pronounced adverse effects. Another critical question is how rapidly recovery occurs. This also has bearing on the appropriateness of at-large camping and whether or not people should be encouraged to use lightly or heavily used sites. Anderson et. al. (1982b) found that crusts recovered within less than 15 years after grazing was removed.

APPENDIX II

COMPLETE STATISTICS FOR
CAMPSITE CONDITIONS AND AMOUNT OF CHANGE

Table 1. Core area and floristic dissimilarity on campsites.

Statistic	Core Area N=24	Floristic Dissimilarity[1] N=22
	-square meters-	---percent---
Mean	44	31
Standard Deviation	34	14
Median	32	31
Range	8-142	7-66

1 - Floristic dissimilarity is a measure of difference in species composition between campsites and controls.

Table 2. Conditions and amount of change on campsite cores.[1]

Statistics	Litter Cover (N=23)	Bulk Density (N=24)	Soil Moisture (N=24)	Initial Infiltrat. (N=24)	Final Infiltrat. (N=24)	Penetr. Resistance (N=24)
	percent	-g/cc-	percent	-------cm/min-------		kg/sq. cm
Camp Core						
Mean	5	1.56	4.4	0.7	0.19	2.7
Stan. Dev.	15	0.32	2.7	0.6	0.12	1.6
Median	<1	1.60	3.8	0.5	0.15	2.8
Range	0-71	0.60-2.21	1.8-12.8	0.1-2.7	0.05-0.50	0.3->4.5
Control						
Mean	59	1.23	7.2	2.0	0.87	0.7
Stan. Dev.	25	0.29	5.6	1.1	0.77	0.4
Median	60	1.27	5.5	1.9	0.56	0.7
Range	10-90	0.72-1.84	1.6-23.8	0.6-5.0	0.20-2.75	0.2-1.8
Absolute Change						
Mean	-55	0.33	-2.8	-1.3	-0.68	2.0
Stan. Dev.	29	0.35	5.2	1.3	0.75	1.7
Median	-60	0.24	-1.2	-1.3	-0.46	2.0
Range	-88-16	-0.12-1.06	-17.8-7.0	-4.6-1.0	-2.55-0.29	-1.5-4.4
Relative Change (%)						
Mean	-91	31	-22	-57	-62	535
Stan. Dev.	27	36	43	43	48	617
Median	-99	20	-21	-73	-79	337
Range	-100-28	-17-112	-82-121	-93-62	-95-138	-83-2200
Significance						
T Test	<.001	<.001	.015*	<.001	<.001	<.001
Wilcoxon	<.001	<.001	.002*	<.001	<.001	<.001

1 - Absolute change is the difference between campsites and controls; relative change is absolute change as a percent of control values. A positive change indicates an increase on campsites. Significance was tested with both parametric paired t tests and nonparametric Wilcoxon matched-pairs, signed-ranks tests. Probabilities ≤ 0.05 are significant. The * denotes a two-tailed test.

Table. 3. Groundcover conditions and change on campsite perimeters.[1]

Statistic	Litter Cover (N=23)	Vegetation Cover (N=23)	Mineral Soil Cover (N=23)	Cryptogam Cover (N=23)	Rock Cover (N=23)	Shrub Density (N=22)
	percent					-#/sq. m-
Camp Perimeter						
Mean	53	51	25	5	8	1.36
Stan. Dev.	21	19	23	6	6	1.08
Median	51	55	15	2	7	0.98
Range	17-90	15-85	2-62	0-19	1-28	0.29-4.09
Control						
Mean	59	58	25	9	7	1.05
Stan. Dev.	25	25	26	16	7	0.58
Median	60	60	10	3	3	0.79
Range	10-90	15-90	0-80	0-60	0-20	0.44-2.38
Absolute Change						
Mean	-7	-8	0	-5	2	0.31
Stan. Dev.	15	16	13	13	7	0.69
Median	-8	-8	2	0	3	0.14
Range	-31-26	-33-20	-29-27	-47-7	-14-14	-0.82-1.90
Relative Change (%)						
Mean	-15	-4	216	8	163	27
Stan. Dev.	34	41	385	147	259	55
Median	-14	-12	36	-22	30	22
Range	-83-51	-66-134	-67-1420	-100-520	-70-780	-65-153
Significance						
T Test	.024	.017	.447	.058	.124	.049*
Wilcoxon	.019	.026	.464	.068	.060	.062*

1 - Absolute change is the difference between campsites and controls; relative change is absolute change as a percent of control values. A positive change indicates an increase on campsites. Significance was tested with both parametric paired t tests and nonparametric Wilcoxon matched-pairs, signed-ranks tests. Probabilities ≤ 0.05 are significant. The * denotes a two-tailed test.

Table 4. Soil conditions and change on campsite perimeters.[1]

Statistic	Bulk Density (N=23)	Soil Moisture (N=23)	Initial Infiltrat. (N=22)	Final Infiltrat. (N=22)	Penetration Resistance (N=23)
	---g/cc---	--percent--	--------cm/min--------		--kg/sq. cm--
Camp Perimeter					
Mean	1.24	6.6	2.0	0.55	1.0
Stan. Dev.	0.22	4.0	1.2	0.33	0.6
Median	1.21	4.9	1.9	0.54	0.9
Range	0.87-1.69	1.9-15.4	0.5-5.8	0.09-1.24	0.2-2.3
Control					
Mean	1.23	7.2	2.0	0.87	0.7
Stan. Dev.	0.29	5.6	1.1	0.77	0.4
Median	1.27	5.5	1.9	0.56	0.7
Range	0.72-1.84	1.6-23.8	0.6-5.0	0.20-2.75	0.2-1.8
Absolute Change					
Mean	-0.01	0.1	0	-0.23	0.3
Stan. Dev.	0.22	3.2	1.0	0.62	0.5
Median	0.01	0.1	-0.1	-0.07	0.1
Range	-0.30-0.65	-8.5-6.7	-1.7-2.3	-1.63-0.90	-0.7-1.5
Relative Change (%)					
Mean	2	13	15	10	95
Stan. Dev.	17	48	70	103	176
Median	1	2	-5	-24	33
Range	-35-27	-46-129	-66-210	-87-272	-57-700
Significance					
T Test	.442	.867*	.468	.047	.005
Wilcoxon	.429	.761*	.455	.057	.003

1 - Absolute change is the difference between campsites and controls; relative change is absolute change as a percent of control values. A positive change indicates an increase on campsites. Significance was tested with both parametric paired t tests and nonparametric Wilcoxon matched-pairs, signed-ranks tests. Probabilities ≤ 0.05 are significant. The * denotes a two-tailed test.

