

# Modeling Wilderness Campsites: Factors That Influence Amount of Impact

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**ABSTRACT/A** standard campsite model is proposed and then manipulated to examine the influence of individual variables on amount of vegetation loss. Amount of impact is influenced by amount of use, vegetation fragility, vegetation density, and the degree to which activities are concentrated

spatially on the site. Degree of concentration also influences the importance of the other explanatory variables. Amount of use and vegetation fragility are equally important determinants of impact and are most influential where activity concentration is low. The curvilinear relationship between amount of use and amount of impact can be explained by the tendency for activities to become increasingly concentrated as amount of use increases. This relationship should not vary with regional or environmental characteristics except where these influence degree of activity concentration.

Wilderness areas have been established "to ensure that an increasing population . . . does not occupy and modify all areas within the United States" (Wilderness Act, PL 88-577). Management objectives stress preserving and protecting wilderness lands in their natural condition and minimizing the evidence of human use. Wilderness also is intended to provide outstanding opportunities for primitive recreation. The goals of recreation use and nature preservation invariably conflict, particularly at campsites where recreational users spend much of their time. Managers generally deal with this dilemma by allowing overnight camping in wilderness, while instituting management programs to keep impacts within acceptable limits.

Numerous management actions have been taken to **limit campsite impacts. Strategies range from use restrictions, such as limits on amount of use, party size, and length of stay, to controls** on the location of camp sites and programs that encourage low-impact camping behavior. Research has attempted to build a stronger knowledge base on which to build campsite management programs. Empirical studies have explored the functional relationships between independent variables, such as amount of use, **and** various dependent measures of campsite impact (Cole 1987a). This approach attempts to identify factors that strongly influence amount of impact-factors that could be controlled to minimize impacts.

Although these empirical studies have helped identify the factors that determine amount of campsite impact, they have been less successful than hoped. It has

proven difficult to isolate the influence of individual variables because the influence of any single variable, such as amount of use, is always confounded by that of another variable, such as type of use. For example, sites that are used frequently often are used by different types of groups than infrequently used sites. In addition, the lack of a theoretical framework for these studies has made it difficult to provide explanations for observed relationships, some of which have been counter-intuitive.

This article utilizes hypothetical campsite models to overcome these difficulties. A standard model is proposed and then manipulated to examine the influence of individual variables on amount of impact. Objectives are to (1) understand how each independent variable influences amount of impact, (2) understand the relative importance of each independent variable, (3) understand the nature of interaction between variables, and (4) provide an explanation for observed relationships between independent variables and amount of impact.

## Factors that Influence Amount of Impact

As such phrases as "overused campsite" suggest, the amount of use a site receives influences amount of impact. In one of the earliest studies of wilderness camp sites, Frissell and Duncan (1965) compared the amount of vegetation loss on low-, moderate-, and high-use campsites in the Boundary Waters Canoe Area Wilderness, Minnesota, USA. They found more vegetation loss on the high-use sites than **on the low-use sites, but** substantial vegetation loss occurred even **on the low-use**

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sites. Numerous studies have shown that at relatively low use levels, the amount of use a campsite receives has a profound influence on amount of impact; however, at higher use levels, amount of use frequently has little effect on amount of impact (Cole 1987a). Although this has been a consistent finding, an adequate explanation for this relationship has never been provided.

While most attention has been focused on the relationship between campsite impact and amount of use, other variables also influence amount of impact. Characteristics of both the camping group and the behavior of individuals can influence impact levels profoundly. For example, in the Bob Marshall Wilderness, Montana, USA, sites used by groups with stock were six times the size of sites used only by backpackers (Cole 1983). Stock sites had 11 times the number of damaged trees, had more severely compacted soils, had lost more of their organic horizons, and had been invaded more extensively by exotic plants.

Although empirical data are lacking, one could hypothesize about other group characteristics likely to influence amount of impact. Large groups have more potential to cause impact; so do groups that travel without a gas stove and cook over wood fires every night. Individual behavior is also important. Some campers chop on trees; others tie horses to trees, build bough beds, and dig ditches around their tents. These and many other behaviors cause much more impact than that caused by campers proficient in low-impact practices.

For many behavioral influences, cause-and-effect relationships are quite obvious, as are the solutions. Individual behavior needs to be changed and educational programs have been developed in an attempt to elicit change. The impacts associated with such behaviors as chopping trees, ditching tents, and tying horses to trees are unnecessary and can potentially be eliminated. In contrast, the campsite impacts caused by trampling—loss of groundcover vegetation, disruption of organic soil horizons, and compaction of mineral soil—are inevitable with use and are the ones most in need of study.

The characteristics of a site that relate to vulnerability also influence amount of impact. Certain plants, particularly those that are low-growing, tufted, and with wiry leaves and stems, are better able to survive trampling than others (Cole 1987a). Coarse soils are less prone to compaction problems than fine-textured soils (Lull 1959). Likewise, the extent to which certain features are present affects amount of impact. For example, sites with little or no vegetation cannot suffer much vegetation loss. A substrate without any coherent structure, such as a sand beach, cannot be compacted. Sites without trees cannot suffer tree damage. Thus, both extent and vulnerability are relevant.