Table 5. Campsite conditions in relation to amount of use.[1]

Impact Parameter	Amount of Use: High Use (N=12) Mean	S.D.	Med.	Range	Low Use (N=12) Mean	S.D.	Med.	Range	Sign. P	NP
Core Area (m^2)	59	34	50	25-142	30	28	22	8-105	.016	.002
Floristic Dissimilarity (%)	35	17	36	11-66	28	11	29	7-46	.126	.204
Shrub Density (#/m^2) Perimeter	1.29	0.95	0.90	0.44-3.14	1.41	1.22	1.01	0.29-4.09	.403	.346
Vegetation Cover (%) Perimeter	54	13	55	28-66	48	24	50	15-85	.206	.249
Soil Cover (%) Perimeter	23	20	15	5-56	27	26	14	2-62	.359	.500
Cryptogam Cover (%) Perimeter	2	5	<1	0-14	6	6	5	0-19	.105	.087
Rock Cover (%) Perimeter	10	8	7	1-28	7	4	6	1-17	.110	.162
Litter Cover (%) Core	1	<1	1	0-2	9	20	3	0-71	.098	.002
Litter Cover (%) Perimeter	56	14	54	33-73	50	27	51	17-90	.279	.415
Bulk Density (g/cm^3) Core	1.72	0.21	1.68	1.39-2.21	1.41	0.34	1.49	0.60-1.75	.007	.007
Bulk Density (g/cm^3) Perimeter	1.26	0.23	1.31	0.91-1.58	1.23	0.22	1.20	0.87-1.69	.406	.415
Soil Moisture (%) Core	5.1	2.3	4.7	2.1-9.8	3.7	3.0	2.9	1.8-12.8	.209	.028
Soil Moisture (%) Perimeter	8.1	4.1	5.1	4.4-15.4	5.3	3.5	4.1	1.9-12.3	.092	.020
Init. Infiltr.(cm/min) Core	0.7	0.7	0.4	0.1-2.7	0.7	0.5	0.5	0.2-1.8	.432	.201
Init. Infiltr.(cm/min) Perimeter	2.1	1.6	1.9	0.5-5.8	1.9	0.7	1.9	0.9-3.6	.354	.474
Final Infiltr.(cm/min) Core	0.16	0.09	0.17	0.05-0.40	0.21	0.14	0.14	0.07-0.50	.170	.343
Final Infiltr.(cm/min) Perimeter	0.56	0.35	0.58	0.09-1.24	0.53	0.32	0.51	0.14-1.23	.437	.371
Penet. Resist.(kg/cm^2) Core	3.7	1.2	4.0	1.4->4.5	1.6	1.3	1.4	0.3-4.2	<.001	.001
Penet. Resist.(kg/cm^2) Perimeter	1.1	0.5	1.1	0.4-2.1	0.9	0.6	0.7	0.2-2.3	.163	.098

1 - Significance was tested using parametric t tests (P) and nonparametric Mann-Whitney U tests (NP). Probabilities ≤0.05 are significant.

Table 6. Absolute changes on campsites in relation to amount of use.[1]

	Amount of Use								Sign.	
	High Use (N=12)				Low Use (N=12)					
Impact Parameter	Mean	S.D.	Med.	Range	Mean	S.D.	Med.	Range	P	NP
Shrub Density (#/m^2)										
Perimeter	0.29	0.76	0.31	-0.82-1.90	0.32	0.66	0.05	-0.31-1.72	.455	.396
Vegetation Cover (%)										
Perimeter	-11	15	-9	-32-10	-4	17	-4	-33-20	.161	.178
Soil Cover (%)										
Perimeter	2	12	6	-25-15	-3	14	-5	-29-27	.176	.088
Cryptogam Cover (%)										
Perimeter	-4	13	0	-43-3	-3	14	-3	-47-7	.388	.103
Rock Cover (%)										
Perimeter	2	7	4	-14-10	1	6	1	-11-14	.363	.109
Litter Cover (%)										
Core	-65	16	-60	-85-45	-45	36	-44	-88-16	.053	.114
Perimeter	-10	15	-13	-27-26	-3	15	-2	-31-26	.154	.074
Bulk Density (g/cm^3)										
Core	0.53	0.37	0.54	-1.01-1.06	0.13	0.19	0.20	-0.12-0.42	.002	.009
Perimeter	0.03	0.17	0.01	-0.25-0.30	-.04	0.26	0.03	-0.65-0.30	.220	.300
Soil Moisture (%)										
Core	-5.4	5.9	-3.1	-17.8-1.2	-0.1	2.5	-0.4	-4.1-7.0	.004	.001
Perimeter	-1.3	3.3	-0.7	-8.5-3.6	1.4	2.6	0.8	-1.6-6.7	.019	.028
Init. Infiltr.(cm/min)										
Core	-1.5	1.5	-1.1	-4.6-1.0	-1.1	1.0	-1.6	-2.3-0.5	.246	.500
Perimeter	-0.1	1.2	-0.3	-2.3-1.7	0.1	0.9	0.2	-1.6-1.3	.329	.322
Final Infiltr.(cm/min)										
Core	-0.94	0.86	-.59	-2.5-0.2	-0.42	.51	-0.25	-4.7-0.29	.041	.034
Perimeter	-0.40	0.67	-.32	-1.6-0.4	-0.09	.57	-0.07	-1.5-0.90	.125	.187
Penet. Resist.(kg/cm^2)										
Core	3.1	1.2	3.5	0.7-4.4	0.9	1.4	1.0	-1.5-3.4	<.001	.001
Perimeter	0.3	0.5	0.4	0-1.4	0.2	0.5	0.1	-0.7-1.5	.063	.064

1 - Absolute change is the difference between campsites and controls; a positive change indicates an increase on campsites. Significance was tested using parametric t tests (P) and nonparametric Mann-Whitney U tests (NP). Probabilities ≥ 0.05 are significant.

Table 7. Relative changes on campsites in relation to amount of use.[1]

	Amount of Use								Sign.	
	High Use (N=12)				Low Use (N=12)					
Impact Parameter	Mean	S.D.	Med.	Range	Mean	S.D.	Med.	Range	P	NP
Shrub Density (%)										
Perimeter	31	63	37	-65-153	23	49	7	-44-126	.367	.346
Vegetation Cover (%)										
Perimeter	-14	22	-14	-53-21	5	52	-5	-66-134	.140	.230
Soil Cover (%)										
Perimeter	351	507	73	-68-1420	92	171	-11	-62-380	.055	.088
Cryptogam Cover (%)										
Perimeter	58	229	-9	-78-520	-19	79	-23	-100-134	.158	.157
Rock Cover (%)										
Perimeter	169	223	79	-70-570	159	298	15	-69-780	.463	.290
Litter Cover (%)										
Core	-99	1	-99	-99-96	-83	36	-95	-99-28	.080	.001
Perimeter	-22	30	-23	-83-37	-8	38	-5	-64-51	.172	.194
Bulk Density (g/cm^3)										
Core	52	40	56	1-112	11	16	18	-17-32	.002	.016
Perimeter	4	15	1	-18-26	0	19	2	-35-26	.288	.333
Soil Moisture (%)										
Core	-41	33	-39	-82-32	-3	45	-14	-57-121	.014	.006
Perimeter	-10	29	-6	-46-32	35	54	29	-35-129	.012	.024
Init. Infiltration (%)										
Core	-63	43	-77	-93-62	-50	43	-57	-92-51	.221	.136
Perimeter	-1	62	-20	-60-116	28	76	5	-66-210	.170	.146
Final Infiltration (%)										
Core	-76	23	-82	-95-10	-47	62	-67	-93-138	.068	.047
Perimeter	-10	88	-32	-87-200	26	115	-24	-72-273	.218	.178
Penetration Resistance(%)										
Core	824	702	525	100-2200	246	350	168	-83-1200	.009	.006
Perimeter	160	233	36	0-7000	35	65	22	-57-188	.043	.078

1 - Relative change is absolute change as a percent of control values; a positive change indicates an increase on campsites. Significance was tested using parametric t tests (P) and nonparametric Mann-Whitney U tests (NP). Probabilities ≤ 0.05 are significant.

Table 8. Campsite conditions on three vegetation types.[a]

Impact Parameter	Vegetation Type: Pinyon-Juniper (N=8) Mean	S.D.	Median	Range	Catclaw (N=8) Mean	S.D.	Median	Range	Desert Scrub (N=8) Mean	S.D.	Median	Range	Signif. P	NP
Core Area (m^2)	68	41	56	23-142	32	27	24	8-87	33	20	24	15-69	.048	.044
Floristic Dissimilarity (%)	35	6	36	28-46	24	15	20	7-54	35	19	33	13-66	.223	.144
Shrub Density ($\#/m^2$)														
Perimeter	1.02	0.36	1.00	0.44-1.49	1.65	1.42	0.93	0.60-4.00	1.41	1.27	0.87	0.29-3.14	.530	.774
Vegetation Cover (%)														
Perimeter	33	12	32	15-52	60	9	66	55-85	52	17	50	17-66	<.001	.001
Mineral Soil Cover (%)														
Perimeter	53	10	57	37-62	7	5	6	2-15	13	9	12	4-31	<.001	<.001
Cryptogam Cover (%)														
Perimeter	4	5	3	0-13	2	2	<1	0-6	9	7	12	<1-19	.032	.060
Rock Cover (%)														
Perimeter	5	3	5	1-11	10	9	7	1-28	9	4	9	4-17	.261	.217
Litter Cover (%)														
Core	1	1	<1	0-4	2	3	<1	0-8	12	26	2	0-71	.287	.091
Perimeter	30	13	27	17-49	74	11	73	54-90	55	8	51	48-71	<.001	<.001
Bulk Density (g/cm^3)														
Core	1.45	0.25	1.54	0.95-1.72	1.69	0.19	1.74	1.35-1.94	1.55	0.46	1.63	0.60-2.21	.362	.171
Perimeter	1.31	0.23	1.38	0.87-1.58	1.16	0.17	1.17	0.91-1.38	1.27	0.26	1.21	0.91-1.69	.377	.319
Soil Moisture (%)														
Core	5.1	3.2	4.2	3.3-12.8	3.7	2.6	2.6	2.1-9.8	4.5	2.4	4.1	1.8-8.1	.588	.235
Perimeter	5.2	2.9	4.6	3.8-12.3	7.0	4.3	5.0	2.5-15.4	7.8	4.7	8.5	1.9-13.3	.457	.664
Initial Infiltration (cm/min)														
Core	0.7	0.8	0.4	0.2-2.7	0.6	0.4	0.4	0.2-1.6	0.8	0.6	0.7	0.1-1.8	.794	.422
Perimeter	2.0	0.8	1.9	0.8-3.3	2.4	1.5	1.9	0.9-5.8	1.7	1.0	1.8	0.5-3.6	.550	.733
Final Infiltration (cm/min)														
Core	0.13	0.09	0.11	0.05-0.33	0.25	0.15	0.19	0.11-0.50	0.19	0.08	0.18	0.07-0.32	.115	.062
Perimeter	0.39	0.19	0.35	0.14-0.61	0.84	0.31	0.82	0.41-1.24	0.36	0.21	0.30	0.09-0.63	.002	.011
Penetration Resistance (kg/cm^2)														
Core	2.5	1.7	2.1	0.3->4.5	2.5	1.7	2.0	0.3->4.5	3.0	1.6	3.3	0.5->4.5	.788	.761
Perimeter	0.6	0.5	0.4	0.2-1.6	1.0	0.4	1.0	0.3-1.5	1.4	0.7	1.3	0.5-2.3	.037	.046

[a] - Significance was tested using parametric oneway analysis of variance (P) and nonparametric Kruskall-Wallis analysis of variance. Probabilities ≤ 0.05 are significant.