## The Modeling Approach

In the subsequent analysis, a model campsite is established, with standard user and environmental characteristics. Amount of impact is calculated for this standard model and for alternative models in which one of several factors is permitted to vary from the standard model. The explanatory variables to be examined are (1) amount of use, (2) vegetation fragility, (3) vegetation density, and (4) the degree to which onsite traffic is concentrated.

The primary response variable used to evaluate amount of impact will be the area of vegetation loss (Cole 1989). Vegetation loss is among the most obvious changes to occur on campsites and, therefore, is a primary indicator of amount of impact. Area of vegetation loss is the best single index for comparing loss across a variety of situations because it incorporates both the proportion of vegetation lost on the campsite and the area of the campsite. It is calculated as follows:

1. Subtract mean vegetation cover on the entire camp site from mean cover on a comparable undisturbed place offsite. This difference, referred to as absolute vegetation loss, is a measure of the per-unit-area vegetation loss. It has a maximum possible value equal to the undisturbed percent vegetation cover (when all onsite vegetation has been eliminated) and a minimum value of zero (when there has been no vegetation loss).
2. Multiply absolute vegetation loss by campsite area.

This index provides a two-dimensional estimate of the amount of vegetation removed by recreational use of a campsite.

## Standard Campsite Model

For the standard model, assume a circular campsite with a center point. Assume the following characteristics of use distribution on the campsite: (1) all trampling occurs with walking back and forth between the center and the perimeter of the site, (2) all directions from the center are trampled equally, and (3) no more time is spent close to the center than at any other distance from the center. Given these assumptions, a gradient of trampling intensity exists in which the number of "tramples" (trampling intensity) decreases 50% with each doubling of distance from the center point. This follows because the circumference of any circle doubles as the radius doubles. The same number of tramples spread across twice the circumference represents half the trampling intensity. For example, if we assume a use level that

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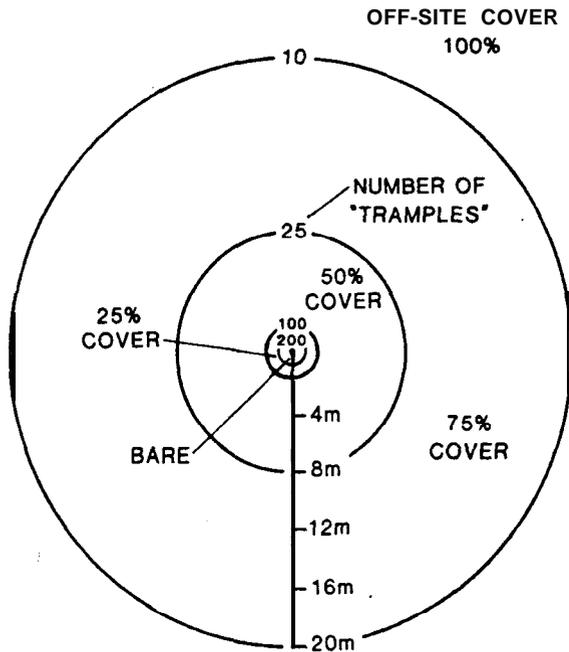


Figure 1. The standard model campsite. showing isopleths of trampling intensity and zones of vegetation cover. Campsite area is 1256 m<sup>2</sup>, vegetation loss is 29%, area of vegetation loss is 364 m<sup>2</sup>.

results in 200 tramples per year at a distance of 1 m from the center, trampling intensity would be 100 tramples per year 2 m from the center and 50 tramples per year 4 m from the center. Figure 1 depicts the standard model, using this arbitrary level of use, showing trampling intensity as a series of isopleths.

For purposes of the model, the campsite will be defined as the area on which vegetation cover is less than 75% of the cover of the surrounding undisturbed area. Experience suggests that only careful observers can detect levels of impact lower than this. This means that the campsite boundary will be located at the trampling isopleth associated with the trampling intensity that causes a 25% reduction in vegetation cover.

For standard vegetative characteristics, assume a dense vegetation cover in which 100% of the ground surface is typically covered by vegetation. Assume the vegetation type is moderately fragile, such as the *Clintonia-Vaccinium* type (Cole 1987b), for which there are data on the vegetation loss associated with controlled levels of trampling. In that type, any place trampled less than ten times per year loses less than 25% of its cover. Therefore, in the standard model, the ten-tramples-per-year isopleth defines the campsite boundary. This isopleth occurs at a radius of 20 m, so the standard campsite has an area of 1256 m<sup>2</sup>.

Cover would be reduced to about 75% of original

Table 1. Calculation of area of vegetation loss for standard model campsite

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	1	200	3
25	2	100	9
50	8	25	188
75	20	10	1056
Campsite area = (20 m) <sup>2</sup> = 1256 m <sup>2</sup>			
Vegetation cover = [(3 m <sup>2</sup> X 0) + (9 m <sup>2</sup> X 0.25) + (188 m <sup>2</sup> X 0.5) + (1056 m <sup>2</sup> X 0.75)] x 3256 m <sup>2</sup> = 71%			
Vegetation loss = 100% - 71% = 29%			
Area of vegetation loss = 1256 m <sup>2</sup> X 0.29 = 364 m <sup>2</sup>			

cover where trampling intensity is between ten and 25 tramples per year (Cole 1987b). Similarly, cover would be 50% of original cover between 25 and 100 tramples per year and 25% of original cover between 100 and 200 tramples per year. Vegetation would be eliminated entirely in places where trampling intensity exceeded 200 tramples per year.

The mean vegetation cover for the entire campsite can be determined by calculating the area that each vegetation cover class occupies, multiplying this area by the mean cover of that class, summing these products, and dividing by campsite area. Mean vegetation cover for the standard site is 71% (Table 1). Because vegetation cover originally was 100%, absolute vegetation loss is 29% (100% minus 71%). Area of vegetation loss—the product of campsite area and percentage of vegetation loss is 364 m<sup>2</sup>. The implication of this figure is that the amount of vegetation removed by camping would cover an area of about 364 m<sup>2</sup>.

The absolute numbers used in the standard model, for number of tramples, undisturbed vegetation density, and the percentage of cover surviving various trampling intensities, are arbitrary but typical. The discussion that follows will focus on relative rather than absolute numbers, so any set of numbers would lead to the same conclusions.

### Influence of Independent Variables

#### Amount of Use

To examine the influence of amount of use, assume that amount of use is reduced to one-half of that in the standard model, but all other variables are held constant., This might result from a decrease in the number

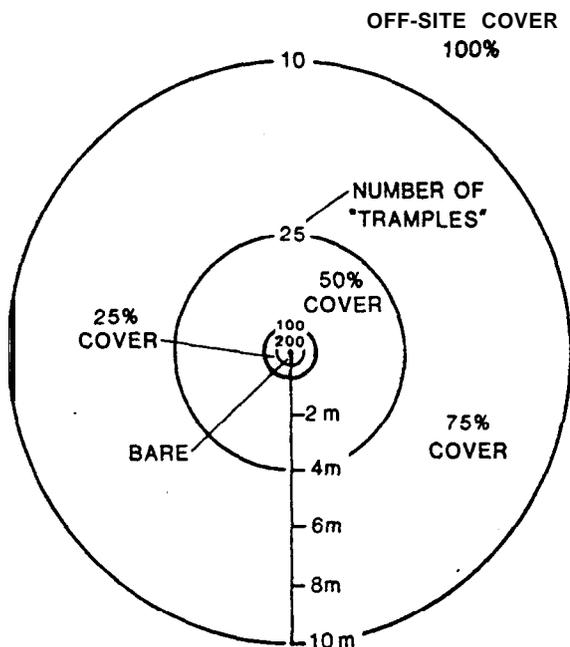


Figure 2. A campsite model identical to the standard, except amount of use is reduced by a factor of two. Campsite area is 314 m<sup>2</sup>, vegetation loss is 29%, area of vegetation loss is 91 m<sup>2</sup>. Note the change in scale from the standard model in Figure 1.

of nights per year that the site is used or a decrease in the average party size. The immediate effect is to reduce the trampling intensity of each concentric ring by a factor of two. In this scenario, the trampling intensity 1 m from the center is only 100 tramples per year. The ten-tramples-per-year isopleth is still the campsite boundary, but it is located only half as far from the center of the campsite as in the standard model, at 10 m. Consequently, the area of the campsite is 314 m<sup>2</sup>-only one-fourth the size of the standard site (Figure 2; note the change in scale from Figure 1).

Now the barren central portion of the campsite extends only 0.5 m from the center. Its area is only one-fourth the size of the barren center of the standard site. Similarly, each vegetation cover class has an area only one-fourth the size of that class on the standard site. Because the area of each cover class is reduced by the same proportion as the total campsite area, mean vegetation cover on the campsite remains 71% (Table 2). The area of vegetation loss is 91 m<sup>2</sup>.

The effect of reducing amount of use by a factor of two, then, is a reduction in area of vegetation loss by a factor of four. Holding all other factors constant, (1) the percentage of vegetation cover on the campsite does not change with a change in amount of use, but (2) campsite area and area of vegetation loss change as the square of any change in amount of use.

Table 2. Calculation of area of vegetation loss for model with 50% reduction in amount of use

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	0.5	200	1
25	1	100	2
50	4	25	47
75	10	10	264
Campsite area = (10 m) <sup>2</sup> = 314 m <sup>2</sup>			
Vegetation cover = [(1 m <sup>2</sup> X 0) + (2 m <sup>2</sup> x 0.25) + (47 m <sup>2</sup> x 0.5) + (264 m <sup>2</sup> X 0.75)] X 314 m <sup>2</sup> = 71%			
Vegetation loss = 100% - 71% = 29%			
Area of vegetation loss = 314 m <sup>2</sup> X 0.29 = 91 m <sup>2</sup>			

#### Vegetation Fragility

To examine vegetation fragility, assume a vegetation type one-half as fragile as in the standard model. In this scenario, one-half as much vegetation is lost at each trampling intensity. For example, as in the standard model, trampling intensity is 100 tramples per year 2 m from the center, but on this more durable vegetation type, 50% of the vegetation survives 100 tramples, instead of only 25%. Consequently, the barren center extends only 0.5 m from the center, to the 400-trample isopleth (Figure 3). The campsite boundary is at 10 m because in this more durable vegetation type it takes 20 or more tramples per year to cause 25% cover loss, instead of ten. The campsite area is 314 m<sup>2</sup>-one-fourth the size of the standard model. Because each cover category is one-fourth as large as on the standard site, vegetation cover is 71%-the same as on the standard site (Table 3). The area of vegetation loss is 91 m<sup>2</sup>.