Table 9. Absolute change on campsites in three vegetation types.*

Impact Parameter	Vegetation Type: Pinyon-Juniper (N=8) Mean	S.D.	Median	Range	Catclaw (N=8) Mean	S.D.	Median	Range	Desert Scrub (N=8) Mean	S.D.	Median	Range	Signif. P	NP
Shrub Density (#/m^2)														
Perimeter	0.02	0.59	0.13	-0.82-0.83	0.52	0.66	0.31	-0.38-1.71	0.46	0.79	0.19	-0.23-1.78	.252	.421
Vegetation Cover (%)														
Perimeter	-3	15	-2	-32-28	-15	9	-14	-27-0	-5	21	4	-33-28	.238	.237
Mineral Soil Cover (%)														
Perimeter	0	15	-5	-19-27	5	5	5	-3-13	-7	16	-6	-29-13	.247	.328
Cryptogam Cover (%)														
Perimeter	-5	17	0	-47-3	-1	3	-1	-7-3	-7	16	-1	-43-7	.712	.443
Rock Cover (%)														
Perimeter	3	3	3	-1-7	0	7	2	-14-8	2	9	4	-11-14	.788	.837
Litter Cover (%)														
Core	-37	28	-38	-68- -10	-79	8	-82	-88- -62	-47	36	-48	-85- -16	.004	.002
Perimeter	-7	11	-9	-27-7	-7	10	-7	-22-4	-5	23	-4	-31-26	.924	.964
Bulk Density (g/cm^3)														
Core	0.17	0.08	0.18	0.01-0.24	0.41	0.49	0.44	-0.11-0.96	0.41	0.34	0.39	-0.12-1.06	.283	.221
Perimeter	0.02	0.12	0.04	-0.14-0.16	-0.12	0.29	-0.16	-0.65-0.23	0.09	0.20	0.06	-0.25-0.30	.184	.284
Soil Moisture (%)														
Core	0.2	3.8	-0.4	-2.4-7.8	-3.2	3.1	-3.8	-6.7-0.6	-5.3	7.2	-1.8	-17.8-0.3	.095	.128
Perimeter	0.3	2.8	-0.1	-2.2-6.5	0	2.7	0.1	-4.8-3.7	0	4.5	-0.3	-8.5-6.7	.982	.924
Initial Infiltration (cm/min)														
Core	-0.7	1.8	-0.8	-2.3-1.8	-2.0	1.7	-1.8	-4.6-0.5	-1.3	0.6	-1.5	-2.1- -0.2	.147	.239
Perimeter	0.6	0.9	0.6	-0.6-1.7	-0.2	1.1	-0.4	-2.3-1.5	-0.4	0.8	-0.3	-1.6-0.5	.130	.188
Final Infiltration (cm/min)														
Core	-0.49	0.32	-0.46	-0.87- -.07	-0.73	0.95	-0.31	-2.31-0.29	-0.82	0.87	-0.59	-2.55- -0.0	.682	.939
Perimeter	-0.18	0.25	-0.08	-0.67-0.05	-0.14	0.87	0.06	-1.63-0.98	-0.39	0.61	-0.52	-1.45-0.42	.743	.424
Penetration Resistance (Kg/cm^2)														
Core	2.3	1.7	1.9	0.1-4.4	1.6	1.8	2.0	-1.5-3.3	2.2	1.7	2.6	-0.1-4.2	.653	.681
Perimeter	0.4	0.5	0.1	0-1.4	0	0.4	0	-0.7-0.5	0.6	0.5	0.4	0.1-1.5	.886	.873

* - Absolute change is the difference between campsites and controls; a positive value indicates an increase on campsites. Significance was evaluated using parametric oneway analysis of variance (P) and nonparametric Kruskall-Wallis analysis of variance (NP). Probabilities ≤0.05 are significant.

Table 18. Relative change on campsites in three vegetation types.*

Impact Parameter	Vegetation Type: Pinyon-Juniper (N=8) Mean	S.D.	Median	Range	Catclaw (N=8) Mean	S.D.	Median	Range	Desert Scrub (N=8) Mean	S.D.	Median	Range	Signif. P	NP
Shrub Density (%)														
Perimeter	13	66	7	-65-126	36	32	45	-3-72	33	68	21	-44-153	.695	.553
Vegetation Cover (%)														
Perimeter	7	56	-3	-53-134	-18	18	-18	-38-0	0	43	8	-66-58	.482	.470
Mineral Soil Cover (%)														
Perimeter	6	35	-9	-23-76	531	498	328	-38-1420	95	216	-32	-68-443	.008	.029
Cryptogam Cover (%)														
Perimeter	86	245	0	-79-520	-36	79	-61	-100-110	-13	80	-18	-88-134	.384	.355
Rock Cover (%)														
Perimeter	255	289	198	-38-660	16	70	25	-70-130	228	313	140	-60-780	.133	.302
Litter Cover (%)														
Core	-97	4	-99	-99- -86	-97	4	-99	-99-89	-77	47	-96	-99-28	.256	.214
Perimeter	-21	42	-29	-83-41	-12	16	-9	-40-5	-10	42	-9	-64-51	.001	.053
Bulk Density (%)														
Core	14	8	16	1-24	44	52	39	-7-112	36	33	29	-17-92	.243	.357
Perimeter	3	10	3	-11-16	-5	21	-13	-35-22	9	17	5	-18-26	.294	.312
Soil Moisture (%)														
Core	5	52	-9	-37-121	-33	39	-37	-76-37	-37	25	-28	-82-12	.098	.138
Perimeter	7	48	-3	-35-111	16	45	20	-46-74	18	58	-4	-39-129	.893	.899
Initial Infiltration (%)														
Core	-46	53	-60	-92-62	-63	48	-82	-93-51	-61	27	-70	-90-19	.703	.652
Perimeter	64	87	68	-43-210	4	54	-22	-46-116	-20	41	-12	-66-43	.058	.096
Final Infiltration (%)														
Core	-72	27	-82	-95-23	-46	75	-67	-92-138	-67	30	-90	-93-10	.551	.497
Perimeter	-28	27	-30	-73-9	62	130	22	-65-273	-14	103	-63	-87-200	.190	.155
Penetration Resistance (%)														
Core	985	777	817	50-2200	192	186	231	-83-425	427	484	211	-8-1400	.023	.032
Perimeter	183	264	50	0-700	5	414	0	-51-71	96	95	50	8-250	.127	.037

* - Relative change is absolute change as a percent of control values; a positive value indicates an increase on campsites. Significance was evaluated using parametric oneway analysis of variance (P) and nonparametric Kruskall-Wallis analysis of variance (NP). Probabilities ≤0.05 are significant.

Table 11. Median conditions on controls in each vegetation type.[1]

Impact Parameter	Vegetation Type			Sign.	
	Pinyon-Juniper	Catclaw	Desert Scrub	P	NP
Vegetation Cover (%)	37	83	50	$\leq$.001	.002
Cryptogam Cover (%)	$<$ 1	3	6	.328	.241
Litter Cover (%)	40	85	50	$\leq$.001	.002
Mineral Soil Cover (%)	50	1	10	$<$.001	.002
Rock Cover (%)	1	9	3	.070	.042
Bulk Density (g/cm^3)	1.35	1.26	1.18	.551	.470
Soil Moisture (%)	4.3	8.0	7.0	.227	.717
Initial Infiltration Rate (cm/min)	1.4	2.2	2.3	.101	.146
Final Infiltration Rate (cm/min)	0.56	0.47	0.71	.553	.934
Penetration Resistance (kg/cm^2)	0.2	0.8	0.7	.001	.001

1 - Significance was tested using parametric oneway analysis of variance (P) and nonparametric Kruskall-Wallis analysis of variance (NP). Probabilities ≤ 0.05 are significant.

APPENDIX III

PLANT SPECIES FOUND
ON CAMPSITES AND CONTROLS

Plant Species List[1]

Trees and Shrubs

Acacia greggii Gray Catclaw
Agave utahensis Engelm. Utah agave
Artemisia arbuscula ssp. *nova* (A. Nels.) G. H. Ward
Atriplex canescens (Pursh) Nutt. Four-wing salt bush
Baccharis salicifolia (R. & P.) Pers. Seep willow
Bernardia incana Morton. Bernardia
Ceanothus greggii Gray Desert ceanothus
Celtis reticulata Torr. Net leaf hackberry
Cercis occidentalis Torr. California redbud
Cercocarpus montanus Raf. Alder-leaf mountain mahogany
Chrysothamnus nauseosus (Pall.) Britt. Rabbit brush
Coleogyne ramosissima Torr. Black brush
Cowania mexicana D. Don. Cliff rose
Echinocereus engelmannii (Parry) Lemaire Hedgehog cactus
Echinocereus triglochidiatus var. *melanacanthus* (Engelm.) L. Benson Claret cup
Encelia frutescens Gray Rayless encelia
Ephedra nevadensis Wats. Nevada joint-fir
Ephedra torreyana Wats. Torrey joint-fir
Ephedra viridis Cov. Mountain joint-fir
Erigeron sp. Fleabane
Fallugia paradoxa (D. Don) Endl. Ponil. Apache plume
Fendlera rupicola Gray Fendlerbush
Fraxinus anomala Torr. Single-leaved ash
Glossopetalon nevadense Gray Grease bush
Gutierrezia sarothrae (Pursh) Britt. & Rusby Broom snakeweed
Haplopappus acradenius (Greene) Blake Alkali goldenbush
Juniperus osteosperma (Torr.) Little Utah juniper
Lycium andersonii Gray Anderson thornbush
Opuntia basilaris Engelm. & Bigel. Beavertail cactus
Opuntia erinacea Engelm. & Bigel. Grizzly bear cactus
Opuntia phaecantha Engelm. Engelmann prickly pear
Pinus edulis Engelm. Pinyon
Prunus fasciculata (Torr.) Gray Desert range almond
Ptelea trifoliata ssp. *pallida* (Greene) V. L. Bailey Pale hoptree
Quercus undulata Torr. Wavy leaf oak
Rhus trilobata Nutt. Squaw bush
Thamnosma montana Torr. & Frem. Turpentine broom
Yucca angustissima Engelm. Fineleaf yucca
Yucca baccata Torr. Banana yucca

Grasses

Aristida arizonica Vasey Arizona three-awn
Bouteloua aristidoides (H. B. K.) Grisb. Six-weeks needle grama
Bouteloua curtipendula (Michx.) Torr. Side-oats grama
Bouteloua eriopoda (Torr.) Torr. Black grama
Bouteloua gracilis (H. B. K.) Lag. ex Steud. Blue grama
Bromus rubens L. Red brome

---

1 - Nomenclature follows Lehr (1978).

Bromus tectorum L. Cheat grass
Elymus glaucus Buckl. Blue wild rye
Elymus salinus M. E. Jones Salina wild rye
Erioneuron pilosum (Buckl.) Nash Hairy tridens
Erioneuron pulchellum (H. B. K.) Tateoka. Fluff grass
Hilaria jamesii (Torr.) Benth. Galleta
Hordeum leporinum Link. Wild barley
Muhlenbergia porteri Scribn. Bush muhly
Oryzopsis hymenoides (R. & S.) Ricker Indian ricegrass
Poa bigelovii Vasey & Scribn. Bigelow's bluegrass
Poa fendleriana (Steud.) Vasey Mutton grass
Sitanion hystrix (Nutt.) J. G. Smith Squirrel tail
Sporobolus cryptandrus (Torr.) Gray Sand dropseed
Stipa arida Jones Needlegrass
Stipa comata Trin. & Rupr. Needle and thread
Stipa speciosa Trin. & Rupr. Desert needlegrass
Vulpia octoflora (Walt.) Rydb. Six-weeks fescue

Forbs
Acourtia wrightii (Gray) Reveal & King Brownfoot
Allionia incarnata L. Trailing four-o'clock
Amsinckia intermedia F. & M. Coast fiddleneck
Androsace occidentalis Pursh. Rock jasmine
Anemone tuberosa Rydb. Desert windflower
Arabis perennans Wats. Rock cress
Artemisia ludoviciana Nutt. Wormwood
Aster sp.
Astragalus newberryi Gray
Astragalus nuttallianus DC. Nuttall locoweed
Astragalus sp.
Calochortus flexuosus Wats. Straggling mariposa
Castilleja chromosa A. Nels. Desert paintbrush
Castilleja linariaefolia Benth. Long-leaved paintbrush
Claytonia perfoliata Donn. Miner's lettuce
Cryptantha sp. Hiddenflower
Cymopterus purpurascens (Gray) Jones Purple cymopterus
Delphinium parishii Gray Larkspur
Descurainia pinnata (Walt.) Britt. Yellow tansy mustard
Dichelostemma pulchellum (Salisb.) Heller. Bluedicks
Draba cuneifolia Nutt. Whitlow grass
Dyssodia acerosa DC. Dogweed
Erigeron concinnus (H. & A.) T. & G. Tidy fleabane
Erigeron lobatus A. Nels.
Erigeron sp.
Eriogonum inflatum Torr. & Frem. Desert trumpet
Erodium cicutarium (L.) L'Her. Filaree
Galium aparine L. Bedstraw
Gilia flavocincta A. Nels. Thread-stemmed gilia
Haplopappus spinulosus (Pursh.) DC. Spiny goldenweed
Hymenoxys acaulis var. *arizonica* (Greene) K. F. Parker Arizona actinea
Lathyrus graminifolius (Wats.) White Peavine
Lepidium lasiocarpum Nutt. Sand peppergrass
Lepidium montanum Nutt.
Leucelene ericoides (Torr.) Greene White aster

Lupinus brevicaulis Wats. Short-stemmed lupine
Mentzelia pumila (Nutt.) T. & G. Blazing star
Parietaria hespera Hinton. Pellitory
Pectocarya recurvata Johnst. Arch-nutted comb bur
Penstemon eatonii Gray Eaton firecracker
Phacelia cryptantha Greene Small-flowered phacelia
Phacelia glechomaefolia Gray
Plagiobothrys arizonicus (Gray) Greene Blood weed
Plantago purshii R. & S. Indian wheat
Porophyllum gracile Benth. Odora
Senecio multilobatus T. & G. ex Gray Groundsel
Solidago sparsiflora Gray Goldenrod
Sphaeralcea grossulariaefolia (H. & A.) Rydb. Globemallow
Sphaeralcea parvifolia A. Nels. Littleleaf globemallow
Streptanthus cordatus Nutt. Twistflower
Swertia albomarginata (Wats.) Kuntze Elkweed
Thelypodiopsis linearifolia (Gray) Al-Shehbaz
Thysanocarpus laciniatus Nutt. Lace pod
Tragopogon dubius Scop. Goatsbeard

APPENDIX IV

DETAILED INSTRUCTIONS FOR REPEAT MEASUREMENTS

INSTRUCTIONS FOR REPEATING DETAILED CAMPSITE MEASUREMENTS

It would be worthwhile to periodically repeat the detailed study of campsites. For this purpose, permanent stakes have been left at each campsite. Studies elsewhere suggest that changes on campsites occur slowly in most cases. Consequently, reexamination of sites every 5-10 years seems appropriate. Reexaminations should be conducted in spring to replicate the timing of the original study and, to be truly consistent, should take into account the fact that the original study was conducted after an abnormally dry year.