Reducing fragility by a factor of two has the same effect as reducing amount of use by a factor of two. It causes a fourfold reduction in area of vegetation loss.

#### Vegetation Density

Amount of vegetation loss is also influenced by how much vegetation was present on the site before camping occurred. If we assume a vegetation type with only half the cover of the standard model, vegetation cover off-site would be 50%-approximately the same as the campsite would have had prior to use. In this scenario, the trampling isopleths remain the same as in the standard model. The campsite boundary still occurs at the ten-trample isopleth because ten tramples still remove only 25% of the vegetation, so campsite area is un-

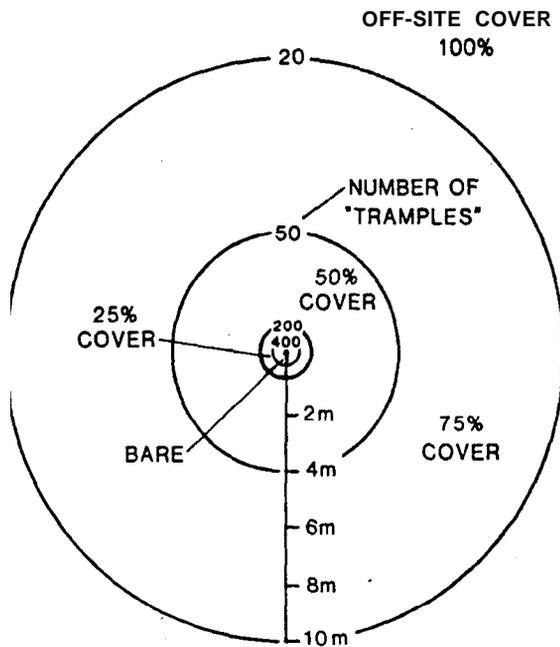


Figure 3. A campsite model identical to the standard, except vegetation fragility is reduced by a factor of two. Campsite area is 314 m<sup>2</sup>, vegetation loss is 29%. area of vegetation loss is 91 m<sup>2</sup>.

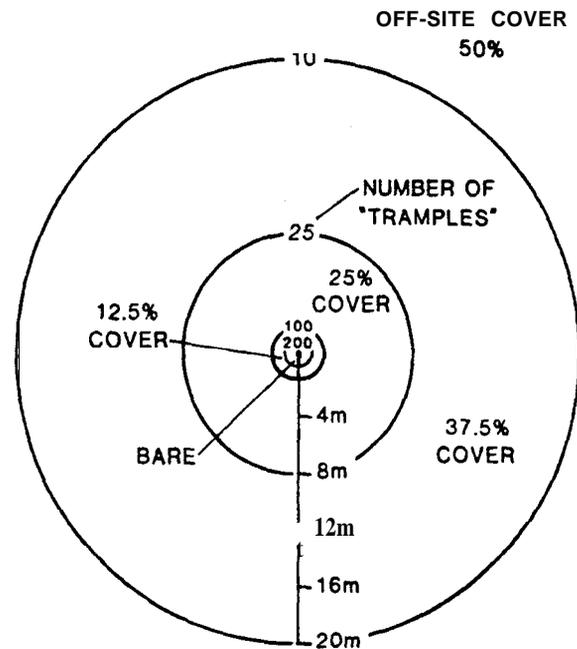


Figure 4. A campsite model identical to the standard, except vegetation density is reduced by a factor of two. Campsite area is 1256 m<sup>2</sup>, vegetation loss is 14.5%, area of vegetation loss is 182 m<sup>2</sup>.

Table 3. Calculation of area of vegetation loss for model with 50% reduction in vegetation fragility

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	0.5	400	1
25	1	200	2
50	4	50	47
75	10	20	264
Campsite area	= (10 m) <sup>2</sup> = 314 m <sup>2</sup>		
Vegetation cover	= ((1 m <sup>2</sup> x 0) + (2 m <sup>2</sup> x 0.25) + (47 m <sup>2</sup> x 0.5) + (264 m <sup>2</sup> x 0.75)) x 314 m <sup>2</sup> = 71%		
Vegetation loss	= 100% - 71% = 29%		
Area of vegetation loss	= 314 m <sup>2</sup> x 0.29 = 91 m <sup>2</sup>		

changed. It is the absolute amount of surviving cover that changes (Figure 4). For example, the area trampled 100-200 times per year will lose 75% of its cover, just as in the standard model, But because the original cover was only 50%, surviving cover is only 37.5% (75% of the undisturbed cover of 50%) The surviving cover of each concentric zone will be reduced by a factor of two, as will the mean vegetation cover of the entire campsite-35.5% in this case. Absolute loss is 14.5% (50% minus

35.5%) and area of vegetation loss is 182 m<sup>2</sup>(Table 4). Each of these is one-half of the loss that occurs under standard conditions.

Campsite area is not affected by vegetation density, but absolute vegetation loss and area of loss change in direct proportion to the change in density. This suggests that vegetation density has less influence on amount Of vegetation loss than amount of use or vegetation durability.

#### Degree of Activity Concentration

Another factor that can influence amount of impact is the degree to which traffic and activities are concentrated spatially, on a small part of the campsite. In the standard model, two important assumptions were that there was (1) no tendency to spend more time close to the center of the campsite than at any other distance from the center and (2) no limit on the distance from the center to the edge of the site. These assumptions seem reasonable on low-use sites where the trampled area is small. On high-use sites, however, the assumptions of the standard model lead to the prediction of extremely large trampled areas. On such sites the tenets of the model are not realistic because there is a clear tendency for virtually all activities to take place When a limited distance from the center of the site.

One way to build an increase in the spatial concen-

Table 4. Calculation of area of vegetation loss for model with 50% reduction in vegetation density

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	1	200	3
12.5	2	100	9
25	8	25	188
37.5	20	10	1056
Campsite area	= (20 m) <sup>2</sup> = 1256 m <sup>2</sup>		
Vegetation cover	= [(3 m <sup>2</sup> x 0) + (9 m <sup>2</sup> x 0.125) + (188 m <sup>2</sup> x 0.25) + (1056 m <sup>2</sup> x 0.375)] x 1256 m <sup>2</sup> = 35.5%		
Vegetation loss	= 50% - 35.5% = 14.5%		
Area of vegetation loss	= 1256 m <sup>2</sup> X 0.145 = 182 m <sup>2</sup>		

tration of activities into the model is to confine all trampling to a finite area. Assume, for example, that all activities are confined to an area with one-half the radius of the standard model. This site, with a radius of 10 m, would have an area of 314 m<sup>2</sup>. Assuming that the total number of tramples remains the same as in the standard, trampling intensity on this site would increase fourfold because activities are now confined to an area only one-fourth the size of the standard. This can be accounted for by increasing the level of each trampling isopleth fourfold (Figure 5). The result is an increase in the size of the more highly devegetated portions of the campsite. Vegetation loss on this site is 70% (Table 5), much higher than on the standard site: however, area of vegetation loss is only 220 m<sup>2</sup>. This is considerably lower than on the standard site—a difference accounted for by the greatly reduced campsite area.

Activity concentration also could be increased by assuming that more time is spent close to the campsite center than elsewhere. This assumption is difficult to build into the model; however, the effect of this change is clear. Trampling intensities would increase close to the center of the site, where most of the vegetation is already gone; intensities would decrease toward the perimeter, where surviving vegetation cover is greatest. These changes would cause a decrease in area of vegetation loss, which results primarily from a decrease in campsite area. Campsite area would always decrease, because trampling intensities at the perimeter would always be reduced. Percentage of cover loss could either increase or decrease, depending on the degree and pattern of concentration, but it would only increase where activities were highly concentrated. In this situation, area of vegetation loss would still decline, because the reduction in campsite area would be much greater than the increase in percentage of cover loss.

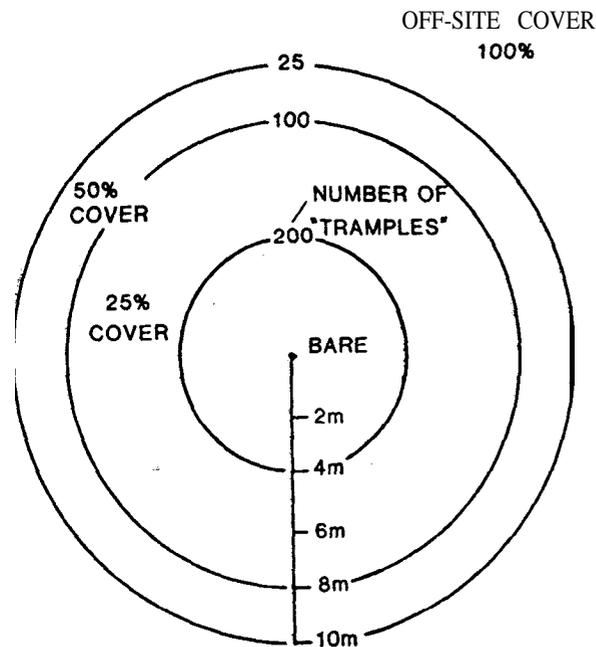


Figure 5. A campsite model identical to the standard, except all activities are confined to an area within 10 m of the campsite center. Campsite area is 314 m<sup>2</sup>, vegetation loss is 70%, area of vegetation loss is 220 m<sup>2</sup>.

Table 5. Calculation of area of vegetation loss for model with activities confined to one-half the radius of standard model

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	4	200	50
25	8	100	151
50	10	25	113
Campsite area	= (10 m) <sup>2</sup> = 314 m <sup>2</sup>		
Vegetation cover	= [(50 m <sup>2</sup> x 0) + (151 m <sup>2</sup> x 0.25) + (113 m <sup>2</sup> x 0.5)] x 314 m <sup>2</sup> = 30%		
Vegetation loss	= 100% - 30% = 70%		
Area of vegetation loss	= 314 m <sup>2</sup> x 0.7 = 220 m <sup>2</sup>		

The influence of activity concentration is more difficult to quantify precisely than the other variables, because it is hard to define a doubling of activity concentration. It is clear, however, that both increasing the proportion of time spent in the central part of the site and limiting the area within which trampling occurs will reduce the amount of vegetation loss.