The campsites studied can be located from the topographic maps and the location description for each site. The photographs of each site should be checked to make sure the same site is being examined. These photos also show the approximate location of the buried nail that permanently marks the center point of each campsite. It can be relocated using a pin locator and the triangulation points established on each site. Measurements are as follows:

1. Barren Core Area:

Once the center point is relocated, measure the distance from this point to the first significant amount of vegetation along the following 16 directions (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW). Significant vegetation was defined as a clump of vegetation with an area of at least 1 m^2. Where other campsite boundaries, such as a rock ledge, were encountered, this distance was recorded and the boundary feature used (other then vegetation) was noted. Generally, barren core was measured to the rear of small rocks or the front of very large rocks. Where a transect started up an access trail, distance was measured to the point where a "smoothed" perimeter would have been encountered. If a transect encountered a clump of vegetation and then reentered bare ground, for at least 1 m, the clump was considered an "island". In this case, bare core extends to the outermost core boundary, with the area of the "island" being subtracted from the total area. In the office, these transects can be plotted on an overlay of the gridded map already drawn for each site (Fig. 1). Then a planimeter is used to determine area. The area of satellite sites is roughly estimated in the field and added to the area of the main core. This permits change in core area over time to be assessed. Comparison of map overlays also identifies where the increase has occurred. This could be helpful in designing a means for halting expansion.

2. Soil Conditions Within the Barren Core:

Of the soil measurements taken in the core, only litter cover and bulk density are not affected by recent weather conditions. Consequently it is hard to assess how useful future evaluations of core soils are likely to be. Perhaps differences between campsites and controls might provide a reliable basis for following change over time. I would recommend collecting soils information from a few sites first and assessing the utility of this information, before reexamining core soils on all sites. Nevertheless, soil sampling techniques are described in detail below.

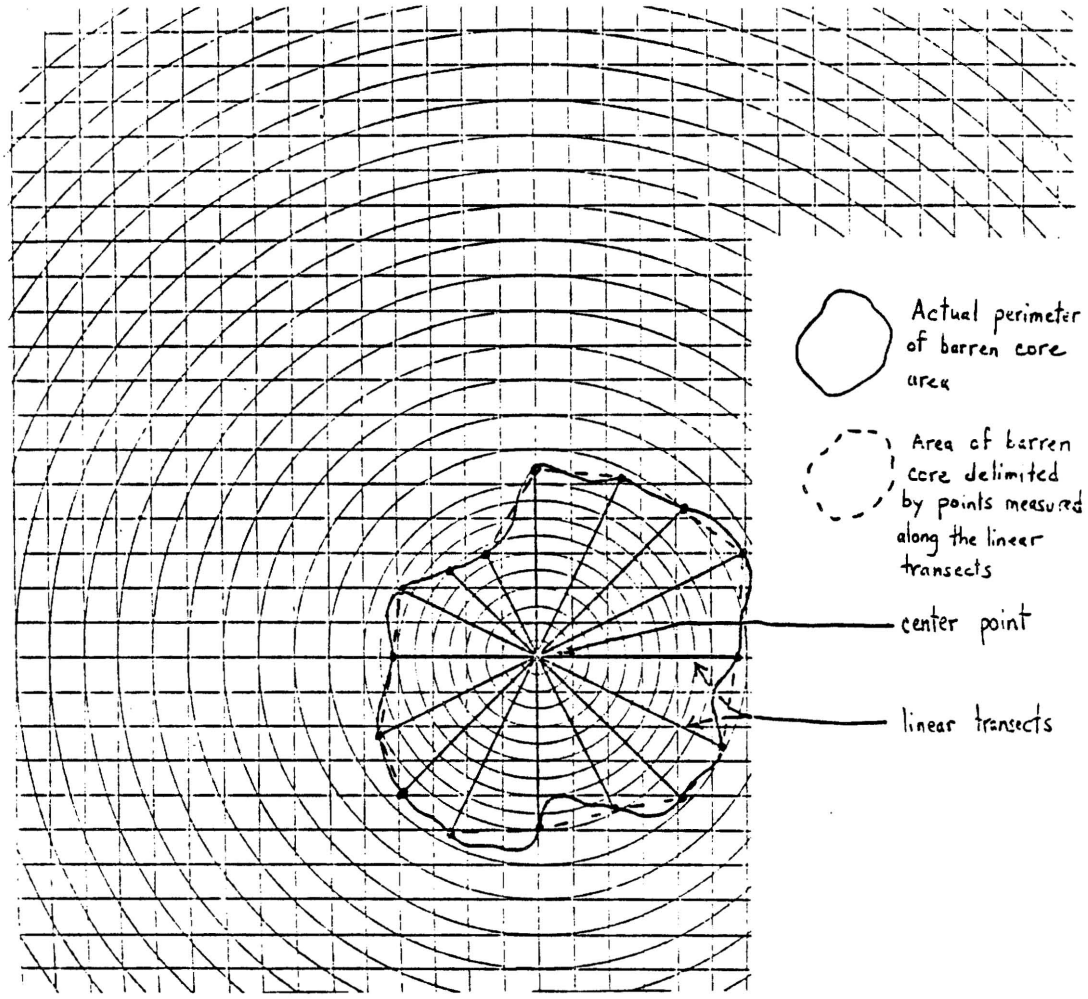


Fig. 1. Example of a radial map for calculating barren core area.

Place 1 m^2 quadrats to the right of the N, S, E, and W transects, at the locations noted on the forms (Fig. 2). The location "4 M S" indicates a location on the right side (facing out from the center point) of the transect to the south, between 4 and 5 m from the center point. Estimate the percent cover of organic matter (litter) in the quadrat, using one of the following coverage classes: <1, 1-5, 6-25, 26-50, 51-75, 76-95, and 96-100 percent. Take 10 penetration resistance readings within each quadrat with a pocket soil penetrometer.

To the left of the transect and quadrat take soil samples for bulk density and moisture content as follows:

A. Level the soil at a depth about 1 cm below the surface.

B. Excavate a hole about 9 cm in diameter and about 3.5 cm deep, retaining the soil sample in a labeled plastic bag that can be sealed.