### Interaction Effects

In addition to influencing amount of vegetation loss,

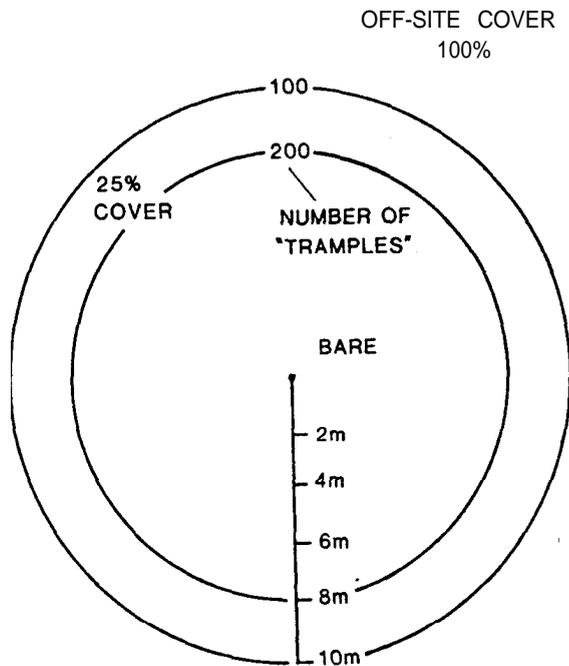


Figure 6. A campsite model with all activities confined to an area within 10 m of the campsite center and with twice the amount of use of the standard. Campsite area is 314 m<sup>2</sup>, vegetation loss is 91%, area of vegetation loss is 286 m<sup>2</sup>.

degree of activity concentration also has a profound influence on the importance of other independent variables. We already have demonstrated that, in the absence of activity concentration, vegetation loss changes as the square of any change in amount of use. A doubling of use, for example, would quadruple vegetation loss. The effect of doubling use on a site with concentrated activities is much less dramatic, however. Assume a doubling of use on the model in Figure 5. This would further increase the size of the barren part of the site (Figure 6) and area of vegetation loss would increase to 286 m<sup>2</sup> (Table 6). This 30% increase in loss with a doubling in use is much less than the quadrupling of loss that occurs in the absence of concentration. As the degree of activity concentration increases, the extent to which amount of use influences amount of vegetation loss decreases.

The degree of activity concentration also changes the relationship between vegetation fragility and amount of impact. As in all other cases, vegetation fragility responds, as an explanatory variable, in a manner identical to amount of use.

The relationship between vegetation density and vegetation loss is not influenced by the degree of activity concentration, however. The relationship between vegetation density and vegetation loss is always linear. For

Table 6. Calculation of area of vegetation loss for model with confined activities and doubling of amount of use

Vegetation cover class (%)	Outer boundary		Area (m <sup>2</sup> )
	Distance (m) from center	Number of tramples	
0	8	200	201
25	10	100	113
Campsite area = (10 m) <sup>2</sup> = 314 m <sup>2</sup>			
Vegetation cover = [(201 m <sup>2</sup> X 0) + (113 m <sup>2</sup> x 0.25)] x 314 m <sup>2</sup> = 9%			
Vegetation loss = 100% - 9% = 91%			
Area of vegetation loss = 314 m <sup>2</sup> x 0.91 = 286 m <sup>2</sup>			

example, a doubling of density will cause a doubling of vegetation loss, regardless of amount of use, vegetation fragility, or degree of activity concentration.

There also has been considerable interest in whether characteristics of the environment alter the relationship between amount of use and amount of impact. Some have suggested that conclusions about the influence of amount of use on amount of impact, derived from studies in the western United States, might not apply in the less fragile environments of the eastern United States. It has been established already that reducing amount of use on the standard site by a factor of two decreased vegetation loss by a factor of four. We can test the hypothesis that the relationship between amount of use and amount of impact is independent of environmental characteristics by assessing whether or not reducing use on a site with more durable vegetation has the same effect. The model shown in Figure 3 had vegetation twice as durable as the standard. Halving use on this site would result in an area of vegetation loss of 22.8 m<sup>2</sup> (Figure 7, Table 7). This is a fourfold reduction, the same as on the more fragile standard vegetation type. In the absence of activity concentration, doubling use should quadruple vegetation loss on all vegetation types, regardless of fragility and regardless of density. The influence of amount of use on vegetation impact is independent of vegetation fragility or other vegetative characteristics, a result that has been suggested by empirical studies (Cole and Marion 1988).

While proportional differences between high- and low-use campsites should remain constant regardless of vegetative characteristics, absolute differences are not constant. The absolute difference in vegetation loss between high- and low-use sites decreases as vegetation fragility and vegetation density decrease. In the extreme case of sites that are naturally barren of all vegetation, the difference between high- and low-use sites

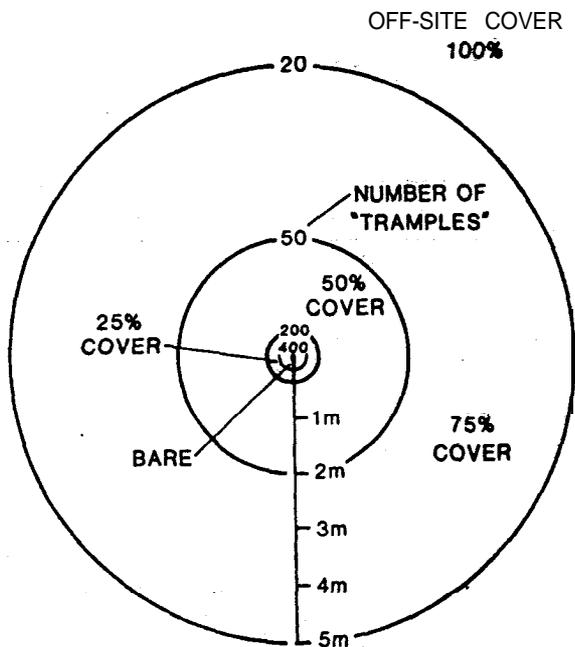


Figure 7. A campsite model with the same durable vegetation as the model in Figure 3, except amount of use is reduced by a factor of two. Campsite area is 78.5 m<sup>2</sup>, vegetation loss is 29%, area of vegetation loss is 22.8 m<sup>2</sup>.