C. Line the hole with cellophane and fill with water until the water just starts to overflow.

D. Measure the volume of water used, using a graduated cylinder.

E. In the laboratory, shake the soil samples through a 2 mm sieve. Measure the volume of the ≥2 mm fraction by measuring water displacement in a graduated cylinder. The volume of the <2 mm fraction is calculated by subtraction.

F. Discard the ≥2 mm fraction. Then weigh the moist soil samples, dry them in a 105 degree Centigrade oven for a day, and weigh them again.

G. Calculate bulk density by dividing the weight of the dry soil by the volume of the <2 mm fraction.

H. Calculate gravimetric water content as the difference between the wet and dry soil weights divided by the weight of the <2 mm sample.

Close to where the soil samples are taken, measure infiltration rates with a double-ring infiltrometer as follows:

A. Pound the infiltrometer a few centimeters into the soil.

B. Add water to the outer ring to prevent subsurface lateral flow of water from the inner ring.

C. Pour 6 cm of water into the inner ring and note the time it takes for each of the first 5 cm to infiltrate the soil. Terminate the measurements after 20 minutes if 5 cm have not infiltrated at that point. Maintain some water in the outer ring at all times.

D. Calculate an initial infiltration rate based on the number of minutes it took the first cm to infiltrate. Express the rate in cm/min. A final infiltration rate will be the mean cm/min it took for the fifth cm to infiltrate. Where less than 5 cm infiltrated in 20 minutes, base final infiltration on an estimation (using interpolation techniques) of the time it took for the last cm to infiltrate.

It should then be possible to compare changes over time in mean litter cover, bulk density, gravimetric moisture, infiltration rates and penetration resistance. Means are based on four organic matter cover estimates, four bulk density and moisture content samples, four initial and final infiltration rate readings, and 40 penetration resistance measurements.

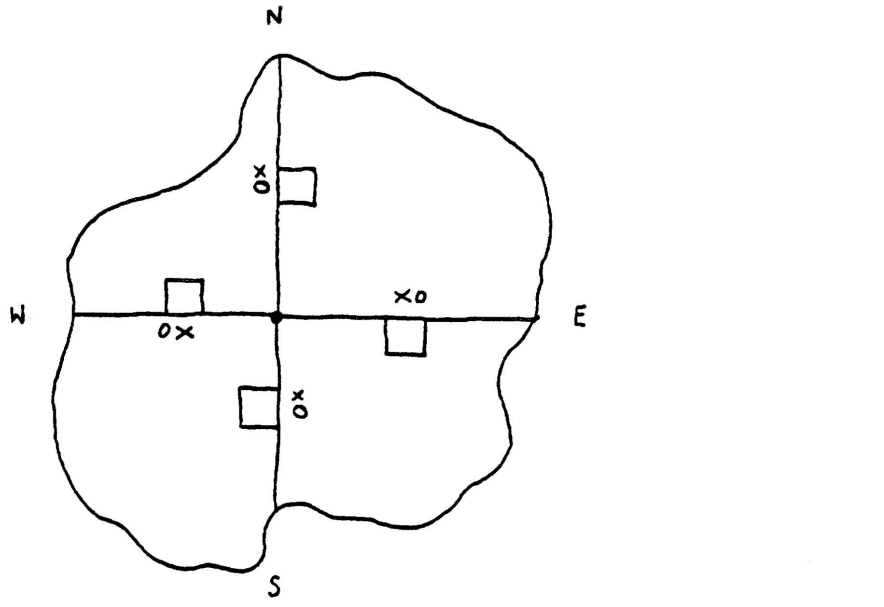


Fig. 2. Sampling locations within the devegetated area.

3. Vegetation and Soil Measurements on the Perimeter Adjacent to the Core:

A method for relocating about 25 1 m^2 plots around the perimeter is as follows:

A. Relocate permanent metal markers, driven below the soil surface, at the distances from the center point along the N, S, E, and W transects noted on the form.

B. Connect each pair of adjacent markers (i.e. S and W, W and N, N and E, E and S) with a transect.

C. Then relocate each quadrat, using the locations noted on each form. For example, location "1 M FROM S TOWARD W R" means on the right side, facing west, of the south to west transect, between 1 and 2 meters. These quadrats were randomly located along these transects (Fig. 3).

D. Within each quadrat, count all rooted shrubs by species.

E. Then estimate the cover of each species in the coverage classes mentioned before. Count coverage of plants rooted outside of the quadrat, as well. For trees, estimate cover if branches are below breast height.

F. Using the same coverage classes, estimate cover of total live vascular vegetation, cryptogams, mineral soil, litter, and rock in each quadrat. To be counted, rocks must be >5 cm across and probably not have been moved by visitors.

G. Calculate a mean density, in shrubs per m^2, based on the number of 1 m^2 quadrats sampled, usually 25. Do this for all shrubs and for each species. This can be compared with earlier density measures.

H. Perform a similar comparison based on the mean cover of total vegetation, cryptogams, mineral soil, litter, and rock, as well as of each species.

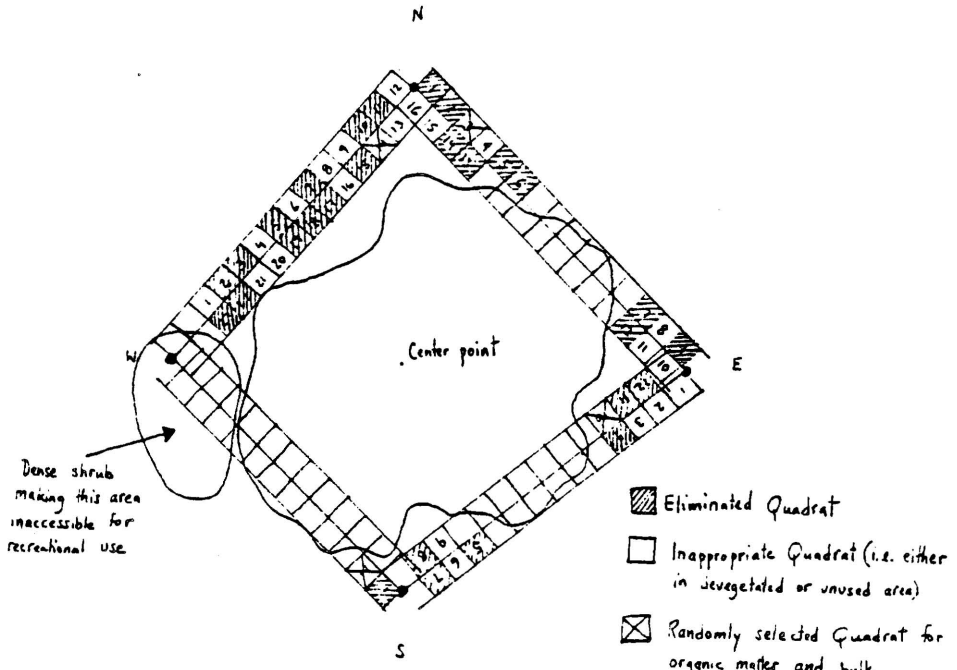
I. Take two penetration resistance readings in each quadrat.