Table 7. Calculation of area of vegetative loss for the model with vegetation that is twice as durable as the standard and with only one-half the amount of use

Vegetation cover class (%)	Outer boundary		Area m <sup>2</sup>
	Distance (m) from center	Number of tramples	
0	0.25	400	0.2
25	0.5	200	0.6
50	2	50	11.8
75	5	20	65.9
Campsite area	= (5m) <sup>2</sup> = 78.5 m <sup>2</sup>		
Vegetation cover	= [(0.4 m <sup>2</sup> x 0) + (0.4 m <sup>2</sup> x 0.25) + (11.8 m <sup>2</sup> x 0.5) + (65.9 m <sup>2</sup> x 0.75)] x 78.5 m <sup>2</sup> = 71%		
Vegetation loss	= 100% - 71% = 29%		
Area of vegetation loss	= 78.5 m <sup>2</sup> x 0.29 = 22.8 m <sup>2</sup>		

decreases to zero. Similarly, the difference between vegetation loss on durable and fragile sites decreases as amount of use and vegetation density decrease. The difference in vegetation loss between sites with dense and sparse vegetation decreases as amount of use and vegetation fragility decrease.

### Discussion

Given the assumptions of this model, it is possible to

draw conclusions about the nature and relative importance of variables that influence amount of impact on campsites. The analysis also points out interaction between certain variables that change the relationship between explanatory and response variables. Finally, it suggests some new explanations for observed empirical results. Conclusions are as follows:

1. Amount of use and vegetation fragility are equally important determinants of amount of vegetation loss. Both camping on a site with durable vegetation and minimizing use levels on a site can be effective means of reducing vegetation loss. The effectiveness of the two strategies is identical. In the absence of activity concentration, vegetation loss increases exponentially with increasing use and with increasing vegetation fragility. As the spatial concentration of activities increases, however, increases in use and in fragility result in smaller increases in vegetation loss. At high levels of concentration, neither the amount of use a site receives nor the fragility of the vegetation have much influence on amount of vegetation loss.

2. The relative explanatory power of amount of use, vegetation fragility, and vegetation density varies with degree of activity concentration and, therefore, between relatively undisturbed and well-established campsites. Where activity concentration is low, amount of use and vegetation fragility influence amount of vegetation loss more than vegetation density does. As activity concentration increases, vegetation density becomes more important than amount of use and fragility. The relationship between vegetation density and vegetation loss is linear and unaffected by the degree of activity concentration.

The primary situation where activities are not likely to be concentrated is where campsites are infrequently used and lightly impacted. Such sites are typically small (e.g., Cole 1982, Cole and Marion 1988), so activities are spread over the entire small site rather than being concentrated in a few parts of a large site. On lightly impacted sites, vegetation loss is strongly influenced by both amount of use and vegetation fragility. Consequently, it is desirable to minimize use of lightly impacted sites and to select sites with durable vegetation. Selecting a site with sparse vegetation can also reduce impact, but this is less important.

Party size and length of stay can also influence vegetation loss on lightly impacted sites, Doubling party size and doubling length of stay should be no different from doubling amount of use. In each of these cases, the area of vegetation loss should increase as the square of the increase in party size or length of stay. For example, a party of ten would cause 25 times as much vegetation loss as a party of two. A party of two that

stayed for three nights would cause nine times the damage it would with a stay of one night. This suggests that, on low-use sites, vegetation loss is minimized by splitting large groups into small groups and by staying only one night.

Activities are clearly quite concentrated on large, well-impacted campsites. Most time is spent around the kitchen and sleeping areas, while the rest of the site is less frequently trampled. There is also some outer limit beyond which little trampling occurs, except on social trails that lead away from the site. On these well-impacted sites, amount of use and vegetation durability have little effect on amount of vegetation loss. The most effective means of minimizing vegetation loss are to select sites in sparse vegetation and to confine use to as small an area as possible.

On large, well-impacted sites, party size and length of stay are less relevant factors than on the lightly impacted sites. Increases in party size and length of stay would increase amount of use, but amount of use has little effect on amount of impact. The primary exception is where party sizes are so large that significant amounts of traffic and activity occur offsite, enlarging the size of the site. In this case, it would be better to distribute large parties among several campsites.

3. The curvilinear relationship between amount of use and amount of impact can be explained by the tendency for activity concentration to limit vegetation loss. Empirical studies have consistently reported a curvilinear relationship between amount of use and amount of impact. Amount of impact increases rapidly with initial increases in amount of use, but the rate at which impact increases declines as amount of use increases (Cole 1987). The campsite model with no activity concentration suggests the opposite, however. Impact increases as the square of any increase in amount of use. Only by introducing increasing levels of activity concentration into the model does the relationship approximate that reported in empirical studies.

This suggests that the explanation for this empirical relationship lies in the tendency for activity concentration to increase as campsites become more heavily used and impacted. Initial increases in use would be expected to cause substantial increases in vegetation loss. Our campsite models suggest that, during these initial increases in use, the area of each vegetation cover class is expanding, but in approximate proportion to each other and to campsite area. Thus, despite an increase in the barren center of the site, percentage of cover loss remains relatively constant. Vegetation loss increases primarily as a result of campsite expansion.

As campsites increase in size, with increasing use, they approach a size limit; activity concentration in-

creases and the rate of vegetation loss decreases. At these higher use levels, the rate of campsite expansion declines. Increases in vegetation loss that accompany increasing use result primarily from an increase in percent vegetation loss (the proportion of the campsite in the more devegetated classes increases).

Results of a study of low-, moderate-, and high-use campsites in the Eagle Cap Wilderness, Oregon, USA, support this explanation (Cole 1982). Area of vegetation loss was 41 m<sup>2</sup> on low-use sites, 110 m<sup>2</sup> on moderate-use sites, and 122 m<sup>2</sup> on high-use sites. The big difference between low- and moderate-use sites was in campsite area. Low-use sites had a mean area of 109 m<sup>2</sup> and mean vegetation loss of 38%, compared with an area of 275 m<sup>2</sup> and a vegetation loss of 40% on moderate-use sites. The difference between moderate- and high-use sites was primarily in percentage of vegetation loss. High-use sites had a mean area of 204 m<sup>2</sup> and a mean vegetation loss of 56%.

The susceptibility of vegetation to trampling damage explains the rapid vegetation loss that accompanies initial use of a campsite and initial increases in amount of use. It does not explain why the influence of amount of use decreases as amount of use increases. The explanation for this appears to be the tendency for activities to be more highly concentrated on already denuded parts of large, well-impacted campsites. According to this theory, the relationship between amount of use and amount of impact should approximate a logistic curve. It should be initially exponential, becoming asymptotic at higher use levels.

4. The relationship between amount of use and amount of impact should not vary regionally. Although this conclusion has been suggested by empirical research, the models provide an explanation for this lack of variation. The relationship between amount of use and amount of impact varies with degree of activity concentration, but not with vegetative characteristics. In the absence of spatially concentrated activities, vegetation loss will increase as the square of any increase in use—whether the vegetation is resistant or fragile, dense or sparse. Given a higher level of activity concentration, the increase in vegetation loss will be less than the square of the increase in use, but the amount of increase will not vary with vegetative characteristics.

Consequently, there should be no difference between fragile and durable vegetation or between wilderness in the eastern United States and wilderness in the western United States. The only environmental characteristics that should influence the relationship between amount of use and amount of impact are characteristics that influence the degree of activity concentration. For example, in desert environments in the Grand Can-

yon- which often have been characterized as highly fragile-extremely rough topography and brushy, thorny vegetation confine camping activities to unusually small sites. This extreme level of concentration, caused by environmental constraints, results in area of vegetation loss values that are only 20-25% of those commonly found in mountainous wilderness areas (Cole 1989).

5. These conclusions should apply to other impacts caused by trampling on campsites. Although the preceding discussion has been confined to an analysis of vegetation loss, similar conclusions would apply to the other impacts that are the inevitable result of trampling-loss of organic soil horizons and compaction of mineral soils. The relative explanatory power of (1) amount of use, (2) environmental fragility, and (3) the extent to which susceptible features are present and the nature of interactions should be identical to those that apply to vegetation loss.

Our knowledge about these other impacts is meager, however, and optimal management strategies are less obvious. Little is known about how sites vary in susceptibility to loss of organic horizons, for example. Moreover, although camping on a site where organic horizons are sparse is a means of minimizing loss of organics, this can have particularly adverse effects on mineral soils, which are more prone to compaction when organic material is absent. More is known about susceptibility to compaction. The most fragile soils are those with a wide range of particle sizes (Lull 1959); however, these soils have desirable qualities as well, such as good drainage and a high potential for plant growth (Montgomery and Edminster 1966). The soil compaction variable comparable to the sparseness of vegetation cover or organic horizons is the proportion of the area that is susceptible to compaction. Certain surface soils, such as the unconsolidated sands of a beach, cannot be compacted significantly regardless of the level of trampling pressure;

Certain actions will minimize impact to all the types of trampling impact associated with camping. Concentrating activities and reducing use are the prime examples; It is more difficult to select an environment that will minimize all these types of impact For example, a site without vegetation or organic horizons is likely to be highly susceptible to compaction of mineral soils. There are some sites, however, such as a sandy beach, where the absence of vegetation, organic horizons. and consolidated soil results in negligible trampling impacts, regardless of use characteristics.

## Concluding Remarks

As with all modeling attempts, the conclusions presented in this article are subject to the limitations inherent to the simplifying assumptions of this model. Therefore, the conclusions should be treated as hypotheses that need to be validated before they can be applied to the real world. Nevertheless, this model does permit, for the first time, an analysis of how each explanatory variable affects amount of impact. This leads to some new perspectives on the influence of these variables on amount of impact and some new explanations for frequently observed relationships.

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