J. Take bulk density, moisture content, and infiltration rate measurements in the four quadrat locations noted under "QUADRAT SOILS". Techniques are identical to those for the core. Compare differences in means over time. Calculate mean penetration resistance on the basis of the first 40 readings.

4. Soil and Vegetation Measurements on Controls.

Controls should be reexamined to facilitate interpretation of changes on the campsites. Changes over time, particularly in annual species and soil conditions, reflect natural changes as well as recreational impact. By comparing changes in campsite conditions to changes on controls, it is possible to "factor out" the natural changes.

Locate the buried permanent nails at the center of each control plot using the location map, triangulation points, and a pin locator. Then delineate the plot using a circle with a radius of 4 m. Within this area count all rooted shrubs by species. Estimate cover of individual species, total live vascular vegetation, cryptogams, mineral soil, litter, and rocks, using the same coverage classes as before.



Transect	Possible Quadrats	Desired Quadrats
N - E	16	7
E - S	12	6
S - W	2	1
W - N	23	11
Total	53	25

Fig. 3. Locations of 25 1 m^2 quadrats for sampling the campsite perimeter.

About 2 m from the center point along the N, S, E, and W axes of the plot, take 4 soil samples and infiltration rate measurements similar to those taken on the core and perimeter. Take 40 regularly-distributed penetration resistance measurements. Calculate means for comparison with both earlier control measurements and concurrent measures on the core and perimeter.

INSTRUCTIONS FOR MONITORING RECOVERY OF CRYPTOGAM CRUSTS

It would also be valuable to follow recovery of the trampled crusts. This would permit an evaluation of the crust's resilience. To do so:

A. Replace, temporarily, the piece of PVC pipe connecting each pair of vertical stakes. Be sure the piece is firmly seated (Fig. 4). Align the pipe so the numbers are toward the southeast. The left lane is on the left when facing northwest.

B.Take measurements every 2 cm along the horizontal piece of pipe using a measuring tape. Always take the measurements by aligning the left side of the tape with the markings on the pipe.

C. Record the distance from the ground surface to the horizontal line on the pipe, to the nearest 2 mm. Then note if the point where a pin, attached to the tape, hits the ground is undisturbed crust, disturbed crust, or bare mineral soil.

D. Calculate mean height and percent coverage of each of the groundcover categories based on the 50 measurements for each lane. Compare these to the measurements taken before and after trampling. In particular, it should be interesting to follow changes in relation to the final measurements after 50 passes on the left lane and 250 passes on the right lane.

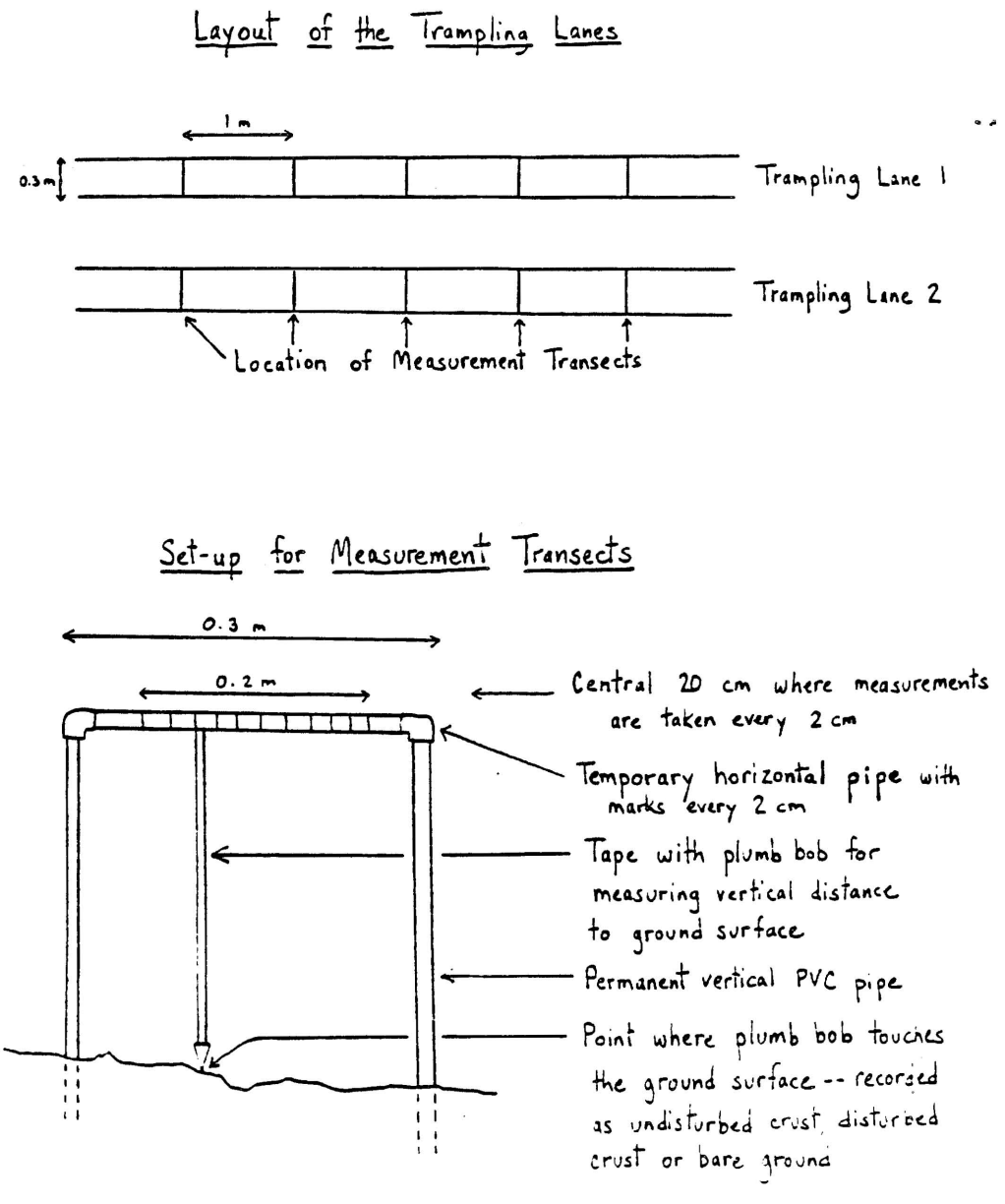


Fig. 4. Design of the experimental trampling lanes and measurement transects.